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THE EFFECT OF PRE-WEANING FEEDING BEHAVIOUR ON POST-WEANING FEEDING BEHAVIOUR IN PIGS WEANED AT 3, 4 AND 5 WEEKS OF AGE

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University of Plymouth

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A thesis submitted to the University of Plymouth

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THE EFFECT OF PRE-WEANING FEEDING BEHAVIOUR ON POST-WEANING FEEDING BEHAVIOUR IN PIGS WEANED AT 3, 4 AND 5 WEEKS OF AGE.

A program of study was undertaken to asses the effect of pre-weaning feeding behaviour on post-weaning feeding behaviour in pigs weaned at various ages (3, 4 and 5 weeks of age) and to identify ways of increasing their post-weaning feed intake. The studies were constructed using time extensive continuous recording methods in order to monitor the 'true' behaviour unbiased by sampling errors.

Piglets weaned at 3 weeks of age had the ability to grow faster and became significantly heavier at six weeks of age (3W: 12.506 ± 0.629 kg) than piglets that had to extent their stay for one (4W: 10.514 ± 0.693 kg) or two more weeks (5W: 10.987 ± 0.376 kg) with the sow. In addition, 4W piglets had the greatest difficulty adapting to their new environment in comparison to 3W and 5W piglets, as they had greater scores on aggressive and abnormal behaviour during the week post-weaning.

This study demonstrated that the provision of a familiar feeder post-weaning i) allowed all 4W piglets, irrespective of their pre-weaning feeding experiences, to allocate the feeding resources unaided and autonomously without having to rely on the feeding temperament of their more experienced littermates or having to imitate them eating, ii) helped the less experienced piglets of the litter (regarding their feeding behaviour) to build a stronger immune system and to become heavier at the end of the first week and iii) improved the welfare of the piglets soon after weaning as they were performing significantly less belly-nosing in contrast to equivalent piglets that were not suited with a familiar feeder. Also, extensive pre-weaning feeding behaviour can help 4W piglets obtain a stronger immune system by the end of lactation independent of their weight and their teat order.

The study reported in this thesis provides good evidence that choosing to use a time-period which was previously applied by other researchers could lead most of the times to incorrect conclusions. Also, short time-sampling strategies have been proven to be insufficient to provide strong or valid statistical associations with the 'true' duration of the behaviours under investigation (r<70%). Continuous weekly recordings during the day hours (8:00 to 17:00h) were shown to be sufficient to provide measurements of strong association with the 'true' duration of the behaviours for the given week.

FREQUENTLY USED ABBREVIATIONS

ADFI	Average daily feed intake
3W	Piglets weaned at 3 weeks of age
4W	Piglets weaned at 4 weeks of age
5W	Piglets weaned at 5 weeks of age
ADG	Average daily gain
Anova	Analysis of variance
ATS-piglets	Anterior teat-suckling piglets
BW	Birth weight
cm^3	Centimetres cubed
CRM	Continuous Recording Method
d.f.	Degrees of freedom
DF	Dietary fiber
DLWG	Daily live-weight gain
DM	Dry matter
F	F statistic (Anova)
FCR	Feed conversion rate
FF	Familiar Feeder treatment
FLF	Fermented Liquid Feeding
g	gram
GI	Gastrointestinal
GLM-analysis	General Linear Model Analysis
h	hour
H-piglets	Heavy weight piglets
kg	Kilogram
L	Liter
log	Logarithm
L-piglets	Light weight piglets
LS	Litter size
LW	Live-weight
LWG	Live-weight gain
m	Meter

min	Minute
M-piglets	Medium weight piglets
MTS-piglets	Middle teat-suckling piglets
NF	No Familiar feeder treatment
NS	Not Significant
°C	Degrees Celcius
P	Probability Level
PMWS	Post-weaning multisystemic wasting syndrome
PTS-piglets	Posterior teat-suckling piglets
Q	Nonparametric S.E.M
r	Coefficient of correlation
R^2	Coefficient of Determination
R^2_{adj}	Coefficient of Determination adjusted
r_s	Spearman rank correlation
s	Second
S.E.	Standard Error
S.E.D.	Standard Error of the Difference
SEW	Segregated Early Weaning
SI	Small Intestine
VRBA	Violet Red Bile Agar
WW	Weaning weight
x^2	Chi-square

Chapter 1

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Chapter 2

The effect of pre-weaning behaviour and weaning age (3, 4 or 5 weeks) of the piglets on post-weaning feeding and drinking motivation, growth performance and agonistic interactions.

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AUTHOR'S DECLARATION

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award.

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Chapter 1

Literature review

1.1 Weaning the pig.

In various parts of the world pig production has become highly specialised, industrialised and concentrated geographically. The market for pork is almost free, and therefore a relatively low cost price is important to keep pig production profitable (Backus *et al.*, 1994). The possibilities for maximising sow productivity and the need to more efficiently utilise the expensive farrowing facilities have led pig producers to wean piglets at an early age. In most mammals studied, weaning seems to be the result of a slow process where the young gradually become less dependent on sow's milk (Jensen and Recen 1989; Boe 1991). In today's industrialised animal farming, weaning is generally defined as that time when mammalian young cease to suckle and start to feed exclusively on solids. Puppe and Tuchscherer (2000) found that the maximum of the nursing frequencies was determined at day 8.5 (31.4 suckling per 24-hour period) and was considered as the biological beginning of the weaning process. As a compensation for the decreasing nursing frequency piglets significantly increased their creep food intake in the last week of the suckling period (week 4 to 5) (Puppe and Tuchscherer 2000).

However, weaning at 3-4 weeks exposes the pigs to nutritional, environmental and social stress that usually results in a post-weaning lag phase manifested by slow growth, scouring and general unthriftiness (Ravindram and Kornegay 1993). This post-weaning lag is a complex phenomenon and available evidence suggests that it may be related, in part, to the inability of the early weaned pig to secrete sufficient quantities of hydrochloric acid within the stomach and to cause optimal enzyme activation and efficient digestion of diets based on plant protein. Insufficient acid secretion, together with the stress of weaning, may also disturb the balance of intestinal flora and allow the proliferation of coliforms, resulting in scours and poor performance (Ravindram and Kornegay 1993). Fowler and Gill (1989) state that these problems are mainly caused by the provision of diets that are unsuited to the physiology of the piglet's immature digestive tract. So, the reduction in food intake can also be described as a defence strategy by the piglet to cope with its new circumstances and try to maintain physiological homeostasis (Fowler and Gill 1989).

Currently, European legislation prohibits weaning before 3 weeks of age, unless it improves the health and welfare of piglets. Broom (1989) stated that 'the welfare of an individual is its state as regards its attempts to cope with its environment'. Welfare can therefore be assessed by measuring the extent of coping strategies, one form of which involves behavioural change (Kelly *et al.*, 2000). However, a comparison of behaviour in different environments can provide indications of modified patterns, and identify whether one system leads to the performance of more potentially harmful behaviours than another (Kelly *et al.*, 2000). Early weaning (5-21 d) is also practised to control the spreading of diseases after piglets have gained passive immunity through ingestion of colostrum (Kim *et al.*, 2001). This early weaning procedure is associated with sudden changes in social and environmental conditions including the feed regimen. Under practical production this method seems to be efficient, in most cases, it enables supernumerary piglets to survive (Orgeur *et al.*, 2001).

The significance of early weaning to pig farming is reported by Hodge (1974) who observed that after weaning pigs at 2 days old, they were growing at 832 g/day between 4 and 7 weeks of age. On the other hand Whittemore and Green (2001) have reported a growth rate of 400 g/day at 3 weeks after weaning at 21 days. According to Williams (2003), the potential for growth of the young pig is extremely high and is between three and four times that which is commonly observed under the best commercial conditions.

Another factor which influences pig production, is the EU legislation, which from July 1st 1999, has withdrawn the license of certain feed antibiotics for use in growth promotion in the diet of pigs, poultry and calves. This is a profound change to the environment of pig production as it transforms the process of weaning to a more challenging action. For nearly 50 years, the evolution of husbandry techniques and strategies has been in the context of the use of these substances. Also, the use of antibiotic growth promoters has been questioned in Europe for several decades. The concern has mainly been related to the risk of creating antibiotic resistant microorganisms that can be transferred to humans. The ethical justification for feeding antibiotics to 'healthy animals' has been debated as well and during the last decade, the growing consumer demand for 'green' food products has further intensified the discussion and created the current situation (Stein 2002).

Feed antibiotics are claimed to have a 'growth promoting' effect. The exact mechanism by which this was and is achieved is not entirely clear. The companies tended to maintain a distinction between 'growth promotion' and 'therapeutic' effects (Fowler *et al.*, 2000). With the complete ban of dietary antimicrobial agents by January of 2006, new ways have to be explored in the feed industry in order to improve and protect the health status of farm animals, to guarantee animal performance and to increase nutrient availability (Wenk 2000). Although this goal can be attained by good housing or climate conditions it can also be achived by the best possible combination of the so-called pronutrients (Rosen 1996) available including pro- and prebiotics, organic acids, dietary fibres, highly available nutrients or herbs (Savoini *et al.*, 2002).

The subsequent effects of pre-weaning factors on post-weaning piglet performance are less well studied. Commonly, a growth check in piglets in response to weaning is noted, but to date it is unknown why some piglets do better than others in this period. Jones *et al.*, (1998) showed that factors such as piglet weaning weight, birth weight and pre-weaning growth, accounted for relatively little of the variation in piglet performance after weaning. However, they found that litter origin of individual piglets was a much more important factor ($P<0.001$) and that there was a strong positive relationship between post-weaning feed intake and post-weaning piglet performance. On the other hand, Williams (2003) supports the Gompertz description of growth, which states that a pig of a large body size will be always larger and grow faster at any given age than a counterpart pig of smaller size.

Another factor which can influence the post-weaning success of the piglets is the amount of milk consumed by them prior to weaning. Newborn pigs are completely dependent on milk for nutrition up to a certain age (12-21 days (de Passille *et al.*, 1989; Pajor *et al.*, 1991)) and thereafter follows a period of combined solid and milk intake (Jensen and Recen 1989). But on commercial farms, weaning has been transformed from a gradual process over 4-10 weeks (Brooks and Tsourgiannis 2003) to a single event. So, the nutritional change at any artificial weaning time may, to a large extent, be determined by the milk consumption of the piglets prior to weaning. Unfortunately, milk and milk-like products, which the piglet can easily digest, are expensive in comparison to cereal-based material and can not constitute the whole of a ration post-weaning.

For pigs, the solid intake increases markedly at about 19th to 23rd day of age (Delumeau and Meunier-Salaun 1995) and thereafter the young are capable of surviving without milk. Jensen and Recen (1989) suggest that suckling after this age can be viewed to some extent as a special case of foraging. Therefore, according to Krebs and McCleery (1984) the young should be expected to optimise their foraging behaviour; by participating in sucklings would be one strategy, and to cease suckling would be another.

Today, the swine industry is an easy target for criticism from animal welfare groups regarding the use of very early weaning ages because the welfare and behavioural implications of this management change have not been thoroughly assessed (Worobec and Duncan 1997; Mormede and Hay 2003). For this reason new legislation has been imposed by the EU (91/630/EEC - 01/12/2001).

The rapid changes in the production system challenges many farmers, and the ability to follow and cope with the current legislation will be crucial as this will characterise the future of the producer. Two of the main challenges that the producer has to face today (related to the management of weaned pigs) are:

1. A change in EU regulations concerning the minimum weaning age of piglets from 21 to 28 days.
2. The total ban of antimicrobials and non-prescription products such as copper sulphate.

Both these challenges have a profound effect on the post-weaning behaviour of the piglet. A piglet of 28 d old has different needs from a piglet weaned a week earlier, as it builds a stronger bond with its dam, has different pre-weaning experiences and this may affect their post-weaning performance and behaviour to that observed by its counterpart which weaned a week earlier. The removal of antimicrobials and non-prescription products, present more challenges to the weaned piglet which under the influence of exhaustion from depressed feed intake, fragile immune system, maldigestion/malabsorption of the pre-mature digestive system, will act in a more unpredictable way than its healthier counterpart.

Although a number of studies have identified that there is great variability in feed intake both before and after weaning, there are no studies that demonstrate a linkage between the pre- and post-weaning feeding behaviour of individuals. This is primarily because pigs have been treated as groups and studies have measured average performance and average response (Pajor *et al.*, 1991). For example, the teat that the piglets possess at suckling (teat order) (Fraser 1980) on the same sow may differ in milk production terms by as much as 200% or more (Algers *et al.*, 1990). So, it may be that different piglets within the same litter will be affected quite differently by the nutritional change.

In order to understand the effect of weaning on post-weaning behaviour of the individual piglet, an identification of the main problems rising from the weaning procedure will take place, comparing studies of previous workers on how weaning age and/or weight can contribute to the success of this transition period for the piglet. Also, the contributed effect to behaviour and success of the weaner pig will be identified from variables such as birth weight (BW), sex, differences between and within litters and the effect of weaning techniques that have been performed in production systems in order to increase the performance of the weaner pig. Feeding practices will be outlined and methods that influence voluntary FI pre- and post-weaning will be also presented. Finally, observation methods on behavioural studies of the piglets will be revealed and differences in feeding-drinking-playing-fighting behaviour between pigs of the same litter, of variable weight and status will be compared among the findings of different workers.

1.2 The weaning process.

In order to understand the problems that the domestic piglet faces in confinement housing systems, it is important to refer to our knowledge of behavioural development in wild pigs and domestic pigs kept under conditions that are more natural. Artificial weaning is a potential source of behaviour and health problems in pigs, as in semi-natural environments piglets are weaned at ~17 weeks of age and the weaning progression is gradual and prolonged (Jensen and Recen 1989; Boe 1991). Commercially weaning is an event but nutritionally it should be a process (Fowler 1985).

In nature, weaning is not an event, but a process that takes place over several weeks. This process has three different but interrelated developmental strands, namely, behavioural, nutritional and immunological. The appropriate development of each strand influences the health of the pig and its ability to function independently from its mother and from its littermates.

The initiation of the weaning process starts, at the earliest, about 10 days post-partum with a decrease in suckling frequency (Jensen *et al.*, 1991), as this time corresponds to when the sow and her litter leave the nest to move close to the group (Jensen and Redbo 1987). The piglet has to adapt from a situation in which it obtains all its food by suckling the sow, which is an instinctive behaviour, to foraging / independent feeding, which has significant learned components. Sows milk provides not only nutrients, but also immunoglobulins, bioactive proteins and peptides, which stimulate and modulate the development of the gut (Zabielski 1998). The sow is the most important factor influencing the microbial environment into which the piglet is born (Conway 1966). The first bacteria that the piglet encounters are organisms colonising the sow's vagina and teats and emanating from her faeces. These organisms are ingested during the birth process and subsequent suckling and have a profound influence on the structure and biochemistry on the gut and also to the development of the gut ecosystem and on immunological development (Kelly and King 2001).

Under natural conditions, the pre-weaning lactation period can be divided into four phases (Table 1.1). For the first 10 days of lactation (range 3-16d), the piglets remain in, or in very close proximity to, a nest prepared by their mother (hiding phase) (Jensen and Redbo 1987). When the piglets leave the nest their mother takes them to rejoin the matriarchal group. From this point on the piglets will accompany the sow on her foraging trips (following phase) (Jensen 1986). The piglets do not necessarily forage, but will rest close by the sow as she forages. As the piglets grow, their fat reserves increase; they gain strength, and will spend increasing amounts of time in the close proximity of the sow and will watch her foraging. They will sample the feed that the sow eats. This sampling of food and non-food substrates (e.g. soil) exposes the gut to novel food sources antigens and microorganisms. In turn, this exposure to novel substrates stimulates the development of the piglet's gut enzyme system (Kidder and Manners 1978) and contributes to the development of active immunity. The period around three weeks of lactation can be considered an immunological low point. Passive (colostrum derived) immunity has declined to a low level and active immunity is only just starting to develop.

Table 1.1 Schematic outline of the development of piglets under natural conditions (after Brooks and Tsourgiannis (2003)).

Week	Phase	Behavioural features	Influence on piglet development
1	Hiding	Piglets initially isolated in nest built by mother. Limited excursions beyond the nest.	Nutrients provided entirely by mother Development of GI tract determined by nutrients and bioactive molecules in sow's milk. Initial microbial colonisation of GIT dominated by flora from sow. Passive immunity provided by immunoglobulins in sow's milk.
2-3	Following (Familiarizing)	Piglets leave nest and follow sow. Sow and litter rejoin matriarchal group. Piglets remain in litter group with little or no integration with other piglets. Piglets start rooting	Milk still dominates nutrition. Bioactive molecules in milk continue to influence GIT development. Limited sampling of environment exposes GIT to other microbes. Active immunity develops in response to sampling of environment.

4-7	Integration (Learning?)	Piglets increase foraging (grazing) behaviour. Piglets start to integrate with others. Sow leaves piglets for increasing periods. Interval between nursing events increases. Sows increasingly terminate nursing events. Piglet become fully integrated with other members of the social group.	Nutritional demand of piglets starts to outstrip supply by sow stimulating pigs to forage for themselves, usually in proximity of sow. Reduced suckling opportunities and limitations of nutrient supply by sow encourage piglets to forage independently. New food sources stimulate development of GIT and immune system. Milk still contributes to gut health and development. Passive immunity is no longer effective. Piglets engage in agonistic behaviour, resolve conflicts and develop new social structure.
8-17	Independent	Nursing by the sow becomes less frequent and at some point ceases (pigs weaned). Piglets function independently as part of extended social group. Piglets may still sleep in family group with sow.	Piglets become increasingly independent of both the sow and their litter group. Piglets develop independent feeding strategies (meal size/ meal interval). Removal of milk represents the final stage in GIT development.

For practical reasons weaning on commercial pig units has little in common with weaning in natural conditions. Brooks and Tsourgiannis (2003) have summarised some of the key differences between natural and commercial weaning (Table 1.2). Sows and their litters are normally housed individually prior to weaning, so there is no opportunity for the pigs to socialise with non-littermates. In order to maximize sow reproductive output piglets are removed from their dams before they have achieved behavioural independence, typically at ages of 14-35 days depending upon the country. At weaning pigs are moved to a new environment and frequently new and larger social groups are formed by mixing unfamiliar pigs. Solid feed and water is provided for them from unfamiliar dispensers. The age at which weaning takes place and the amount of experience that the piglet has had of alternative feed sources, influence its ability to cope with these changes. In addition, the environment into which the pig is weaned and the way the pig is managed following weaning contribute to the success or failure of the transition.

Table 1.2 Key differences between natural and commercial weaning (after Brooks and Tsourgiannis (2003)).

Natural weaning	**Commercial weaning**
Piglets integrate with other members of an extended group before and during the weaning process.	Piglets generally have no opportunity to integrate with non-littermates before weaning.
Weaning is an extended process occurring over a period of around three months.	Weaning is a single event, taking place on a specific day (generally varies between 14 and 28 days).
Sow milk continues to be available to the piglet while it samples novel foods and while its gut adapts microbiologically and immunologically to these new food sources.	Sow milk (and its bioactive constituents) is not available to support the transition to dry feed.
The slow changeover from total dependence on sow's milk to total dependence on solid food maintains continuity of nutrient input and prevents transient starvation.	Sudden removal of sow milk results in transient starvation, adverse effects on the gut architecture and limited, zero, or negative growth for a period immediately post weaning
Solid food contains around 200 g DM per kg	Solid food contains around 900-920 g DM per kg.
No change of environment at weaning	Piglets usually moved to a new environment and have to adapt to different feeding and drinking equipment.
Piglets continue to sleep with sow(s) in the matriarchal group even after weaning.	Piglets removed from the sow.
The piglet integrates into the larger social group over a period of time and with a minimum of aggression.	Piglets frequently regrouped and mixed unfamiliar pigs at weaning, resulting in considerable aggression and potential physical damage.

1.3 Understanding the complication of weaning procedure.

Weaning age has declined over time in order to increase sow productivity. Moreover, approximately 3 weeks after farrowing, milk yield of sows becomes insufficient to support maximal pig weight gain (Zijlstra *et al.,* 1996). However, decreasing weaning age has increased post-weaning stress in pigs (Dybkjaer 1992). Under these circumstances, the piglets' pre-weaning experiences are more likely to be important factors in their ability to adapt to the post weaning environment. Weaning stressors are of environmental, behavioural (Worobec *et al.,* 1999), immunological (Blecha *et al.,* 1983) and nutritional origin (Mormede and Hay 2003; Williams 2003). The diet changes from sow's milk containing highly digestible nutrients to a diet of different digestibility, texture, composition, smell and taste. As a consequence, the digestive system must adapt with respect to pH regulation, enzyme secretions, motility and absorption (Hansen *et al.,* 1993). Signs of post-weaning stress include reduced feed intake, villus atrophy, and diarrhea, resulting in lower digestive and absorptive capacity and ultimately, reduced weight gain (Cera *et al.,* 1988).

According to Algers *et al,* (1990) the possible negative factors that a pig is exposed to in connection with weaning can be divided into different categories. Firstly, artificially weaning demands a nutritional change and although piglets already voluntarily consume creep feed in appreciable quantities from about 4-5 weeks of age, they still rely on milk as an important food source for a long time (Boe 1991). Secondly, the need to utilise the feeders more may increase the frequency of agonistic interactions between litter mates, particularly if feeding space is limited. Thirdly, there may be an effect of environmental change if the pigs are moved after weaning. If newly weaned piglets undergo reduced intake and /or digestion of food, their lower critical temperature can rise (Curtis 1983), so piglets may be uncomfortably cold unless the effective environmental temperature is increased. Finally, Algers *et al.* (1990) states that the removal of the sow will itself probably cause a broad spectrum of various psychological stresses. The sudden loss of sow's milk with the inclusion of IgA component as well as other protective factors that it contains can be extremely serious (Fowler and Gill 1989).

The nutritional change at any artificial weaning time may to a large extent be determined by the milk consumption of the piglets prior to weaning, as piglets suck their 'home' teat (Spinka and Algers 1995) and the production between different teats on the same sow may differ by 200% or more (Algers *et al.*, 1990). Algers and Jensen (1991) estimated that within-udder variations in average milk production fluctuated between a few and up to 67 g per nursing. Thus different piglets within the same litter can be assumed to be affected quite differently by the nutritional change at weaning (Algers *et al.*, 1990).

The piglet also has to cope with a very large increase in DM intake if a growth similar to pre-weaning performance is to be maintained. It has been estimated by Williams (2003) that during lactation (3-4 weeks), a piglet consumes on average 200 g DM per day (1114 Kcal/L) from sow's milk and after weaning has to consume at least 300 g/day (50% increase) of a high-density creep feed (15-16 MJ/kg), and even more if lower-quality creep diets are used, due to a decreased digestibility.

Weary and Fraser (1997) observed that intense activity and characteristic patterns of vocalisation are commonly seen in the minutes and hours after separation and then disappear gradually over one or more days. This reaction may indicate a form of separation distress upon loss of the mother. Varley (1995) states that stress at weaning is also associated with the rough handling received from the stockmen.

Mixing of pigs after weaning is another well-recognised stress and has been shown to elevate saliva cortisol levels (Merlot *et al.*, 2004), increase fighting (McGlone and Curtis 1985), increase the frequency of sitting position and behavioural transition (Jensen *et al.*, 1996), reduces feeding behaviour (de Jong *et al.*, 1999) and eating duration (Graves *et al.*, 1978). Merlot *et al.*, (2004) suggested that mixing young piglets is stressful but that animals develop behavioural strategies (increased behavioural desynchronisation from day 0 to day 2 in order to avoid conflicting encounters) to adapt to the situation. It was observed that dominant pigs had lower saliva cortisol levels than subordinate pigs, and it was speculated that this was due to the fact that winners are supposed to have more control over the situation than losers (Tuchscherer *et al.*, 1998) and that they should be less affected by social reorganisation than losers.

Gonyou *et al.*, (1998) observed that drinking, belly-nosing and chewing on objects all reached their peak between two and four weeks post-weaning. If these behaviours are indicative of an immediate response to stressful conditions, the same authors suggest that the most stressful period is several days or weeks after weaning. It is likely that early-weaned pigs develop a higher base-line of these behaviours, or a coping strategy, which is more dependent upon behavioural responses to whatever stressors exist in the growing/finishing environment. Also, individual variation in behaviour can be a result of either fluctuations in uncontrolled external or motivational factors or consistent individual specific reaction patterns (Jensen *et al.*, 1995).

The factors that have been described briefly in the above paragraphs are summarised in Figure 1.1. The failure to meet with these factors will lead to post-weaning stress of the piglets and to further depression of growth. Each of these factors will be analysed and the behavioural and production impact of them to the piglet will be identified.

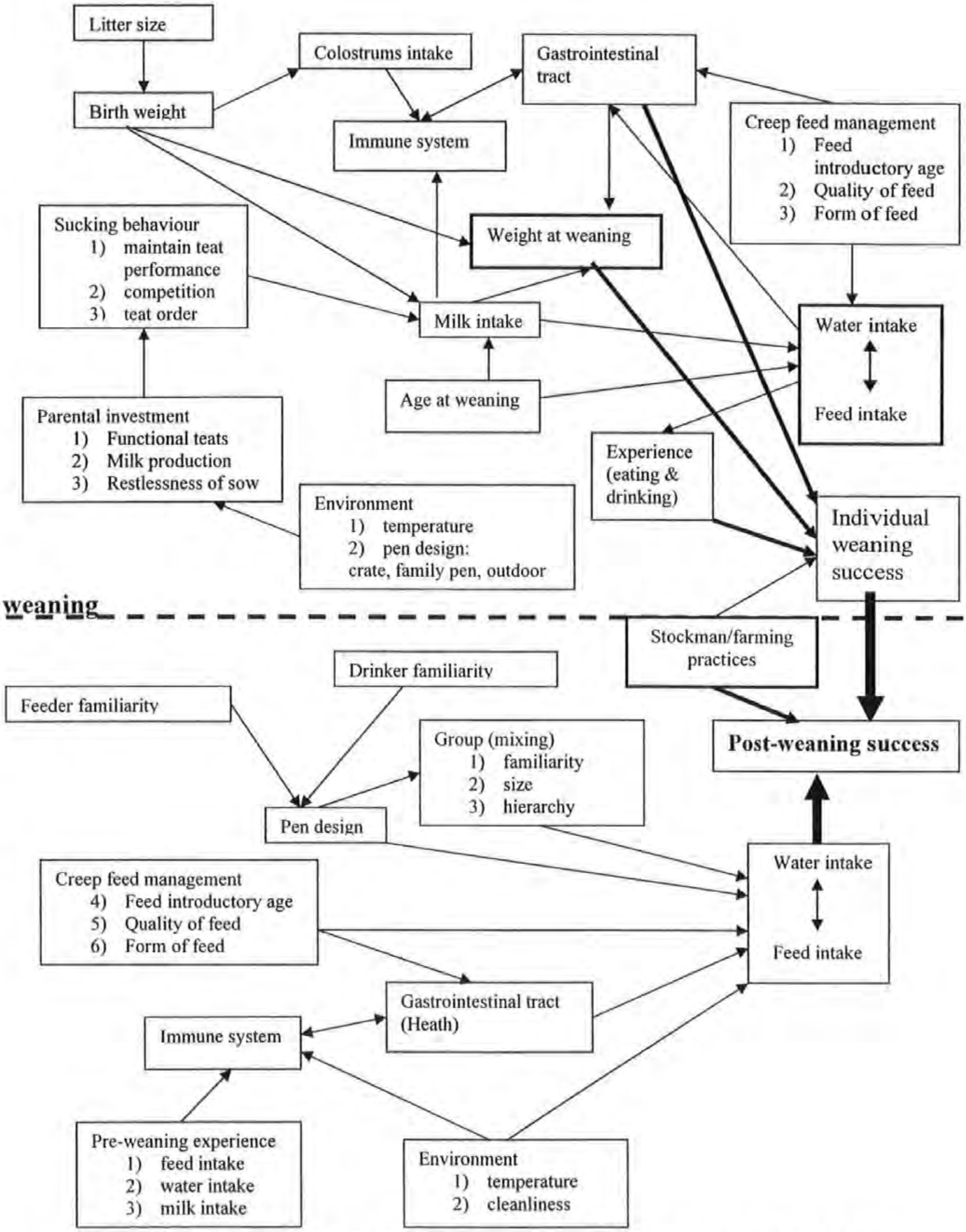


Figure 1.1 The effect of individual factors (environmental, immunological, behavioural and parental) to pre- and post-weaning success.

1.4 The effect of birth-weight and ways to tackle the variation.

1.4.1 Birth-weight

Producers have always known that heavier pigs at birth are heavier at weaning (McConnell *et al.*, 1987; Orihuela and Solano 1995) and that heavier (6.5 kg) pigs at weaning (21 to 25 days old) grow faster (233 *vs.* 136 g/day; P<0.05) after weaning than smaller (3.8 kg) pigs and, in most instances, are also heavier at slaughter (Lawlor *et al.*, 2002). However, other scientists did not record such an effect (Wolter and Ellis 2001).

While dead piglets are an obvious loss to swine producers, piglets with poor weight gains are also commercially important, because they tend to require extra facility costs, eat more, produce less pork, and complicate the management of the unit. Kavanagh *et al.*, (2002) stated that unless a diet of high nutrient density is offered post-weaning, the post-weaning benefits that arise from having a heavy pig at birth are lost.

An analysis of data from over 9,000 litters for litter weights and feed intakes found that average pig weights at weaning were higher for litter sizes between 6 and 10 than between sizes 1 and 4 or 11 and 22 (range: 5.06-50.9 kg, 4.45-4.78 kg, 4.94-4.27 kg, respectively P<0.01) (Koketsu and Dial 1998). Also, the same authors observed that piglets farrowed during summer were lighter at weaning than those farrowed during the autumn (4.59 *v.* 4.79 (s.e. 0.03) kg; P<0.01) independent of parity number.

To improve pre-weaning survival and decrease variation in weight gain, pig producers are often encouraged to reduce birth weight variation by: cross-fostering piglets between litters (English 1998), segregated early weaning (Kim *et al.*, 2001), split weaning (Zijlstra *et al.*, 1996) and teeth clipping (Robert *et al.*, 1995). The latter comprising part of the routine practices of many units during the first hours post-partum.

1.4.2 Manipulating the variation in weight-gain after birth.

1.4.2.1 Cross-fostering.

Fostering piglets from one litter to another is often carried out in swine production to equalise litter size and thus reduce pre-weaning mortality. English *et al.*, (1982) have suggested that cross-fostering is normally performed during the first 2 days after birth, before the teat order has been established, with little apparent impact on sow or piglets. With the introduction of segregated early weaning (SEW), cross-fostering has become widely used throughout lactation in order to meet the system's requirements for heavy piglets of highly uniform body weights at weaning (Robert and Martineau 2001).

Piglets suffer large pre-weaning mortality (10-25% in domestic herds) during the first days of life (Herpin *et al.*, 2001). The low-weight piglets are at much higher risk (Weary *et al.*, 1998) and this early loss of low-prospect progeny may be a case of adaptive litter size reduction (Fraser *et al.*, 1995). Low within-litter competition lead to a reduction of begging and improved milk utilisation (Dostalkova *et al.*, 2002).

The presence of 'alien' (cross-fostered) piglets in the litter resulted in increased fighting and squealing at the udder. As a result the sow become restless and terminated nursing by standing up or sitting before milk letdown (Robert and Martineau 2001). It has been observed that sows have more suckling periods after cross-fostering, but the proportion of suckling attempts resulting in milk letdown is reduced, mainly because the sow terminates suckling (Wattanakul *et al.*, 1998). Robert and Martineau (2001) also observed that fostered piglets had a high incidence of face and body scratches, which suggested that resident piglets were more often the offenders. The frequency of lacerations has been suggested by Robert *et al.*, (1999) to raise the problem of lesion contamination by opportunistic infectious agents, and may suggest that cross-fostering could be one of the risk factors involved in the development of skin diseases often diagnosed in SEW nurseries. Robert and Martineau (2001) report that fighting at the udder restricted the amount of milk ingested as 'alien' piglets were present at only 66% of nursings and increased the 'wandering-squealing' syndrome (Horrell 1982) which could have contributed to a loss of energy and to less time spent under the heat lamp conserving this energy.

Wattanakul *et al.*, (1998) concluded that increased competition had a much greater effect than unfamiliarity with the environment, as the cross-fostered piglets that performed as well as resident pigs on the day of mixing, when substituted into the litter were severely disadvantaged at the time they were added to the litter.

On the other hand, cross-fostering is also a labour cost practise, and can have negative effects such as the spread of infectious diseases (McCaw 2000) and increased piglet fighting when compared with non-fostered litters (Robert and Martineau 2001) but other workers reported no such negative effects (Milligan *et al.*, 2001). They suggested that cross-fostering overcomes the problem of birth weight variation and that this practise helped to reduce later variation in piglet weight, did not alter competitive behaviour, and had a tendency to improve pre-weaning survival.

1.4.2.2 Segregated Early Weaning (SEW)

Early-weaning management practices remove pigs from sows on average between 7 and 14 days of age and isolate them in a clean facility. SEW limits vertical disease transmission from dam to offspring, resulting in more efficient pigs, which spend less energy on immune system activity (White 1995; Kim *et al.*, 2001). Segregated early weaning (SEW) may result in improved feed efficiency and growth rate (Tang *et al.*, 1999; Hohenshell *et al.*, 2000a). Dunshea *et al.*, (2003) reports that even though it seems that during the immediate post-weaning period, pigs weaned at younger ages (14 d or less) do not grow as quickly as pigs weaned at approximately 3 weeks of age or more, early-weaned pigs can grow as well as, or even better than, conventionally weaned pigs when optimum conditions are provided. They also observed that early weaned piglets had higher P2 backfat depth at 23 weeks than pigs weaned at 28 days (13.1 *vs.* 10.9 mm, $P<0.009$). Among the challenges of SEW management is the provision of adequate nutritional support as the young pigs are abruptly switched from sow milk to dry feed (Nessmith *et al.*, 1997).

The study of Hohenshell *et al.*, (2000a) has also shown that most differences found between early-weaned (approximately 10d) and late-weaned pigs (approximately 30d) were evident soon after weaning, but they disappeared before slaughter.

1.4.2.3 Split weaning.

Split weaning might ameliorate the weaning transition for light-weight pigs and achieve an overall decrease in time to reach market weight (Zijlstra *et al.*, 1996). From day 14 to day 21, heavy split-weaned pigs (4.47 kg) had a weight gain similar to that of heavy pigs (4.19 kg) in the group to be weaned conventionally, which were still suckling, indicating that intake of milk replacer and starter diet was enough to support growth similar to that of suckled pigs. For the same period (day 14 to 21), Zijlstra *et al.*, (1996) reports that light split-weaned pigs had superior weight gains (349 *vs.* 250 (s.e. 15) g; P<0.01) compared with lightweight (5.68 *vs.* 4.56 kg; P<0.01) conventionally weaned pigs (both groups were suckling), indicating that growth of lightweight pigs in large litters was suppressed during suckling. 'Light' piglets (5.5 kg) in split weaned litters grew 61% faster (*P*<0.001) than their counterparts in control litters and were 15% heavier (*P*<0.01) at weaning. This was explained by 49% increase in milk intake (64 *vs.* 43 g/sucking *P*<0.001) (Pluske and Williams 1996b). The same authors observed that heavy piglets (7.0 kg) at day 22 of lactation remained heavier (22.0 *vs.* 19.3 (s.e.d. 0.95) kg; *P*<0.001) at 62 days of age irrespective of weaning management. If creep food intakes are high then it can be worthwhile to provide it and economical since 1 kg of creep feed consumed by a litter results in an increase in litter weaning weight of 1.14 kg (Kavanagh *et al.*, 2002). Also, high intakes of creep feed (600 g/pig) have been reported by English *et al.*, (1980) who managed to increase growth rate in the post-weaning period as they reduced litter size by split-weaning and resulted in an increase in weaning weight (Pluske and Williams 1996a).

1.4.2.4 Teeth-clipping.

A useful technique which has been used in order to improve the competitive ability of low-birth-weight piglets is selective tooth clipping (Robert *et al.*, 1995). Clipping of the 'eye' teeth (the deciduous canines and third incisors) is done routinely by many pig producers on the first day after birth in order to prevent the damage that these teeth may cause to litter-mates or the sow's udder while suckling (Robert *et al.*, 1995). Fraser and Thompson (1991) showed that when litters of 12 piglets had the 4 lighter litter-mates teeth either clipped or intact, those with intact teeth achieved greater weight gains and had fewer deaths, but this improvement was achieved largely at the expense of the heavier litter-mates. Robert *et al.*, (1995) states that the selective tooth-clipping can influence the distribution of benefits within a litter by giving an advantage to small piglets with intact teeth at the expense of their larger, treated littermates, and also, there is no overall reduction in mortality or increase in weight gain between treated and untreated litters.

1.5 The effect of suckling behaviour on pre- and post-weaning behaviour and growth performance of the piglets.

Gill and Thompson (1956) refer to suckling in the domestic pig as a more complex affair than in species that give birth to only one or two young at a time, such as cattle and sheep, and that a coordination of massaging of the udder and sucking of the teats is necessary before a brief period of milk ejection and flow. Whittemore and Fraser (1974) and Fraser (1980) described the whole process as consisting of five phases: i) gathering and finding teat position, ii) massaging the udder, iii) interspersed with periods of slow steady sucking which increasingly predominate, iv) culminating in 15-20 s of rapid sucking movements coinciding with milk ejection, and v) a return to alternating periods of massage and slow sucking after let-down. Horrell (1997) found that those five basic phases of suckling were the same in wild boar as in the domestic pig; clearly delineated and all specific features present.

The udder doesn't only function as a means of milk intake for the piglet. It is also a mechanism on which the piglet has to invest time and effort in order to make it more productive and also, has to be able to maintain its teat dominance via extensive fights throughout the course of the day. The function of the udder and the behaviour of the piglets observed around it, will be considered next.

1.5.1 Milk let-down.

Suckling in pigs is a highly structured behavioural interaction (Spinka and Algers 1995). Within the first 1-3 days of life, each piglet forms an attachment to one teat of its mother and sucks almost exclusively from that teat until weaning (Puppe and Tuchscherer 1999). Horrell (1997) observing a limited number of wild sows (n=2), found that individual teat preferences develop as strongly in wild boar as in the domestic pig. McBride (1963) found that 75% of piglets achieved specificity in the nursing order by 12 hours after farrowing. This behaviour is an advantage to the young because it reduces competition and fighting at the udder (de Passille *et al.*, 1988). The nursing session is initiated either by the piglets, which approach and begin to nuzzle the teats, or the sow that exposes her udder and begins to grunt rhythmically. After the sow assumes the lying nursing position, the piglets quickly arrange themselves at the udder, each occupying its allocated teat (Spinka and Algers 1995).

The typical posture of piglets during milk let-down (true sucking) is a rigid stance, with their ears back and their tails tightly curled (Worobec and Duncan 1997). The piglets first massage the udder with their snouts and after 1-3 min, this stimulation induces a sharp rise of oxytocin in the mother's blood. Spinka and Algers (1995) state that synchronously with oxytocin release, the grunting rate increases and probably in reaction to this auditory signal by the mother, the piglets switch from massaging to suckling on the teats with slow irregular jaw and tongue movements. Piglets switch to faster and more regular movements when the milk is ejected some 20 seconds later. Piglets are nursed at about 1 hr intervals during distinct nursing periods lasting several minutes, but the actual milk intake occurs only during 15-20 s of milk ejection period in the middle of nursing (Fraser 1980). Finally, the piglets resume massaging and may stimulate the udder for a period of up to 15 min before the sow abandons the nursing position or before they switch to other activities (Fraser 1984a; Jensen 1988). This nursing frequency is typical for suckling at any stage of lactation, in both domestic and wild (*Sus scrofa*) sows, except in the first few hours after parturition, during which time colostrum consumption is much less synchronised (de Passille *et al.*, 1989; Fraser and Rushen 1992).

Another worker has observed that the way suckling was initiated varied over the 24 hour period. During the day the piglets often started massaging the udder while the sow was standing, but during the night the piglets frequently slept by the udder and began suckling from there (Boe 1991). Earlier work characterised the final massaging as a scent-marking behaviour which helps the piglets to recognise their own teats in subsequent nursing periods (McBride 1963).

There is some evidence that a more intensive massage increases the amount of milk received in future nursings (Spinka and Algers 1995; Jensen *et al.*, 1998), although it is unclear whether the effect is central or local (Dostalkova *et al.*, 2002). Fraser (1984a) suggested that a large pig may massage its teat more vigorously before ejection, thus achieving a greater blood flow to the teat and thereby bringing more of the limited oxytocin to its own teat.

Massaging also consumes extra energy since piglets lose weight at a faster rate during the non-nutritive phase of the nursing than when resting (Noblet and Etienne 1986). Klaver *et al.*, (1981) calculated that the weight loss of a 4 day old piglet is about 0.5 g per min during suckling and massaging compared with about 0.1 g per min during resting.

Nursing is terminated by the sow in 30-50% of cases during week 1, whereas this proportion rises to 90-100% by the 4th week (Jensen and Recen 1989). Arey and Sancha (1996) compared the behaviour and productivity of 48 sows and their litters kept in farrowing crates (FC) or in a 'family pen' (Stolba and Wood-Gush 1984) system (FS). They observed that the occupancy of farrowing pens by FS sows fell from 92.5% on day 1 to 35.5% by day 28 in comparison with FC sows. Similar results obtained from Hotzel *et al.*, (2004) who were observing outdoor sows inside the hut in contrast to confined sows in crates.

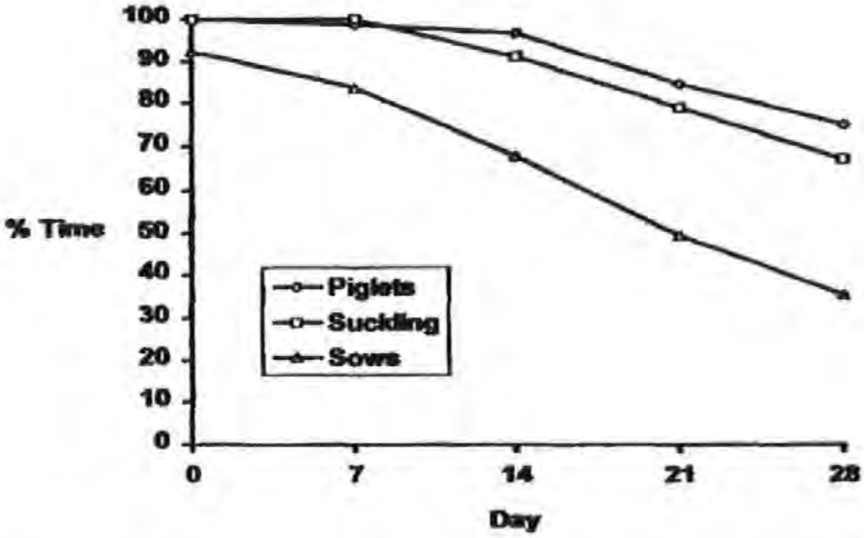


Figure 1.2 The proportion of time spent by the sows (FS) and piglets in the pen and the proportion of suckling which occurred in the pen in which the sow had farrowed (after Stolba and Wood-Gush (1984)).

The data in Figure 1.2 shows that the sows in the family system spent less time in the farrowing pens as the lactation progresses. Stolba and Wood-Gush (1984) report that between 10 and 14 days after farrowing, the sows observed to suckle their piglets outside the pens and this increased over time. In another study Whatson and Bertman (1980) observed that the sow prevents the piglets from lying against her udder within a fairly short space of time after most milk ejections. It has been suggested that the stimulation provided after milk ejection is not satisfying enough to cause the sow to continue lying with her udder available (Whatson and Bertman 1980; Boe 1991). The nursing periods get shorter from about 5-10 min to approximately 3 min by the 4^{th} week (Jensen 1988; Jensen and Recen 1989). Stolba and Wood-Gush (1984) suggested that maternal behaviour was improved in an enriched environment (14.9 *vs.* 0.3 stereotypes sow^{-1} h^{-1} ($P<0.05$)) as the animals showed less stress in a non-confined environment during lactation (Arellano *et al.*, 1992), and it would appear that this has a beneficial effect on productivity. The intervals between nursing increase with ongoing lactation (Jensen and Recen 1989) (Figure 1.3).

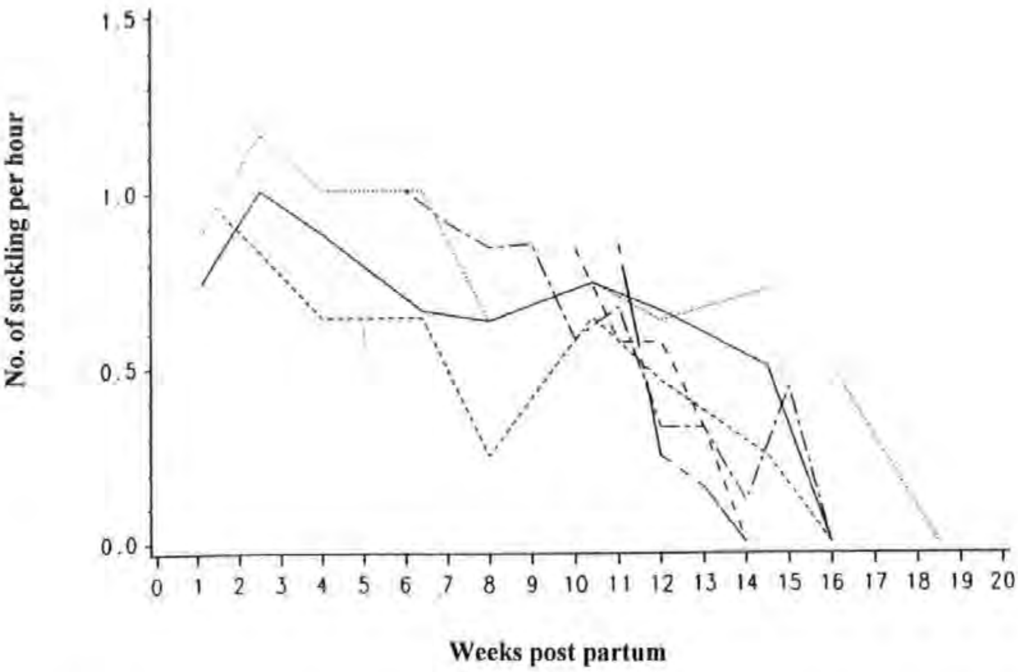


Figure 1.3 Average numbers of sucklings h^{-1} for six different lactations from five different sows. Each line represents the observations of one specific lactation (after Jensen and Recen (1989)).

Boe (1991) also found that sows with small litters maintained a higher number of nursings per day towards the tenth week, which obviously entailed a higher daily gain for the piglets even though the intake of dry feed consumed by the sow was lower. This seems reasonable as a smaller litter will demand less total investment and thus be less costly for the sow (Boe 1991).

Whatson and Bertman (1980) have observed that 27% of all nursings were found to be incomplete (did not result in the let-down of milk) with little difference between the grouped and individual sows. They have documented that incomplete nursings often occurred within 40 min of a complete nursing and increased the interval between successive complete nursings. The peak of incomplete nursings was observed to take place during the 2nd and 3rd week post-partum (Whatson and Bertman 1980).

1.5.2 Sucking to maintain teat-performance (the 'Begging' behaviour).

Non-nutritive pre-suckling massage of the sow's nipple determines the future availability of milk at that nipple in pigs (Boe and Jensen 1995). Jensen *et al.*, (1998) concluded that the intensity of massage (i.e. number of massage movements/min) is another important method for the piglet to stimulate milk production. Illmann *et al.*, (1998) suggests that additional massage on separate teats has little if any influence on milk production in subsequent nursings. However, it may reside in affecting the milk production in a systemic way, and possibly the effect is only discernible after a longer period later in lactation when nursings are less frequent and milk production has declined (Illmann *et al.*, 1998). Illmann *et al.*, (1998) also states that non-nutritive suckling can have different and probably more effect on free-ranging sows (Jensen and Recen 1989) or in specially designed pens (Boe 1991) when the sow is able to leave her piglets. In farrowing crates, many sows have been observed to remain in lateral recumbence for an 'unnaturally' long time after milk ejection as they don't have many options left to them. It is possible that the long lasting massage by piglets during regular nutritive nursing in crates already reaches the ceiling of the influence on milk production, and that additional massage during the non-nutritive nursing has no further effect (Illmann *et al.*, 1998).

In a study that included free-ranging domestic pigs weaned over 17 weeks (Jensen and Recen 1989) reported that the final massage, which is believed to increase the milk production, decreased during lactation, and there was a tendency for the pre-massage to increase.

During the rest of the nursing period each piglet noses, rubs and (non-nutritively) sucks its own teat. Non-nutritive suckling, where the infant is making nipple contact and sucking but without milk being transferred, is widespread, having been observed in most species in which suckling has been investigated (Newberry and Wood-Gush 1985; Boe and Jensen 1995; Spinka and Algers 1995).

The non-nutritive nursings may have other effects besides increasing milk output at a stage. The amount of teat massage performed by the piglets is related to the release of several hormones (prolactin, somatostatin, glucagon and vasoactive intestinal polypeptide) during nutritive nursing (Algers *et al.*, 1991). Furthermore, it has been shown that prolactin and somatotropin plasma concentrations increase following a non-nutritive nursing, although the levels are still lower than after a nutritive nursing (Rushen *et al.*, 1993). The increased prolactin concentrations during such suckles, can influence the production of such growth hormones and improve the sow's digestive efficiency without affecting quantity of milk produced (Algers *et al.*, 1991). This manipulation affects milk release (Bruckmeier 2001) and possibly also milk production (Jensen *et al.*, 1998), which enables a tactile form of begging to evolve. The intensity and duration of this teat massage ('begging behaviour') is enhanced if the piglets are hungry or are gaining weight too slowly (Spinka and Algers 1995) and it has been shown that young in lower condition beg more and parents provide more food in response to higher begging (Godfray 1991). Thus, begging carries honest information about the need of an individual young and parents use it to allocate care more efficiently. Yet because of the sibling competition, this honesty is only achieved at a cost: the begging itself consumes a substantial part of the energy provided by the food. In pigs, milk is transferred only during the fast suckling, regardless of the time spent in slow sucking, so the onset of fast sucking marks the onset of nutritive suckling (Dostalkova *et al.*, 2002).

In addition, some suckles may be primarily social rather than nutritive, because offspring often seek their mothers and suckle when distressed or alarmed. Therefore, it is likely that suckling satisfies emotional as well as nutritional needs (Carson and Wood-Gush 1983).

1.5.3 Suckling interval

Sow milk yield is an important factor limiting piglet growth up to weaning (Zijlstra *et al.*, 1996; Puppe and Tuchscherer 2000) . However, the majority of experiments to date have revealed that milk production is relatively insensitive to manipulation of the management and nutritional strategies for sows. In contrast, the suckling demand imposed by the number (Auldist *et al.*, 1998) and size (King *et al.*, 1997) of piglets in a litter can have a major influence on milk yield. The increased sow milk yield associated with a larger litter is mainly a function of an increased number of functional glands, whereas the increased milk yield in response to heavier piglets is associated with increased production per gland. Milk production from individual glands may also be influenced by suckling frequency (Auldist *et al.*, 2000). Spinka and Algers (1995) did not detect any relationship between preceding milk intake or weight gain and subsequent final massage during the first 2 days post-partum.

The removal of milk from the mammary gland is of the utmost importance for the maintenance of milk secretion (Auldist *et al.*, 2000). Secretion of milk that is available to the piglet is almost complete within 35 min after the preceding suckling bout (Spinka *et al.*, 1997). Thus, piglets will receive a similar amount of milk at various suckling intervals above approximately 35 min. Piglets suckling less frequently will collect this standard dose of milk less frequently and hence have a lower daily milk intake (Auldist *et al.*, 2000). Algers *et al.*, (1990) reports that the fewer the piglets stimulating the udder, the longer it takes to induce milk release. The relatively long initial massage gives all piglets time to assemble at the udder, and may thus prevent milk transfers to only a few of the litter. As a response to the long lasting initial massage, milk flow occurs (Algers *et al.*, 1990). As the sow does not have teat cisternae, both the increased intramammary pressure and active pumping by the piglet jaws and tongue (German *et al.*, 1992) are necessary for the milk to be extracted. During most of the milk let down period, each piglet is occupied in extracting milk from its own teat (de Passille *et al.*, 1988).

Suckling frequencies differ among sows (Table 1.3); the typical suckling interval varies from 30 to 70 min for individual sows during the first week of lactation (Jensen *et al.*, 1991). Spinka *et al.*, (1997) observed that sows nursing at short intervals (35 min) during the first 3 days post-partum, had more nursings without milk ejection, but they gave 27% more milk (755 *v.* 595 g/24h; $P<0.05$) and their litters gained 44% more weight (198 *v.* 135 g/24h; $P<0.01$) during the experimental 24 h than sows nursing at long intervals (70 min). A decrease in suckling interval from 44.9 to 34.9 min, tended to increase milk yield by 14% during early lactation (d 10-14) (Auldist *et al.*, 2000). The same study shows that in late lactation (d 24-28) a 9% decrease in suckling interval was accompanied by a difference in milk yield of +4%.

Table 1.3 Estimates of intra-suckling intervals (after Brooks and Tsourgiannis (2003))

Interval (minutes)	Day of lactation	Reference
40 to 45	1 to 13	(Arey and Sancha 1996)
40 to 60	1 to 14	(Gustafsson *et al.*, 1999)
29 to 78	1 to 42	(Newberry and Wood-Gush 1985)
76	3	(Spinka *et al.*, 1997)
51and 63 (range 26-96)	6 to 51	(Barber *et al.*, 1955)
44 range (21 to 92)	7 to 28	(Ellendorff *et al.*, 1982)
48 to 52	10 to 24	(Auldist and King 1995)
52 (range 42 to 68)	14 to 54	(Wechsler and Brodman 1996)
53± 9.7	First 48 h	(Horrell 1997)
42± 2.4	6 to 8	
91± 6.7	14-28	
86± 21.3	42-49	
64	14	(Boe 1991)
72	28	
102	42	
182	56	
334	70	

The period from around four to around eight weeks of age can be regarded as an integration and learning phase in the piglet's behavioural development. Despite being part of the group, there is little mixing or interaction with other pigs before four weeks of age (Jensen 1986). The family affiliations loosen between six and eight weeks, with piglets increasingly associating with pigs in the group that are not littermates (Jensen 1995). There is considerable variation in the relationship between sows and individual pigs in their litter. The proportion of sucklings at which one or more piglets of the litter were missing increased up to 12 weeks post-partum. The pigs that missed sucklings were within the lighter half of litters and although near the sow did not seem to take any interest in suckling. The average age for complete weaning of litters appears to be around 17 weeks of age (Jensen and Recen 1989; Petersen 1994). However, there were large variations between pigs within litters (range 15.6 to 19.5). This implies that piglets suckling less productive teats invest less time and effort in trying to obtain nutrients from their dam and increasingly adopt an independent foraging strategy. From around four weeks onwards, piglets become members of a larger matriarchal group and will forage alongside the adults within that group (integration/learning phase).

1.5.4 Nipple position – teat order.

The amount of milk released can vary at each nipple (Fraser 1984b). Piglets sucking anterior nipples receive more milk than posterior end sucklers for no extra time spent suckling (Figure 1.4) (Fraser 1984b; Newberry and Wood-Gush 1985; Pluske and Williams 1996b).

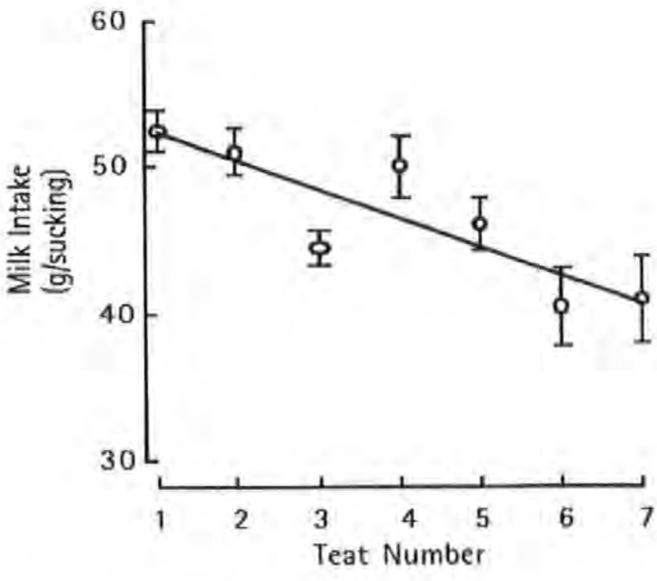


Figure 1.4 The relationship between average milk intake of piglets prior to split weaning (y-axis) and teats numbered one to seven from the anterior to the posterior end of the udder ($y=-1.929x + 54.214$; $R^2= 0.757$; $P<0.001$) (from Pluske and Williams (1996b)).

It has been measured that anterior teats give 3 to 5 times more colostrum during the initial minutes of milking, with a nearly monotonic decline from front to rear (Fraser 1984b). Fraser (1984a) also states that the piglets show a clear preference for the more anterior teats, at least during the first hours of life when specific associations are being formed. The heavier piglets usually win possession and they show particularly large weight gains because of having the anterior position. Scheel *et al.*, (1977) suggests that anterior teats are in a safer region than those near the dam's hind legs; piglets suckling front teats are thus less likely to be trampled if the sow should rise. Orihuela and Solano (1995) includes a number of other factors which can probably explain the preference for the anterior teats. They suggest that piglets may be choosing functional teats, or those closest to the sow's grunts or they may prefer teats where suckling stimulates the sow to grunt. Also, piglets may tend to avoid smaller, conical teats, which are more common at the posterior end and show a preference for the anterior teats which have a better milk flow during the first hours after farrowing.

In another study, the piglet's typical teat pair number (numbered 1-7, anterior to posterior) had a significant negative within-litter correlation with weight gain in the suckling period ($P<0.05$) and in the early creep feeding period ($P<0.001$) but not with feed consumption, birth weight or any other measure of weight gain (Pajor *et al.*, 1991). The same workers found that teat number explained no significant amount of variation in any measure of weight gain or any other variable, taking into account the variation attributable to litter and birth weight. Mason *et al.*, (2003) provided evidence that piglets of heavier relative weight were found to be more likely to use the anterior teats. Neither relative weight nor teat preference were correlated to consistency of suckling position. Their results are summarised in Table 1.4.

Table 1.4 Pearson correlation coefficients[a] between behavioural and physiological measures during the pre-weaning period (after Mason *et al.*, (2003)).

Behaviours	Relative weight	Teat preference[b]	Teat consistency[c]
(a)Pre-weaning period of observations			
Teat preference	0.352***		
Teat consistency	0.002	0.075	
High vocalisation	-0.296**	-0.141	0.204
Low vocalisation	-0.023	-0.157	-0.084
Aggression	0.260*	0.218*	-0.090
Nosing littermate	0.379***	0.088	-0.084
Chew littermate	0.142	0.135	0.064
Belly nosing	0.106	0.132	-0.035
Cortisol (ng/nl)	0.072	-0.083	-0.149
(b) Post-weaning period of observations			
Teat preference	0.419***		
Teat consistency	0.081	-	
High vocalisation	-0.312**	-0.208	-0.000
Low vocalisation	0.331**	0.162	0.018
Aggression	0.295**	0.361***	-0.088
Nosing littermate	0.208	0.182	-0.115
Chew littermate	0.163	0.019	-0.044
Belly nosing	-0.115	-0.214	-0.146
Cortisol (ng/nl)	0.058	0.227	-0.159

For (a) behaviours, relative weight, teat preference and consistency are measured during the pre-weaning period.
For (b) behaviours and relative weight are measured during the post-weaning period with teat preference and consistency being measured during the pre-weaning period.
[a]Correlations are based on individual residuals, (n=79).
[b]Teat preference is recorded on as (1) posterior to (7) anterior.
[c]Consistency of teat position is recorded as 0% stable (inconsistent) to 100% stable (consistent).
**P<0.05, **P<0.001, ***P<0.001*

Algers *et al.*, (1990) found that eating and drinking were negatively correlated with teat quality. They also concluded that the piglets occupying more productive teats fulfilled a larger part of their nutritional demands with milk than their litter mates. It has been assumed that these piglets were not frequently involved in fights at the feeder before weaning and thus did not effectively learn to compete for food with their litter mates (Algers *et al.*, 1990) (Figure 1.5). Pajor *et al.*, (1991) observed that larger piglets consumed more solid food pre-weaning (from day 10 to day 28-weaning).

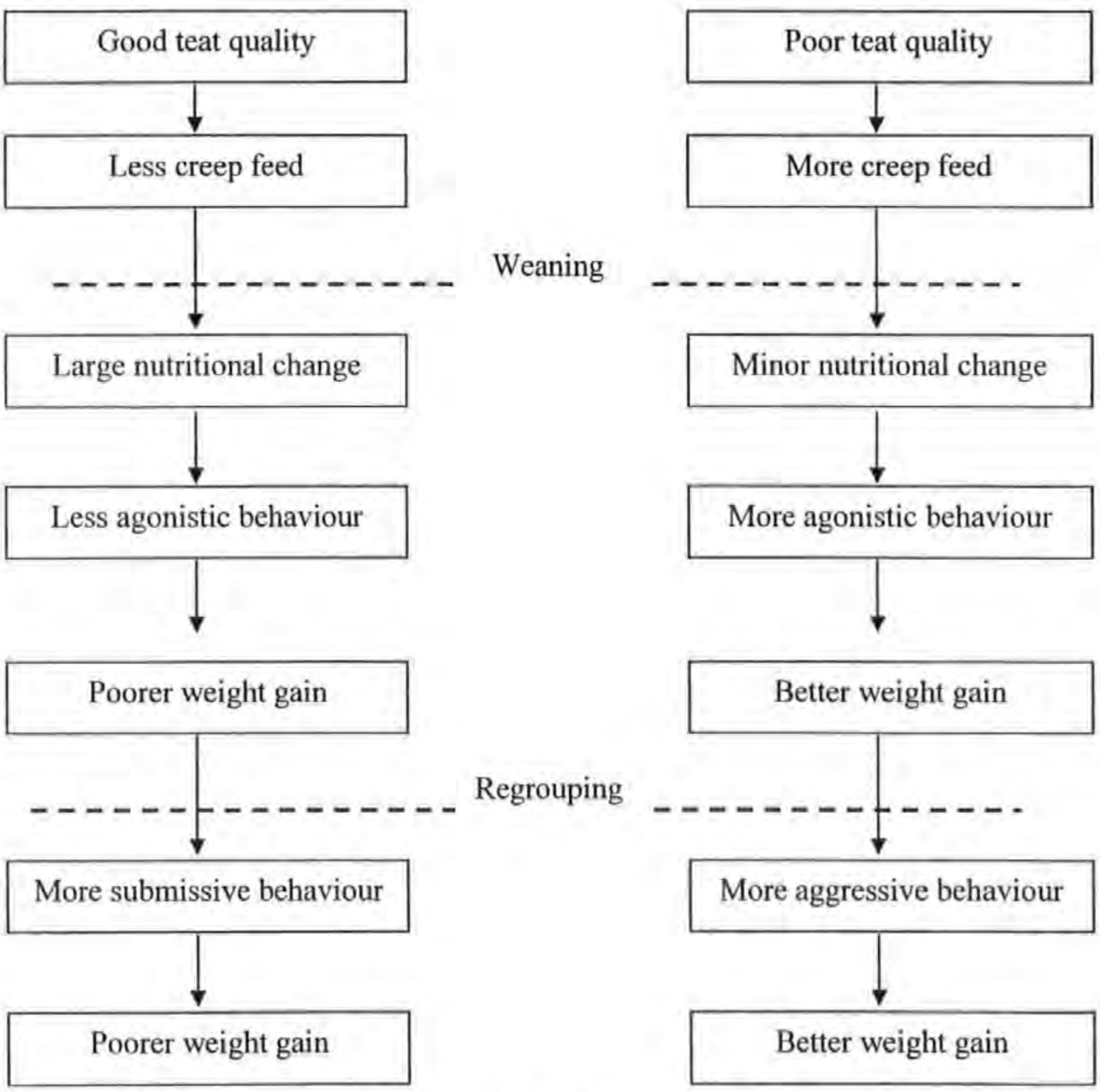


Figure 1.5 A model of teat quality sequels to weaned and regrouped pigs (after Algers *et al.*, (1990)).

Boe and Jensen (1995) found no significant differences when the behaviour and weight gain of piglets occupying middle teats were compared with those on anterior and posterior teats, but there were trends which appeared to be mutually consistent. Piglets occupying the middle teats had a higher proportion of sucklings where they accomplished the whole post-massage phase than piglets preferring anterior or posterior teats (84 ± 18% *vs.* 77 ± 22%, NS). Also, piglets that were occupying the udder in the middle tended to have a lower but non-significant weight gain up to week 3 (4.9 ± 1.7 vs. 5.1 ± 1.2 kg) but a higher gain from week 4 to 8 (10.4 ± 3.4 vs. 9.5 ± 3.4 kg). Delumeau and Meunier-Salaun (1995) did not observe any relationship between the teat order and the creep feeding activity in pigs weaned at 28 days.

Pluske and Williams (1996b) report that heavy piglets in control and split-weaned litters occupied predominantly the first 2 pairs of anterior teats, with the percentage occupation of light piglets on these 2 teat pairs averaging 12.6 and 43.2% respectively. Light' piglets in split-weaned litters grew 61% faster (*P* less than or equal to 0.001) than their counterparts in control litters and were 15% heavier ($P < 0.01$) at weaning. This was explained by a 49% increase in milk intake (64 *v*. 43 g/sucking, *P* less than or equal to 0.001). They have observed that increased milk intake was due to multiple teat-swapping with an associated longer duration of sucking during letdown.

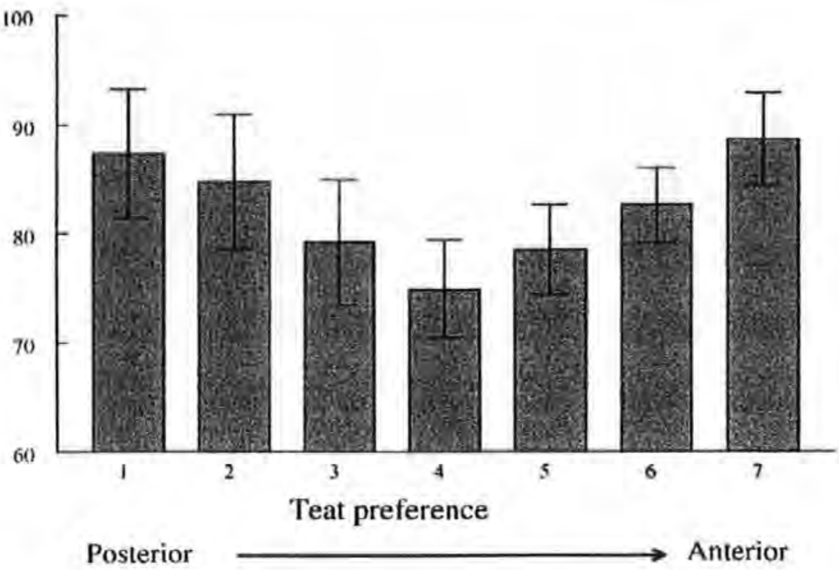


Figure 1.6 The relationship between teat preference (1=posterior, 7=anterior) and teat consistency (percentage of suckling on preferred teat pair). Error bars indicate the S.E. (after Mason *et al.*, (2003)).

Mason *et al.*, (2003) have shown that the relationship between consistency (% of suckling on preferred teat pair) and teat preference was not linear but it was quadratic (R^2=12.9%, $F_{2,76}$=5.64, P<0.005). Therefore, the change in consistency with increasing teat preference is U-shaped (Figure 1.6), with piglets at the most anterior and posterior teats showing greatest consistency. They conclude that out of these two aspects of suckling style, it appears that teat preference is a better correlate of behaviour around weaning.

1.5.6 Competition at the udder.

A sow nursing her litter of piglets is such a picture of peace and fecundity that it was often used as a decorative motif in medieval churches (Fraser *et al.*, 1995). In reality, domestic piglets fight vigorously with their litter-mates for access to the sow's teats during the first hours after birth, and this competition plays a major role in neonatal deaths and also, in piglets' later growth. Such an intense neonatal competition is usual among mammals, but even more remarkable is the pig's unique dentition which allows the newborn to wound the faces of its litter-mates during disputes over teats. Frank *et al.,* (1991) notes that the piglets are born with the four deciduous canines and four deciduous third incisors fully erupted at birth and angling slightly outward from the jaw. Furthermore, the anterior portion of the jaw is rotated at birth such that the third incisor temporarily assumes a canine-like orientation, thus giving the piglet eight canine-like teeth which can deliver a damaging sideward bite to the faces of litter-mates during competition at the udder. In the clutches of more than one young, there is also 'sibling competition' with each offspring striving to get a larger share by occupying any part of the udder for longer period of time than its nest-mates (Mock and Parker 1998).

There are two distinct types of piglet competition before weaning according to Fraser (1990). In direct, aggressive competition for teats, occurring primarily in the first few days after birth, most piglets establish 'ownership' of a particular teat while others either die or survive by suckling opportunistically (de Passille *et al.,* 1988). This direct competition may be reflected by the frequency of fighting at the udder, the frequency of failing to obtain milk during suckling, and the degree to which piglets return consistently to the same teats. In indirect competition, larger piglets tend to gain more weight than their litter, likely by stimulating and/or draining their teats more effectively and thus appropriating a larger proportion of hormones and nutrients involved in milk production to their respective teats (Algers *et al.,* 1991).

Milligan *et al.,* (2001) states that it is expected that piglets will persist in competing for access to a functional teat even when they have a substantial disadvantage in body weight or fighting ability. Weary *et al.,* (1996) states that piglets by being present at a teat at the beginning of the nursing may gain a resident's advantage and thus improve their likelihood of retaining access when the milk ejection occurs. Data from De Passille and Rushen (1989) shows that a piglet with a teat already in its mouth is more likely to win contests for that teat. Hence, a starving piglet may accept a greater risk of being crushed in return for these or other benefits associated with proximity to the sow (Weary *et al.*, 1996).

Robert *et al.*, (1995) observed that intact 'eye' teeth may also contribute to 'indirect' piglet competition whereby piglets stimulate their own teats to greater milk production, partly at the expense of the teats, by massaging and draining the teats effectively. Fraser, (1979) and Thomson and Fraser (1986) described how intact teeth may help a smaller pig to be more competitive, to stimulate its teat more effectively and by allowing the animal to avoid being pushed away by littermates.

1.6 The importance of water intake on pre- and post-weaning behaviour and performance.

Water, is one of the more critical nutrients and apart from water required to support the growth of muscle tissue and clear wastes from the body, young pigs require water to replace that lost by evaporation and respiration (King and Pluske 2003).

Water is the nutrient that is required in the largest quantity by swine, and it fulfils a number of physiological functions necessary for life. It is a major structural element giving form to the body through cell turgidity, and it also plays a crucial role in temperature regulation (Thacker 2001). The need to maintain water homeostasis is essential to all life, since failure to maintain a constant balance of water across cell membranes disturbs many metabolic and physiological functions and ultimately leads to death (Patience and Zijlstra 2001). On the other hand Fraser *et al.,* (1993) reports that water consumption is likely to be only important when piglets are subjected to very warm environments or in a piglet suffering diarrhoea. The water content of a pig varies with its age. Water accounts for as much as 82% of the empty body weight (whole body weight less gastrointestinal tract contents) in the 1.5 kg, neonatal pig and declines to 53% in the 90 kg, market hog (Shields *et al.,* 1983).

Some pig producers provide supplementary water for piglets from birth, others begin supplying water at a later age, and others provide no supplementary water before weaning at 3 to 4 weeks of age (Fraser *et al.,* 1993). In the latter case, it was observed by the author that some piglets learned to climb up the farrowing crate and were drinking from the sow's nipple drinker 0.6m above the floor. This variety of practices reflects the lack of consensus on whether supplementary water is of benefit to suckling piglets.

It seems logical that a piglet on an all-milk diet will have no need for additional water, and in most cases this is true. However, if, a piglet is uncompetitive and fails to establish ownership of a teat, or if the sow produces little milk in the first days after farrowing, the young piglets are likely to be severely malnourished (Fraser *et al.,* 1993). Data from these authors show that piglets show an unusually strong interest to water when the litters obtain relatively little milk from the sow in the early lactation.

Swine obtain water from three main sources: (1) water that is consumed (i.e., drinking water); (2) water that is a natural component of feedstuffs; and (3) metabolic water produced from the breakdown of the carbohydrates, fats and proteins contained in feed ingredients (Thacker 2001). The oxidation of 1 kg of fat, carbohydrate, or protein produces 1190, 560, or 450 g of water respectively (Burrin 2001).

Domestic pigs weaned at 21 days or less will have been used to having both their hunger and their thirst satisfied by the sow's milk. When weaned these piglets have to learn to distinguish between the physiological drives of hunger and thirst. They also have to learn how to satisfy these drives by consuming water and solid food. Lack of familiarity with food and water means that it may take some time for the pig to learn how to satisfy its requirements and maintain its homeostatic balance. Some years ago Brooks *et al.*,(1984) reported a study demonstrating that in the immediate post-weaning period, piglets consumed water rather than eating food (Figure 1.7).

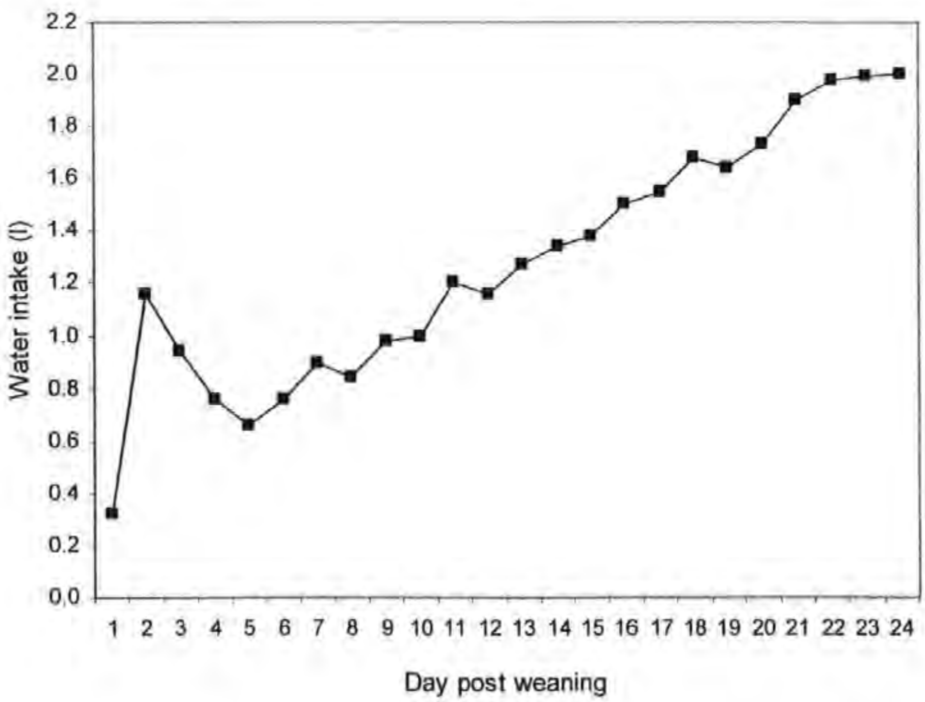


Figure 1.7 Water intake (litres per pig per day) of piglets weaned at 21 days of age. (Brooks *et al.*, 1984).

Gill (1989) showed that it could take more than a week for the pig to restore its daily fluid intake to the equivalent of that on the day before weaning. Thus the pig is seriously dehydrated for a prolonged period of time. Therefore, it is very important for the weaned pig to learn to locate the water. Piglets may find some difficulty identifying nipple drinkers as a supply of water. However, there is little evidence that providing waterers that drip encourages water consumption (Ogunbameru *et al.*, 1991). Providing readily available water in a bowl has been shown to encourage water consumption and increase feed intake (English *et al.*, 1981) at least in the initial period after weaning.

One nipple drinker should be provided for every 10-15 pigs and the height of the drinker should be adjusted to that of the pig's back (Madec *et al.*, 2003). However, if bowls are used, their management is critical as fouling may reduce the palatability and consumption of water (Phillips and Phillips 1999). Many UK producers are now using turkey drinkers to water newly weaned pigs. They claim that these drinkers encourage water consumption because the suspended drinker attracts the attention of the piglet and the free water surface encourages exploration and subsequent consumption. Although there appears to be no research data to support these claims, performance on commercial units has been improved by the use of this type of drinker in the immediate post-weaning period. Table 1.5 represents differences in daily performances which recorded on piglets that provided with water from five different drinker types. It was identified that Arato 76 nipple drinker was the only type of drinker that could have a significant impact on the daily gain of the weaned piglet ($P<0.05$) discouraging at the same time higher water losses from spillage.

Table 1.5 Water use by weaned piglets from 3 to 6 weeks of age, provided with water from five different drinker types (after Gill (1989)).

Drinker type	Daily gain (g)	Water to feed ratio (l/kg)	Water to weight ratio (l/kg LW)
Mono-flo nipple	199[b]	5.32	0.23
Arato 76 nipple	260[a]	3.23	0.13
Lubing bite type I	213[b]	3.68	0.12
Lubing bite type II	221[b]	2.90	0.13
Alvin bowl	224[ab]	3.49	0.14

a, b Means with different superscript are significantly different (P<0.05)

Drinkers placed at the incorrect height and angle or in an inappropriate part of the pen will inhibit intake. Building designs that provide a warm kennelled area for sleeping and a cooler (cold) area where the pigs feed, drink and eliminate are particularly problematic. The necessity to leave the comfort of the litter in a warm environment and go to a colder area to feed or drink will inhibit these behaviours. There is very limited data on the effects of water temperature on consumption, but the limited information that is available indicates that, as might be expected, warm water encourages consumption in cold environmental conditions and cold water encourages consumption at high ambient temperatures (Standing Committee on Agriculture - Pig Subcommittee 1987).

In the weaned pig, the rate and velocity of the water delivered by the drinker affects feed intake and performance (Table 1.6). Restricting the flow rate of nipple drinkers significantly affected both water and food intake with consequent effects on the performance of pigs weaned at 21 days of age (Barber *et al.*, 1989). The interesting observation in this study was that pigs given drinkers with low flow rates would not increase the amount of time that they spent drinking in order to optimise their intake. In a study involving somewhat older pigs, drinking times were extended, but they still did not increase the time spent drinking sufficiently to compensate for the restricted intake (Nienaber and Hahn 1984). In another study, increasing water flow rate from 70 to 700 ml/min did not increase the performance of pigs weaned at 28 days of age (Celis 1996). In the study of Barber *et al.*,(1989) pigs provided with water at the lowest flow rate (175 ml/minute, Table 1.6) spent only 268 seconds per day drinking. This is not dissimilar to the 290 seconds per day that they would have spent actively drinking milk while being suckled by the sow (milk ejection per suckling event =10-20 seconds; nursings per day = 25-29 at 3 weeks lactation). These results suggest a degree of activity scheduling by the pig, once again conditioned by the behavioural patterns imposed by the sow during suckling, which becomes less stringent as the animal becomes more familiar with food and water.

Table 1.6 The effects of water delivery rate on the voluntary food intake and water use of weaned pigs (after Barber *et al.*,(1989)).

	Water delivery rate (ml/ minute)				
	175	350	450	700	SE_d
Daily feed intake (g)	303^c	323^b	341^a	347^a	3.68
Daily gain (g)	210^c	235^b	250^a	247^a	5.57
FCR	1.48	1.39	1.37	1.42	0.03
Daily water used (l)	0.78^d	1.04^c	1.32^b	1.63^a	0.01
Time spent drinking (sec./d)	268^b	176^a	175^a	139^a	14.4

[a, b, c, d] *Means with different superscript are significantly different (P<0.05)*

It is clear from the above (Table 1.6) that the amount of food that the piglet will eat is determined by the amount of water that it consumes and not the reverse. Therefore, strategies that increase water consumption may have a positive effect on feed intake. Where water has a poor taste the addition of flavourings or sweeteners may encourage greater water consumption. However, if the water has good taste characteristics, the addition of a flavour or sweetener may encourage over consumption of water to the detriment of feed intake (Table 1.7). Barber (1992) offered weaned pigs water containing two sweetener/flavour products from nipple drinkers for the first three days post-weaning and found that it increased the average number of visits to the drinker in the first hour post weaning from 4 to 10 but did not significantly affect the number of visits made subsequently. Therefore, where facilities exist to make additions to the water it may be desirable to use a product of this type on the day of weaning to help the pigs locate and start using the water supply.

Table 1.7 Effect on water and feed intake of including a sweetener in the drinking water of 21 day old weaners for the first three days after weaning (Barber 1992).

	Control	Palasweet™	Palasweet Plus™	SE_M
Water intake (L/pig)				
Days 1-3	1.23^a	1.63^b	1.65^b	0.09
Days 4-7	1.99^a	2.25^{ab}	2.62^b	0.12
Days 8-16	6.99	7.30	7.51	0.39
Feed intake (g/pig)				
Days 1-3	414^a	314^b	283^b	21
Days 4-7	721	728	691	34
Days 8-16	2580	2214	2434	112

$^{a, b}$ *Means with the same superscript are not significantly different (P>0.05)*

Maenz *et al.*, (1994) agreed with McLeese *et al.*, (1992) that water intake was lowest during day 3 to 7 post-weaning a period that corresponded to peak scouring. Maenz *et al.*,(1994) also found that water intake had no correlation with scour scores, suggesting that fluid loss due to scouring was not sufficient to induce a compensatory increase in water consumption. The fact that there is a positive correlation between water consumption and feed intake, fails to support the view that pigs may consume excessive quantities of water immediately post-weaning to achieve some sense of satiety, due to the fact that feed intake is low (Maenz *et al.,* 1994).

1.7 The pre- and post-weaning feeding behaviour of the piglet.

The pig is an opportunistic feeder and is primarily herbivorous (Baber and Coblenz 1987). Ninety percent of the diet of the wild pig is vegetable matter, of which 50% comprises seeds and fruits (Spitz 1986). The remaining 10% of the diet comprises ground-dwelling insects, molluscs and earthworms. Consequently, when the wild piglet starts taking solid food, that food will have a dry matter content of between 15 and 30%.

The consumption of supplementary solid 'creep feed' before weaning is thought to prepare piglets for a solid, post-weaning diet, and thus promote a more successful adjustment to weaning, even when weaning is as early as 4 weeks of age. However, the evidence for this benefit is rather sparse, and consists mainly of studies done at a whole-litter level (English *et al.,* 1980). Piglets' feed level accounted for only 1% (Pajor *et al.,* 1991), 3% or 2% (Appleby *et al.,* 1991; Appleby *et al.,* 1992) of variation in weight gains during the first 2 weeks after weaning, after litter differences and the effect of antecedent variables (birth weight and early weight gains) had been taken into account.

Fraser *et al.,* (1994) states that the above studies cast a doubt on how effectively creep feed consumption prepares the 4 week old piglet for weaning as they were using a low-cost creep starter diet containing 25% soybean meal and although these diets are commonly used, are not easily digested by the 3 to 4 week old piglet. The same authors suggested that with a diet well suited to the young piglet, creep feed intake might show less extreme variation and a clearer relationship with performance after weaning. It has been shown that piglets fed a 'high quality' medicated commercial diet without soybean meal, consumed 2 and 3 times more ($P<0.05$) creep feed during weeks 3 and 4 respectively, tended to gain more during the week pre-weaning (263 *vs.* 232, $P<0.10$) and gained more weight in the 2nd week after weaning (week 6, 463 *vs.* 315, $P<0.01$) than piglets fed a 'low complexity' diet based on corn, barley and soybean meal (Fraser *et al.*, 1994). Regardless of dietary treatment (high-quality *vs.* multiphase starter feeding program), pigs suffered post weaning growth retardation and used body fat as an energy source during the first week after weaning (21 days) and growth priority was observed to be given to growth deposition (Whang *et al.*, 2000). Growth compensation was achieved when adequate feeding was provided in the growing finishing period.

Edge *et al.*, (2000) after manipulating the physical form of the pre- and post-weaning diet with regard to pellet size (1.8 *vs.* 2.4 *vs.* 5.0 mm), observed that presentation of the diet can attract the piglet to the feeder but does not improve feed intake.

Special diets and management schemes have been developed to overcome nutritional problems associated with early weaning. Diets containing milk proteins were developed because non-milk proteins cause digestive disorders (Zijlstra *et al.*, 1996). Systems using liquid diets have demonstrated pig growth performance comparable to suckled pigs. However, liquid diets can be difficult to handle under practical conditions (Zijlstra *et al.*, 1996).

Williams (2003) concluded that supplementary feeding while piglets are suckling can stimulate weaning weight if the food is offered in a liquid form early in life. When the creep diet is offered in dry form, it is likely to be of value where piglets are weaned at 4 or 5 weeks of age.

Laitat *et al.*, (1999a) observed that pigs need more time to consume meal than to eat pellets post-weaning (20.0 *vs.* 18.2 hr/day occupation time of feeders by 30 pigs; $P<0.01$) and concluded that the number of pigs per feeder has to be adapted to the food presentation.

Feeding behaviour is an area for research which truly links the nutritional and behavioural science (Nielsen 1999). Different emphasis may be given to different aspects of feeding behaviour depending on the researchers' field of expertise and interest, but the measurements used by both disciplines, yet with different focus, are those describing the time course of food intake. In the short-term, these are meal size, frequency and duration, and the daily measures include daily food intake and time spent feeding per day. A feeding pattern can be seen as having three parameters: meal frequency, meal size, and meal duration (Nielsen 1999). These parameters differ between animals of the same species, age and size, when they are observed under different housing and management conditions/practices, or when they are under stress.

The factors that influence pre-weaning feed intake will be analysed and their immediate effect on post-weaning performance will be considered at different weaning ages.

1.7.1 Pre-weaning feed intake (FI).

Pigs are known to be opportunistic animals that spend a lot of time investigating their surroundings. It has been observed that free-ranging piglets started to perform a grazing behaviour as they start to eat solid food (Petersen 1994). Pluske *et al.*, (1995) reported that creep feed consumption pre-weaning is highly variable and can contribute between 0 and 17% of energy intake.

It would appear that while the sow is available as a provider of nutrients, the piglet concentrates its efforts on stimulating the sow to suckle more frequently and provide more milk, rather than utilising other available sources of nutrients to maximise its feed intake. This is demonstrated by the data of Boe and Jensen (1995) (Figure 1.8). In their study piglets continued to suckle sows for eight weeks. The intake of creep feed by individual pigs ranged between 0-437 g/d at four weeks of age and 0-1571 g/d at eight weeks of age. The range in weight of piglets at eight weeks of age (range 6.3-26.6; mean 17.7) reflected the wide difference in nutrient intake.

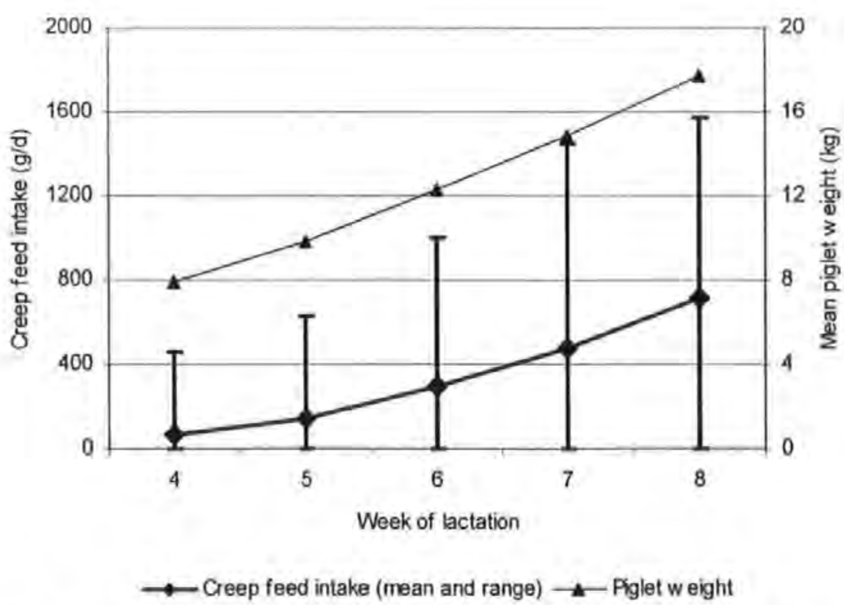


Figure 1.8 Variation in the creep feed intake of individual pigs during weeks 4-8 of lactation. N.B. the bars represent the range of individual pig intake at each sampling point (after Boe and Jensen (1995)).

Mendl *et al.*, (1997) have shown that domestic pigs have well-developed spatial memory abilities, but there are some piglets that can show a failure to recognise and master unfamiliar food sources (Delumeau and Meunier-Salaun 1995). Wood-Gush *et al.*, (1990) noted that in the wild, spatial memory would be of value to pigs in a number of contexts including relocating nest and wallow sites, and keeping track of the locations of productive food patches. Mendl *et al.*, (1997) observed that piglets in relocation trials, found food using fewer area visits than expected by chance, indicating that they could remember the location of food across both 10-min and 2-h retention intervals.

Piglets' pre-weaning experiences are likely to be important factors in their ability to adapt to the post weaning environment (Cox and Cooper 2000). Thus, they have observed that a piglet that has experienced the relative freedom of an outdoor system for the first 3 to 4 weeks of its life may respond differently when it is moved into an intensive indoor growing/finishing system from a piglet that has been raised in an intensive system. Outdoor bred piglets performed more rooting and chewing of the sows' roll-nuts, than the same breed of piglets while grown indoors (Cox and Cooper 2000). Also, Cox and Cooper (2000) agreed with Webster and Dawkins (2000) that after weaning (24 days of age) outdoor-reared piglets were more likely to be seen at the food trough and engaged in fewer aggressive interactions than indoor-bred pen-mates. Although, differences in behaviour persisted till day 57 post-weaning, such effects appear not to lead to differences in carcass weights, rigor following dressing or blemish at slaughter (Webster and Dawkins 2000).

Pajor *et al.*, (1991) defines two competing hypotheses which may explain the variation in creep feed intake. The first hypothesis is based on much older work done by Aumaitre (1972) and states that certain individuals may eat more creep feed because of a greater developmental maturity, especially of the digestive system, which allows them to assimilate nutrients from solid feed at an earlier age. According to this model, the large, faster-growing piglets which are likely to indicate greater developmental maturity would eat more creep feed during the period when digestive maturity is developing. The alternative hypothesis states that piglets may consume creep feed in compensation for inadequate nutrition from milk (Algers *et al.*, 1990). English *et al.*, (1996) state that piglets at 4 weeks of age will obtain the majority of their nutrients from milk and use creep feed as a supplement.

Pluske and Dong (1998) suggest that there are two major reasons why piglets sucking the sow are restricted in their rate of growth. Firstly, the amount of milk produced by the sow constrains the growth of the piglets. Harrel *et al.*, (1993) calculated that milk produced by the sow during lactation becomes limiting to the suckling piglets at around 8-10 days post-partum and that the difference between need and supply progressively increases as lactation proceeds (Figure 1.9).

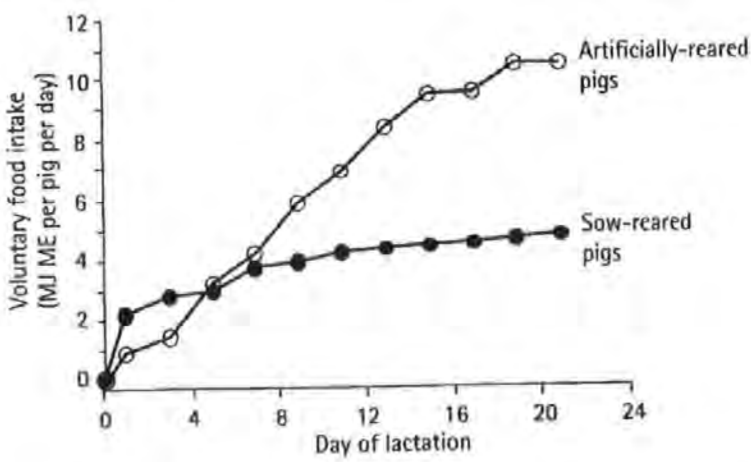


Figure 1.9 Voluntary Food intakes (MJ ME/pig/day) of pigs suckled by the sow (●—●) or fed milk replacer (○—○) following weaning at 2-3 days of age (from Harrel *et al.*, (1993)).

Harrel *et al.*, (1993) calculated that, by day 21 of lactation, the sow would need to produce in excess of 18 kg/day of milk in order to supply piglets with enough energy to grow at rates comparable to artificially reared piglets of the same age (Table 1.8 and 1.9). Apart from small increases in production that may be expected with indirect genetic selection for milk yield, the inconsistency in growth rate between what is achievable when pigs are raised artificially and the growth rates observed commercially during lactation, will remain a concern for researchers interested in maximising piglets growth (Pluske and Dong 1998).

Table 1.8 Mean (± SE) milk yield, piglet growth rates, and milk composition determined at two different stages of lactation in primiparous sows which were restrictedly-fed (Restrict), ad libitum-fed (Ad libitum), or superalimented (Super) (from Pluske and Dong (1998)).

	Treatment		
Item	**Restrict**	**Ad libitum**	**Super**
Mid lactation (d 10-15)			
Milk yield, kg/d	8.9 ± 0.65	9.2 ± 0.51	9.8 ± 0.57
Piglet growth, g/d[1]	248 ± 21.8	280 ± 16.9	290 ± 19.2
Milk composition, %			
Protein	5.2 ± 0.13	5.1 ± 0.13	5.1 ± 0.57
Fat	7.9 ± 0.92	7.4 ± 0.22	7.8 ± 0.23
Lactose	5.6 ±.011	5.5 ± 0.07	5.3 ± 0.16
Total Solids[2]	19.6	18.9	19.1
Late lactation (d 21-25)			
Milk yield, kg/d	7.3 ± 0.53	8.8 ± 0.46	8.3 ± 0.61
Piglet growth, g/d[1]	210 ± 17.9	269 ± 15.6	206 ± 20.3
Milk composition, %			
Protein	5.2 ±0.16	5.2 ± 0.18	5.1 ± 0.15
Fat	7.1 ± 0.37	6.8 ± 0.43	7.6 ± 0.24
Lactose	5.3 ± 0.11	5.6 ± 0.06	5.3 ± 0.18
Total Solids[2]	18.5	18.5	18.9

[1] *Pig growth rate as determined within each milk production estimation period (adjusted for litter size at the start of each milk production period).*
[2] *Assumes an ash concentration of 8.8 g/kg (Elliot et al., 1971)*

Table 1.9 Daily milk yield (kg) and Net Energy at 3 different litter sizes (small, average and large) (from Whittemore *et al.*,(2003)).

Daily milk yield (kg)[a]	Net energy (MJ NE/day)[b]
Sow live weight of 150 kg	
6	40.7
8	51.5
10	62.3
Sow live weight of 225 kg	
9	61.5
11	72.3
13	83.1
Sow live weight of 300 kg	
10	70.9
12	81.7
14	92.5

[a] *Total litter gains per day from milk alone may be approximated as mikl yield/4. The three levels of milk yield are also indicative of small, average and large litters. If each piglet in the litter consumes 1 kg of milk daily it is presumed to gain an average of 0.25 kg live weight daily (reaching 8 kg at 28 days). 10 piglets consuming 12 kg of milk daily will reach 9.5 kg at 28 days.*

[b] *The energy content of milk is 5.4 MJ/kg.*

Secondly, the potential for lean tissue growth in the baby pig is most likely restricted by the composition of sow's milk *per se* (Pluske and Dong 1998). This is because baby pigs have more water in their muscles than adult animals as 97% of their muscle content is water and the rest is fat (English *et al.*, 1996). So, in order to increase their lean tissue growth they need extra water that is mainly coming from sow's milk.

There is little evidence that larger creep feed intake prepared animals for better post-weaning adaptation compared with their litter mates. Appleby *et al.*, (1992) subsequently characterised pigs on the basis of their individual creep feeding behaviour (Table 1.10) and suggested that low consumption of solid food before weaning is a predictor of poor growth after weaning, but not a cause.

Table 1.10 Weights and performance of piglets according to their creep feeding category (based on the proportion of time they were seen at the creep feeder; weaned at 42d; after Appleby *et al.*,(1992)).

	Creep feeding category			
	Very low	Low	Medium	High
Body weight (g)				
Birth	1572	1509	1471	1280
42 days	10939	11308	10774	10601
Gain (g/d)				
Day 0-21	218	198	170	177
Days 21-28	240	267	244	254
Days 28-42	224	271	284	257

Piglets that gained more weight in the week before weaning continued to gain better in the post weaning period (Aherne *et al.*, 1982). High feed intake consumption gave rise to heavier piglets at weaning (>5.6 kg) than those in low creep feed intake (<4.2 kg) (Koketsu and Dial 1998). However, Bruininx *et al.*, (2003) have shown that the beneficial effects were not associated with the prevention of damage to small intestinal morphology. The results are illustrated in Table 1.11.

Table 1.11 Performance, feed intake characteristics and small intestinal morphology of piglets differing in pre-weaning feed consumption (weaned at 28d; after Bruininx *et al.*, (2003)).

	Non-eaters	Moderate eaters	Good eaters	SEM
Post-weaning performance and feed intake[1]				
ADFI, g/d	105[a]	132[ab]	154[b]	10.6
ADG, g/d	-34[a]	2[ab]	20[b]	15.0
Daily visits to the feeder	37.7	38.5	44.4	2.94
Daily visits with feed intake	6.7[a]	7.5[ab]	8.9[b]	0.54
Rate of feed intake of the successful visits, g/min	3.9[a]	4.7[ab]	5.0[b]	0.24
Post-weaning morphology				
Villous height, μm	278	305	289	15.2
Crypt depth, μm	225	266	258	11.4
Villous/crypt ratio	1.3	1.1	1.1	0.07

[1] Performance and feed intake characteristics are calculated for day 0 to 4 after weaning.
[ab] Data within row different superscript differ ($P<0.05$).

The results on feed intake and gain indicate that piglets consuming more dry feed during the suckling period are better able to adapt to the dietary and social changes. van Beers-Schreurs and Bruininx (2002) made observations in individual feed intake data and showed that about 50% of the eaters (piglets shown green coloured feces at three sampling moments pre-weaning) started eating within 4 hours after weaning whereas 50% of the non-eaters and non-fed piglets needed 6.7 and 6.9 hours respectively. However, crypts of the moderate eaters tended to be deeper than those of the non-eaters whereas the good eaters had intermediate crypt depths (Bruininx *et al.*, 2003).

Hohenshell *et al.*, (2000b) reported that weaning pigs at 10 days, had greater average daily gains soon after weaning when compared with pigs weaned at approximately 30 days of age.

The use of phase-feeding strategies, involving complex initial diets enriched with milk-products and animal plasma proteins has generally worked well to minimise post-weaning growth stasis, especially when health status is high and when animals are of sufficient size and (or) age (Dritz *et al.*, 1996). However, it is not uncommon for very young and light-weight pigs to suffer prolonged growth retardation.

Brooks and Tsourgiannis (2003) have suggested that piglets with a less productive teat will often take creep feed while littermates with productive teats suckle the sow. This is consistent with the findings of Appleby (1991) and Appleby (1992) who compared creep feed intake of piglets provided with 2 or 8 creep feeding spaces (Figure 1.10). On average 4.1 piglets per litter consumed very little on the day before weaning when only two feeding spaces were provided. These tended to be pigs that had a high birth weight and high growth rates on days 0 to 21 but low birth weights from day 28 (weaning) to day 42. Conversely, piglets that ate the most creep feed were often those that had gained least on days 0-21. Providing eight feeding spaces increased the average intake on the three days before weaning and reduced the number of pigs eating very little on the day before weaning to 0.6 pigs per litter.

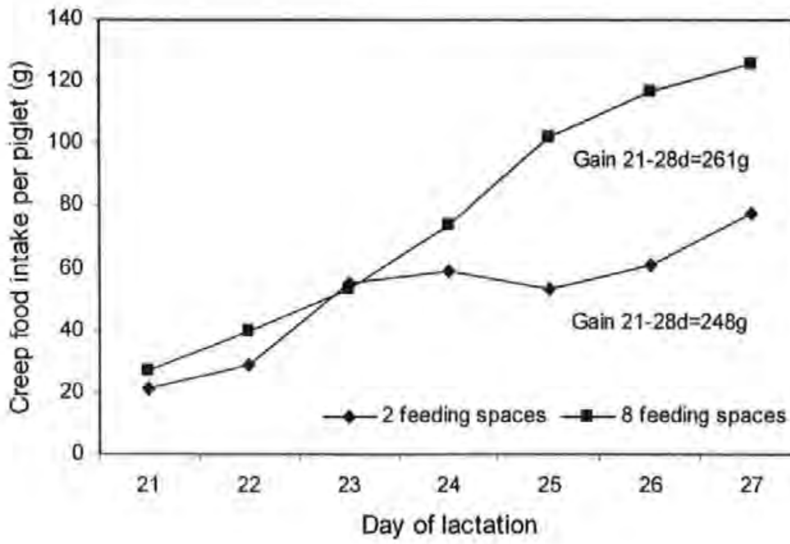


Figure 1.10 Consumption of creep feed by piglets provided with 2 or 8 creep feeding places (after Appleby (1992).

Whereas the importance of understanding ontogeny of endocrine control of growth is recognised (Lee *et al.*, 1991), little related information exists with regard to the effect of management practices associated with nutritional changes imposed at different ages. Observations on the pre-weaning feeding behaviour of piglets weaned at various ages will be mentioned in the following sub-sections.

1.7.1.1 Pre-weaning feeding behaviour of piglets weaned at 3 weeks of age.

Wood-Gush *et al.*, (1990) recorded that in 2-3-week old piglets, the presence of a new object in their pen, firstly causes avoidance, and then orientation, approach, and finally biting. Carrol *et al.*, (1998) found that weaning at 2 weeks of age and changing diets (starter to growing diet), can more severely affect patterns of early growth and related hormones secretion, but effective compensatory mechanisms restore normal physiological and physical development.

Koketsu and Dial (1998) observed that farms which were using creep feed had similar pig weights to farms not using creep feed (weaning >19d: 4.92 *v.* 4.75 (s.e. 0.34) kg; P>0.05). De Passille *et al.*, (1989) reported that piglets which are heavier at 21 days of age had a more developed digestive system. As piglets are getting older, all litter mates may pass some threshold of digestive maturity, so that even the smaller piglets can consume and assimilate creep feed (Pajor *et al.*, 1991). At this stage, creep feed intake may become more driven by nutrient need and smaller piglets may consume more creep feed to compensate for the poor gains they were achieving from milk (Pajor *et al.*, 1991).

Fraser *et al.*, (1994) have observed that pigs that used creep feed more than their littermates tended to be those with low gains in weeks 1-3 after birth ($P<0.001$) and tended to gain more weight during the week before and during the 2nd week after weaning ($P<0.01$). On the other hand, the between-litter analysis showed no tendency for litters that had eaten the most creep feed to gain more in weeks 5 and 6 or week 7 plus, to consume more feed in these periods, or to convert feed more efficiently.

1.7.1.2 Pre-weaning feeding behaviour of piglets weaned at 4 weeks of age.

In the case of the un-weaned piglets, the practice of a pre-weaning experience with supplementary solid 'creep feed' is recommended to prepare the pig for a solid, post-weaning diet, and thus to support a more successful adjustment to weaning as early as 4 weeks of age (Delumeau and Meunier-Salaun 1995).

Pajor *et al.*, (1991) observed that greater creep feed intake was typical of the larger and more mature piglets, rather than serving as compensation of poor milk intake among the more deprived litter-mates. In their study, total creep feed consumption before weaning varied greatly between individuals (mean 468 g range 13-1385 g) and even between litter-mates. Also the within-litter differences in weight-gain during the 2 weeks after weaning (weaning 4 weeks), were correlated with weight at birth and weight gain before weaning ($P<0.05$), but not with pre-weaning creep feed intake (Pajor *et al.*, 1991). Delumeau and Meunier-Salaun (1995) observed that the female pigs as also the piglets that exhibiting an estimated feed intake higher than 100 g between 2 and 3 weeks of age, had higher creep feed intakes during the first three days after weaning (28 days) ($P<0.05$; median 254 g, range 74-739 g *vs.* median 185 g, range 64-352 g), but this enhanced performance had no effect on post-weaning weight gain. According to Pajor *et al.*, (1991) and Aherne *et al.*, (1982) creep feed intake appeared to contribute to pre-weaning gains and these in turn were correlated with post-weaning gains; however, a more direct effect of pre-weaning creep feed intake on post-weaning gain could not be detected.

Before weaning, 2 week old piglets spent on average 0.3% of their time consuming 7 g of solid feed per day compared with the 4 weeks-old piglets who spent 3.6% ($P<0.001$) of their time consuming 127 g ($P<0.001$) (Metz and Gonyou 1990).

Piglets weaned at 4 weeks of age had weight gains the day after weaning similar to those seen before weaning (Pajor *et al.*, 1991). Individuals in this study varied widely in post-weaning weight gains (mean 2845 g, range 907-5136 g). Although litters with the greatest average creep feed intake had the highest post weaning gains, there were little evidence of a similar relationship within litters (Pajor *et al.*, 1991).

1.7.1.3 Pre-weaning feeding behaviour of piglets weaned at 5 weeks of age.

Boe (1991) observed that as the number of nursings was gradually reduced, the piglets' intake of concentrates increased, especially after the fifth week. There was no drop in daily weight gain as commonly observed in commercial herds with an early and abrupt weaning.

Fraser *et al.*, (1994) also found that there was higher compensatory creep feeding on the high complexity diet and suggests that this maturational process may have been more advanced with the diet that was better suited to the young pig. Other workers have reported that between 3 and 5 weeks of age, piglets show rapid developmental changes in secretion of digestive enzymes (Aumaitre 1972), with large differences between individual piglets (de Passille *et al.*, 1989) and only limited effects of creep feed intake on enzyme levels (Shields *et al.*, 1980). These findings presumably help to understand the limited relationship between creep feed intake and adaptation to weaning.

In piglets weaned at 9 weeks of age, Boe and Jensen (1995) found that the average intake of solid food was closely related to the weight of the pig, with heavier piglets consuming more solid food. They estimated that the average intake of creep feed increased from 66 g d^{-1} at week 4 to 717 g d^{-1} at week 8 and a relatively high early intake of solid food (week 4) was associated with a high intake later while they are with the sow. Also, they concluded that piglets eating more solid food at weeks 4 and 5 will continue to do so until 8 weeks of age.

1.7.2 Post-weaning FI.

The removal of the security of the mother is stressful and this is compounded by the simultaneous removal of milk as the source of water and nutrients. Following abrupt weaning the piglet has to adapt its feeding and drinking behaviour very rapidly to take account of its new environment. Generally, it fails to do this and as a result, there is a dramatic reduction in its dry matter intake (Figure 1.11) following weaning. Dry matter intake does not recover to the pre-weaning level until the second week post weaning.

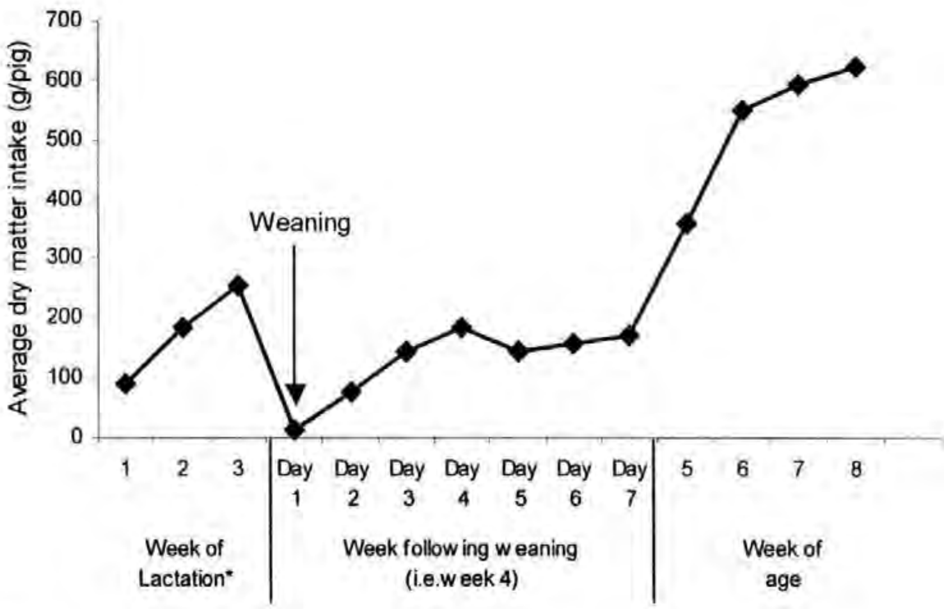


Figure 1.11 Typical (mean) feed intake pattern of pigs weaned at 21 days.

* *Dry matter intake in lactation is the sum of sow milk and creep feed.*

(Brooks and Tsourgiannis 2003)

Nutrition during the early life of pigs is very important because, in addition to influencing early growth performance, it also may affect subsequent growth (Pollman *et al.*, 1992). Nutritional problems associated with early weaning have led to the development of complex starter diets containing large amounts of expensive milk products and plasma proteins (Hansen *et al.*, 1993) as well as various management schemes to improve the performance of early weaned piglets.

Le Dividich and Herpin (1994) have stated that the level of metabolisable energy (ME) intake attained at the end of the 1st post-weaning week is about 750 $kJ/kg^{0.75}$, which accounts for only 60% of the pre-weaning milk intake. The ME requirements for maintenance (MEm) is estimated to be 550 $kJ/kg^{0.75}$ d^{-1} (Close 1987), and Le Dividich and Herpin (1994) concluded that the MEm requirement is not met until 5 days post-weaning (461 $kJ/kg^{0.75}$ d^{-1}) as it is also represented by van Beers-Schreurs and Bruininx (2002) in Figure 1.12.

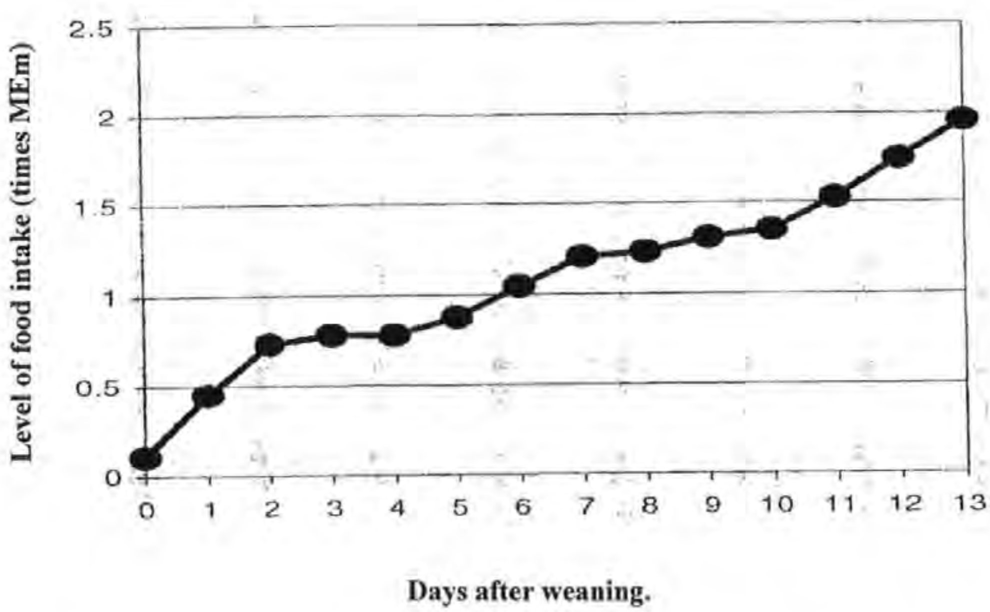


Figure 1.12 Interval between weaning and the day on which weanling piglets meet the MEm requirement of 461 $kJ/kg^{0.75}$ d^{-1} (Bruininx, unpublished data in van Beers-Schreurs and Bruininx (2002)).

Patience (1998) states that daily feed intake will be influenced by i) the number of meals per day, ii) food intake per meal and iii) length of meal, and that the feeder design and food presentation can influence feed intake per meal.

The desirable behavioural characteristics of a piglet living in nature are: (1) consume only small quantities of new food; (2) have a good memory for different food characteristics; (3) be able to seek out special foods; (4) sample foods whilst eating staple foods; (5) prefer familiar foods; (6) prefer foods with small amounts of toxic compounds; (7) have a searching strategy which compromises between maximising variety and maximising intake (Fraser and Broom 1997).

Held *et al.*, (2000) reported that pigs are able to exploit successfully the knowledge of others by switching foraging tactics. In order for this tactic to become more successful, Morgan *et al.*, (2001) state that the experienced piglets of the litter should be removed/weaned at 21 days in order for them to become accustomed to solid food before their litter mates are going to be weaned at 28 days (weight gain of experienced and inexperienced piglets: 597 *vs.* 307 (s.e.d. 78.6) g/day; $P<0.05$). They also state that they cannot be certain that the inexperienced piglets retained the recognition of their littermates. Ewbank and Meese (1971) observed that with growing pigs the top ranking pig in the group could be removed for up to 25 days and returned without fighting but the lowest ranking pig experienced attacks when removed for 3 days only. In another study, it has been observed that gilts retain their memory of long-term relationship after 4 weeks of separation (Spoolder *et al.*, 1996). This may not necessarily mean that the latter was not recognised.

It has been observed that dominant non-informed pigs followed and displaced their informed, subordinate co-foragers in pair trials. It has been suggested by Held *et al.*, (2000), that this action increased their foraging success, in comparison with solitary search trials, by reducing the number of investigations required to locate the food and by decreasing the 'informed' piglet's time advantage at the food. Hutson (1989) similarly identified the 'worker piglet' which shows an operant response of lever lifting in order to gain access to the trough, which was filled with earth. In order for subordinate piglets to overcome the continued exploitation of their privileged knowledge, development of advanced social tactics such as deception has been observed when animals are living in complex social groups and emigration from the group is not an a viable tactic (Byrne and Whitney 1988).

Appleby *et al.*, (1991) suggests that some piglets began feeding partly by imitating others at the feeder, but in order to do that, sufficient space feeder (feeding spaces) have to be provided to allow such imitation that may be important to establish feeding behaviour.

Nielsen *et al.*, (1996) have demonstrated that within groups, individual pigs develop stable feeding patterns ranging from individuals that have a large number of small meals to those that have a small number of large meals. Morgan and Lawrence (2000) provided two theories which can explain the differences in individual feeding strategies: i) the feeding pattern is initially flexible and develops after weaning and may be influenced by the social conditions prevailing at the time of development; or ii) all individuals have a predisposition to a preferred pattern but under certain conditions particular types of pig may be forced to deviate from this pattern more than others.

Patience (1998) states that pigs consume pelleted diets more rapidly than mash, and by adding water to the mash and not to the pellets, will increase the rate of feed intake. Fraser (1978) observed that a very rapid increase in feeding behaviour during the first day after weaning was accompanied by a much slower rise in the frequency of defecation. He speculates that this may reflect some difficulty in the animals' physiological adaptation to the solid food, perhaps indicated in extreme cases by diarrhoea. Discomfort from this source might account for the animals' restlessness and increased aggression. He supports this hypothesis by the fact that there is an association between loose faeces, aggressiveness and feeding behaviour in the few piglets that displayed anomalous feeding during the first day after weaning.

It would seem likely that in order to register information about the foods on offer, the piglet must test them individually and then wait for the resultant consequences in order to associate the subsequent feelings with them. Dalby *et al.*, (1995) reported that for weaner piglets a training period prior to the choice of two foods is not necessary, as the selection of the right feed has been done successfully by both trained and non-trained piglets. It may be that young animals, with no prior experience of solid food, quickly learn the physiological consequences of the food choices. Dalby *et al.*, (1995) agrees with Kyriazakis *et al.*, (1990) that piglets and growing pigs can detect difference in the protein content of the feed (High-Low) within 24 hours and did not require longer to associate the post-ingestive consequences with the food, although the feeding behaviour within this time period was not observed and should be the subject of further investigations.

Fowler (1985) suggests that post-weaning diets for pigs weaned between two and four weeks of age should be highly digestible as this allows pigs to feed *ad libitum* without inducing scour, minimises the management input, and greatly reduces the need for antibiotic therapy. According to the same author, the transition from a milk based – high fat diet to a cereal/soya diet should be gradual and progressive to allow time for the immature digestive tract to adapt. Therefore the hindgut must be developed as it has only a minor function during the sucking period (Bolduan *et al.*, 1988).

Gonyou *et al.*, (1998) and Song and McGlone (1998) observed that early weaning (at 12 and 21 days of age) resulted in a slight delay in the development of eating behaviour post-weaning.

Fowler and Gill (1989) have calculated that at 3 weeks of age a normal piglet will require about 475 g/day of a typical starter diet in order to maintain a live growth rate of 280 g/day (7.8 MJ DE). In practice such intakes are not commonly observed to be consumed by the small piglet for several days after weaning (Brooks and Tsourgiannis 2003), therefore weaning causes severe disruption of intake and of the growth curve (McCracken 1989) and there are other factors involved including social disturbance and stress.

The positive correlation between weight gain and a passive response to the stress of isolation and novelty measured during the first 7 days post-weaning, could indicate, according to Giroux *et al.*, (2000), that piglets reacting more calmly to the stress of weaning at 17 days (spending more time standing still, low level of exploration and squealing less) would dissipate less energy than piglets reacting actively to stress, thereby gaining more weight. Horrell (1982) named the active response to stress as the 'wandering-squealing' syndrome which was associated with decreased growth.

Whittemore *et al.*, (1981) have stated that the contribution of the reduction in live-weight to the energy economy of animals is an important 'unknown factor' in the estimation of energy requirement. Since at these ages, body fat is mainly backfat, the loss of body fat in the immediate post-weaning period implies a decrease in backfat thickness and therefore in body thermal insulation contributing to an increased heat demand of piglets after weaning (Close 1987).

Keeling and Hurnik (1996) showed that weight gain after weaning at 28 days, was significantly greater in groups of unfamiliar males (0.53 ± 0.06 kg) than in groups of familiar males (0.28 ± 0.06 kg), but there was no difference between unfamiliar and familiar females. Their results suggest that the higher weight gain in groups of unfamiliar males comes from the fact that they spent proportionally more time at the feeder than the familiar males. Whatever the reason for the initial treatment/sex interaction, by day 4 these differences were no longer significant, and that is presumably because unfamiliar piglets had become more known to each other during this period. Friend *et al.*, (1983) have also observed that although mixing affects growth rate initially, there are no long term effects.

Keeling and Hurnik (1996) observed that males had a 252% increase in feed consumption from day1 to day 2, whereas in females the corresponding increase was only 90.4% when weaned at 28 days of age. In contrast Bruininx *et al.*, (2001b) showed that gilts had higher (P<0.05) initial feed intakes than barrows (25 g day^{-1}) and also had greater (P<0.05) ADFI (190 *vs* 165 (s.e.m=7.5) g; P<0.05) and ADG (133 *vs* 105 (s.e.m=7.1) g; P<0.05) during the period 0 to 13 days after weaning (28 days).

According to the literature stated above, there are many and various factors (sex, litter size, feeding experience etc.) which can influence the growth performance and post-weaning success of the piglets. There are two initial factors though, from which these variations come: the weaning age and the weaning weight. Each factor will be addressed separately in the following sections.

1.8 The effect of weaning age to piglet's growth performance and behaviour.

It is well known that with current agricultural practices, newly weaned piglets often show weight loss, gastrointestinal disorders, health and behavioural problems and occasional death (Fraser 1978; Pluske *et al.*, 1996a). These problems may be the result of an abrupt weaning, often on day 21-28, far earlier than the weaning age of 80-120 days in semi-natural conditions (Newberry and Wood-Gush 1985; Jensen and Recen 1989; Boe 1991). This is because antibody-mediated immunity, derived from colostral immunoglobulins, reaches a maximum in the pig at 24 to 36 h post-partum and then decreases logarithmically to precariously low levels when the piglet become about 3 weeks old (Porter 1975) (Figure 1.13). It has been suggested that weaning pigs when younger than 5 weeks old causes physiological changes detrimental to cellular immune reactivity, *in vivo* and *in vitro* (Blecha *et al.*, 1983).

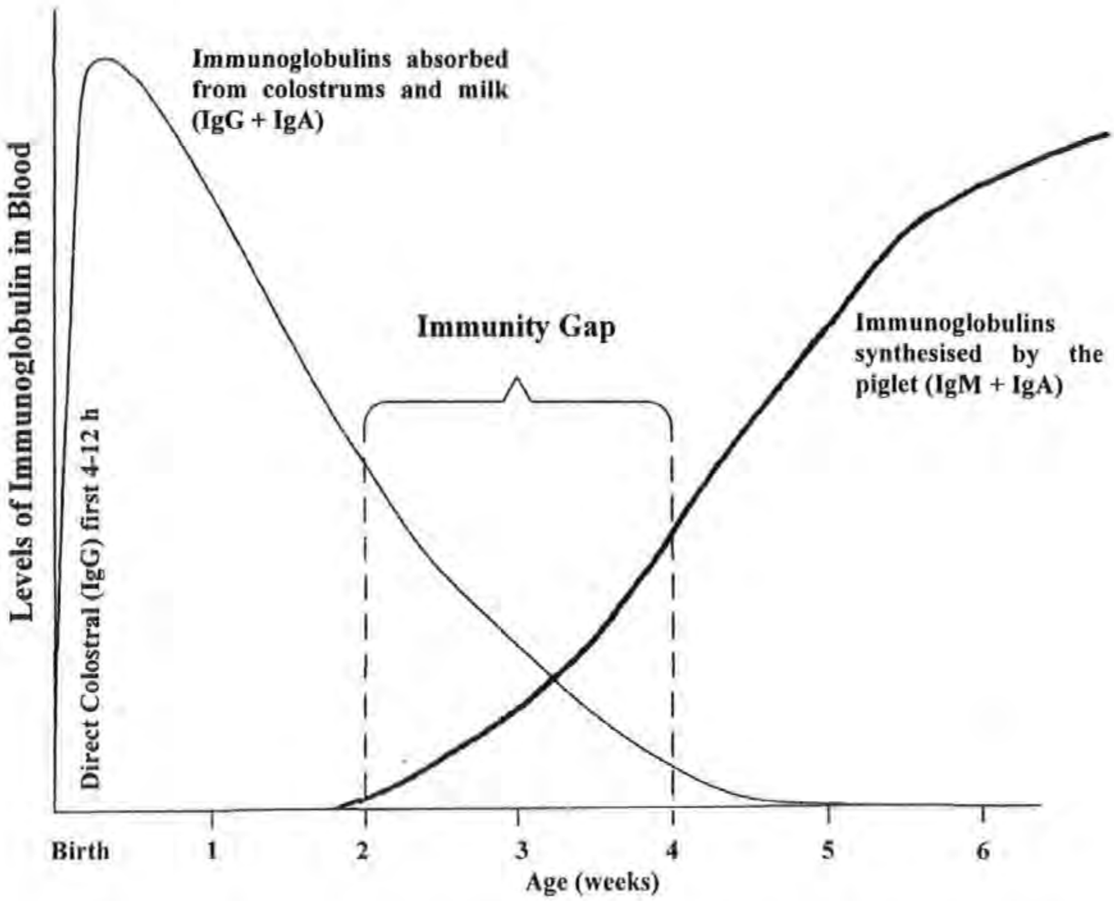


Figure 1.13 The immunological development of the newborn piglet (after Geary (1997)).

Artificial weaning (current agricultural practice) takes place at an age when the energy intake from suckling milk is still very high (Newberry and Wood-Gush 1985; Petersen 1994) (Figure 1.14). Martin (1984) on the other hand, suggests that lactation constitutes the major component of parental investment for many mammals. Hence, the relationship between the rate of parental investment (e.g. the suckle bout frequency) and offspring age can be drawn in a curve in which weaning may be viewed as the phase of parental care where the rate of parental investment drops most sharply. According to Martin (1984), this suckling frequency reaches the maximum at day 8.5 (see Figure 1.15).

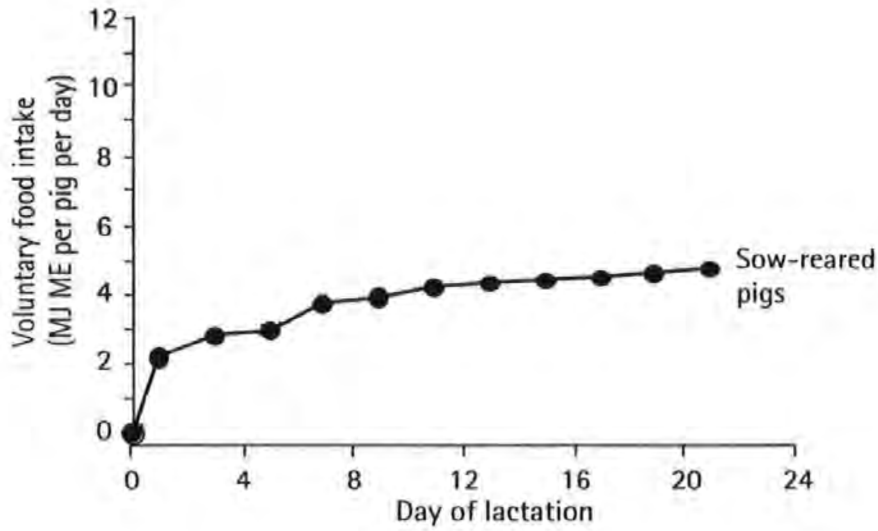


Figure 1.14 Voluntary Food intakes (MJ ME/pig/day) of pigs suckled by the sow (from Harrel *et al.*, (1993)).

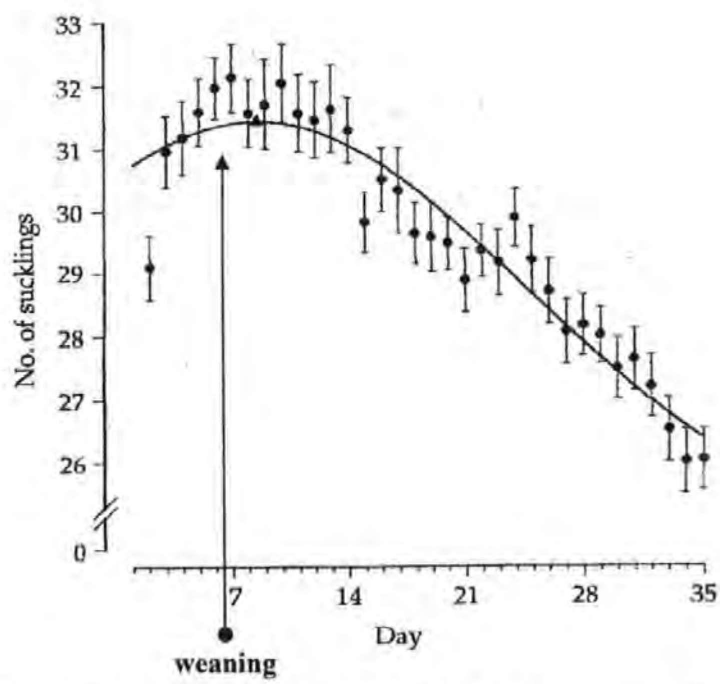


Figure 1.15 The development of the daily suckling frequency over a 35-day lactation period: mean number of suckling bouts per day (mean ± s.e.) (after Martin (1984)).

The drop of sucking frequency in the above figure does not directly mean that there is a drop of energy intake at least till day 24 post-partum (Harrel *et al.,* 1993).

The severity of post-weaning problems is highly inconsistent both within (among littermates) and between litters. One possible factor contributing to this variation is the animals' pre-weaning experience with supplementary solid creep feed (Pajor *et al.,* 1991). In studying factors that influence creep feed intake, it is important to distinguish variation between litters from variation between piglets within litters (Pajor *et al.,* 1991). It has been stated that between-litter differences in creep feed intake may be dominated by genetic and environmental differences between litters and by differences between sows in their health and milk production, while variation between litter-mates is likely to include effects of within-litter competition for milk (Thompson and Fraser 1986) and probably for creep feed itself. Pajor *et al.,* (1991) states that conclusions based on between –litter studies may not apply to differences between individuals and vice versa.

Improving feed intake during the immediate post-weaning period is very important for the development of the small intestine and subsequent growth performance (Zijlstra *et al.,* 1996; McCracken *et al.,* 1999). Orgeur *et al.,* (2001) reported a delay of 12 to 48 hours of dry feed consumption the first day post-weaning when they weaned the piglets at 6 days of age and growth rate remained low until day 22. They have concluded that this is related to the fact that food intake (g kg^{-1} body weight) in the immediate period following early weaning is also low. The physical form of the diet during the immediate post-weaning period can have an immediate and lasting impact on pig growth performance (liguid vs. dry: 113.9 vs 110.6 kg; $P < 0.05$)(Kim *et al.,* 2001).

Worobec *et al.*, (1999) recommended that weaning piglets on or before 14 days of age may result in reduced performance and the development of behaviour patterns that either cause, or are indicators of, reduced welfare.

Piglets weaned before 21 days generally exhibit more escape behaviour (Worobec *et al.*, 1999) and higher rates of distress vocalisation (Weary *et al.*, 1999) and take longer to begin feeding immediately after weaning than piglets weaned after 3 or 4 weeks (Gonyou *et al.*, 1998), which may indicate that their well-being is compromised. They also develop higher levels of belly-nosing behaviour than piglets weaned later (7, 14 days *vs.* 28 days) (Gonyou *et al.*, 1998; Worobec *et al.*, 1999).

Other scientists have reported that even when piglets are weaned at 6 weeks of age, an increase on eating, drinking and aggression frequencies occurred even when no change of environment was involved (Algers *et al.*, 1990).

Weary and Fraser (1997) looked at the vocal response of piglets to weaning at 3, 4 and 5 weeks of age. They found that calling did not relate to gains or intake after correcting for weaning weight, and that no significant relationship was found between calling and performance within each of the three age groups. The finding of their work also reflects a general decline in vocalisations with age, and not an easier transition to weaning for the older animals. They stated that the fact that older piglets produced lower frequency calls may have been due to the larger size of these animals. Other available research, argues against a general decline in call rate with age. The theory of Horn *et al.*, (1985) indicate that signalling is less costly for the larger animals, and thus these animals could be expected to call more in response to the same conditions.

1.9 The effect of weaning weight on piglets' growth performance and behaviour.

Weaning weight is considered an important determinant of post-weaning and lifetime growth performance programme (Mahan and Lepine 1991). Weaning age, lactation, food intake, parity, season and litter size are possible factors affecting average pig weight at weaning (Koketsu and Dial 1998). They observed that a piglet has to be weaned at an older age during the summer in order to obtain a similar pig weight at weaning during the other seasons. Koketsu *et al.*, (1997) recorded that farrowing room temperatures during the summer are higher than during the winter, and high ambient temperature has a direct effect on milk yield (Black *et al.*, 1993).

Work done by Jensen and Recen (1989) in free-ranging pigs showed that weaning was to a large extent a result of the behaviour of the young, i.e. the piglets stopped suckling without any aggressive rejection by the mother. There were some signs that smaller piglets tended to stop suckling before the larger litters mates, which led the authors to suggest that weaning could be a result of an optimal foraging decision. According to the hypothesis, if a piglet occupies a productive teat, it might be better off from an optimal foraging point of view if it composes its total diet of a larger amount of milk than those piglets occupying less productive teats (Jensen and Recen 1989).

There is normally a large spread of weights within a piglet litter. In some very early studies, McBride *et al.*, (1964) found that the weight at 8 weeks of age was determined to a large extent by the weight at 3 weeks and the social rank within litter (as determined by competitive success at the feed trough).

The weight of pigs at weaning has been shown to have a significant effect on their subsequent growth performance. For example, Mahan *et al.*, (1998) demonstrated that compared with heavier pigs (7.5 kg), lighter pigs (5.5 kg) at weaning (23 days) had lower growth rates after weaning (617 *vs.* 547 (s.e.m 7) g/day; P<0.01) and required a greater number of days (156.7 vs. 164.8 (s.e.m. 0.43) days; P<0.01) to reach a common slaughter weight. In addition, variation in piglet weights within a group at weaning can affect the productivity of commercial pig production systems, particularly those implementing all-in all-out animal management (Hardy 1998). Weaning weight has been shown to be closely related to birth weigh (Wolter and Ellis 2001) and to the amount of sow's milk consumed by the piglet during lactation (Lewis *et al.*, 1978). Providing piglets with supplementary liquid milk replacer during lactation can increase weaning weights (Azain *et al.*, 1996). On the other hand Gardner *et al.*, (2001) found that average daily feed intake (ADFI) was not influenced by the inclusion of milk products in the diet of piglets weaned at 14 to 18 days or the addition of milk replacer, but average daily gain (ADG) was. Wolter and Ellis (2001) and Hohenshell *et al.*, (2000a) after applying SEW as a weaning strategy to accelerate the growth of lighter pigs after weaning have had limited success in decreasing the time required to reach slaughter weight. Campbell (1990) reported that every extra kg of weight gain at weaning was worth 2.9 kg at 10 weeks of age and also, that pigs which were heavier than 7 kg at weaning were less susceptible to post-weaning diarrhoea than lighter littermates.

According to Gardner *et al.*, (2001) smaller weight-for-age piglets (4.16 *vs.* 5.21 kg) have been found to be more 'needy' (greatest need for energy and nutrients) than their larger littermates and spend more time massaging the sow's udder (Weary *et al.*, 1999). Higher weight-for-age piglets have been found to ingest more creep feed (Pajor *et al.*, 1991; Dunshea *et al.*, 2003) prior to weaning and have better developed digestive capacities than lower weight-for-age piglets (de Passille *et al.*, 1989), which reflects differences in physiological maturity. Dunshea *et al.*, (2003) observed that the heavy for age pigs grew faster than light for age pigs, particularly in the immediate post-weaning periods (weaned at 14 or 28 d). Thus, a difference in liveweight of 0.37 kg (1.86 *vs.* 1.39 kg) at birth had increased to 1.9 kg (5.22 v. 3.21 kg) by 2 weeks of age and ultimately 13 kg (107.1 *v.* 94.3 kg) by 23 weeks of age.

Kavanagh *et al.*, (2002) found that weaning weight (at 4 weeks age) was a good determinant of weight at day 26 post-weaning when terms for litter origin were included and that weaning weight can be increased by pre-weaning management; but this weight advantage is lost in the early post-weaning period. Kavanagh *et al.*, (2002) and Lawlor *et al.*, (2002) come to a similar conclusion that where weaning weight was naturally higher the weight advantage was still evident at day 26 post weaning.

1.10 The process of weaning and its influence on gut morphology and response.

The porcine intestinal microflora is established within 48 h after birth via ingestion of maternal faeces, and involves complex successional changes until dense, stable populations colonise the gastrointestinal tract (Mackie *et al.*, 1999). According to Aumaitre *et al.*, (1995), the activity of the majority of the digestive enzymes is low at birth, gradually increases during the first week of their life and reaches a minimum level to cope with dry feed consumption and weaning at 3 to 4 weeks of age. At that time, the large intestine of the piglet, which was poorly developed at birth and had limited importance during lactation, becomes functional at weaning when concentrated feed is the only diet of the animal (Aumaitre 2000). The same authors concluded that the slow process of maturation of the gastrointestinal tract of the piglet is due to the fact that all the major organs adapt only progressively to changes in the body and in the diet of the piglet (Aumaitre 2000).

Montagne *et al.*, (2003) summarised that there was a numerically great and diverse range of bacteria in the large intestine of non-ruminant animals: *Bacteroides, Prevotella, Eubacterium, Lactobacillus, Streptococcus* (Jensen 2001) and the bacterial composition is species specific and varies depending on age, physiological state, gut size, as well as the diet composition and especially the presence and nature of digestible fibre (DF) that is the main bacterial substrate.

The sow is the initial source of inoculum for piglets after birth, and the Lactobacilli are the common hosts of the digestive tract of suckling animals, while continuous changes in the composition of flora occur during the early life of the piglet (Krause *et al.*, 1995). Aumaitre (2000) reports that the composition of the starter diet, particularly the lactose content, does not modify the total counts of lactobacilli in the ileum or the caecum.

Madec *et al.*, (1998) reported that the hygiene level at the reception of the piglets (cleanliness, level of temperature), management and husbandry level (air quality, group size and stocking procedure) were found to be important factors leading to risky or secure profiles. The feed intake of the piglet during the first week post-weaning was strongly associated with the severity of the digestive disorders over a month after weaning (Madec *et al.*, 1998).

Bolduan *et al.*, (1988) state that nearly all non infectious pig diseases and most depressions of performance are caused by intestinal microbes and since the piglet is able to adapt its enzymes and mucosa (immune response, morphology) to solid feed, the issue of microbiological adaptation remains uncertain. They concluded that most dangers to the health and life of weaner piglets do not result from a temporary nutritional deficiency but from the gut flora and their feed should always be perceived both as a nutrient supply and as a bacterial substrate. Lindemann *et al.*, (1986) found that except for the period shortly after birth and a week after weaning, the pig appears to have sufficient enzymatic capability to digest proteins, starch and lipids at a rate at least as great as the need that could possibly be presented based on physical capacity of the digestive tract. More specifically, they found that increases with age in total activity of chymotrypsin, trypsin, amylase and gastric proteases were due to increases in both tissue weight and enzyme activity per gram of tissue.

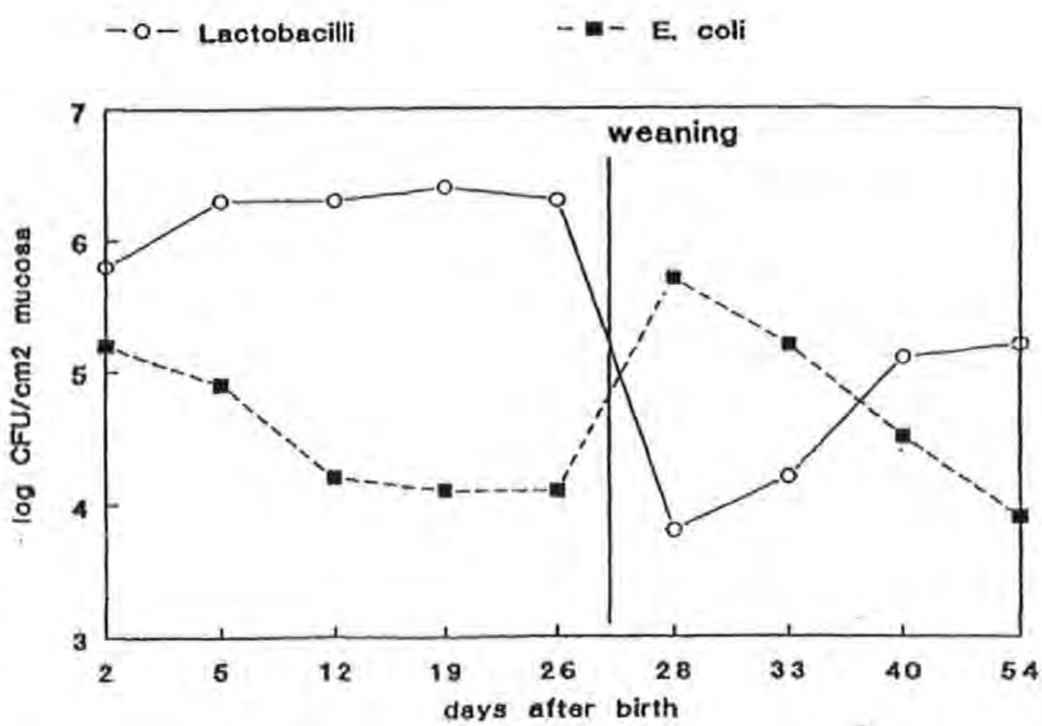


Figure 1.16 Changes in the numbers of lactobacilli and *Escherichia coli* in the gastrointestinal tract of the piglets at weaning (after Geary (1997)).

Weaning creates an environment suitable for the proliferation of *E.coli* in the small intestine. During this period (see Figure 1.16), the numbers of lactobacilli dropped dramatically, while the numbers of *E.coli* increased far above the numbers of lactobacilli. This change in microflora could lead to an overgrowth by enteropathogenic *E.coli* resulting in diarrhoea (Hampson *et al.*, 1985). This is due to the slower gut transit time and gut stasis immediately after weaning, which allows bacteria the opportunity to attach and time to multiply (Pluske *et al.*, 2002). Madec *et al.*, (1998) reports that the sudden transition from sow's milk to solid feed results in the loss of any passive protection provided by the milk, and feed intake in excess of 1000 g during the first week post weaning placed piglets in less risk of post-weaning colibacillosis (PWC). PWC caused by *Escherichia coli* specifically affects the small intestine in the first 3-10 d post-weaning. It is common for haemolytic *E.coli* to appear in the faeces of pigs in increased numbers in the first week after weaning in both healthy and diarrhoeic pigs, although the numbers of *E.coli* in diarrhoeic pigs is higher (Hampson *et al.*, 1985).

Social stresses from mixing, fighting and crowding trigger cortisol release, most likely increasing transit time (via the sympathetic nervous system) and depressing the immune response to bacterial infection. Moving to a new pen environment causes increased antigenic exposure to microbes residing in fresh or dry faecal matter (Pluske *et al.*, 2002).

Pigs, have a permanent microflora in the proximal regions of the digestive tract, mainly consisting of *Lactobacillus* and *Streptococci* (Jensen 2001). Reid and Hillman (1999) proposed that an assessment of a pig's capacity to resist pathogens could be based on the faecal ratio of lactobacilli:coliforms in the gut contents, since lactic-acid bacteria are known to inhibit the growth of enteroroxigenic *E.coli* (Hillman *et al.*, 1995). Reid and Hillman (1999) reported that although it could be argued that faecal populations and numbers do not represent those present in the SI, where *E.coli* attaches and causes disease, the lactobacilli:coliforms ratio suggests that a larger population of lactic-acid bacteria relative to coliforms provides some indication that enhanced numbers of those strains that are capable of inhibiting coliforms, including pathogens, might be present. Rodtong *et al.*, (1993) reported that lactobacilli can increase the concentration of organic acids, decrease pH in the intestine and thus inhibit the growth of bacteria (Bomba *et al.*, 1999); particularly those which are pathogenic. More specific, Nout *et al.*, (1989) reports that lactic acid has antibacterial effects on *E.coli* and *Salmonella* species, and lactobacilli can inhibit adhesion of *E.coli* to the intestines (Hillman *et al.*, 1994). Microbial counts and pH of the digesta in various parts of the piglet's intestines are shown in Table 1.12. It was shown that no coliform bacteria (<3.0 $\log_{10}$ colony forming units/ml) were detectable in the terminal ileum of pigs fed FLF, and reduced concentrations were found in the large intestine, in comparison to pigs fed dry feed or non-fermented liquid feed. It has gone unnoticed by Moran *et al.*, (2001) that the lactobacilli:coliforms ratio was higher (and greater than 1) in the terminal ileum, caecum and colon of pigs fed FLF, which suggest that they had greater capacity to resist pathogens (Reid and Hillman 1999) than piglets fed on DF, NFLF or even sow's milk.

Table 1.12 Microbial counts (log_{10} colony-forming units per ml) and pH of the digesta in the terminal ileum, caecum and colon of pigs fed different diets after weaning at 23 d of age (after Moran *et al.*, (2001).

	Diet type			
Site along gastrointestinal tract	FLF	NFLF	DF	S
Ileum				
pH	6.1	6.4	6.3	5.9
Lactobacilli	8.8^{a}	7.0^{a}	<3.0	7.3^{a}
Coliforms	<3.0	8.1^{ab}	8.5^{a}	6.0^{b}
lactobacilli:coliforms^{c}	>2.6	0.86	<0.35	1.22
Caecum				
pH	6.0	6.0	5.8	6.1
Lactobacilli	8.5^{a}	8.1^{a}	5.5^{b}	7.3^{a}
Coliforms	5.5^{a}	7.4^{ab}	8.4^{b}	7.5^{ab}
lactobacilli:coliforms^{c}	1.55	1.09	0.65	0.97
Colon				
pH	6.2^{a}	6.0^{a}	5.9^{a}	6.6^{b}
Lactobacilli	8.6^{a}	7.9^{a}	5.0^{b}	8.0^{a}
Coliforms	5.6^{a}	8.1^{a}	8.6^{b}	7.3^{a}
lactobacilli:coliforms^{c}	1.54	0.98	0.58	1.1

FLF: fermented liquid feed; NFLF: non-fermented liquid feed; DF: dry feed; S: sow's milk
^{a,b} Values within a row with different superscript letters were significantly different *(P*<0.05)
^{c} Added calculations to the original source table

Another mechanism to keep the pH of the stomach as low as possible is the consumption of small amounts of feed at regular intervals. However, van Beers-Schreurs and Bruininx (2002) note that a change of diet may result in a period of fasting followed by a period of 'over eating'. During the later period the stomach will be filled and emptied too fast to keep the pH at a low level. Subsequently, bacteria will pass the stomach and enter the small intestine (van Beers-Schreurs and Bruininx 2002). The large intestine is the major site of microbial colonisation because of the high residence time of the digesta (Pluske *et* *al.*, 2002). The effect of microbial colonisation on the morphology and function of the small intestine (SI) will be analysed in the following section.

1.10.1 Factors which influence the health status of the SI.

At weaning, the diet composition of piglets changes drastically. The liquid sows' milk is replaced by pelleted dry feed with carbohydrates, instead of fat, as the main energy source. In addition, lactose, the main carbohydrate in milk is replaced by starch. The weaning transition (27 d) is accompanied by low feed intake and reduction in villus height (Kelly *et al.*, 1991; Pluske *et al.*, 1996c) which is followed by a partial recovery within 10 days post-weaning (Vente-Spreeuwenberg *et al.*, 2003b). The alteration in morphology and function of the small intestine may impair the ability to digest and absorb nutrients and predispose the weanling piglet to development of malabsorption and diarrhoea (Montagne *et al.*, 2003; Vente-Spreeuwenberg *et al.*, 2003a). More specifically, Miller and Skadhauge (1997) observed that the intensity of absorption of water and minerals is directly proportional to the length of the villi. This is because shortening results in an absolute loss of intestinal surface area and also, because cells that are lost are generally the mature cells (Nabuurs 1998). Deprez *et al.*, (1987) reported that there was a significant difference ($P<0.05$) in villus height between the piglets weaned on a dry or a liquid diet on days 6 and 8 after weaning.

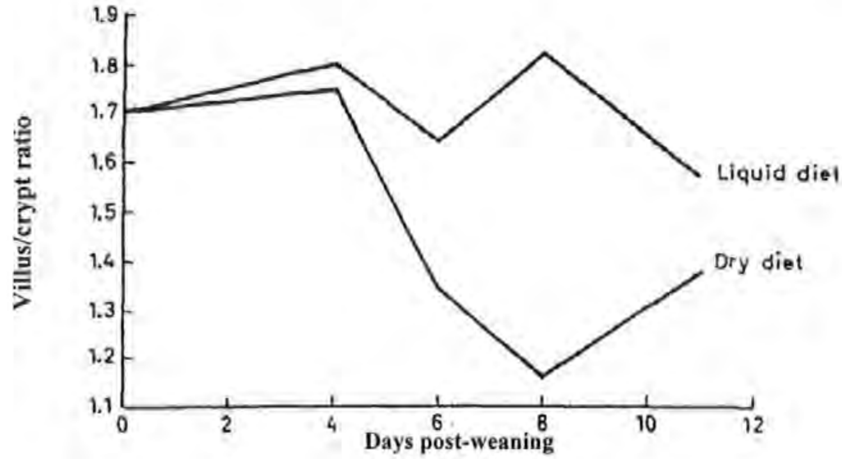


Figure 1.17 Villus/crypt ratio in the ileum of piglets fed a liquid or a dry diet (after Deprez *et al.*, (1987)).

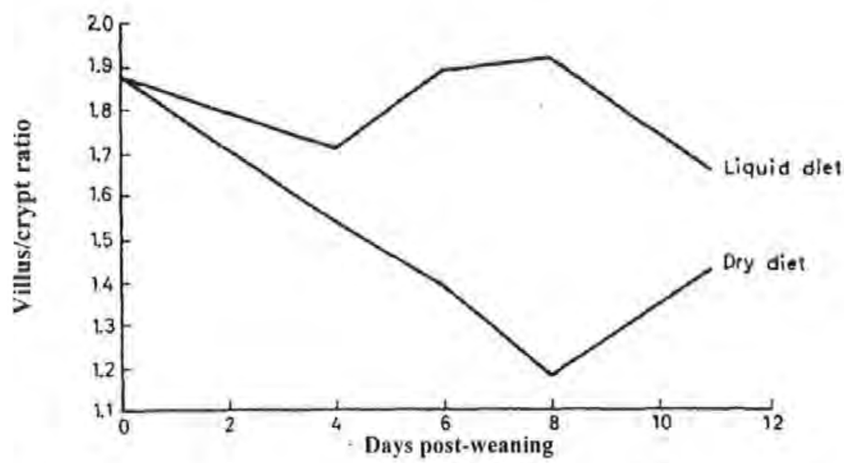


Figure 1.18 Villus/crypt ratio in the distal jejunum of piglets fed a liquid or a dry diet (after Deprez *et al.*, (1987)).

Minimal values were obtained at day 8 post-weaning in piglets on the dry diet whereas in the piglets receiving a liquid diet villus heights remained quite stable (Figures 1.17 and 1.18).

van Beers-Schreurs and Bruininx (2002) suggest that when feed/energy intake is maintained after weaning, the typical villus atrophy at 4 to 5 days post-weaning can be avoided (Table 1.13).

Table 1.13 The relative effect of early post-weaning energy intake on average villus height in the small intestine of pigs (from Bruininx *et al.*, (2001a)).

Author	Energy source	Energy intake	Age at		Villus height (weaning =100%)
			weaning	slaughter	
(Pluske *et al.*, 1996b)	Starter diet	5.7 MJ GE/d	28 d	33 d	-30%
(Pluske *et al.*, 1996b)	Ewes' milk	7.4 MJ GE/d	28 d	33 d	-2%
(Pluske *et al.*, 1996b)	Cows' milk	2.3 MJ GE/d	29 d	34 d	-27%
(Pluske *et al.*, 1996c)	Starter diet	5.1 MJ GE/d	29 d	34 d	-18%
(Pluske *et al.*, 1996c)	Cows' milk	5.2 MJ GE/d	29 d	34 d	-4%
(Pluske *et al.*, 1996a)	Cows' milk	8.9 MJ GE/d	29 d	34 d	+11%
(Pluske *et al.*, 1996a)	Cows' milk	5.5 MJ GE/d	28 d	33 d	-4.8%
(Kelly *et al.*, 1991)	Starter diet	2.9 MJ GE/d	14 d	20 d	-55%
(van Beers-Schreurs *et al.*, 1998)	Starter diet	0.53 MJ ME/BW$^{0.75}$/d	28 d	32 d	-40%
(van Beers-Schreurs *et al.*, 1998)	Sows' milk	0.48 MJ ME/BW$^{0.75}$/d	28 d	32 d	-35%
(van Beers-Schreurs *et al.*, 1998)	Sows' milk	1.4 MJ ME/BW$^{0.75}$/d	28 d	32 d	-11%

Pluske *et al.*, (1996c) found a strong relation ($r=0.82$; $P<0.001$) between total DM intake and villus height in pigs fed cow's milk for 5 days after weaning. Zijlstra *et al.*, (1996) reported that pigs fed milk replacer had longer villi than did suckled pigs, which supports the link established with feed intake. Villus height also remained unchanged in suckled pigs from day 18 to day 25, which could indicate that daily intake of sow milk remained unchanged during this week. At 7 days after weaning, Zijlstra *et al.*, (1996) and McCracken *et al.*, (1999) suggested that pigs fed the starter diet had shorter villi than did suckled pigs, which could be due to reduced feed intake; however soy hypersensitivity response cannot be eliminated as a possible cause for villus atrophy at this time-point after weaning (McCracken *et al.*, 1995).

Alpers *et al.*, (1992) described how maldigestion and malabsorption result in accumulation of fluid and digesta in the small intestine. The osmotic activity of the digesta increases and the absorption of water will further decrease. Due to a larger volume, the small intestines are extended, resulting in an increased motility of the intestinal wall. Subsequently, the digesta has less time to be digested. The overflow of undigested and unabsorbed nutrients reach the colonic area and there they i) will be fermented by microbial agents, ii) may act as substrate for pathogenic strains of *E.coli* and iii) will enhance the osmotic activity, possibly resulting in osmotic diarrhoea. Moreover, an increased crypt depth is associated with an increased water secretion into the intestinal lumen. In young animals, the large intestine is often not well developed, and in weanling pigs may not be capable of absorbing enough fluid to prevent clinical diarrhoea and dehydration (Nabuurs 1998). An increase of water secretion by the crypt cell is one of the primary mechanisms by which toxin-producing bacteria such as *E.coli* or *Salmonella* initiate hypersecretory diarrhoea (Montagne *et al.*, 2003).

Vente-Spreeuwenberg *et al.*, (2003a) report that piglets identified as eaters had longer villi than non-eaters ($P<0.01$) and piglets without diarrhoea had longer villi than piglets with diarrhoea ($P<0.05$). Piglets that were labelled non-eaters with diarrhoea had the lowest group-mean villus height at the proximal and mid small intestine, whereas eaters without diarrhoea had the longest villi. There is also a positive correlation between food intake and villus height, whereas the presence of more-liquid feaces on days 4 to 6 and villus height were negatively correlated (Vente-Spreeuwenberg *et al.*, 2003a). Finally, they also report a reduction in small intestine weight on day 3 post-weaning when compared with either weaning day (d 26) or day 7 after weaning.

It was anticipated by Etheridge *et al.*, (1984) that because of a lower digestibility of the creep food compared with sow's milk, pre-weaning creep feed consumption would result in an accumulation of undigested nutrients. Bruininx *et al.*, (2004) reported that the consumption of creep feed did not affect the morphology of the SI nor the microbial activity in the colon while the piglets were still suckling (d 28).

1.11 Factors which contribute on the outcome of observational studies.

There are numerous behavioural/observational studies, which fail to come in agreement on the response of the piglets to similar situations. This section will attempt to identify the main causes for the disagreement between the studies, and the experimental factors which can contribute to the variation of the observational conclusion.

1.11.1 The observer effect.

Lay *et al.*, (1999) reported that an unfortunate consequence of quantifying animal behaviour is that merely observing the animal may change its behaviour. This is called 'the observer effect', and it is a challenge for ethologists, who are concerned with obtaining accurate data that reflect the true behaviour of animals (Lay *et al.*, 1999). There are numerous factors other than the physical presence of a person which can be responsible for changing animal behaviour during observations. It has been emphasized that although subjects may appear well-habituated, certain behaviours and classes of individuals (e.g., juveniles) may be more apt to be affected by the observer than others (Martin and Bateson 1986).

Researchers are aware of the possibility that their very presence could change the behaviour of the animals they are observing. This awareness has led to the widespread use of video cameras to record the behaviour of the subjects in question, thus eliminating the human observer. However, in order to use these cameras during the night, lights are usually left on to illuminate the study subjects. Kelly *et al.*, (2000) have described that the observer in their trial was always positioned outside the pens in order to gain a clear view of the pigs' activity but making no attempt to hide from them. Their observer allowed 2-3 min to elapse before starting to record behaviour, in order to allow any interest caused by her entry to subside; but there is no clear evidence which can determine the exact time that animals and especially piglets need in order to familiarise themselves with the presence of a human appearing sporadically during the course of the day.

1.11.2 Recording methods.

Martin and Bateson (1986) suggested that when deciding on systematic rules for recording behaviour, two levels of decision must be made: the sampling rules and the recording rules. Sampling rules specifies which subjects to watch and when and covers the distinction between *ad libitum* sampling, focal sampling, scan sampling and behaviour sampling. *Ad libitum* sampling means that no systematic constraints are places on what is recorded and when and can be useful during preliminary observation, or for recording rare but important events. Focal sampling means observing one individual, one litter or some other unit for a specified amount of time and recording all instances of its behaviour- usually for several different categories of behaviour. Focal sampling is considered the most satisfactory approach to studying groups. Scan sampling means that a whole group of subjects is rapidly scanned at regular intervals, and the behaviour of each individual at that instant recorded. Scan sampling usually restricts the observer to recording only one or a few simple categories of behaviour, such as whether or not a particular activity is occurring, or which individuals are fighting. An obvious danger with scan sampling is that results will be biased because some individuals or some behaviour patterns are more conspicuous than others. For example, Boe (1991) found that by observing the whole 24 hour cycle that the initiation of the nursings was clearly different during the day- and night-time. Behaviour sampling means that the observer watches the whole group of subjects and records each occurrence of a particular type of behaviour, together with details of which individuals were involved. This sampling rule is mainly used for recording rare but significant types of behaviour.

Recording rules specifies how the behaviour is recorded and it covers the distinction between continuous recording and time sampling. Time sampling is divided into instantaneous sampling and one-zero sampling. Continuous recording means that one or more subjects are observed for a specified amount of time and all instances of their behaviours are continuously recorded. The objective is to produce an exact record of the behaviour that has occurred, or began and ended. Time sampling means that the behaviour is sampled periodically, therefore less information is preserved and an exact record of the behaviour is not necessarily obtained. With instantaneous sampling, one or more subjects are scanned at regular intervals and the behaviour of each individual at that moment is recorded. The underlying idea of this sampling method is that by recording large numbers of samples, you can get an unbiased estimate for the total duration of each behaviour. With one-zero sampling, the observation session is divided into sample intervals. On the instant of each sample point, the researcher records for each relevant behaviour whether or not it has occurred during the preceding sample interval, regardless of the duration of the behaviour and how often the behaviour has occurred during the interval (Anon. 2003).

1.11.3 The lighting pattern.

A trial conducted by Lay *et al.*, (1999) show that piglets subjected to 24:0 (light:dark) regime were more active than the 12:12 pigs ($P<0.001$) between 1830 and 0630. According to their study, this increase in night time activity resulted in a trend for 24:0 pigs to be more active during the entire day ($P<0.08$). A factor which contributed to the above observation might be that the pigs of their study were born in an environment with a light pattern scheme and changed when they became 24 days old. So the change of the light regime proved to be significant in altering their behaviour. There are still un-resolved questions whether the exposure of the piglets to 24:0 regime from day 1 of their life could have the same influence to their behaviour, as production management techniques consider maintaining pigs with a shorter period of darkness as this will possible lead the pigs to eat more and grow more rapidly (Lay *et al.*, 1999).

Bruininx *et al.*, (2002) observed that exposing weaner pigs (28 d) to 23:1 h lighting schedule, stimulated ADFI (418 *v.* 302 g/d; $P<0.05$) and ADG (381 *v.* 240 g/d; $P=0.05$) during the second week post weaning in comparison to those on the 8:16 h schedule. When weaner piglets need to leave a warm environment to eat in a cold environment, influences their meal frequency and meal volume but not total daily intake (Zijlstra *et al.*, 1996) as they will try to minimise their daily visits to a feeder that is suited in an uncomfortable environment.

Giving adequate feeder access, pigs demonstrate a peak of intake during the morning and the afternoon, if a diurnal lighting pattern is followed, and where continuous lighting is applied, the morning and afternoon peaks will blend into a single peak (Patience 1998). Fraser *et al.*, (1994) reported that the diurnal pattern of creep feeding differed somewhat between high and low complexity diets. On the low complexity diet, feeding activity was concentrated in three periods: 08:00-10:00 when staff was present, 11:00-14:00 h when sows were fed and staff were present, and 21:00-23:00 hours before the lights were turned out with only 13% of feeding activity during night-time hours. For pigs on the high-complexity diet, 22% of feeding activity occurred at night. Blackshaw *et al.*, (1997) observed that an increased frequency of play in the older piglets for individual activity (spring and run) and social behaviour (nudge and push) were characterised by a higher frequency in the afternoon. This may reflect a general increase in wakefulness and physical activity at this time according to the same authors.

1.11.4 Other factors.

Bruininx *et al.*, (2001b) observed that in 4-week old piglets the mean time to initiate feeding after weaning was 15.4 hours, with a very large variation among individual piglets, ranging from a very short time up to 4 days after weaning.

Boe (1993) observed that piglets weaned in flat decks spent a greater amount of time eating than piglets weaned in farrowing pens. It has been hypothesised (considering no difference in actual consumption was recorded) that in a barren environment food becomes one of the few interesting stimuli for sniffing and rooting.

In studies of mammalian parental investment, time spent suckling, is often used as a predictor of the milk transferred from mother to infant (Fletcher 1971). It is assumed that the rate of milk transfer is positively related with the time spent suckling, but this assumption has only lately been questioned (Babbit and Packard 1990; Birgerrson and Ekvall 1994). Cameron (1998) reviewed a number of studies that have correlated time spent suckling with growth rates or weight gain during a suckle bout as indices of milk intake. Of the studies that correlated infant growth rates with time spent suckling, only one found a significant positive relationship between growth and time spent suckling, three a significantly negative relationship and 16 no significant relationship (Cameron 1998). However, the relationship between growth and suckling can be obscured when the mother's milk is not the only source of nutrition for the young. Even where milk is the primary source of nutrition other factors such as differences in activity (Duncan *et al.*, 1984) could lead to differences in growth rate despite ingestion of the same quantity of milk. In addition, variation in milk quality and composition both between and within individuals could cause marked differences in energy intake even if the amounts of milk ingested were similar (Oldham and Friggens 1989). Cameron (1998) also performed a meta-analysis of previous studies that were estimating milk intake by different methods (suckle bout duration, bout frequency, total time suckling, growth test weighing), and it has been shown that different methods produced quantitatively different results. Meta-analyses are a quantitative technique for combining the results of statistical tests on previous studies that have looked at the same relationship taking into account the sample size of each study (Cameron 1998; Sheu and Suzuki 2001). The same author came to a conclusion that from the behavioural sampling methods, only suckle bout frequency and total time suckling were significantly correlated with estimated milk intake, with total time suckling providing a better estimate. Although there was a significant positive relationship, the power to predict milk intake from time spent suckling was low and was different between species, between studies and even within studies of the same species (Cameron 1998). Hemsworth *et al.*, (1976) have reported that the amount of time that each teat was suckled during the period of continuous suckle was positively correlated with the growth performance of the piglet which preferred the teat at day 21 of lactation. Other studies have shown that there is a large variation in the suckle ability of the offspring. Weaker offspring may take longer to drain teats but receive no more milk (Clutton-Brock 1991) and male lambs, spent less time suckling but grew faster than did female lambs, suggesting that males obtained more milk per second while suckling and emptied the udder more quickly (Festa-Bianchet 1988).

Metz and Gonyou (1990) observed that before weaning, the 2-week and 4 week old piglets spent 20.7 and 14.8% respectively of their time suckling. Puppe and Tuchscherer (2000) and Hohenshell *et al.*, (2000a) believes that the large differences between numerous studies on nursing and sucking behaviour in pigs derive from the population used, housing condition, breed, individual sow or observed week of lactation. Some examples of the great variation on different time sampling techniques are given in Table 1.14 below.

Table 1.14 Differences in methodologies and observational sampling techniques between studies.

Source	Observations	No. Animals	Weaning age (d's)	Piglet's observed for the following days of their life	Method of Observation: Periodicity	Total observatio-nal time (hours day^{-1})	Apportio-ned (Days)
(Delumeau and Meunier-Salaun 1995)	Feeder familiarity	28litters 3pigs/lit (those which had increased feeding behaviour)	28	5-27	5 min scan sampling for 90min		12 days
(Delumeau and Meunier-Salaun 1995)	Teat order	28litters 3pigs/lit (those which had increased feeding behaviour)	28	14-28	>10 suckling episodes		
(Delumeau and Meunier-Salaun 1995)	Play Fighting drinking	28litters 3pigs/lit (those which had increased feeding behaviour)	28	14-28	5 min scan sampling for 90min		8 days
(Spinka *et al.*, 2002)	Nursing	11, 14 sows	28	7, 11, 28	Continuous for 2-5 milk ejections		
(Laitat *et al.*, 1999b)	Feeder usage	60,80,100 pigs/pen, pen behaviour not individual's	28-35	0-42	1day/week	24 hours	5 days
(Merlot *et al.*, 2004)	Locomotion, resting, feeding	48 female healthy piglets (8.9kg)	28	33-36	5 min scan sampling (8:00-18:00)		3 days
(Hotzel *et al.*, 2004)	Piglet-sow interact Nursing Belly nosing Oral activity Standing	16 sows	21	1,12,20,21,35, 50	Instantaneous scan sampling (every 15 min, 6scans with 20 sec interval)	8:30 to 11:30 and 14:00 to 18:30	6 days
(Widowski *et al.*, 2003)	aggression	Variable 60-100 piglets	18-28	26-46	1min continuous every 5 min interval for 2 hours	24 min	1 day
(Schroder-Petersen *et al.*, 2003)	biting	96 piglets	28	28-56	1day/week (7:00 to 19:00) continuous	12h	4 days
(Rushen and Fraser 1989)	Sucking behaviour	1 pig/litter 4 litters		9-15	10 recordings 3-5 min long/piglet		5 days

(Fraser 1978)	Suckling, nosing, lying, feeding, drinking, aggression, pawing floor	8 piglets/litter Total 80 pigs	21 and 42	1-42	Pre-weaning: 2h day^{-1}, 3d wk^{-1}, for 3-5 weeks Post-weaning: 2h day^{-1}, 5days	2 hours	15 days
(Horrell 1997)	sucking	2 wild sows		0-49	opportunistic	1.5-5h	49 incidence
(Boe 1991)	sucking	16 sows		14-70	5 min scan except suckling	24 h	288 days
(Boe and Jensen 1995)	Feeding behaviour	115 piglets 11 litters	63	28-56	Continuously 1d/week	24 h	5 days
(Boe and Jensen 1995)	Sucking behaviour	115 piglets 11 litters	63	28-56	Continuously 1d/week	20h	5 days
(Auldist *et al.*, 2000)	Sucking behaviour	18 litters	28	9-23	continuously	24 h	2 days
(Appleby *et al.*, 1991)	Feeder usage	72 piglets	28	20-28	1 frame/min over 24 hours		8 days
(Gonyou *et al.*, 1998)	Feeding Lying Drinking standing	60 piglets	12 and 21	Week 6 and week 5 respectively	Every 8 min in a 2 hours period twice day^{-1} Scan sampling		3 days
(Gonyou *et al.*, 1998)	feeding	60 piglets	12 and 21	12-14 and 21-23	5min scan sampling in a 6 hours period		2 days
(Hohenshell *et al.*, 2000a)	Lying, standing, sitting, drinking, feeding, playing	8+8 = 16 litters	10 and 30	10-15 30-34	10min observations/4 times a day	40 min	4 days
(Jensen and Redbo 1987)	Mother-offspring interaction	4 gilts		5-10	2min scan sampling	8h	4 days

1.12 The effect of weaning procedure on piglets' post-weaning social behaviour.

Normal farming practices require that pigs are frequently grouped and mixed, for example at weaning, at the start of finishing and during transport (McGlone and Curtis 1985). This results in a disruption of social organisation which can lead to an increase in aggression (Arey and Franclin 1995) and social stress which in turn can compromise welfare and growth.

To control aggressive behaviour in newly regrouped weaned pigs, Van der Heyde (1972) suggests that the nursery has to be free of vibrations or sounds and that the working time in the nursery be kept to a minimum to prevent disturbance. Weaning early in the evening to reduce the time that the pigs spent agonistic interactions and (or) regulating their feeding time to stimulate feed intake post-weaning may be a practical management alternatives for improving post-weaning performance. Ogunbameru *et al.*, (1992) found that weaning piglets between 21 to 26 days of age (BW 7.1 kg) at 2000 hours, consumed 5% more feed ($P<0.01$) and grew 6% faster ($P<0.05$) than pigs weaned at 0800 considering that pigs exposed to a 12:12 light:dark regime. According to Gonyou (1986) domestic animals are often exposed to physiological trauma at weaning and the establishment of a new social order involves aggression that reduces the animals comfort and well being. The characteristic post-weaning growth lag may have been reduced by weaning at 2000 hours, because the pigs had less time to engage in unproductive agonistic interactions than pigs weaned at 0800 (Ogunbameru *et al.*, 1992). Friend *et al.*, (1983) found that spreading a commercial odour agent on the pigs, which is used commonly to reduce tail-biting and fighting, only created a temporary diversion from fighting with no overall reduction in aggression.

Sex and body weight can also affect social interactions and performance of weanling pigs (Mahan *et al.*, 1998), but the effects on individual animal feed intake characteristics between weaning and feeding are unknown. Possibly, identification of various determinants of individual feed intake characteristics, especially during the first week after weaning, could serve to improve health and performance of weanling pigs housed in groups. Hessing *et al.*, (1993) found no significant sex and litter effects in the occurrence of aggressive behaviour.

Also, birth weight may influence according to Pajor *et al.*, (1991) the dominance hierarchy at the feeder, especially if feeding space is limited. Increasing feeding space (from 1 to 3 spaces per pen) has been reported to increase the amount of creep feed consumed (2.1 times at week 3 ($P<0.05$), and 1.4 times on week 4 ($P<0.05$)), especially among those piglets that were very little when only one feeder was available (Appleby *et al.*, 1991).

Waitt and Buchanan-Smit (2001) observed that anticipation of feeding routines had a considerable negative impact on behaviour, such as self directed behaviour, inactivity, vocalisation and abnormal behaviours, and these behaviours were prolonged as the feeding was more and more delayed past the mean routine time.

Restricted amount of feed or feeding places, absence of bedding, unpredictable feeding regime and crowding increases the agonistic behaviour of pigs (Carlstead 1986).

1.12.1 The form of hierarchy.

Groups of newly weaned pigs are aggressive and spend the first hours up to the first week post-weaning establishing their dominance order (Graves *et al.*, 1978). Thus, establishing the social order may have deleterious effect on the pigs, as that aggressive behaviour immediately after weaning can lead to serious wounds, impair disease resistance and result in performance setbacks (McGlone and Curtis 1985). Assuming heavy pigs are more dominant than light pigs (Rushen 1987), it follows that in homogenous groups of heavy pigs the establishment of social hierarchy lasts a relatively long time, which in turn decreases initial feed intake. Also it has been suggested by Rushen (1987) that fighting among pigs of dissimilar weights is limited because size itself also affects dominance.

Blackshaw (1981) reports that biting was displayed by high-ranking pigs and may be functional in the establishment of dominance hierarchies. Also, they have observe that biting behaviour was spread between pens where there was only visual contact, suggesting that pigs imitate other pigs that are biting.

1.12.2 Belly-nosing & flank-biting.

Early weaning may increase aberrant behaviours such as belly nosing and flank biting which can be important indicators of stress (Metz and Gonyou 1990; Boe 1993). Fraser (1975) defined that 'an animal is said to be in a state of *stress* if it is required to make abnormal or extreme adjustments in its physiology or behaviour in order to cope with adverse aspects of its environment and management'. Broom and Johnson (1992) have suggested that animals that are stressed may pay less attention to their environment than animals which are relaxed. Worobec *et al.,* (1999) proposed that the difference in the amount of time that the piglets spent in exploring objects and interacting with neighbours suggests that very early weaned piglets may be stressed, more apathetic, and less responsive to their environment.

It was observed by Petersen (1994) that piglets perform behaviours such as rooting, biting objects, chewing, sniffing at substrate and walking/standing during the first days post partum. The behaviours mentioned earlier combined with the manipulation of the udder are the activities which are performed more frequently by free-range domestic pigs during the first 4 weeks and it is assumed that piglets familiarise themselves with their surrounding during this period (Petersen 1994).

Belly-nosing involves the repetitive rooting motivation on the belly of another piglet, similar to massaging the sow's udder (Fraser 1978), and can result in the development of lesions on the recipient piglet. Because this behaviour pattern resembles massaging the udder and sucking, it may be associated with hunger. Alternatively, it may be stimulated by feeding (Gardner *et al.*, 2001). Petersen (1994) observed that nibbling and chewing other piglets occurs only very rarely in domestic piglets which live under natural conditions in a varied environment and with ample space. According to this author, environment is the main factor which causes the high frequency of nibbling, chewing and sucking littermates which is seen in intensive housing systems.

It is well established that piglets weaned at younger ages perform more belly-nosing, and this behaviour increases under stressful conditions after weaning (Dybkjaer 1992). Amaral *et al.*, (2003) observed in groups presenting suckling vice to perform lower growth rates ($P<0.005$) after weaning (d 30) and identified that the main risk factors associated with suckling vice were: weaning weight lower than 6.3 kg, unavailability of drinkers for piglets pre-weaning, occurrence of post-weaning diarrhoea, unfamiliarity with post-weaning drinkers to those been available pre-weaning, no all-in-all-out procedure in the post-weaning facilities, and the use of restricted feed the first days post-weaning. However, in most experiments, age is confounded with diet composition. In other words, early-weaned piglets are fed diets containing a high percentage of milk products. Gardner *et al.*, (2001) thought that it is possible that the milk in the diet stimulates belly-nosing. They found that feeding a poor quality diet or even including milk in the diet had no effect on belly-nosing or other oral-nasal behaviour patterns during the first 3 weeks after weaning. In other studies the onset of belly nosing behaviour has been observed around day 4 after weaning (Gonyou *et al.*, 1998; Worobec *et al.*, 1999; Orgeur *et al.*, 2001) which is when the establishment of feeding occurred. According to Gardner *et al.*, (2001), belly-nosing does not seem to be associated with feeding. Orgeur *et al.*, (2001) suggests that this activity confirms the need of contact of these young piglets and indicates the modifications of social relations after an early weaning.

Li and Gonyou (2002) suggested using a sequence model, that social interaction and belly-nosing frequently occurred in sequence, suggesting that these two behaviours may share common motivational factors. According to their study, when only active behaviours were considered, belly nosing appeared to substitute for other social behaviours during the nosing segment of bouts of belly nosing, and also, their results offer support of a social motivation for belly nosing.

Many other researchers have recorded difference in behaviour of early- and late-weaned pigs. Fraser (1978) compared pigs weaned at 3 weeks of age to pigs left on the sow and found the earlier weaned pigs belly-nosed more at 6 weeks of age ($P<0.05$) but had less weight gain (8.86±0.51 *vs.* 10.75±0.44 kg, t=2.81, P<0.01). This lower frequency of aggressive acts most likely resulted from the piglets being able to form a stable social hierarchy at 6 weeks and not at 3 weeks of age (Worobec and Duncan 1997).

1.12.3 Negative effects of belly nosing on piglets' performance.

Li and Gonyou (2002) found that belly-nosing was negatively correlated with eating and lying, but if hunger was the triggering factor, then it should be evident shortly after weaning and not after 4 days as other workers have observed. Similarly, Gonyou *et al.*, (1998) and Hohenshell *et al.*, (2000b) reported that belly-nosing did not develop immediately after weaning and peaked 2-3 weeks afterward. It is though positively correlated with standing, which indicates that belly nosing is more common in active, low-intake piglets. Gonyou *et al.*, (1998) found that belly-nosing was associated with the more active pigs within a pen, which were also those which grew slower, but the relationship of belly-nosing to growth was not significant.

Dietary factors are also cited as causes of tail and flank biting. These include low dietary fibre, inadequate or poor-quality protein, excessive dietary energy, and deficiencies or imbalances of iron, copper, sodium chloride, calcium, phosphorus or iodine (Fraser 1987).

Fraser (1978) observed that the very rapid increase in feeding behaviour during the first day after weaning at 3 weeks was accompanied by a much slower rise in the frequency of defecation, as defecation pattern re-established 4 days after weaning. This may reflect some difficulty in the animals' physiological adaptation to the solid food, perhaps indicated in extreme cases by diarrhoea. Discomfort from this source might account for the animal's restlessness and increased aggression.

1.12.4 Others factors which can influence the post-weaning behaviour of the piglets.

1.12.4.1 The effect of pen design to piglets' performance and behaviour.

Pen design should reflect two components of space, quantity and quality (Wiegand *et al.*, 1994). Quantity refers to the amount of space provided. Quality refers to the features of the space which facilitate or restrict usefulness by the animal. These components not only affect the physical space an animal has access to, but also imposes limitations on social interactions (Wiegand *et al.*, 1994).

Williams (2003) suggests that a pen has to permit individual piglets to find their own comfort zone (not to be heat stressed or too cold) as there can be a difference of 12 ^{o}C in lower critical temperature between a pig that is not eating and a pig that is consuming 4 times maintenance.

Most studies have focused on determining the quantity of space needed and have not considered the quality of the space. One way of manipulating space quality is to change the ratio of perimeter to area (Wiegand *et al.*, 1994). A second option provided by the same authors is to increase the maximum distance two animals can separate in a pen (D_{max}). In shapes with larger D_{max}, animals may have an increased ability to withdraw from conspecifics, resulting in greater control over their social environment. Madec *et al.*, (2003) suggests that pigs on bedded solid floors require some 20-25% more space.

During an aggressive act, it has been observed that a pig focuses its bite on its opponent's head and ears (Kelly *et al.*, 1980). So, when a pig submits to another pig in close quarters, it tries to hide its head and ears. It has been observed that crowded pigs spent more time with their heads in a feeder, and also consumed less feed, than did those with more floor space (Bryant and Ewbank 1974).

In a study conducted by McGlone and Curtis (1985) it was reported that corners acted as hide areas, which have been found to decrease aggression in newly regrouped pigs. They also observed that the provision of wooden hide areas in the pen decreased the attack duration during the initial 30 min after weaning by 42% (2,036 vs. 1,171 sec; $P<0.01$). In a study performed by Wiegand *et al.*, (1994), pigs housed in rectangular pen shapes, defecated near corners and walls, with pigs in circular pens using feeder edges as corners. They also found that the interaction of D_{max} and the presence of pen corners affected the number and size of social groups in the pen. Shapes with corners have only two or three places where subgroups may form while maintaining the maximum distance between groups. Circular pens have, theoretically according to the same source, an infinite number of such locations but according to Wiegand *et al.*, (1994) more social groups (1-3 pigs) were formed in rectangular and square pens than in other shapes ($P<0.01$).

Olesen *et al.*, (1996) used a partition in order to transform the pen into a more complex environment and divide it into two parts. Unfortunately this practice did not reduce the agonistic behaviour or injuries caused by such behaviour.

1.12.4.2 The effect of feeders to post-weaning feeding and aggressive behaviour.

Feeders represent the final interface between pigs and the diets designed to meet their nutrient needs and it has been reported that the economic efficiency of a feeder depends on a number of factors, including its costs, the number of pigs that can use it, their ability to achieve appropriate feed consumption and the amount of feed wasted (Gonyou and Lou 2000).

Laitat *et al.*, (1999a) states that space requirements must take into account the behaviour of the pigs such as the agonistic interactions when feeding in groups between pen-mates or the association of feeding and drinking bouts. Baxter (1984) demonstrated that protecting head and shoulders to prevent interruption of feeding bouts due to aggression was important.

Ideally, nursery pigs should be equipped with feeder space that allow at least half of the pigs in the pen to eat at any one time, however this scenario is not always attained and the issue of the 'correct' number of pigs per feeding space is always a topic of discussion and contention (Madec *et al.*, 2003). Baxter (1984) described the equation: $W = 61xBW^{0.33}$, where W = width of the pig at the shoulder (in mm) and BW is bodyweight (kg) that represents the minimum feeding space. Madec *et al.*, (2003) suggests that a 10% margin has to be allowed in order to address individual pig variation. So, a pig weighing 10 kg requires available feeder space of 133 mm, allowing a 10% margin.

Pluske and Williams (1996a) states two factors which may have profound effects on voluntary food intake, particularly in the first few days after weaning, and these are i) the design of the feeder and ii) the association between feeding behaviour and aggression. However, few studies assessed the effects of type of feeder on performance and feeding behaviour of young pigs. Barber *et al.*, (1989) recorded a direct correlation between water intake and food intake after weaning, and they suggested that 'wet and dry' single space feeder may increase feed intake because pigs prefer to eat their food in the presence of water. Pluske and Williams (1996a) did not come to the same conclusion as they found no significant effect on growth rate or voluntary food intake of piglets during the 28 days after weaning. From a behavioural point of view, weaned pigs observed in experimental conditions (social isolation) eat for a longer time than later during the fattening period, and this has to be related with a higher frequency of feeding bouts; concerning water intake, the association with eating bout reaches 91 to 97% when pigs weigh between 10 and 30 kg (Bigelow and Houpt 1988).

Group housed pigs make less frequent feeder visits of longer duration, and eat at a faster rate than pigs housed individually, having as a consequence lower growth rates due to increased stress levels resulting from changes in the concentrations of hormones, such as cortisol and adrenaline which are associated with aggression and social stress (Bornett *et al.*, 2000). Social facilitation in group housed pigs results in synchronised feeding, but can lead to increased competition for feeder space in pigs kept in groups, caused by the motivation to feed simultaneously (Hisa and Wood-Gush 1983). It was found that pigs in individual housing have higher digestibility coefficients related to smaller, more frequent meals (Gonyou *et al.*, 1992; de Haer and de Vries 1993).

Kornegay *et al.*, (1979) found that increasing stocking density by decreasing floor space allowance per pig, decreased growth rate, with depressed feed intake being the major factor. Even when stocking density is altered by increasing the number of pigs per pen, it reduced individual pig performance very little, as Lindemann *et al.*, (1987) have demonstrated, that feeder space allowance (2 to 12 spaces at 15.2 cm sections) had no significant effect on feed/gain and was generally without effect on feed intake and daily gain (weaning at 28 days, see Table 1.15).

Table 1.15 Performance levels of weanling pigs (28 days) provided varying amounts of feeder space (after Lindemann *et al.*, (1987)).

	Feeder sections, 15.2 cm/section					
Feeder spaces	2	3	4	6	12	SE
Average daily gain (kg)	0.35	0.37	0.35	0.36	0.36	0.01
Average daily feed (kg)	0.69	0.73	0.69	0.74	0.70	0.02

Barber *et al.*, (1989) found that maximum levels of food intake were achieved at drinker flow rates of 750 ml/min, and it has been suggested by Pluske and Williams (1996a), that in situations where the water flow to the drinker in the bowl can not be controlled, 'dry' single-space feeders may be more suited to weaner piglets as they appear to reduce food wastage.

Patience (1998) documents that most of the aggression related to feeding is initiated by the pig in the process of eating and is rarely initiated by the pig waiting to gain access to the feeder and it will protect this resource against intruders. According to the above observation, Patience (1998) suggests that providing a head and shoulder barrier fitted on the feeder, will minimise visual contact with other pigs in the pen.

Gonyou (1999) observed that pigs spent less time consuming their feed from wet/dry feeders than from dry feeders. Also, pigs fed with a dry/wet feeder, did not have to interrupt their meal in order to get a drink of water and there was also less activity as the pigs remained in the feeder for longer periods. Gonyou (1999) also reports that feed intake and daily gain increased by 5% and pigs on wet/dry feeders reached market weight a week earlier than those pigs fed on dry feeders.

1.12.4.3 The effect of draughts on piglets' post-weaning performance and behaviour.

Scheepens *et al.*, (1991) observed that piglets exposed to unpredictable and uncontrollable draught, piglets redirected their explorative behaviour on penmates and excessive aggression could be detrimental for health and the performance of pigs even during periods without draught.

Maenz *et al.*, (1994) found that maintaining pigs at a constant chilled environmental temperature of 21°C had no effect on feed intake but did reduce feed efficiency and tended to lower weight gains and water intake.

The comfort zone (ambient temperature at which pigs are comfortable) will usually range 1 °C above and below the values given (Table 1.16). The pigs are assumed to be fed to appetite and able to lie on a floor with a thermal resistance that is not different to that of air.

Table 1.16 Comfort temperature values in relation to liveweight of the pig (after Whittemore (1998)).

	Liveweight of pig (Kg)	Comfort temperature (Tc) (°C)
Sucking pigs	<2	32
	<5	28
Weaner pigs	<8	28
	<10	26
	10-15	22

Le Dividich *et al.*, (1980) reported that the lower critical temperature to be in the region of 26-28°C during the first week post-weaning where the average level of feed consumption is lower than the MEm. Le Dividich (1981) suggested that keeping a high ambient temperature during the critical first weeks post-weaning can prevent a possible overfeeding and therefore can help to prevent scouring. To maintain relatively high ambient temperature and maximise performance, high energy inputs in the form of heating have to be supplied (Le Dividich 1981). Le Dividich and Herpin (1994) reported that the weaned pig is to some extent able to deal with sub-optimum environmental conditions by increasing its voluntary food intake.

1.12.4.4 The effect of floor type on piglets' post-weaning performance and behaviour.

The pig, and particularly the young one, is an active animal by nature. Nevertheless it is willing to sleep for four-fifths of the day if the environment is satisfactory (Ekkel *et al.*, 2003). If the animal does not feel comfortable it becomes restless, but such activity can be repressed by total darkening of the building, or by giving the pigs long straw of good quality which keeps them busy biting, moving or eating it (Van Putten 1969; Beattie *et al.*, 1995).

Housing with fully perforated floors is commonly used for early-weaned pigs, since this encourages the physical separation of the pig and its dung, and allows increased stocking density (Kelly *et al.*, 2000). Beattie *et al.*, (1998) reported that pigs given the choice between various floor substrates spent most of their time on peat, mushroom compost and sawdust, subsequently on sand, whereas bark and straw scored only better than concrete. The authors hesitatingly concluded that pigs are attached by substrates with a similar texture to earth. Bedded housing systems on the other hand may redress the behavioural problems but can encourage enteric problems (Silver 1989) and have other practical management disadvantages such as increased labour requirement. Perforated have been reported that increases belly-nosing to weaned piglets (McKinnon *et al.*, 1989). However, Farmer and Christison (1982) reported that in preference studies, weanling piglets preferred plastic-coated expanded metals and that foot lesions were also reported to be the lowest for plastic-coated floors.

It has been reported by McKinnon *et al.*, (1989) that the level of activity was higher in pens with solid floors compared with perforated floors, and even higher when straw was provided. The introduction of a trough containing sterilised earth in flat-deck cages decreased the frequency of piglets lying inactive.

Boe (1993) observed that piglets weaned in flat decks were sniffing/rooting pen mates and tail biting significantly more than piglets weaned in the farrowing pen. Metz and Gonyou (1990) found no such effect when comparing weaning in nursery pens with farrowing pens without bedding. The frequency of massaging and sucking was higher among piglets weaned in farrowing pens compared to flat decks at 12 weeks of age (Boe 1993).

Dybkjaer (1992) noticed that piglets weaned into crowded pens with un-bedded floors often sat motionless. Fraser (1975) observed that this behaviour may indicate a reluctance to lie on an uncomfortable floor, perhaps because the un-bedded floor created excessive heat loss. Kelly *et al.*, (2000) states that the provision of bedding is recommended for early-weaned pigs, and that only a small quantity of straw is required to provide welfare benefits. Lindvall (1981) demonstrated that ADG of the pigs was not affected by floor material (expanded metal *vs.* partial slats), even though the pigs of the partial slats were dirtier than those on the expanded metal.

Morrison and co-workers (1987) found that the preference for particular floor characteristics or bedding materials depends, however, on the thermal conditions inside the pig house. These observations explain the variability in conclusions between different floor-preference studies reported earlier. Weaners prefer to lie on straw in a cold environment but choose bare floors at higher temperatures (Fraser 1985). On hot summer days deep-bedded houses may therefore lead to problems if pigs have no provision to cool off.

1.13 Rationale of the study.

The success of weaning procedure to different pigs, associate's with the individuality of the piglet and the knowledge that it gained according to its needs, during the period that it was with the sow. The weaning age (3, 4 or 5 weeks) and weaning weight (heavy, small and medium weight piglets of the litter) are two different factors which correlate variable in each combination both on growth performance and on behavioural characteristics. For each of these cases, the feeding management, environment and farm practices affect in addition the individual performance of the piglets. Also, the fact that different observers use variable time-sampling techniques (x – minutes) and number of animals from a litter (y- animals) in order to observe a specific behaviour, is another variable (and probable the most crucial) which influence the outcome of each study.

Therefore, further research on pre-weaning feeding behaviour and how this performance influence the piglets post-weaning thriving or failure, has to be done and needs to look beyond 'average' values. The 'average' piglet does not become 'runt', does not suckle the posterior teats only, does not become dehydrated or failing to find the feed for 48 h post weaning; yet this does not mean that there are no problems. The difference between good and excellent management may rest on how well the system caters for the atypical needs of the more vulnerable animals, which can be anyone piglet in the litter, depending on the knowledge and experiences that is carrying from the period that it spent with the sow.

Therefore, the aim of this study was to investigate the behaviour of several individual piglets that constitute a representative sample of each litter (heavy, medium and light weight piglets) under recording method and observe how individual piglets of the litter react to different weaning management practices.

The specific objectives of this study were to:

- Characterise the feeding behaviour of individual pigs during the pre- and post-weaning period at three different weaning ages (3, 4 and 5 weeks of age).
- Investigate the relationship between pre- and post-weaning behaviour.
- Investigate ways in which management practice (the use of a familiar trough in the post-weaning accommodation) can modify the development of individual feeding behaviour.
- Correlate individual feeding behaviour to post-weaning gut adaptation under two weaning practices.
- Apply various time sampling recording methods, which were previously used by other researchers, in the current study and validate the results obtained using such recording rules with the 'true' behaviour of the piglets obtained using an extensive continuous recording method.
- Suggest optimum time-sampling periods for various behaviours of the piglets for the pre- and post-weaning period (28d) which could give a reasonable approximation to continuous recording and which could be used as a reference for future research.

Chapter 2

The effect of pre-weaning behaviour and weaning age (3, 4 or 5 weeks) of the piglets on post-weaning feeding and drinking motivation, growth performance and agonistic interactions.

The protocols for all animal experiments were approved by the University of Plymouth Animal Ethics Committee.

2.1 Introduction

Weaning is generally defined as that time when mammalian young cease to suckle and start to feed exclusively on solids and this, in nature, is a slow process (Jensen and Recen 1989). In commercial pig production, weaning is not the gradual process often found in nature but involves abrupt nutritional, social and environmental changes which often lead to reduced growth and increased morbidity and mortality (Rantzer *et al.,* 1995). Modern production systems are unable to adopt this gradual process, as it reduces sow productivity and makes production uneconomical. At weaning there is a sudden change in the gastrointestinal environment (change from milk-liquid to dry-pellets 91% DM), and this can lead to a severe reduction in feed intake in the first week post weaning which in turn can result in enteric disease. Pig behaviour is highly affected by weaning, and one important factor is the change in feed. From eating many small meals of liquid food, the pigs must instead eat larger quantities of dry feed a few times a day or *ad libitum* from a feeder. Their behaviour must change from massaging and sucking to rooting and chewing (Rantzer *et al.*, 1995). Commonly, a growth check in piglets in response to weaning is noted, but to date it is unknown why some piglets do better than others in this period. Jones *et al.*, (1998) showed that factors such as piglet weaning weight, birth weight and pre-weaning growth, accounted for relatively little of the variation in piglet performance after weaning. However, they found that litter origin of individual piglets was a much more important factor ($P<0.001$) and that there was a strong positive relationship between post-weaning feed intake and post-weaning piglet performance.

Morgan *et al.*, (2001) states that the removal of the security of the mother is stressful and this is compounded by the simultaneous removal of milk as the source of water and nutrients. Weaning age may also have a significant impact on the event of weaning and increase variability in the response, as pigs of the same social status can be affected differently dependent on their age, size for age and nutritional background for age. This is explained by the fact that pigs are slow to develop normal levels of eating (Blackshaw 1981) and it is common for some piglets in a litter to take a few days to discover and accept solid food as a source of nutrients and this results in a loss of weight, described as 'the weaning growth lag' by Fraser (1984a). Also, even when creep food is offered from an early age while the piglets are still with the sow, some piglets consume little or no solid food before weaning (Brooks and Tsourgiannis, 2003) and, of those that do consume food, there is a large variation between piglets (Pajor *et al.*, 1991).

The effects of weaning age on individual animal feed intake characteristics are still unknown. Bruininx *et al.*, (2001b) states that identification of various determinants of individual feed intake characteristics, especially during the first days after weaning, could serve to improve health and performance of weanling pigs housed in groups.

Therefore, the aim of this study was to identify the main problems that the piglets face during the first days post-weaning at three different weaning ages (3, 4 and 5 weeks of age).

The principal objectives of this study were:

- to determine feeding behaviour characteristics among piglets of different weaning weight within a litter (heavy, medium, light) and also between piglets of three weaning ages
- to identify whether teat order and sucking performance correlate with the growth performance of the piglets pre-weaning
- to determine if pre-weaning suckling and feeding experiences of different size piglets within a litter (heavy, medium, light), had an effect on post-weaning feeding success and performance
- to identify groups that are more vulnerable to weaning procedure (those which take them longer to acclimatise and to establish, or re-establish, a normal feeding pattern after the weaning event) under the three weaning age practices.

2.2 Materials and methods.

2.2.1 Experimental animals

The experiment was conducted according to a randomised block design, with two replicates and three treatments. Twelve primiparous sows (Landrace x Large White) and their litters (50% Large White x 25% Landrace x 25% Duroc) were used in the experiment (n=125 piglets). A replicate comprised six litters weaned at 3 (3W), 4 (4W) or 5 (5W) weeks of age respectively. Nine litters were selected randomly for pre- and post-weaning behavioural observations. From each litter, six piglets were selected (6 piglets x 3 litters for each weaning age, n=54 piglets). All the piglets in the litter were observed from the 14^{th} day of their life to their respective date of weaning. As the weight of piglets is often inversely related to their pre-weaning experience of feed (Algers *et al.,* 1990), the 2 heaviest (H), the 2 lightest (L) and the 2 piglets closest to the median (M) weight of the litter at weaning were selected to provide a uniform sized group for study in the post weaning period. The experiment was divided into two phases: i) farrowing and pre-weaning period and ii) post-weaning period.

2.2.2 First phase: farrowing and pre-weaning period

2.2.2.1 Sow's management and accommodation

In gestation, the gilts were loose-housed in groups of six animals, they were fed individually twice a day and were provided with deep-straw bedding, which was used as comfort material and rooting substrate. The gilts were moved to the farrowing crates ((0.60 x 2.45 m), total pen 2.31 x 2.45 m) 4 days prior to their anticipated delivery date (see Figure 2.1) and were given 3.0 kg DM of pelleted feed daily.

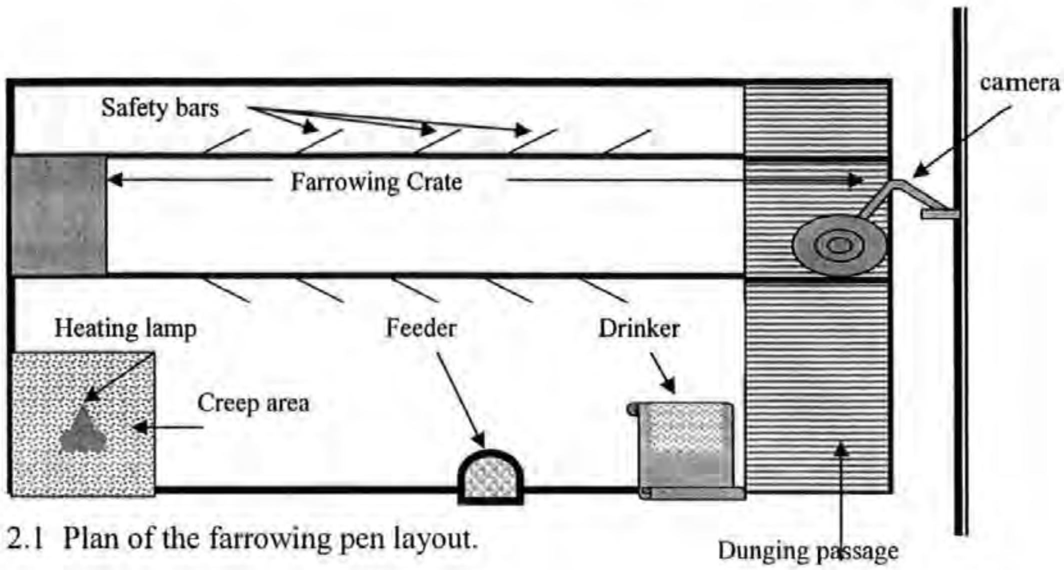


Figure 2.1 Plan of the farrowing pen layout.

The farrowing rooms were maintained at 20°C. Heating lamps were also provided at the creep area, which raised the local temperature to 30°C. The gilts were accommodated individually in farrowing crates and provided with water *ad libitum* and fed twice daily according to the Stotfold Feeding Scale for lactating sows which was developed by the MLC (1999). The feed was supplied by BOCM (Bigbreed classic nuts, BOCM, Pauls Ltd, Ipswich), and had a specification designed to meet the nutritional requirements of the gestating and lactating gilts and maintain a good health status and vigour (Table 2.1).

Table 2.1 Declared composition of the experimental diet for gilts (gestation/lactation).

Ingredient	Inclusion g kg^{-1} DM
Oil	45
Protein	160
Fibre	65
Ash	75
Lysine	7
Moisture	138
Copper	25 mg kg^{-1}
Sodium selenite-selenium	0.4 mg kg^{-1}
Vitamin A –retinol	10,000 iu
Vitamin D3 –cholecalciferol	2,000 iu
Vitamin E α-tocopherol	60 iu
Digestible energy (DE)	14 MJ kg^{-1}

*Feed supplied by BOCM (Bigbreed classic nuts, BOCM, Pauls Ltd, Ipswich)

2.2.2.2 Pre-weaning piglet's management

Piglets had their teeth and tails clipped and were given an iron injection on the day of birth. A high quality commercial creep feed (2mm Startercare Easywean Pellet, BOCM Pauls Ltd, Ipswich) (Table 2.2) was provided *ad libitum* (day 14) and the daily intake of the litter was recorded from the 14th day of lactation. Feed was added twice daily (0900 and 1500 hours) in order to ensure that feed was always available. Every afternoon, before scheduled feeding at 1500 hours, the amount of feed present in the feeding trough was deducted from the total amount of feed which was provided the previous day in order to keep a record of the amount of feed usage of the litter for that day. Water was also provided daily and presented in 18 litres cube-drinkers (J.F.C. Manufacturing (EUROPE) Ltd, Maes Y Clawdd Industrial Estate, Maesbury Road, Oswestry, Shropshire), after they had been thoroughly cleaned. The location of the feeders and drinkers is also presented in Figure 2.1.

On the day of weaning, the piglets were removed from the sows at approximately 1400 hours. Weaning and transferring the pigs to the weaning accommodation was completed at approximately 1500 hours.

Table 2.2 Declared composition of the experimental creep feed diet for piglets (2-6 weeks of age).

Ingredient	Inclusion g kg^{-1} DM
Oil	80
Protein	215
Fibre	20
Ash	55
Lysine	16.5
Moisture	138
Copper (copper sulphate)	175 mg kg^{-1}
Sodium selenite-selenium	0.40 mg kg^{-1}
Vitamin A –retinol	10,000 iu
Vitamin D3 –cholecalciferol	2,000 iu
Vitamin E α-tocopherol	250 iu
Digestible energy (DE)	16 MJ kg^{-1}

*Feed supplied by BOCM (2mm Startercare Easywean Pellet, BOCM Pauls Ltd, Ipswich)

2.2.3 Second phase: post-weaning period

2.2.3.1 The weaning accommodation

After weaning, the piglets were housed in an environmentally controlled, flatdeck weaner house, comprising 10 pens. The layout of the building is illustrated in Figure 2.2. Each pen was 1.44 x 1.25 m in floor area giving a space allocation of 0.30 m^2 per pig when stocked at six pigs per pen. The pen floor was totally perforated (Cumfideck, Big Pig, Deeside, Clwyd) and beneath each pen was a stainless steel effluent tank which could be emptied *via* a valve outside the building.

Weaning took place in the afternoon (1400 hours) in order to minimise stress (Ogunbameru *et al.*, 1992). Uniform replicates were formed as piglets were retained in groups with their littermates. Electric heaters were used to raise the temperature and ventilators were used to distribute evenly the warm air in the unit. A thermostat was also installed in order to keep the temperature of the weaning accommodation at the desirable levels (28°C) (Whittemore 1998). A min-max thermometer was used for the daily recordings of the temperature.

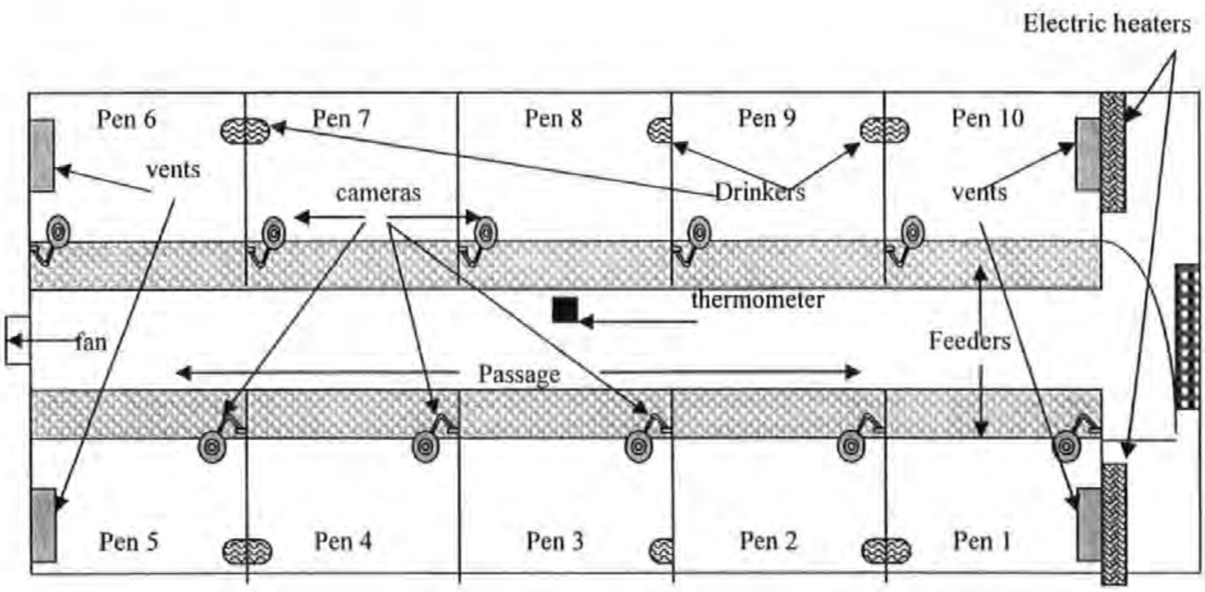


Figure 2.2 The flatdeck weaner accommodation.

2.2.3.2 Feeding and watering management

The piglets were weighed at weaning and every 7 days post-weaning in order to minimise stress as much as possible. Following weaning, the piglets were offered, *ad libitum,* the diet on which they fed pre-weaning. The feed was provided according to the pre-weaning time-table (0900 and 1500 hours) in order not to disturb the feeding patterns that might have been established during the lactation period and also, not to influence their behaviour as anticipation of feeding routines could have a considerable negative impact (e.g. aggression) on their behaviour (Waitt and Buchanan-Smith 2001). Adequate feed was given in the afternoon and additional feed was also provided the following morning in order to ensure the *ad libitum* status of the study and to avoid the sight of an empty feeder which could discourage the piglets from eating. The feed was supplied in pelleted form and in a trough that would enable all 6 pigs of the group to feed simultaneously (in order to minimise agonistic behaviour at the feeders). The feed usage was estimated daily at 1500 hours after cleaning thoroughly the feeding troughs and providing the piglets with fresh feed.

Each pen was provided with water from a bowl drinker (Alvin piglet bowl drinker, Fisher Founderies Ltd., Birmingham) positioned 20 cm above the floor, and supplied from a low pressure break tank system (Zerh$_2$opipe, Carbro Consultants, Newton Abbot, Devon). The water delivery rate from the drinkers was adjusted to exceed 450 cm^3 min^{-1} as flow rates below this were shown to adversely affect the performance of weaner pigs (Barber 1992). Water intake was recorded using turbine flow water meters (PSM-L, Kent Meters, Luton, Bedfordshire) at 1500 hours daily after thoroughly cleaning the bowls and calculating in all cases the amount of water used for this action. The pigs were kept in the weaner accommodation until the 6th week of their life.

2.2.4 Behavioural observations during the pre- and post-weaning period.

All the piglets in the litter were identified from the 14th day of lactation by means of a unique combination of coloured stripes on their backs. The piglets were monitored, using a time-lapse video recording device (VCR, Panasonic Time lapse video cassette recorder, AG-6730), 24 hours a day, from day 14 of lactation to the respective date of weaning. Each camera (Sanyo VCC 6572) was fitted to the ceiling of the building, in order to get a panoramic view of the pen. The cameras were fitted with colour lenses to make it possible to distinguish the individual piglets in each litter, as a combination of different colours (Net Ex, Perkins Ltd, Ottery St Mary) was used on their backs (red, blue green and yellow stripes in three combinations for each of the colours used: I, II and III stripes). A colour quad splitter (Panasonic Digital Field Switcher, WJ-FS20) had the ability to handle the signal of four different cameras, which were attached onto it and was recording the four signals on a single tape through the VCR (see Figure 2.3). A videotape (S-VHS) was used for the recordings of a 24 hour period and was replaced daily at approximately 1600 hours. Once the selection had been made at weaning, the feeding behaviour of the chosen piglets (n=54) was analysed from videotapes using *Observer 3.0* (Noldus, Tracksys Ltd, Nottingham) software. The piglets were also observed for suckling, fighting and drinking behaviour during the course of each experimental day (Table 2.3). Observations were also made of the teat preference of individual piglets i.e. if they were suckling the anterior (AST-piglets), middle (MTS-piglets) or the posterior teats (PTS-piglets) of the sow's udder (see Plate 2.1). At the end of the pre-weaning period, each litter of piglets weaned at 3, 4 and 5 weeks of age was observed for 168, 336 and 504 hours respectively (x 9 litters = 9,072 hours total observing time).

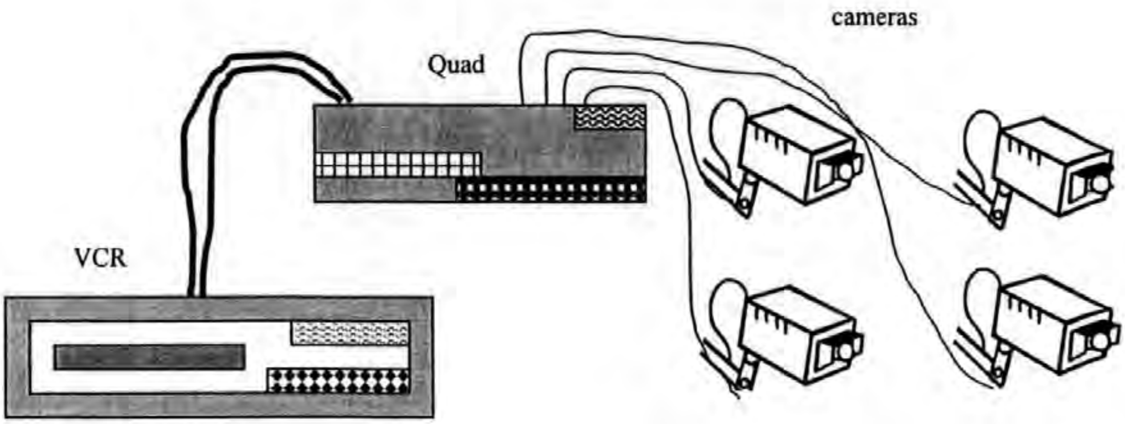


Figure 2.3 Representation of the hardware arrangement for the video recordings

Table 2.3 Ethogram used in analysis of various behaviours pre-weaning.

Behaviour	Characteristics
Sucking	Focal pig had a teat in its mouth and performed a suckle
teat order	A teat characterised as anterior – middle – posterior, by its position on the sow's udder (it has been divided into three parts at proximity, Plate 2.1)
Eating	Focal pig's head was in the feeder trough, and was in contact with the feed (Plate 2.2)
Drinking	Focal pig's head was in the water trough, and was in contact with the water
Fighting	Two or more pigs had violent contact with each other performing biting behaviour or continuous displacement of its opponent (Plate 2.3). Identification of the location that the contact initiated was also made: at the udder (while one of the actors was suckling), at the feeder (while one of the piglets was eating), and playing (at any other part of the farrowing pen).

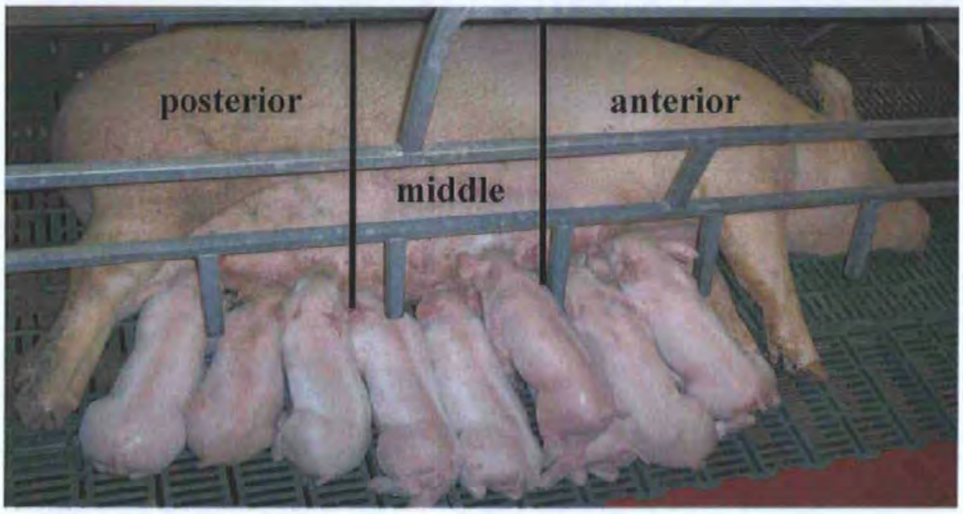


Plate 2.1 The teat-order identification on the sow's udder.

Plate 2.2 Illustration of pre-weaning feeding behaviour.

Plate 2.3 Illustration of pre-weaning fighting behaviour.

Weaning had been completed by 1500 hours of the 21st, 28th and 35th day post-partum (for 3, 4 and 5 week weaning treatment respectively). The cameras in the weaning accommodation had been set to recording mode before the piglets were moved into the pens, to enable estimation of the period of time needed for each piglet to find and sample the feed for the first time. This interval was defined as the 'eating stasis'. The piglets were weighed at weaning and marked with their individual colour stripes, in order to be clearly identifiable. For the first day after weaning, the amount of feed offered to the piglets was pre-measured and it was given immediately after the entrance of each group into the pen (time 0). The procedure was necessary in order to ensure a more accurate calculation of the 'eating stasis'. All piglets were re-marked daily so that an equal amount of handling was applied to all piglets of all treatments. The pigs were observed for the first 7 days post weaning (168 hours each pen x 9 pens = 1512 hours total observational time). The behaviours recorded and the way that they have been identified is described in Table 2.4.

Table 2.4 Ethogram used in analysis of various behaviours post-weaning.

Behaviour	Characteristics
eating	Focal pig's head was in the feeder, and was in contact with feed (Plate 2.4)
drinking	Focal pig's head was in the drinker, and was in contact with the water (Plate 2.5)
belly nosing	Focal pig rubbing its nose in a rhythmic pattern on the belly (abdomen) of another pig
fighting	Two or more pigs come to a violent contact performing biting behaviour or continuous displacement of their opponent
chewing	Focal pig manipulating the chain which were hanging from a pen-wall or chewing the boundaries of the pen (Plate 2.6)

Plate 2.4 Illustration of post-weaning feeding behaviour.

Plate 2.5 Illustration of post-weaning drinking behaviour.

Plate 2.6 Illustration of post-weaning chewing behaviour.

2.2.4.1 *Observing the behaviours and logging them in through the Observer 3.0 software*

The behavioural analysis took place at the very end of the experimental period and different actions were logged into the software by observing the pre-recorded video tapes through a monitor. The video player was linked to the PC so the software could 'read' the time code of the tapes and 'identify' the exact time an action took place, when an observation logged into the software. A colour-monitor (Panasonic video monitor, WV-CM11450/B), which was connected to the video, was used for behavioural observations of the piglets (see Figure 2.4). Each tape contained the recordings of four different cameras (or pens). The splitter had the function to 'switch' between the pre-recorded pictures of the four cameras and made it possible to observe one pen at a time. Any of the above behaviours (Table 2.3 and 2.4) was determined from the moment that a pig was observed to perform an action until the moment that it stopped performing it for more than 5 seconds (simplifying the observation procedure as there was a chance for the piglet to come back and continue) or had started another behaviour. In any of these incidences, the videotape was paused, the behaviour was recorded to the program (typed in the Observer software spreadsheet), and then the tape was resumed for further behavioural observations.

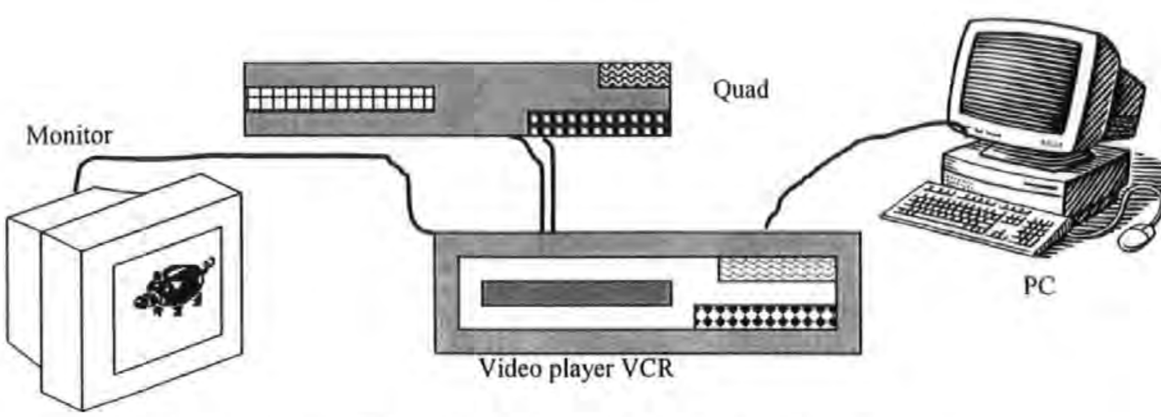


Figure 2.4 Representation of the links between the hardware components.

2.2.5 Animal growth performance

The piglets were weighed on day 1 post-partum and then subsequently every 7 days in order to calculate individual weekly live-weight gain. The piglets were weighed again at weaning, and then every 7 days until they reached 6 weeks of age.

2.2.6 Statistical analysis

The data derived from the study were analysed in the following sequence in order to understand better the behavioural differences between the weaning treatments, the effect of weaning age on behavioural and growth performance characteristics and subsequently, the effect of pre-weaning behaviour on post-weaning performance between and within the three weaning ages.

For this reason, the data analysis was divided into two phases: a) pre-weaning and b) post weaning behaviour and performance.

For the pre-weaning observations the following recordings were analysed:

i) Differences in suckling behaviour

ii) Eating and drinking behaviour

iii) Piglets' aggressiveness during the week pre-weaning

iv) Live-weight gain (LWG)

The effect of body-size (heavy, medium, light piglets in the litter) and teat-order (anterior, middle and posterior teats) was analysed to identify differences on the expression of the above behaviours between and within treatments.

From the post-weaning observations the following recordings were analysed:

i) Differences in belly-nosing behaviour

ii) Eating and drinking behaviour

iii) Piglets' aggressiveness during the week post-weaning

iv) The effect of pre-weaning feeding and drinking behaviour on post-weaning adaptation and success

v) Live-weight gain (LWG)

All the statistical analysis was carried out in Minitab v. 13 for Windows (Minitab Inc., Pennsylvania, USA, 2000). All the statistical tests which have been employed for the analysis of the pre- and post-weaning behavioural and growth performance data are presented in Table 2.5. The data are presented in the sequence which will be analysed in the Results section.

Table 2.5 Statistical tests used for the analysis of pre- and post-weaning data.

Comparison	Data transformation applied	Covariates	Test used
Pre-weaning statistical analysis			
Average weekly data for suckling, feeding, drinking and fighting (duration and frequency) *vs.* weaning age		Birth-weight (BW), weaning weight (WW), litter size (LS)	GLM-Anova[a]
Individual daily data of suckling duration *vs.* week of lactation			Linear Regression[d]
Average weekly data for suckling, feeding, drinking and fighting (duration and frequency) *vs.* body-weight classification (within treatment)	$\log_{10}$ or square root (as appropriate)[b]	BW, live-weight gain (LWG) at week 2: the week before the initiation of the behavioural recordings	GLM-Anova[a]
Teat suckling preference *vs.* BW classification			Cross tabulation[c]
Weekly performance of eating, drinking and suckling activities *vs.* BW classification and teat suckling preference (within treatment)			Pearson Correlation
Feeding *vs.* drinking behaviour for each weaning age (3, 4 and 5 weeks of age).			Linear Regression[d]
Feeding *vs.* drinking duration (the week pre-weaning for each treatment)			Kruskal-Wallis[e]
Feeding and drinking behaviour *vs.* BW classification and teat suckling preference (within treatment)	$\log_{10}$[b]	live-weight gain (LWG) at week 2	GLM-Anova[a]

Total LWG from birth to the week on question pre-weaning *vs.* week post-partum			Linear Regression[d]
Total LWG from birth to the week on question pre-weaning *vs.* week post-partum		Teat suckling position	GLM-Analysis [ax]
DLWG the week pre-weaning *vs.* teat-position			GLM-Anova[a]
Post-weaning statistical analysis			
Eating and drinking 'stasis' *vs.* weaning age	$\log_{10}$ [b]	Total pre-weaning feeding duration	GLM-Anova[a]
Eating and drinking 'stasis' *vs.* body-weight classification (within treatments)			Kruskal-Wallis[c]
Eating and drinking 'stasis' *vs.* teat preference (within treatments)			Kruskal-Wallis[c]
Eating and drinking 'stasis' *vs.* pre-weaning drinking and feeding behaviour			Pearson Correlation
LW the week post weaning for each weaning age *vs.* various pre- and post-weaning recordings	$\log_{10}$ or square root (as appropriate)[b]		Multiple Regression
Daily post-weaning eating and drinking behaviour *vs.* pre-weaning drinking and feeding behaviour			Pearson Correlation
Daily post-weaning eating behaviour *vs.* pre-weaning drinking suckling and feeding behaviour, sex and teat preference)			Multiple Regression
Daily eating and drinking duration *vs.* weaning age			GLM-Anova[a]

Daily and average feeding *vs.* drinking duration for the week post-weaning for each weaning age			Kruskal-Wallis[c]
Daily drinking/feeding duration *vs.* average weekly drinking/feeding duration			Kruskal-Wallis[c]
Daily eating and drinking duration *vs.* WW (within treatment)			GLM-Anova[a]
Daily fighting behaviour *vs.* weaning age			Kruskal-Wallis[c]
Daily belly nosing *vs.* weaning age			GLM-Anova[a]
Weekly belly nosing for 4W piglets *vs.* various pre- and post-weaning recordings.			Multiple Regression
Weekly fighting between pen-mates and belly nosing *vs.* weaning age	$\log_{10}$ or square root (as appropriate)[b]		GLM-Anova[a]
Weekly chewing behaviour (chains or other parts of the pen)			Kruskal-Wallis[c]
Weekly post-weaning feed and water intake *vs.* weaning age		BW, WW (of the 6 selected piglets for each cage)	GLM-Anova[a]
Weekly feed and water intake at week 6 post-partum *vs.* weaning age		BW, weight at 5 weeks of age (of the 6 selected piglets for each cage)	GLM-Anova[a]
Feed Conversion Ration (FCR) *vs.* weaning age		WW (of the 6 selected piglets for each cage)	GLM-Anova[a]
Weekly feed to water intake ratios *vs.* weaning age			GLM-Anova[a]
Daily feed to water intake ratios *vs.* weaning age			GLM-Anova[a]

Weekly post-weaning LWG *vs.* weaning age			GLM-Anova[a]
LWG for the growth periods 3 to 5 and 3 to 6 weeks of age *vs.* weaning age		WW (of the 6 selected piglets for each cage)	GLM-Anova[a]
LWG a week post-weaning *vs.* BW classification and teat suckling preference (within treatment)		BW, WW (of the 6 selected piglets for each cage) and LS	GLM-Anova[a]
LWG at 6 weeks of age *vs.* BW classification and teat suckling preference (within treatment)		BW, WW (of the 6 selected piglets for each cage) and LS	GLM-Anova[a]
LWG for the period commencing birth to week 6 post-partum *vs.* treatment		BW and LS	GLM-Anova[a]
LWG for the period commencing week 3 to week 6 post-partum *vs.* BW classification and teat suckling preference (within treatment)		BW, WW (of the 6 selected piglets for each cage) and LS	GLM-Anova[a]
LWG for the period commencing week 3 to week 6 post-partum *vs.* weaning ages for the same body-weight classification at weaning (heavy, medium, light)		BW, WW (of the 6 selected piglets for each cage)	GLM-Anova[a]
LW at 4, 5 and 6 weeks of age *vs.* weaning age		BW, WW (of the 6 selected piglets for each cage)	GLM-Anova[a]
LW at 6 weeks *vs.* various measurements (pre-weaning feeding, drinking, suckling and fighting frequency, post-weaning feeding, drinking fighting and belly nosing frequency, weekly BW, sex, birth-weight, litter size, weaning age, BW classification, teat order	log_{10} [b]		Linear Regression[d]

BW at 6 weeks *vs.* Birth weight, post-weaning sucking frequency, BW at 2 weeks of age and pre-weaning fighting frequency.	$\log_{10}$ [b]		Multiple Regression[d]
'feed consumption for age' on day 7 post-weaning for 3W piglets *vs.* day 1,2,3, and 4 post weaning for 4W and 5W piglets[f]		BW, WW (of the 6 selected piglets for each cage)	GLM-Anova[a]
'feed consumption for age' on day 7 post-weaning for 4W piglets *vs.* day 1,2,3,4,5,6 and 7 post weaning for 5W piglets[f]		BW, WW (of the 6 selected piglets for each cage)	GLM-Anova[a]
'water consumption for age' on day 7 post-weaning for 3W piglets *vs.* day 1,2,3, and 4 post weaning for 4W and 5W piglets[g]		BW, WW (of the 6 selected piglets for each cage)	GLM-Anova[a]
'water consumption for age' on day 7 post-weaning for 4W piglets *vs.* day 1,2,3,4,5,6 and 7 post weaning for 5W piglets[g]		BW, WW (of the 6 selected piglets for each cage)	GLM-Anova[a]

[a] Tukey test was employed every time a GLM-ANOVA analysis was carried out in order to determine the significance of the differences between the treatments.
[ax] GLM-Analysis of covariance with a subsequent comparison using Tukey test for multiple comparisons among slopes (Zar 1999).
[b] For clarity of the presentation, untransformed values are shown in the tables and text.
[c] There were no expected frequencies less than 5.
[d] For each case, a histogram of the residuals was plotted and it was checked that the data conformed to a normal distribution (Eddison 2000).
[e] The non-parametric Kruskal-Wallis test, can be applied instead of the parametric ANOVA test (Eddison, 2000). The non-parametric Q test is equivalent to the parametric Tukey test, which is used in the GLM-ANOVA analysis (Eddison, 2000).
[f] It has to be clarified that at day 7 post-weaning, piglets which had been weaned at 3 weeks of age, were 4 weeks old. In order to identify differences in 'feed consumption for age' between treatments the following tests were applied. A GLM analysis was carried out in order to identify differences in feed consumption recorded at day 7 post-weaning for piglets of 3W treatment, and feed consumption recorded for piglets weaned at 4 and 5 weeks of age during day 1, 2, 3 and 4 post weaning. BW and WW were used as covariates in the analysis. The same statistical test was applied to identify differences between FI on day 7 of 4W piglets and feed consumption of 5W piglets on each day of the post-weaning week. The same principles were applied for the analysis of 'water intake for age' between piglets of different weaning ages.

[g] It has to be clarified that on day 7 post-weaning, piglets which had been weaned at 3 weeks of age, were 4 weeks old. In order to identify differences in 'water consumption for age' between treatments the following tests were applied. A GLM analysis was carried out in order to identify differences in water consumption recorded at day 7 post-weaning for piglets of 3W treatment, and feed consumption recorded for piglets weaned at 4 and 5 weeks of age during day 1, 2, 3 and 4 post weaning. BW and WW were used as covariates in the analysis. The same statistical test was applied to identify differences between water intake at day 7 of 4W piglets and feed consumption of 5W piglets each day of the post-weaning week.

2.3 Results

2.3.1 Pre-weaning period.

2.3.1.1 Suckling behaviour.

Because of the great variability in daily suckling performance between piglets (Figure 2.5), the total weekly activity for the week pre-weaning was considered in the analyses between treatments as shown in Table 2.6.

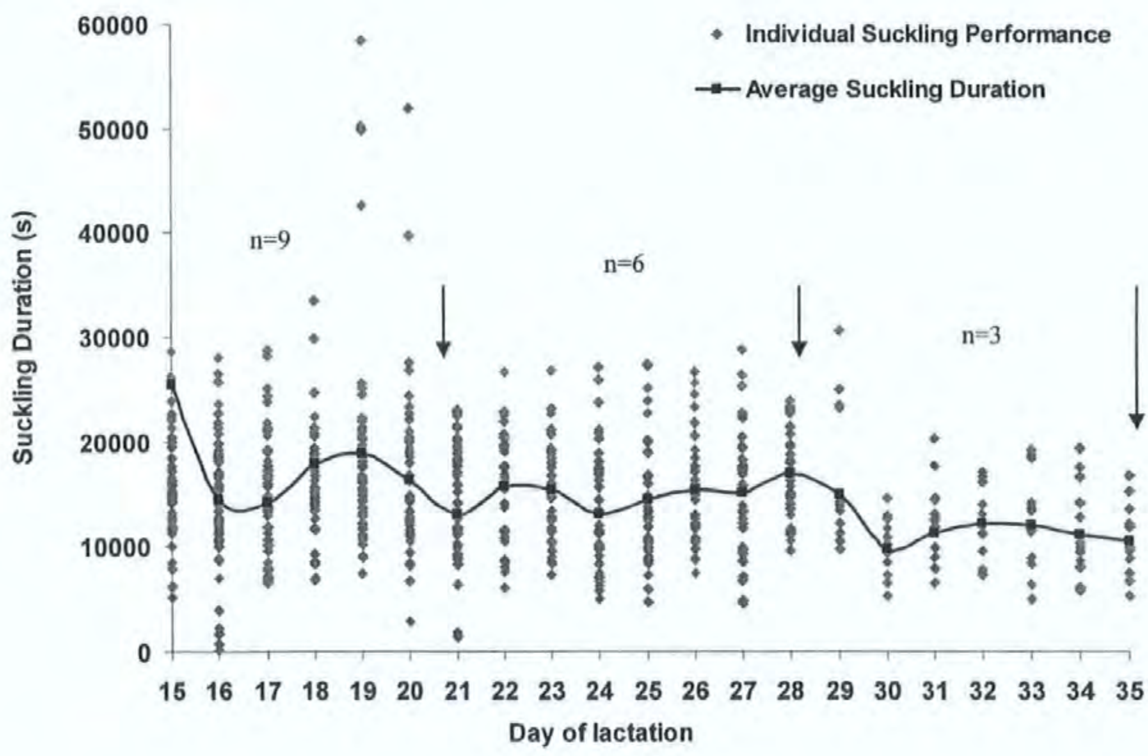


Figure 2.5 Individual piglet's teat suckling performance and presentation of average values of this behaviour (the arrows represent the time of weaning and (n) is the number of litters used for the behavioural observations).

In order to be able to estimate the average daily suckling duration of a piglet on a given week of lactation, the number of phases that the suckling behaviour consisted of and the average duration of each phase have to be known. According to a combination of the observational data given by Whittemore and Fraser (1974); Fraser (1980); Spinka and Algers (1995) and Worobec and Duncan (1997), the four phases were identified and presented as follows: (3min pre-massage + 20 s sharp suckling + 20 s milk let-down + 3 min post massage (up to 15 min)) x 25 times day^{-1} = 10,000 to 28,000 s day^{-1}. Even though the above equation provides an estimate, the variation between minimum and maximum daily suckling duration is very large. Using the individual suckling duration values, which are presented in Figure 2.5, and the four phases of suckling behaviour that were identified by the workers mentioned above, it was calculated that the average time that a piglet spends on teat manipulation during the third, fourth and fifth week of lactation can be given by the following equation:

average daily suckling duration of a piglet = 25673 – 2752week (week 3=3, week 4=4, week 5=5) (F=19.11, d.f.=1,19, R^2=50.1, P<0.0001) (Equation 2.1)

According to the previous regression, it is possible to estimate the average suckling duration on a given week of lactation:

i) average daily suckling duration of a piglet during week 3 of lactation = (11 min pre- and post-massage + 20 s sharp suckling + 20 s milk let-down) x 25 times day^{-1} = 17,420 s day^{-1} (Equation 2.2)

ii) average daily suckling duration of a piglet during week 4 of lactation = (9 min pre- and post-massage + 20 s sharp suckling + 20 s milk let-down) x 25 times day^{-1} = 14,668 s day^{-1} (Equation 2.3)

iii) average daily suckling duration of a piglet during week 5 of lactation = (7 min pre- and post-massage + 20 s sharp suckling + 20 s milk let-down) x 25 times day^{-1} = 11,916 s day^{-1}

(Equation 2.4)

The above equations provide a single value for pre- and post-massage of the udder, as a distinct pattern could not be identified due to the way observational recordings were taken. These equations illustrate that the duration of suckling is gradually decreasing. More specifically, the amount of time that they spend on pre- and post-massage of the udder decreased, and this value was estimated to be 2 min suckling^{-1} week^{-1}.

Table 2.6 Total weekly teat manipulation (frequency and duration of suckling behaviour), during the week pre-weaning, for piglets weaned at 3, 4 and 5 weeks of age.

Behaviour	Weaning age			SED		
	3 weeks	4 weeks	5 weeks	3-4	3-5	4-5
Suckling Frequency (a)	335	303	258	0.016	0.021 ***	0.021 ***
Suckling Duration (s)	108019 (30h)	106259 (29h 31m)	78040 (21h 41m)	5365	6886 ***	7237 ***
% of their total time	17.86%	17.57%	12.9%			
Preferred teat Frequency (a)	291	255	113	0.626	0.80 ***	0.845 ***
Preferred teat Duration (s) (a)	97850 (27h 11m)	88221 (24h 30m)	34529 (9h 36m)	12.66	16.2 ***	17.09 ***
% of their total time	16.18%	14.58%	5.71%			
Total suckling duration *vs.* preferred teat duration	s.e.d.= 5300	s.e.d.= 7429*	s.e.d.= 8248**			

*P<0.05, **P<0.01, ***P<0.001.
Duration is represented as s week^{-1} piglet^{-1} and frequency as scores week^{-1} piglet^{-1}.
(a) = transformed data using $\log_{10}$
SED refers to the data which have been treated using $\log_{10}$ transformation

It was observed that suckling activity of the piglets was greater during weeks 3 and 4 of the lactation than during the 5th week post-partum (*P*<0.001) (Table 2.6). Teat manipulation did not differ significantly between weeks 3 and 4 (*P*>0.05). Suckling frequency was in all cases directly proportional to suckling duration.

Suckling duration and frequency of the 'home teat' manipulation, is also illustrated in Table 2.6. It was observed that piglets of 3 weeks of age sucked their 'home' teat very consistently (90.6% of the total teat manipulation) and the duration of suckling their 'home teat' did not differ significantly from the total time spent manipulating the sow's udder (*P*>0.05). During the fourth and fifth week of lactation, piglets were engaging significantly less time in manipulating their 'home teat' (week 4: 83% of the total time, *P*<0.05; week 5: 43.4% of the total time, *P*<0.01) in comparison with the total time recorded for this behaviour. 'Home teat' sucking was significant greater during weeks 3 and 4 of the lactation than week 5 (*P*<0.001). Behavioural observations have also been made for teat manipulation within treatments according to the body-size classification of the piglets. The body-weight of the piglets and their subsequent classification at weaning, are illustrated in Table 2.7. In all treatments, piglets classified as large were almost a kg heavier than medium weight piglets of the litter, with small difference between piglets of the remaining two weight classifications.

Table 2.7 Weaning weight (kg) of piglets and body-weight classification (mean ± SE).

	3 weeks weaning	4 weeks weaning	5 weeks weaning	SED 3-4	SED 3-5	SED 4-5
Large	7.93±0.342	8.26±0.420	8.69±0.595	0.542	0.687	0.584
Medium	6.81±0.319	6.80±0.391	7.08±0.548	0.511	0.636	0.671
Small	5.95±0.314	6.61±0.384	6.63±0.545	0.496	0.630	0.666

Behavioural observations have also been made for teat manipulation within treatments according to the body-size classification of the piglets (Table 2.8). There were no significant differences in teat-suckling frequency and duration during the week pre-weaning or during the total pre-weaning observational period among piglets of different body-size classification at any weaning age.

Table 2.8 Suckling frequency and behaviour recorded within treatments for piglets of different body size.

Behaviour	Classification of the piglets within their litter			SED		
	Heavy (1)	Medium (2)	Light (3)	1-2	1-3	2-3
		3 weeks				
Suckling Frequency (a)	337	330	339	25.60	27.36	25.08
Suckling Duration (s) (a)	115997 (32h 13m) 276 min d^{-1}	111665 (31h 1m) 266 min d^{-1}	96394 (26h 47m) 230 min d^{-1}	9406	10051	9212
		4 weeks				
Suckling Frequency the week pre-weaning	309	321	280	14.97	15.87	15.29*
Suckling Duration the week pre-weaning (s)	110913 (30h 18m) 264 min d^{-1}	108830 (30h 14m) 259 min d^{-1}	99033 (27h 31m) 236 min d^{-1}	10368	10993	10593
Total Suckling Duration (s) (wk2 to wk4)	224223 267 min d^{-1}	221367 264 min d^{-1}	203494 242 min d^{-1}	24449	26081	24483
		5 weeks				
Suckling Frequency the week pre-weaning (a)	253	267	265	0.03365	0.0366	0.0355
Suckling Duration the week pre-weaning (s) (a)	73102 (20h 18m) 174 min d^{-1}	78907 (21h 55m) 188 min d^{-1}	82103 (22h 48m) 195 min d^{-1}	0.05162	0.0561	0.0545
Total Suckling Duration (s) (wk2 to wk5)	320561 382 min d^{-1}	304737 363 min d^{-1}	272977 325 min d^{-1}	25597	27980	26675

*$P<0.05$
Duration is expressed as s week^{-1} piglet^{-1} and frequency as scores week^{-1} piglet^{-1}.
(a) = transformed data using $\log_{10}$
SED refers to the data which have been treated using $\log_{10}$ transformation

Observations have also been made to identify if the teat-preference of individual piglets is affected by their body-weight. According to the data in Table 2.9, it was more likely for piglets of large size to suckle the front teats of their dam and partially the middle section of the udder with no chance at all to observe them suckling any of the posterior teats ($P<0.01$). Medium size piglets were more likely to be seen suckling the middle and posterior teats of the sow's udder and the light piglets of the litter to suckle only the posterior part of their dam's udder ($P<0.01$).

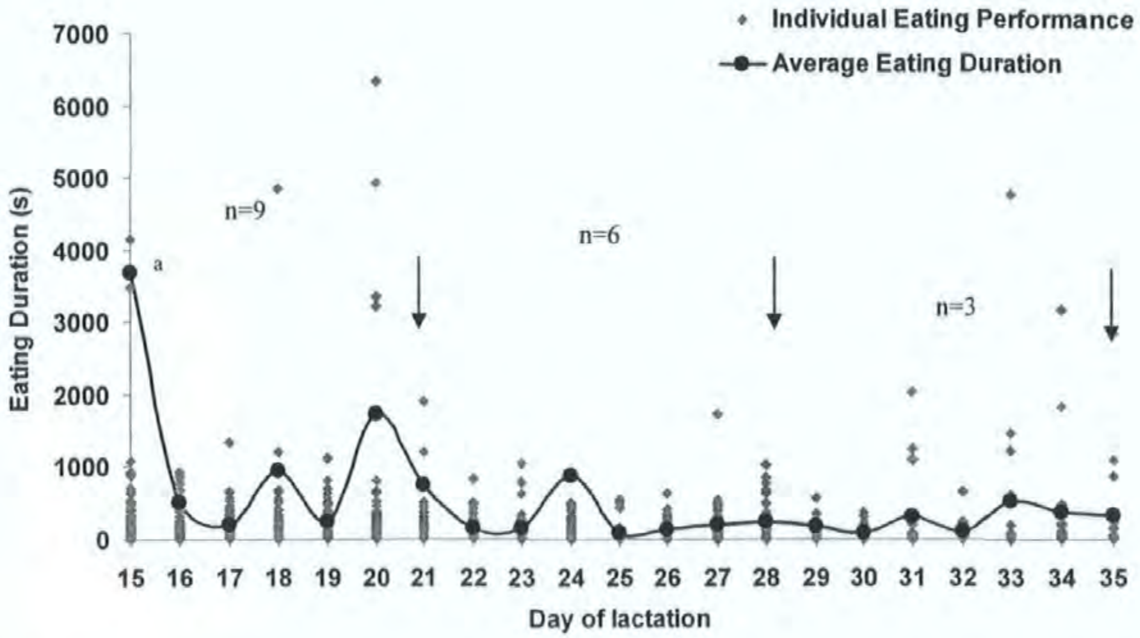
Table 2.9 Teat preference according to piglet size.

Teat suckled	Piglet classification % of attendance		
	Heavy	**Medium**	**Light**
Anterior	(+) 57.89[a]	(-) 15.79[a]	(-) 26.32[a]
Middle	(+) 38.89[b]	(+) 38.89[b]	(-) 22.22[a]
Posterior	(-) 0[a]	(+) 52.94[b]	(+) 47.06[a]

Chi-square = 14.858, DF=4, P=0.005
[a]= medium strength of association ($0.1<P<0.05$), [b]= strong strength of association ($P<0.01$)
The sign referrers to the degree of association between categories: (+) likely to happen, (-) likely not to happen

2.3.1.2 Feeding and drinking behaviour

During the third week of lactation there was an initial enthusiasm of the piglets for eating and drinking after the introduction of the drinkers and feeders (Figures 2.6 and 2.7). Also, a great variability between individual piglets in the expression of these behaviours was observed during week 3 of lactation. The enthusiasm for feeding reduced during the following weeks. Only rarely did piglets have high feeding duration values during the fifth week of lactation. A more narrow distribution of drinking duration was observed from the 23rd to the 35th day of lactation. Overall, the piglets showed a preference to spend more time feeding than drinking during the 3rd and 5th week of lactation (Table 2.10, $P<0.05$) except for week 4 when they were observed to engage almost identical periods of time in each behaviour ($P>0.05$).



[a] the high average value for eating behaviour on day 15 was due to some individual piglets' performances which were exceeding the 7,000 s.

Figure 2.6 Piglets' individual feeding activity and average values for this behaviour (the arrows represent the time of weaning and (n) is the number of litters used for the behavioural observations).

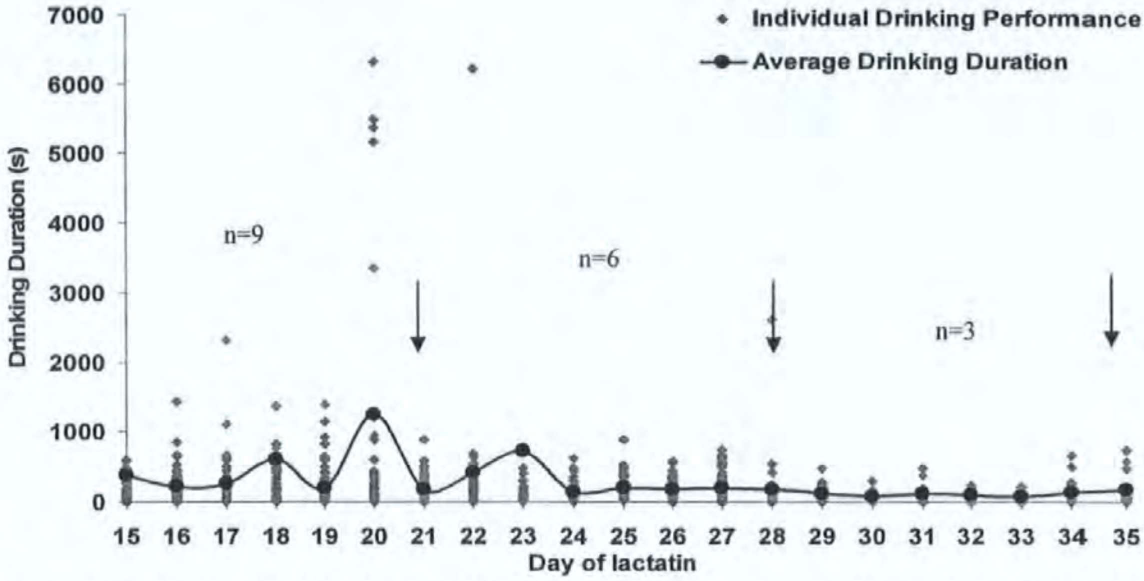


Figure 2.7 Piglets' individual drinking activity and average values obtained for this behaviour (the arrows represent the time of weaning and (n) is the number of litters used for the behavioural observations).

Table 2.10 Comparison of total feeding and drinking duration on each weaning age during the pre-weaning week (analysis of medians).

Weaning age	Pre-weaning drinking duration (s week^{-1})	Pre-weaning feeding duration (s week^{-1})	Q [a]
3 weeks	818	1271	6.660*
4 weeks	1034	1038	0.512
5 weeks	558	841	5.638*

*P<0.05
[a] = statistics performed with non-parametric Kruskal-Wallis (for 2 treatments the estimated Q value must be over 1.960 for significant difference (Eddison, 2000)).

The piglets were sampling the feed and visiting the feeders more often during week 3 of lactation than weeks 4 and 5 (Table 2.11, P<0.01). Also, piglets spent less time at the drinkers during week 5 of lactation than during week 3 and 4 post-partum (P<0.001 and P<0.05 respectively).

There were no significant differences found on feeding and drinking behaviour between different classes of pigs within treatments (Table 2.12). It is useful though to identify the main behavioural trends in feeding behaviour among piglets of different body-weight classification according to their age. During week 3 of lactation, piglets of heavy and light body-weight were spending numerically more time at the feeders than piglets of medium weight. During week 4 post-partum, it has been observed that piglets of medium size spent more time feeding than piglets of the other two classes (P>0.05) and they continued to do so on the following week (week 5 of lactation) having spent 4 and 4.3 times longer periods on feeding than piglets of heavy and light body-weight respectively (P>0.05).

Table 2.11 Average weekly frequency and duration of eating and drinking behaviour, during the week pre-weaning, for piglets weaned at 3, 4 and 5 weeks of age.

Behaviour	Weaning age			SED		
	3 weeks	4 weeks	5 weeks	3-4	3-5	4-5
Eating Frequency the week pre-weaning (b)	38	27	25	0.064 **	0.082 **	0.086
Eating Duration the week pre-weaning (s) (b)	1602 229 d^{-1}	1123 160 d^{-1}	1763 252 d^{-1}	3.236	4.154	4.366
% of their total time	0.26%	0.19%	0.29%			
Total pre-weaning feeding duration (s) (a)	1602 229 d^{-1}	2981 213 d^{-1}	4753 226 d^{-1}	0.147	0.142 **	0.1338
Drinking Frequency the week pre-weaning (a)	41.1	48.1	20.8	0.057	0.073 ***	0.077 ***
Drinking Duration the week pre-weaning (s) (b)	1350 193 d^{-1}	1328 190 d^{-1}	766 109 d^{-1}	2.414	3.099 ***	3.256 *
% of their total time	0.22%	0.22%	0.13%			
Total pre-weaning drinking duration (s) (a)	1350 193 d^{-1}	2329 166 d^{-1}	4329 206 d^{-1}	0.102 ****	0.098 ****	0.096 **

*P<0.05, **P<0.01, ***P<0.001.
Duration is represented as s $week^{-1}$ $piglet^{-1}$ and frequency as scores $week^{-1}$ $piglet^{-1}$.
SED refers to the data which have been treated using square root or $\log_{10}$ transformation (a) = transformed data using $\log_{10}$, (b) = transformed data using square root.

Table 2.12 Eating and drinking frequency and duration of behaviours recorded for piglets of different body-weight within treatments.

Behaviour	Classification of the piglets within their litter			SED		
On a weekly basis	Heavy (1)	Medium (2)	Light (3)	1-2	1-3	2-3
		3 weeks				
Eating Frequency (a)	45.50	33.33	35.94	0.08437	0.0901	0.0826
Eating Duration (a)	2119	1140	1547	0.1422	0.1520	0.1393
Drinking Frequency (a)	42.11	40.17	41.06	0.1018	0.1088	0.0996
Drinking Duration (a)	1372	1343	1335	0.1231	0.1315	0.1205
		4 weeks				
Eating Frequency	28.12	33.18	20.59	7.259	7.697	7.417
Eating Duration	1064	1312	992	369.1	391.3	377.1
Drinking Frequency	47.45	48.87	49.29	10.76	11.41	10.99
Drinking Duration	1489	1232	1262	334.0	354.2	341.3
		5 weeks				
Eating Frequency (a)	22.83	30.17	22.83	0.1895	0.2063	0.2004
Eating Duration (a)	1472	5824	1326	0.2702	0.2941	0.2857
Drinking Frequency (a)	18.50	20.17	23.67	0.1576	0.1715	0.1666
Drinking Duration (a)	797	849	653	0.2326	0.2531	0.2459

Duration is represented as s week^{-1} piglet^{-1} and frequency as scores week^{-1} piglet^{-1}.
(a) = transformed data using $\log_{10}$
SED refers to the data which have been treated using $\log_{10}$ transformation

Data were also analysed to identify behavioural associations between sucking, feeding and drinking activities within treatments (Figure 2.8). Using Pearson correlation analysis it was identified that for week 3 of lactation there was no association between sucking, feeding and drinking activities. However, for week 4, Regression analysis suggested that there was a positive association between total pre-weaning feeding and drinking behaviour (F= 16.677, d.f.=1,16, P<0.001, R^2_{adj} = 48.0%) and a negative correlation between total suckling duration and feeding (r=-0.614, d.f.=16, P<0.01) or drinking (r=-0.508, d.f.=16,

P<0.05) behaviour. During week 5, the association between feeding and drinking remained positive but less strong (F= 7.776, d.f.= 1,16, P<0.05, R^2_{adj} = 28.5%).

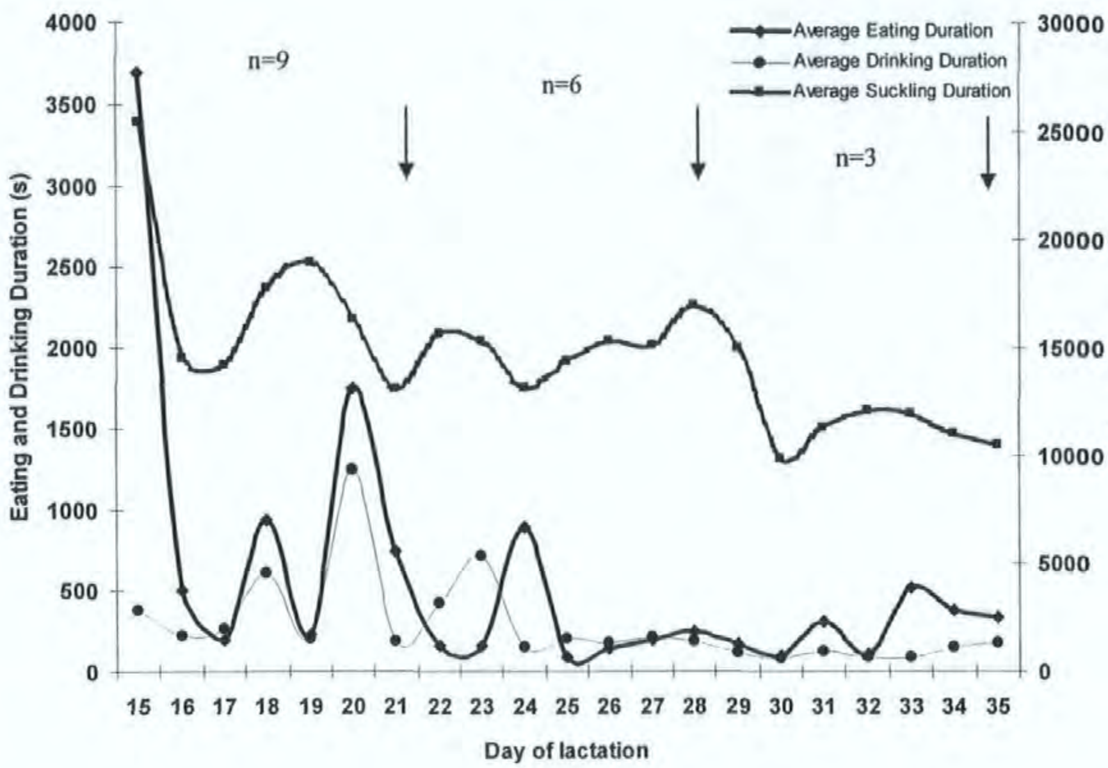


Figure 2.8. Diagrammatic representation of the average daily performances of eating, drinking and sucking activities (the arrows represent the time of weaning and n the number of litters used for behavioural observations).

Analysis was also carried out to identify differences in eating and drinking behaviour of piglets suckling different parts of the udder within treatments (Table 2.13). No significant differences were found except for week 4, where MTS-piglets were spending significantly more time at the drinkers than PTS-piglets (P<0.05).

Table 2.13 Eating and drinking frequency and duration recorded for piglets sucking different parts of the udder at each weaning age.

Behaviour	Classification of the piglets within their litter			SED		
On a weekly basis	Anterior (1)	Middle (2)	Posterior (3)	1-2	1-3	2-3
		3 weeks				
Eating Frequency (a)	44.6	35.6	34	0.087	0.088	0.089
Eating Duration (a)	2009	1369	1392	5.306	5.386	5.456
Drinking Frequency (a)	43.9	38.8	40.5	0.0986	0.100	0.101
Drinking Duration (a)	1514	1223	1301	4.375	4.440	4.498
		4 weeks				
Eating Frequency	28.9	29	16.7	0.1372	0.1838	0.1769
Eating Duration	1029	1334	727	4.982	6.674	6.421
Drinking Frequency	53.2	48.7	35	0.0899	0.1204	0.1159
Drinking Duration	1395	1504	684	4.181	5.601	5.389*
		5 weeks				
Eating Frequency (a)	26.2	31.3	11.8	0.1569	0.1875	0.1779
Eating Duration (a)	1556	4959	681	18.15	21.69	20.58
Drinking Frequency (a)	27.7	19	14	0.1519	0.1816	0.1722
Drinking Duration (a)	956	806	402	6.260	7.483	7.099

Duration is represented as s $week^{-1}$ $piglet^{-1}$ and frequency as scores $week^{-1}$ $piglet^{-1}$.
(a) = transformed data using log_{10}
SED refers to the data which have been analysed using log_{10} transformation

2.3.1.3 Aggressive behaviour

Individual fighting performance was more variable during week 3 of lactation, than week 4 and 5 post-partum (Figure 2.9).

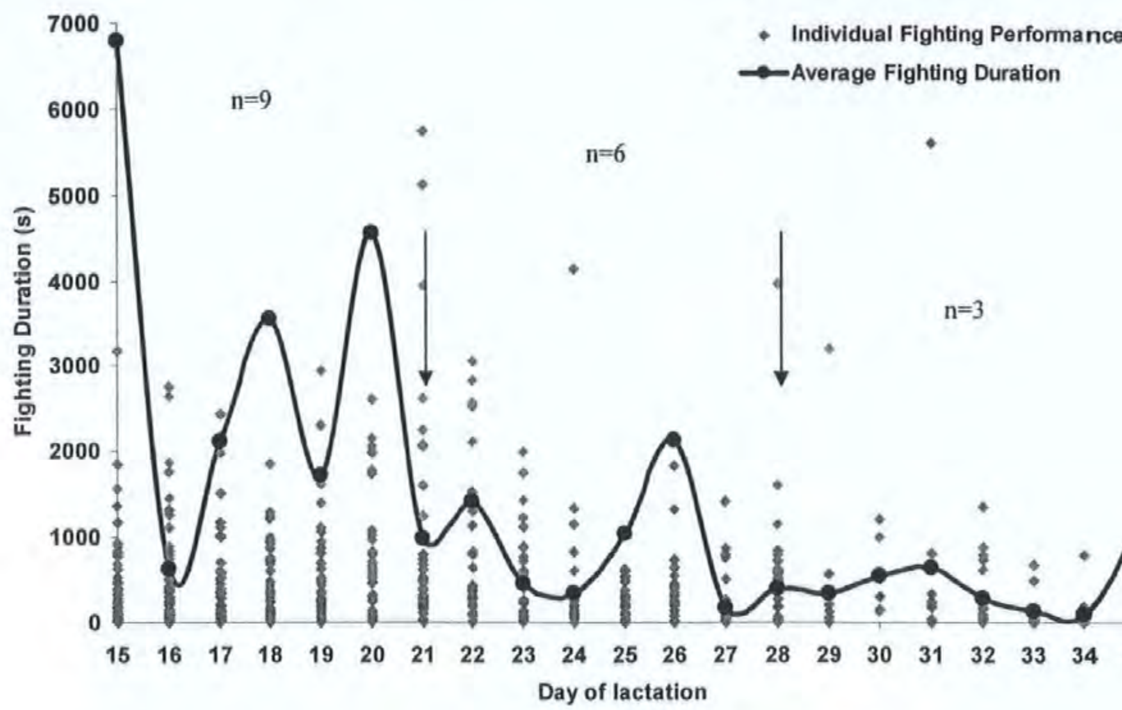


Figure 2.9 Piglets' individual aggressive behaviour and presentation of the average values of this behaviour (the arrows represent the time of weaning and (n) is the number of litters used for the behavioural observations).

Piglets of three and four weeks of age were spending significantly more time on fighting behaviour than piglets at five weeks of age ($P<0.001$) (Table 2.14). On the other hand, fighting duration per conflict was calculated to be 27 s longer during the 5th week of lactation than the other two treatments (mean for week 5 = 86 s). It has been identified that as the piglets were younger they spent more time fighting for creep feed. More specifically, piglets weaned at the youngest age spent more time fighting at the feeders than piglets weaned at the 4th ($P>0.05$) and 5th week of lactation ($P<0.01$). A clear representation of the positive correlation between the increased feeding activity and aggressive behaviour is illustrated in Figure 2.10 ($r = 0.299$, d.f.=52, $P<0.05$). The aggressive competition at the udder was not influenced by treatment ($P>0.05$) and there was no correlation between aggression at the udder and suckling or drinking behaviour ($P>0.05$).

Table 2.14 Total frequency and duration of aggressive behaviours, during the week pre-weaning, for piglets weaned at 3, 4 and 5 weeks of age.

Behaviour	Weaning age			SED		
On a weekly basis (s)	3 weeks	4 weeks	5 weeks	3-4	3-5	4-5
Total Fight Frequency (b)	26.7	19.6	10.9	0.075	0.097 ***	0.101 ***
Total Fight Duration (a)	2334 333 d^{-1}	1746 249 d^{-1}	1246 178 d^{-1}	0.075	0.097 ***	0.101 ***
% of their total time	0.39	0.29	0.21			
Fight at teat Frequency (b)	4.8	4.4	5.4	0.229	0.295	0.309
Fight at teat Duration (a)	499	379	522	0.081	0.104	0.109
Fight at creep Frequency (b)	1.4	0.6	0.2	0.105	0.135 ***	0.142
Fight at creep Duration (a)	76	44	13	0.051	0.065 ***	0.069
Fight at play Frequency (b)	20.6	14.6	5.4	0.341	0.437 ***	0.460 *
Fight at play Duration (a)	1762	1323	711	0.078*	0.100 ***	0.105 **

*P<0.05, **P<0.01, ***P<0.001.
Duration is represented as s $week^{-1}$ $piglet^{-1}$ and frequency as scores $week^{-1}$ $piglet^{-1}$.
SED refers to the data which have been treated using square root or log_{10} transformation
(a) = transformed data using log_{10}, (b) = transformed data using square root.

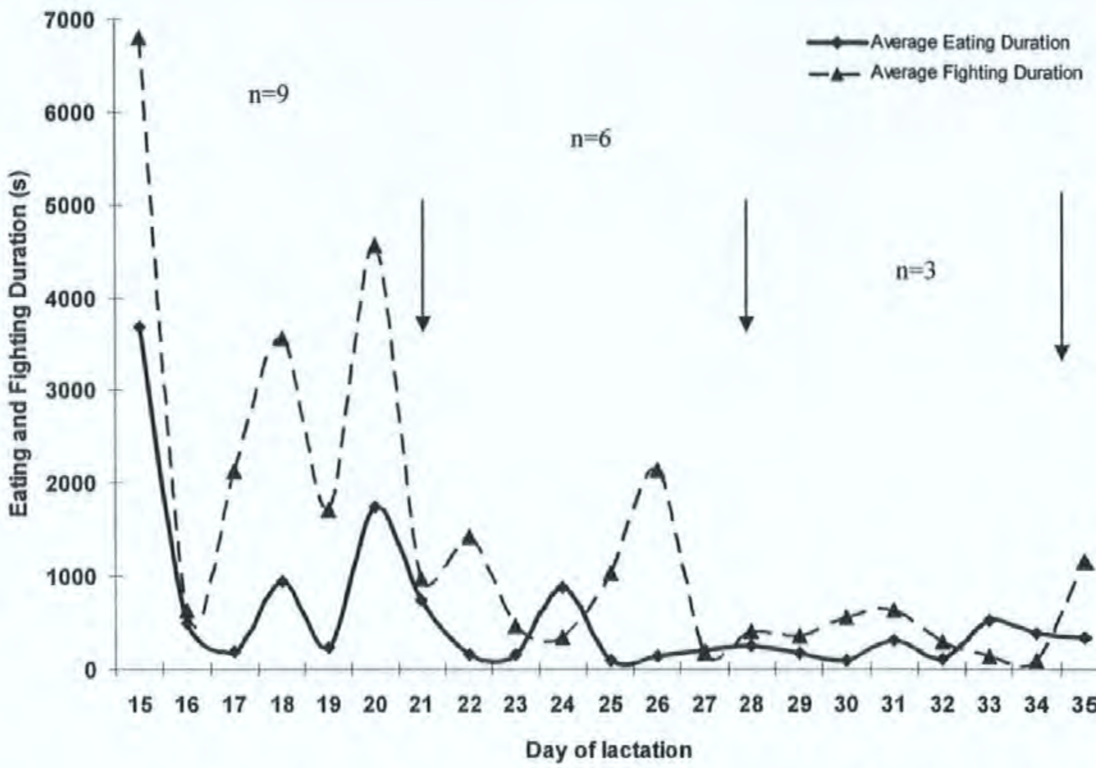


Figure 2.10 Illustration of the average daily performance of eating and fighting behavioural observations during the course of the experimental period (the arrows represent the time of weaning and (n) is the number of litters used for the behavioural observations).

There was no significant difference in aggressive behaviour between piglets of different body-weight during week 3 of lactation (Table 2.15). During this week, medium size piglets were observed to spend numerically more time fighting than small and large piglets of the litter. On week 4 though, the heavier the animal in the litter, the more aggressive interactions they were observed to have. More specifically, heavy weight piglets were engaged for significantly more time in aggressive behaviour than light-weight piglets ($P<0.05$), however, the latter had fights which were 25.6% longer (mean = 117 s $conflict^{-1}$). During week 5, medium size piglets were significantly more aggressive than large and small size piglets ($P<0.05$).

Table 2.15 Frequency and duration of aggressive behaviour between piglets of different body size within treatments.

Behaviour	Classification of the piglets within their litter			SED		
On a weekly basis (s)	Heavy (1)	Medium (2)	Light (3)	1-2	1-3	2-3
		3 weeks				
Fight Frequency (a)	34	23	23	0.1072	0.1146	0.1050
Fight Duration (a)	1878	2655	2468	0.1481	0.1582	0.1450
		4 weeks				
Fight Frequency	31	19	8	5.884	6.238*	6.011
Fight Duration the week pre-weaning	2704	1597	936	694.6	736.4 *	709.7
Fight duration total (wk2-wk4)	6480	5512	4007	2744	2927	2748
		5 weeks				
Fight Frequency (a)	11	14	8	0.2303	0.2507	0.2435
Fight Duration the week pre-weaning (a)	995	1925	819	0.3620	0.394*	0.382*
Fight duration total (wk2-wk5)	4329	6191	2752	1604	1754	1672

*$P<0.05$
Duration is represented as s week^{-1} piglet^{-1} and frequency as scores week^{-1} piglet^{-1}.
(a) = transformed data using $\log_{10}$
SED refers to the data which have been treated using $\log_{10}$ transformation

2.3.1.4 Pre-weaning growth performance according to teat order

There was no significant difference in LWG between piglets suckling different parts of the sow's udder during the pre-weaning week for each treatment (Table 2.16).

Table 2.16 Pre-weaning average DLWG performance of piglets in relation to their teat order (g/d).

		LWG a week pre-weaning (kg)			SED		
	Teat-order	Anterior (1)	Middle (2)	Posterior (3)	1-2	2-3	1-3
Age	3 weeks	200	207	173	27.00	26.85	26.71
	4 weeks	279	272	222	52.71	80.43	78.43
	5 weeks	247	216	229	32.85	42.57	38.28

Regression lines were fitted to weekly LWG performance data of piglets suckling different parts of the sow's udder (Figure 2.11), and subsequently the slope of each line was compared. The analysis among the slopes of each line suggests, that the position of the teat that the piglets were nursing had a significant effect on live-weight gain (P<0.05) from birth to week 5 of lactation, with piglets suckling the posterior teats gaining significantly less weight (190g week^{-1}) than piglets suckling the anterior part of the udder ($q_{anterior-posterior}$ = 6.384, $q_{0.05,298,5}$= 3.858, (Zar 1999). There was no correlation between suckling duration and pre-weaning weekly LWG except for ATS-piglets during the third week of lactation (r=0.298, d.f.=52, P<0.05).

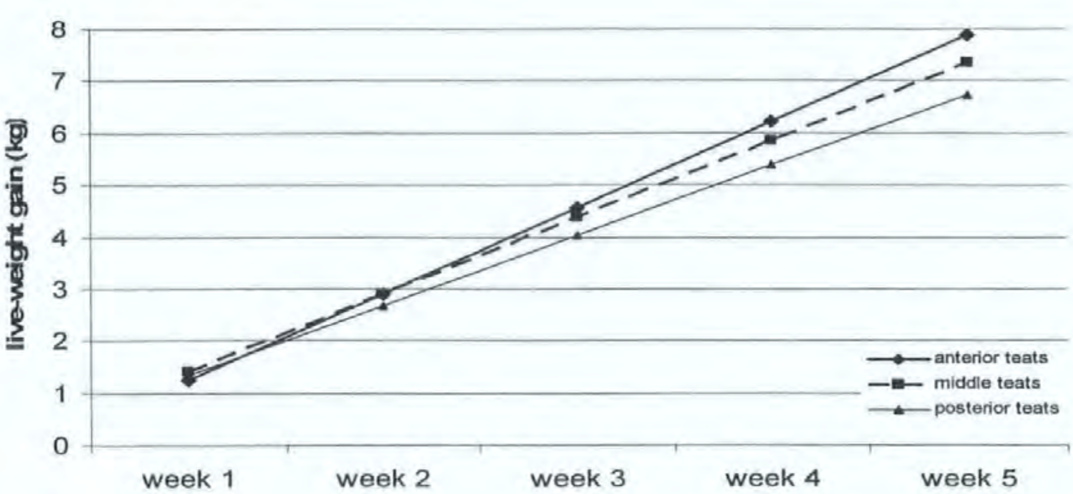


Figure 2.11 Total LWG from birth to the week on question, achieved by piglets sucking different positions at the udder (after fit of regression lines: anterior LWG = -0.410585 + 1.66074week (F=1310.57; d.f.=1,3; P<0.0001; R^2_{adj} =99.7%); middle LWG = -0.0724683 + 1.48426week (F=4529.39; d.f.=1,3; P<0.0001; R^2_{adj} =99.9%); posterior LWG = -0.027145 + 1.35376week (F=552.651; d.f.=1,3; P<0.0001; R^2_{adj} =99.3%)).

2.3.2 Post-weaning period.

2.3.2.1 Eating and drinking behaviour

Eating and drinking 'stasis' are the behavioural observations which express the difficulty that piglets were facing while trying to locate the feeding and drinking resources during the first hours or days of their life in a new environment, away from their dam. The average amount of time needed for a piglet to reach and sample the feed for the first time after weaning ('eating stasis'), did not differ significantly between piglets weaned at different ages (P>0.05) (Table 2.17). On the other hand, 'drinking stasis', was significantly different between piglets weaned at 3 and 4 weeks of age, with the latter needing 59% less time (P<0.05) to drink for the first time after weaning (mean for 4W= 48 ± 21.2 min). Even greater differences were observed to occur between piglets weaned at 5 and 3 weeks of age, as piglets of the older weaning age drank water for first time in 9.5% of the time recorded for the younger piglets (mean for 5W= 11 ± 1.95 min, P<0.05). Independent of their weaning age, piglets could locate the drinkers in significantly less time (P<0.01) than the period of time they need in order to find the creep feed.

Table 2.17 Eating and drinking stasis at three different weaning ages.

	Weaning age			SED		
Measurements in minutes	3 weeks	4 weeks	5 weeks	3-4	3-5	4-5
'eating stasis'	179	190	170	62.75	62.75	61.84
'drinking stasis'	117	48	11	28.04*	28.04*	27.64
Eating vs. drinking 'stasis' Q^a	7.69**	8.61**	8.74**			

*P<0.05, **P<0.01

[a] = statistics performed with non-parametric Kruskal-Wallis (for 2 treatments the estimated Q value must be over 1.960 for significant difference (Eddison, 2000)).

Table 2.18 Eating and drinking 'stasis' between piglets of different body-weight and teat-order classification (mean ± SE).

	Classification of the piglets within their litter			Classification of the piglets according to teat-order		
Measurements in minutes	Heavy	Medium	Light	Anterior	Middle	Posterior
			3 weeks			
'eating stasis'	187.7±72.1	173.2±20.3	175.8±24.6	149.4±5.29	201.1±61.9	177.8±24.2
'drinking stasis'	142.0±73.1	119.8±28.5	107.0±28.7	144.6±89.5	112.9±21.1	118.6±33.4
			4 weeks			
'eating stasis'	82.3±57.2	274.0±105	214.8±77.3	218.4±98.2	188.0±72.8	145.0±83.8
'drinking stasis'	40.5±25.2	75.8±56.0	28.0±24.3	35.3±21.9	73.1±49.6	24.8±26.8
			5 weeks			
'eating stasis'	158.7±73.0	149.0±134	201.8±58.8	108.5±59.0	159.8±59.4	283.0±191.0
'drinking stasis'	6.17±1.33	11.83±3.79	14.17±4.0	11.17±4.29	11.75±2.86	±8.0±3.14

There were no statistically significant differences in eating or drinking 'stasis' between piglets of different body-weight classification at weaning or according to teat-sucking order within treatments (Table 2.18).

There was a significant difference in daily eating duration between piglets weaned at three, four and five weeks of age, for a large period of the post-weaning week (Figure 2.12). During Day 1 post-weaning, 5W piglets spent more time at the feeders than 3W and 4W piglets (3000 *vs.* 559 (s.e.d. 639.5) s; $P<0.01$, 3000 *vs.*1286 (s.e.d 617.4) s; $P<0.05$ respectively). During the following day, piglets of the older weaning ages (4W and 5W) were more keen to visit the feeders and sample the feed than 3W piglets (6647 *vs.* 1441 (s.e.d. 878.8) s; $P<0.001$, 8118 *vs.* 1441 (s.e.d. 954.4) s; $P<0.001$ respectively). During day 3 post-weaning, piglets of the youngest age managed to spend the same amount of time at the feeders as piglets of the older weaning ages. On day 4, 3W piglets spent more time feeding than piglets of 4W (7870 *vs.* 5587 (s.e.d. 689.3) s; $P<0.05$) and 5W (7870 *vs.* 6643 (s.e.d. 867) s; $P>0.05$). Similarly, on day 5 post-weaning, piglets of the youngest age spent more time at the feeders than piglets on the other two treatments (3w *vs.* 4w: 7799 *vs.* 5861 (s.e.d. 798.2) s; $P<0.05$ and 3w *vs.* 5w: 7799 *vs.* 6643 (s.e.d. 867) s; $P>0.05$). So, after the fourth day post-weaning, 3W piglets were spending more time feeding than 4W ($P<0.05$) and 5W ($P<0.01$) piglets, when the latter spending significantly longer periods of time at the feeders until that day.

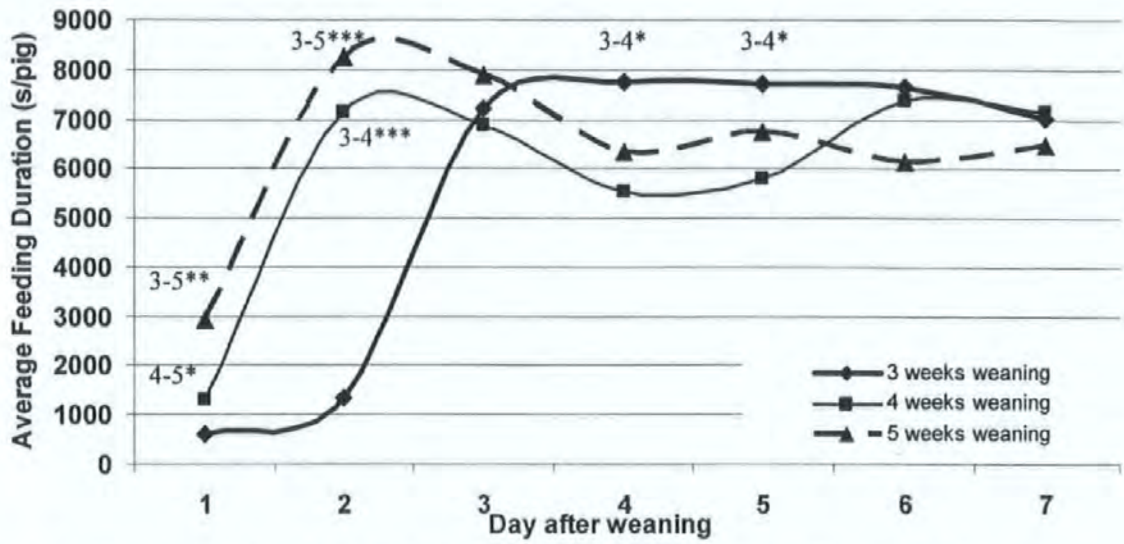


Figure 2.12 Average feeding duration of piglets weaned at 3, 4 and 5 weeks of age.

The numbers represent the treatments between which the difference was significant.
*$P<0.05$, **$P<0.01$, ***$P<0.001$

There was no significant effect of weaning age on daily post-weaning drinking duration, except for day 2 post-weaning when 5W piglets spent more time at the drinkers than 3W piglets (577 *vs.* 1363, (s.e.d. 260) s; $P<0.05$). The effect of weaning age on post-weaning drinking behaviour is shown in Figure 2.13.

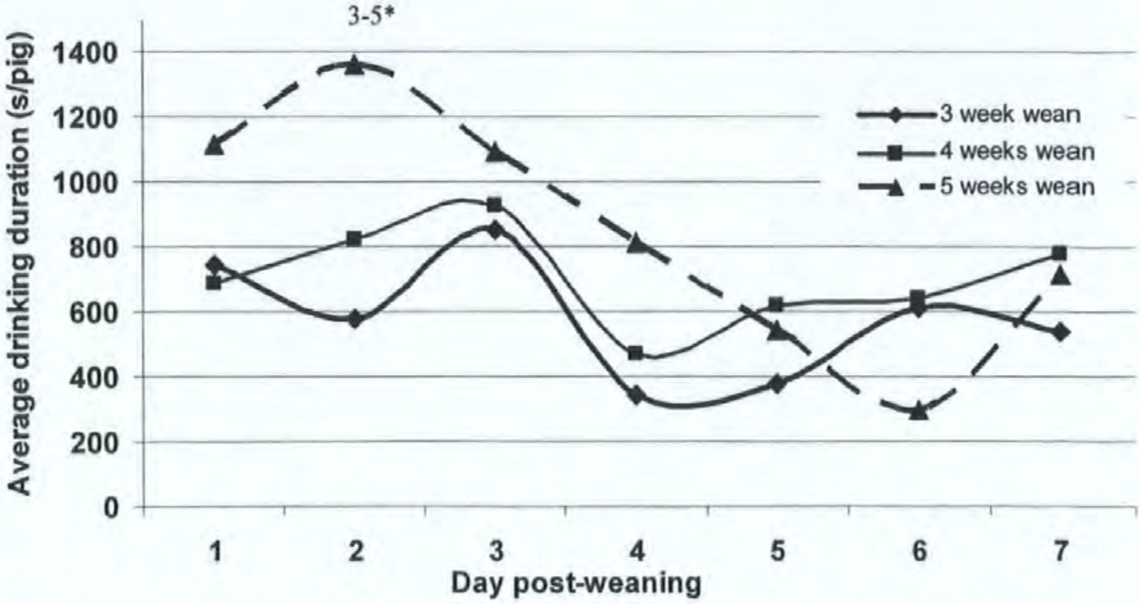


Figure 2.13 Average drinking duration of piglets weaned at 3, 4 and 5 weeks of age.

It has been observed that on a weekly basis and irrespective of their weaning age, piglets need more time to engage in feeding than in drinking activities ($P<0.0001$, Table 2.19). In order to achieve that level, a certain period of time was needed according to their weaning age. It took 3 days for 3W piglets to establish a behavioural feeding and drinking pattern, which would have the same proportional characteristics to the average weekly performance of their first week post-weaning. On the other hand 4W and 5W piglets needed two days to establish that pattern.

Table 2.19 A comparison between daily drinking and feeding duration (analysis of medians)

	Drinking duration piglet^{-1} (s)	Feeding duration piglet^{-1} (s)	Q [a]	Drinking/feeding duration (s) [b]	Q [b]
3W day 1	683	687	2.56	0.415	6.84*
3W day 2	621	706	1.88	0.533	11.45****
3W day 3	625	7209	10.65****	0.086	3.41
3W day 4	367	7824	13.66****	0.041	11.95****
3W day 5	359	7789	13.66****	0.039	10.76****
3W day 6	456	7245	13.66****	0.068	7.00*
3W day 7	559	7201	13.66****	0.076	6.49*
Average weekly performance	584	6020	14.95****	0.097	
4W day 1	701	1020	5.29	0.466	11.78****
4W day 2	744	6172	15.21****	0.111	1.02
4W day 3	564	6424	15.37****	0.104	1.87
4W day 4	465	5393	15.37****	0.096	4.44
4W day 5	493	5401	15.20****	0.085	3.92
4W day 6	427	6401	15.20****	0.065	7.00*
4W day 7	393	6668	14.52****	0.066	6.57*
Average weekly performance	620	5952	15.37****	0.124	
5W day 1	777	1572	6.83*	0.501	9.90**
5W day 2	1011	7624	14.95****	0.111	1.02
5W day 3	649	8168	14.69****	0.071	1.87
5W day 4	431	6505	14.86****	0.067	4.95*
5W day 5	438	6724	15.37****	0.069	3.93*
5W day 6	405	6535	15.37****	0.072	7.00**
5W day 7	389	6720	15.20****	0.061	6.57*
Average weekly performance	698	6471	13.66****	0.105	

*$P<0.05$, **$P<0.01$, ****$P<0.0001$

[a] = statistics performed with non-parametric Kruskal-Wallis (for 2 treatments the estimated Q value must be over 1.960 for significant difference (Eddison, 2000)).

[b] = direct comparison between daily drinking/feeding duration with average weekly ratio.

The effect on weaning to feeding frequency of piglets within the treatments was also determined (Figures 2.14-2.16). No significant difference was recorded for the recordings of feeding or drinking frequency and duration between piglets of different weaning weight (heavy, medium and light piglets) within treatments ($P>0.05$). The few exceptions where significant differences occurred will be mentioned in the following paragraphs.

Correlation analyses were carried out to identify the effect of pre-weaning eating and drinking experience i) on post-weaning feeding and drinking 'stasis' as well as ii) with total feeding and drinking behaviour recorded during the first 3 days after weaning between piglets of the same weaning age.

Piglets weaned at 3 weeks of age.

There was no correlation between pre-weaning feeding duration and post-weaning 'eating stasis' for the piglets on this treatment. Pre-weaning feeding and drinking duration had no correlation with post-weaning feeding and drinking duration during the first day after weaning. On the other hand, pre-weaning drinking duration had a consistent negative relationship to 'drinking stasis' ($r=-0.513$, d.f.=16, $P<0.05$). From the multiple regression analyses that have been employed in order to identify which of the pre- and post-weaning recordings had an effect on the LW of the piglets for the first week post-weaning, it was concluded that WW was the most crucial factor as it was expressing 77.7% of the variation. Their relationship is described by the following equation which predicts that the average weight of the piglets in a litter during the first week post-weaning will be 900g heavier than their average weaning weight:

LW the week post-weaning (kg) = 0.888 + 0.997WW ($F=56.59$, d.f.= 1,15, $P<0.001$, $R^2_{adj}=77.7\%$) (Equation 2.5)

Piglets weaned at 4 weeks of age.

There was no correlation between pre-weaning feeding and drinking activities with post-weaning eating and drinking 'stasis'. However, feeding duration was significantly greater in medium (9016 ± 1909) weight piglets during the second day post-weaning than in heavier (6600 ± 1061 s; $P>0.05$) or lighter (5860 ± 1356 s; $P<0.05$) piglets of the litter (Figure 2.15). Pre-weaning drinking duration had a very strong positive correlation with post-weaning drinking behaviour during the first day after weaning ($r=0.707$, d.f.=16, $P<0.001$). There was no significant correlation between pre-weaning and post-weaning feeding duration on day 1 after weaning. Multiple regression analyses have been employed in order to identify which of the pre- and post-weaning recordings had an effect on the LW of the piglets for the first week post-weaning. It was identified that WW (93.25%) and total pre-weaning feeding duration (1.85%) were the most crucial factors as they accounted for 95.1% of the variation and their relationship is described by the following equation:

LW the week post-weaning (kg) =-2.43 +1.05WW +1.21tot pre-weaning feeding duration ($F=134.55$, d.f.= 2,15, $P<0.001$, $R^2_{adj}=95.1\%$) (Equation 2.6)

Piglets weaned at 5 weeks of age.

There was no correlation between pre-weaning eating behaviour and post-weaning 'eating stasis'. However, piglets of medium weaning weight, spent more time at the feeders than their heavier (4367 *vs.* 2063 (s.e.d=1105) s; $P<0.05$) and lighter (4367 *vs.* 2330 s; $P>0.05$) littermates (Figure 2.16). The regression analysis showed that the longer pre-weaning feeding activity of the medium weight piglets significantly influenced them to spend more time at the feeders during the first day after weaning ($F=53.12$, d.f.= 1,15, $P<0.001$, R^2_{adj}

=75.4%). On the other hand, there was a consistent positive relationship between pre-weaning drinking duration and post-weaning 'drinking stasis' (r=0.566, d.f.=16, P<0.05). No significant relationship was found between pre-weaning eating or drinking duration with post-weaning feeding and drinking behaviour during the first day after weaning. Multiple regression analyses were employed in order to identify which of the pre- and post-weaning recordings had a significant effect on the LW of the piglets for the first week post-weaning. It was identified that WW (46.44%) and BW (14.2%) had a significant positive effect on LW, as on the other hand total suckling duration (18.26%) had a significant negative effect on LW of the piglets. These were the most crucial factors as they accounted for 78.9% of the variation. Their relationship is described by the following equation:

LW the week post-weaning (kg) = 1.19 + 0.694WW -0.00218total suckling duration + 3.39BW (F=22.22, d.f.= 3,14, P<0.001, R^2_{adj} =78.9%) (Equation 2.7)

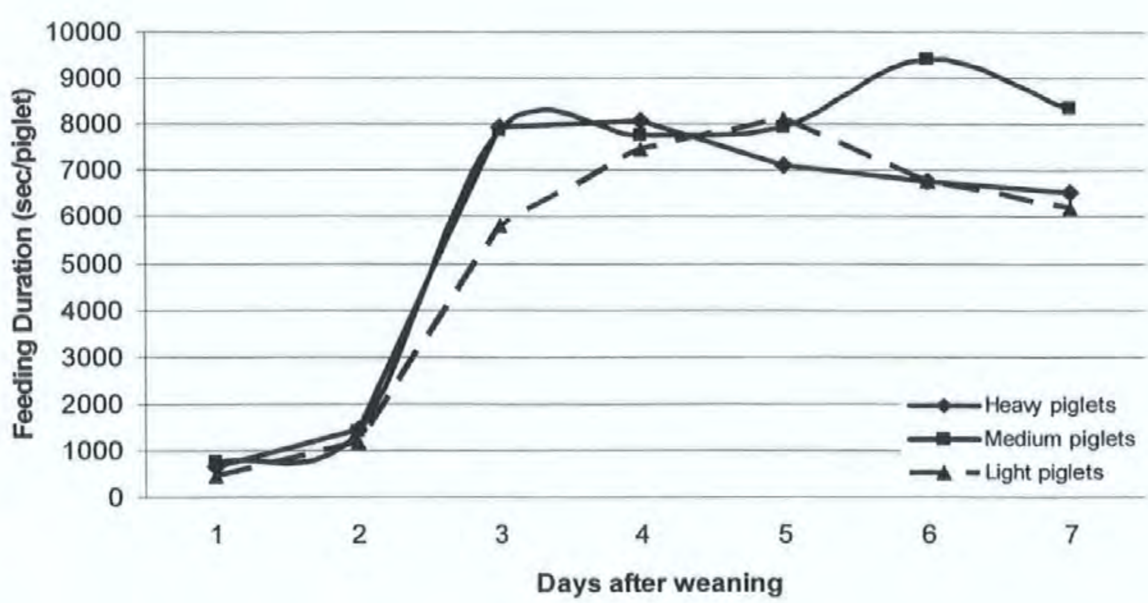


Figure 2.14 Daily observations of feeding frequency between piglets of different weaning weight at 3 weeks of age.

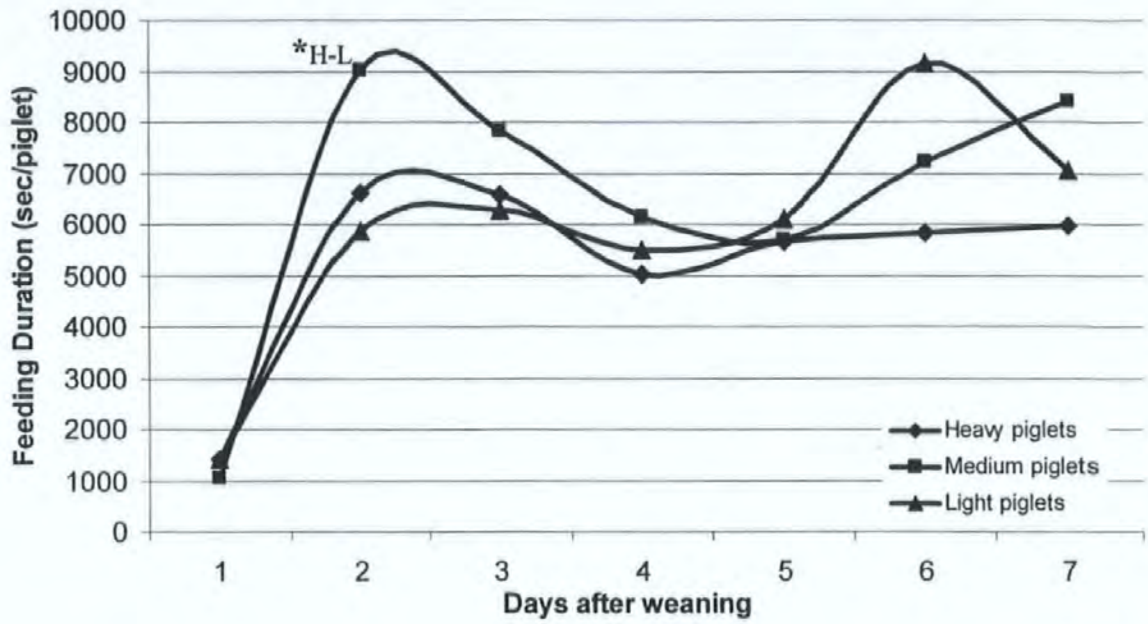


Figure 2.15 Daily observations of feeding frequency between piglets of different weaning weight at 4 weeks of age (*P<0.05).

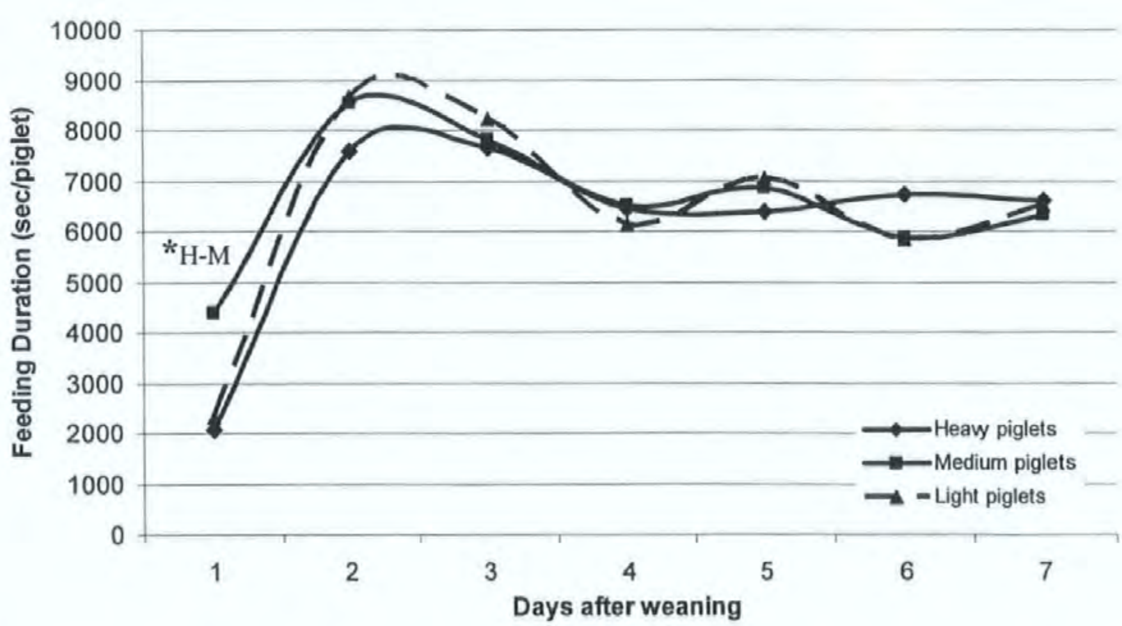


Figure 2.16 Daily observations of feeding frequency between piglets of different weaning weight at 5 weeks of age (*P<0.05).

2.3.2.2 *Aggressive and stereotypic behaviour during the week post-weaning*

The piglets were observed for incidents of aggressive behaviour like fighting as well as for the expression of some stereotypic behaviour like chewing objects and belly nosing throughout the course of the day, for the week post-weaning.

Piglets weaned at 28 days, were significantly more aggressive on day 2 (P<0.0001), 5 (P<0.01) and 6 (P<0.05) post-weaning than piglets weaned at 21 and 35 days of age (Table 2.20).

Table 2.20 Average daily fighting duration of piglets weaned at three weaning ages (s pig^{-1}).

Day post-		Treatment			Q	
weaning	3W	4W	5W	3-4	3-5	4-5
1	286	174	124	3.03	4.00	-0.972
2	47	3393	254	11.488****	2.814****	8.673****
3	115	522	282	6.542	3.271	3.271
4	368	436	495	0.743	0.629	0.114
5	398	1433	550	10.354**	3.203**	7.150**
6	1097	1100	367	1.259	5.724*	6.985*
7	1249	1557	897	0.572	3.833	4.405

*P<0.05, **P<0.01, ****P<0.0001
a= statistics performed with non-parametric Kruskal-Wallis (for 3 treatments the estimated Q value must be over 2.394 for significant difference (Eddison, 2000)).

Belly nosing, performed by piglets weaned at 28 days of age, was significantly higher from day 2 (P<0.01) to day 7 (day 3 to day 7 P<0.001) post-weaning than for piglets on the two other weaning treatments (Figure 2.17). A multiple regression analysis was performed in order to identify which of the various pre- and post-weaning recordings had influenced the expression of post-weaning belly nosing recorded on 4W piglets. It indicated a significant negative effect of total pre-weaning suckling duration (45.04%), and a significant positive effect of total fighting duration (11.03%) and teat position (10.53%) on belly nosing performance the week post-weaning and described by the following equation:

Total weekly belly nosing for the week post weaning (4W) (log s) = 3.69 – 0.000013 tot suckling duration + 0.000136 tot fighting duration + 0.651 teat position (1=anterior, 2=middle, 3=posterior) ($F=12.29$, d.f.=3,14, $P<0.0001$, $R^2_{adj}=66.6\%$) (Equation 2.4)

The equation suggests that piglets that had suppressed suckling behaviour and that were suckling the most posterior teats (hence, less milk intake) had significantly more chance to express longer belly nosing behaviour.

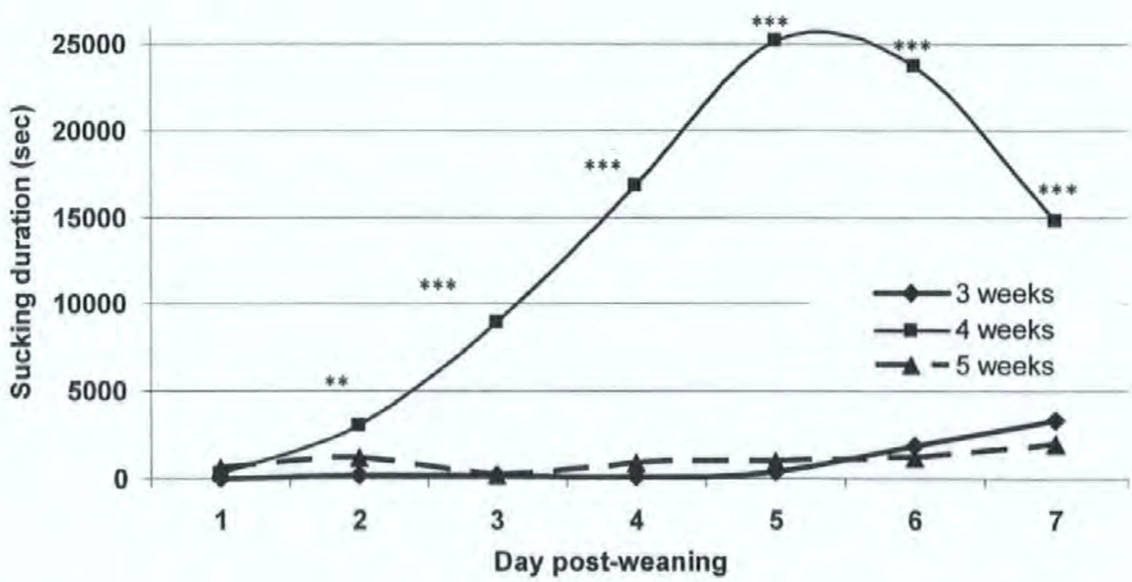


Figure 2.17 Average daily belly-nosing of piglets weaned at three different weaning ages. $**P<0.01$, $***P<0.001$

Abnormal behaviour, in the form of fighting, chewing of pen objects and belly nosing was also analysed using the average values of weekly behavioural observations. Piglets weaned at four weeks of age spent significantly more time on biting behaviour than 3W and 5W piglets ($P<0.05$ and $P<0.001$ respectively) as shown in Table 2.19. 3W piglets were also observed to be significantly more aggressive than 5W piglets during the week post-weaning ($P<0.05$).

Piglets weaned at four weeks of age engaged in more chewing behaviour (manipulation of chains and other pen objects) than 3W ($P<0.05$) or 5W piglets (Table 2.21, $P>0.05$). Average weekly performance of belly nosing, was significantly higher for 4W piglets than for 3W and 5W piglets ($P<0.01$).

Table 2.21 Average weekly aggressive and stereotypic behaviours of pigs at different weaning ages (s pig^{-1}).

	Weaning age			Q values and SED		
	3 weeks	4 weeks	5 weeks	3-4	3-5	4-5
Fighting	6580	9535	5093	Q 3.947*	Q 4.634*	Q 8.581***
Duration (a)	16 min d^{-1}	23 min d^{-1}	12 min d^{-1}			
Chewing	3769	5946	4358	SED 8.872*	SED 9.052	SED 9.345
Duration (b)	9 min d^{-1}	14 min d^{-1}	10 min d^{-1}			
Belly nosing	334	5159	386	Q 9.148**	Q 1.898	Q 7.25**
(a)	0.8 min d^{-1}	12 min d^{-1}	0.9 min d^{-1}			

***($P<0.05$), **($P<0.01$), ***($P<0.001$)
a= statistics performed with non-parametric Kruskal-Wallis (for 3 treatments the estimated Q value must be over 2.394 for significant difference (Eddison, 2000)).
b= statistics performed with parametric GLM-ANOVA. SED refers to the data which have been treated using log10 or square root transformation

2.3.2.3 Daily feed and water intake during the week post-weaning

Weekly feeding and drinking performance of piglets weaned at three different ages are presented in Table 2.22. Piglets weaned at three weeks of age were consuming significantly less feed ($P<0.01$) and water ($P<0.0001$) during the week post-weaning, than piglets weaned at four and five weeks of age without noticing a significant difference between the latter two treatments ($P>0.05$). When the piglets reached six weeks of age, those that were weaned at three and four weeks of age were consuming significantly higher amounts of feed than 5W piglets. It was also noticed that 3W piglets were consuming significantly more water ($P<0.01$) at 6 weeks of age than 5W piglets.

FCR was not significantly different between treatments for the week post-weaning although 3W piglets converted the feed twice as efficiently as 4W and 5W piglets ($P>0.05$) in the week post-weaning. The feed:water ratio was significantly different for the week post-weaning between piglets of different weaning age, with the younger piglets consuming proportionally more water to creep feed the week after weaning than piglets of 4 ($P<0.01$) and 5 weeks of age ($P<0.001$).

Results of a more detailed analysis of feed and water consumption is presented in Figures 2.19 and 2.20, which shows differences in consumption of these resources by piglets of different weaning ages on a daily basis. Due to the lack of individual feeding facilities, the recordings that have been made represent feed and water consumption of each pen, which consisted of 6 piglets from the same litter. 4W and 5W piglets were consuming greater amounts of feed than 3W piglets for the whole post-weaning week ($P<0.01$). Although piglets of the 4W and 5W treatment were consuming more feed than 3W piglets from day 1 post weaning, the daily difference became significant towards the end of the post-weaning week (days 5, 6 and 7 post weaning, $P<0.05$). 4W piglets, were consuming almost identical amounts of feed to those recorded for 5W piglets.

Piglets weaned at three weeks of age, on day 7 post-weaning became 4 weeks old. At the time 3W piglets became 4 weeks old (Figure 2.18, [a]Line), they were consuming 88 and 77% more feed during day 1, than newly weaned piglets of 4 ($P<0.001$) and 5 ($P<0.01$)

weeks of age (feeding for age). The difference continued to be significant until day 2 post-weaning, when piglets that had already been weaned for a week (3W treatment) were consuming 63 and 58% more feed than piglets weaned at 4 ($P<0.01$) and 5 weeks ($P<0.05$) of age. It took 4 days for piglets weaned at 4 and 5 weeks of age to consume identical amounts of feed to those recorded on 3W piglets at day 7 post-weaning.

Similarly, 4W piglets, at day 7 post-weaning, became 5 weeks old and they had already been fed only on creep feed and water for a week. On their 7th day post-weaning, they were eating 81 and 67% more feed than newly weaned 5W piglets on their day 1 ($P<0.01$) and day 2 ($P<0.05$) post weaning (^{b}Line Figure 2.18).

Table 2.22 Average daily feed and water intake, FCR and feed:water ratios of pigs weaned at three different ages.

Weaning age	3 weeks	4 weeks	5 weeks	SED 3-4	SED 3-5	SED 4-5
Average daily FI (g/d/pig) during the week post-weaning (a)	153	261	281	35.5**	35.5**	35.5
Average daily FI (g/d/pig) during week 6 (a)	502	463	281	43.8	34.6 ****	43.6*
FCR a week post-weaning (a)	0.61	1.21	1.11	0.281	0.296	0.548
FCR at 6 weeks (a)	1.11	1.17	1.11	0.115	0.121	0.099
Average daily water consumption (l/d/pig) the week post-weaning (a)	0.553	0.897	0.872	0.0724 ****	0.0724 ****	0.0763
Average daily water consumption (l) on week 6 (a)	1.176	1.019	0.872	0.117	0.092 **	0.116
Feed/Water ratio for the week post-weaning (a)	0.1085	0.2152	0.3063	0.019**	0.025***	0.019**
Feed/Water ratio for week 6 post-weaning (a)	0.46	0.53	0.3063	0.054	0.043	0.054**

*$P<0.05$, **$P<0.01$

[a] Represents the performance achieved by the 6 selected pigs at weaning.

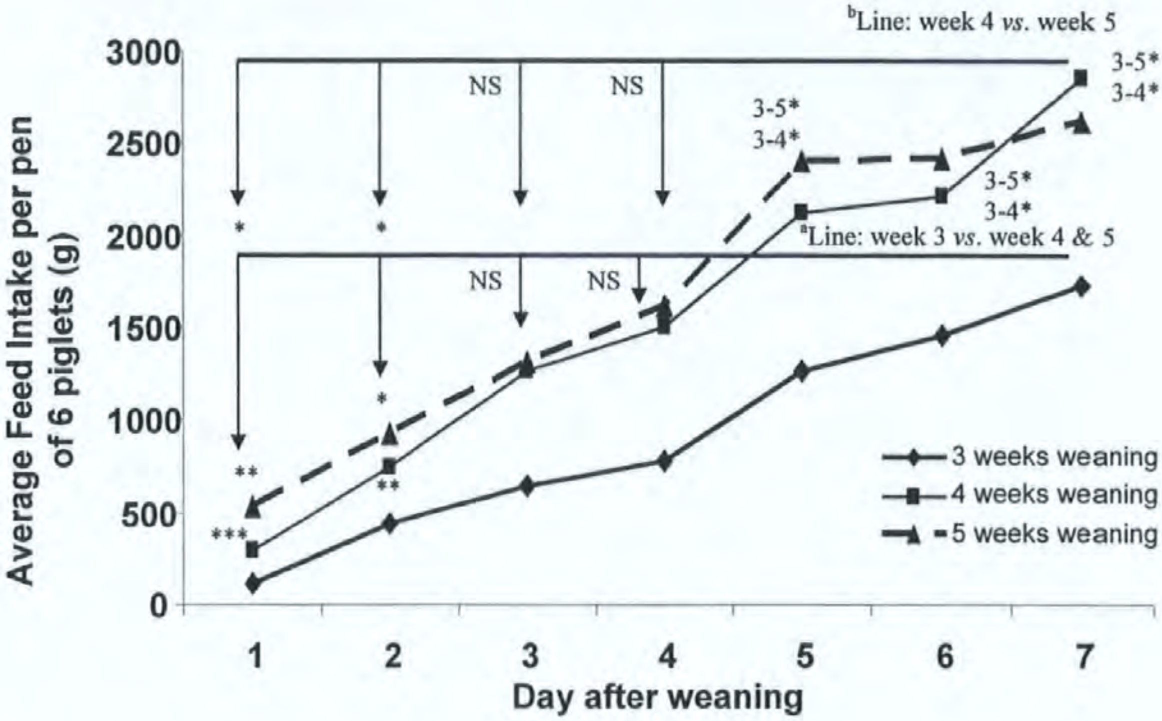


Figure 2.18 Average daily feed consumption, during the week post-weaning, from piglets weaned at three different ages.

[a] The horizontal line represents the difference in feed consumption recorded on day 7 for 3W piglets and days 1, 2, 3 and 4 post-weaning for piglets weaned at 4 and 5 weeks of age, and the statistical difference between the three treatments.
[b] The horizontal line represents the difference between feed consumption recorded on day 7 for 4W piglets and days 1, 2, 3 and 4 post-weaning for piglets weaned at 5 weeks of age, and the statistical difference between the two treatments.
[c] The expression 3-4 and 3-5 illustrates the comparison of the specific treatments and the statistical difference between them.
[d] *$P<0.05$, **$P<0.01$, ***$P<0.001$

Daily water consumption was not significantly different between piglets of different weaning age (Figure 2.19). Water intake for age was only significantly different between 3W and 4W piglets for day 1 of the latter (4.290 vs. 2.305, s.e.d=0.7201, $P<0.05$).

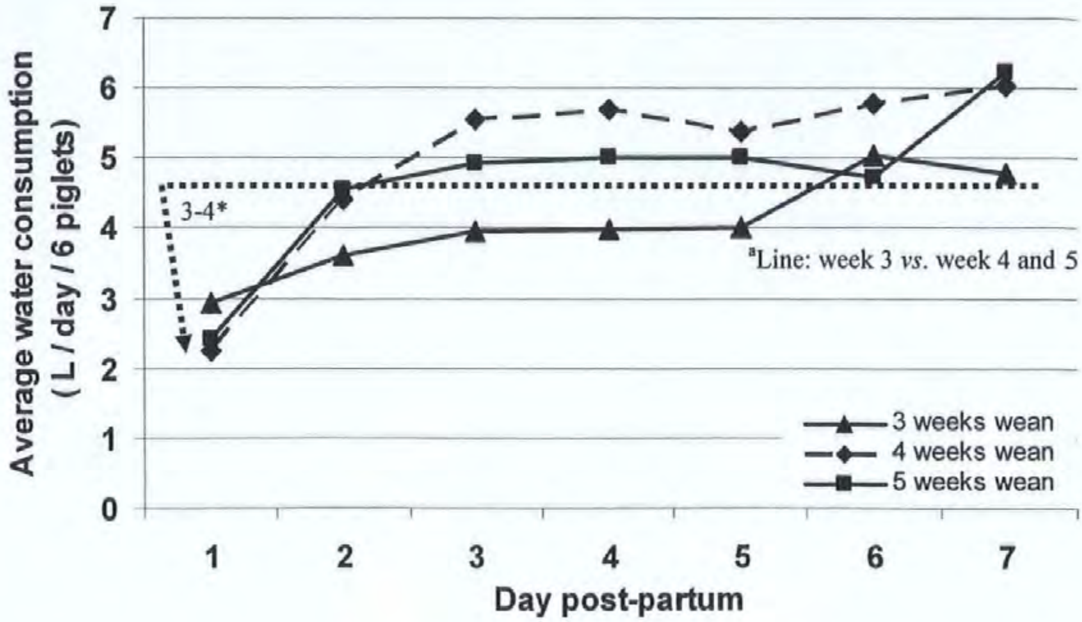


Figure 2.19 Average daily water consumption, during the week post-weaning, from piglets weaned at three different ages.
[a] The horizontal line represents the statistical difference in water consumption recorded between 3W piglets on day 7, and piglets weaned at 4 weeks of age on day 1.
[c] $*P<0.05$,

It was also calculated that the daily feed to water ratio was not significantly different between piglets of different weaning ages (Figure 2.20). It can be seen that on day 1 for 3W, 4W and 5W piglets, feed constituted 7, 9 and 17% of their total intake (or of the average piglet's gut fill as they could only consume feed and water). At the end of the post-weaning week, piglets of 3W, 4W and 5W treatment managed to gradually increase their dry matter (DM) consumption to 47% (3W: day1= 0.071 *vs.* day7= 0.471 (s.e.d.= 0.0575) kg/L; $P<0.0001$), 50% (4W: day1= 0.096 *vs.* day7= 0.502 (s.e.d.= 0.1644) kg/L; $P<0.05$) and 38% (5W: day1= 0.1702 *vs.* day7= 0.385 (s.e.d.= 0.0681) kg/L; $P<0.05$) respectively of their total daily intake.

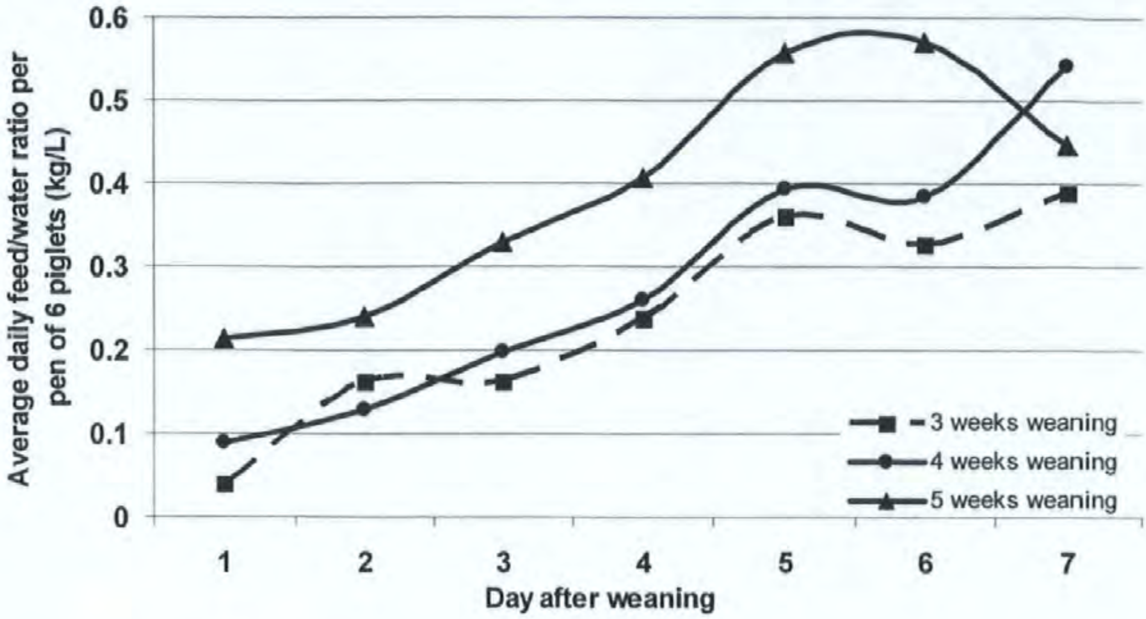


Figure 2.20 Average daily feed to water ratio recorded per pen of six piglets after weaning for each weaning age.

2.3.2.4 Post-weaning growth performance between piglets of different weaning age

Average DLWG was not significantly different between piglets weaned at 3, 4 and 5 weeks of age (Table 2.23). Only at six weeks of age, 3W piglets were growing 45 and 27% faster than piglets weaned at 5 ($P<0.05$) and 4 ($P>0.05$) weeks of age.

Table 2.23 Average DLWG of piglets weaned at different ages (g/d).

Treatment	3W	4W	5W	SED 3-4	SED 3-5	SED 4-5
DLWG at 4 weeks of age	317	266	153	94.171	99.185	81.400
DLWG at 5 weeks of age	378	281	240	50.286	52.957	43.471
DLWG at 6 weeks of age	436	319	239	53.543	56.4*	46.285

*$P<0.05$

There were no significant differences in LWG between piglets of different treatments for the period commencing week 1 to week 3 post-partum (P>0.05, Table 2.24). From birth to week 6 post-partum, 3W piglets gained on average 1.131 kg (P>0.05) and 2.192 kg (P<0.05) more weight than piglets weaned at four and five weeks of age respectively. Total LWG of 3W piglets was 40% higher (P<0.05) for the period commencing week three to week five post-partum than the growth performance of litters that have been kept with the sow for two more weeks (5 weeks treatment) (Table 2.24). Total LWG for the period commencing week 3 to week 6 post-partum was significantly higher for 3W piglets than piglets of the other two treatments. More specific, 3W piglets gained 1.270 and 2.630 kg more weight than piglets weaned a week or two later (P<0.05 and P<0.01 respectively). Also, during the same period, piglets weaned at four weeks of age gained 1.360 kg more weight (P<0.05) than piglets weaned a week later.

Table 2.24 LWG of piglets weaned at 3, 4 or 5 weeks at three periods of time.

Weaning age	3 weeks	4 weeks	5 weeks	SED 3-4	SED 3-5	SED 4-5
Live weight gain (LWG) from birth to 6 weeks of age (kg)	11.003	9.872	8.811	0.614	0.505*	0.665
Live weight gain (LWG) from 3 to 5 weeks of age (kg)	3.863	3.118	2.321	0.417	0.44*	0.361
Live weight gain (LWG) from 3 to 6 weeks of age (kg)	6.614	5.343	3.985	0.48*	0.51**	0.419*
Live weight gain (LWG) from 1 to 3 weeks of age (kg)	4.379	4.189	4.083	0.211	0.267	0.284

*P<0.05, **P<0.01

From the first week post weaning, 3W piglets were numerically heavier than piglets that were still suckling their dam (P>0.05). After the 5th week of their life, the difference became significant between 3W and 4W piglets with the latter being 1,700 g lighter.

Finally at the end of the experimental period (42 days), piglets weaned at three weeks of age were on average 1,990 and 1,520 g heavier than piglets weaned at four and five weeks of age respectively ($P<0.05$) (Table 2.25). No significant difference observed in LW between piglets of 4W and 5W treatment.

Table 2.25 Live-weight (kg) of pigs weaned at three different ages.

	Treatments			SED		
LW at	3W	4W	5W	3-4	3-5	4-5
4 weeks	7.330	6.197	6.938	0.4825	0.3992	0.4635
5 weeks	9.805	8.108	8.614	0.6209*	0.5138	0.5965
6 weeks	12.506	10.514	10.987	0.6949*	0.5750*	0.6676

*$P<0.05$

2.3.2.5 Post-weaning growth performance according to body-weight classification (within treatment comparison)

Average DLWG of piglets of different body-weight classification was analysed for the following reference dates: i) a week post-weaning, ii) at six weeks post-partum (at the end of the experimental period) and iii) for the period commencing 3 weeks of age (at which time all piglets were suckling) to week six post-partum (at which time all piglets had been weaned for at least a week). There were no significant differences in average DLWG between piglets of different classification independent of their weaning age (Table 2.26).

Table 2.26 Within treatment average DLWG (g/d) between piglets of different body-weigh classification at weaning, for the periods: i) a week post-weaning, ii) 6 weeks of age and iii) the period commencing week 3 to week 6 post-partum.

	Classification of the piglets within their litter			SED		
	Heavy (1)	Medium (2)	Light (3)	1-2	1-3	2-3
		3 weeks				
DLWG one week post-weaning (g/d)	170	223	197	64.185	81.728	66.386
DLWG @ 6 weeks (g/d)	387	416	334	50.028	81.771	63.228
DLWG between 3-6 weeks of age (g/d)	308	322	217	36.833	60.204	46.552
		4 weeks				
DLWG one week post-weaning (g/d)	303	296	251	45.828	53.928	40.071
DLWG @ 6 weeks (g/d)	313	371	421	75.814	93.257	52.943
DLWG between 3-6 weeks of age (g/d)	255	273	275	38.104	46.871	26.614
		5 weeks				
DLWG one week post-weaning (g/d)	221	384	374	63.585	71.986	58.800
DLWG between 3-6 weeks of age (g/d)	208	260	239	24.090	27.271	22.276

2.3.2.6 Post-weaning growth performance of piglets which had the same body-size classification at weaning (between treatments comparison)

A comparison was made to identify differences in LWG performance between piglets of the same body-size classification from each treatment, for the period commencing week 3 to week 6 post-partum (Table 2.27). 3W 'heavy' piglets had a tendency to gain more weight than piglets weaned at four and five weeks of age (680 and 1,680 g, $P>0.05$ respectively). 'Medium' size piglets weaned at three weeks of age gained significantly superior weight to piglets weaned a week (1,550 g, $P<0.05$) or two later (2,040 g, $P<0.01$) and 3W 'light' weight piglets gained significantly more weight than piglets weaned at four (580 g, $P>0.05$) and five weeks of age (1,220 g, $P<0.05$). The comparison shows that early weaning significantly influenced the piglets to gain more weight, and those that were helped the most to express their growth potential were the medium and light piglets of the 3W litters.

Table 2.27 Differences in LWG between piglets of the same body-weight classification for the period commencing week 3 to week 6 post-weaning.

	Weaning age			SED		
	3 weeks	4 weeks	5 weeks	3-4	3-5	4-5
Heavy piglets (kg)	6.54	5.86	4.86	1.480	1.021	1.298
Medium piglets (kg)	6.90	5.35	5.17	0.4975*	0.444**	0.4856
Light piglets (kg)	5.63	5.05	4.41	0.3924	0.4183*	0.4525

2.3.2.7 Post-weaning growth performance according to teat-preference classification (within treatments comparison)

Teat suckled position had no significant effect on average DLWG performance of 3W piglets during the first and third week post-weaning (Table 2.28). 3W piglets that had suckled either the posterior or middle teats of the sow, had over 115 g day^{-1} greater average DLWG for the period commencing weaning to the end of the experimental period, than piglets that had suckled the anterior teats ($P<0.05$). No significant difference in LWG was found for 4W and 5W piglets suckling different teats ($P>0.05$).

Table 2.28 Within treatment post-weaning average DLWG (g/d) of piglets according to their teat-preference during lactation.

	Classification of the piglets according to their teat-order			SED		
	Anterior (1)	Middle (2)	Posterior (3)	1-2	1-3	2-3
		3 weeks				
DLWG @ 4 weeks	178	180	239	61.943	79.543	64.814
DLWG @ 6 weeks	319	384	409	55.171	58.343	42.000
DLWG for the period commencing 3-6 weeks	194	309	316	26.638*	28.166*	20.276
		4 weeks				
DLWG @ 5 weeks	284	273	300	38.018	46.643	45.414
DLWG @ 6 weeks	395	328	406	42.328	66.185	57.428
DLWG for the period commencing 3-6 weeks	261	260	305	21.019	32.862	28.519
		5 weeks				
DLWG @ 6 weeks	360	311	307	66.457	86.714	78.057
DLWG for the period commencing 3-6 weeks	258	216	241	20.800	27.143	24.433

Several regression analyses were carried out to identify the main factors that influence the body-weight of all piglets at 6 weeks of age irrespective of their weaning age (Table 2.29). Weaning age significantly negatively affected the LW of the piglets at 6 weeks of age (11.2%), as the earlier they have been weaned the heavier they could become at that age ($P<0.05$). Some of the most crucial factors of the analysis were the body-weight of the piglets during the first three weeks of their pre-weaning life, which suggests that as the piglets maintained their heavy weight status from birth to weaning, they had increasing chances to remain the heaviest at 6 weeks of age ($P<0.0001$). Teat preference of the piglets had no effect on LW at 6 weeks of age. On the other hand the sex of the piglets accounted for 15.3% of the variation (male: 12.02 *vs.* female: 10.31 (s.e.d.= 0.5906) kg;

$P<0.01$). Pre-weaning feeding duration had a very low but positive effect on LW at 6 weeks of age (8%, $P<0.05$). Longer suckling periods (observed in older weaning ages), affected negatively the LW of the piglets at the end of the 6th week of their life, as the analysis suggests that the longer period of time that the piglets had to depend on sow's milk was a limiting factor for the full expression of the potential for growth ($P<0.01$).

Table 2.29 Regression analysis between LW at 6 weeks of age and various pre- and post-weaning measurements of all experimental piglets independent of their weaning age.

Comparison	*F*	d.f.	P	R^2_{adj} %	Equation: LW at 6weeks =
Weaning age	6.17	1,41	*	11.2	= 15.0 - 0.893 X 3weeks=1; 4weeks=2; 5weeks=3
Birth weight	20.66	1,41	****	32.4	= 3.20 + 5.23 X
Weaning weight	24.20	1,41	****	36.1	= 5.83 + 0.782 X
LW week 1	39.36	1,41	****	48.3	= 0.77 + 3.73 X
LW week 2	84.90	1,41	****	67.2	= 1.67 + 2.16 X
LW week 3	124.64	1,41	****	75.1	= 2.35 + 1.53 X
Body-weight classification at weaning	6.75	1,41	*	12.3	= 13.2 - 0.946 X heavy =1; medium =2; light =3
Teat preference	0.69	1,41	NS	0	
Litter size	5.29	1,41	*	9.5	= 15.1 - 0.348 X
Sex	8.43	1,41	**	15.3	= 13.7 - 1.72 X male=1; female=2
Total pre-weaning behavioural durations					
Feeding (log) [a]	4.55	1,41	*	8.0	= 3.97 + 2.24 logX
Drinking (log) [a]	0.00	1,41	NS	0.0	
Suckling (log) [a]	10.16	1,41	**	18.3	= 31.4 - 3.79 logX
Fighting (log) [a]	1.52	1,41	NS	1.3	
Post-weaning behavioural durations during the first week after weaning					
Feeding (log) [a]	4.29	1,41	*	7.4	= 32.6 - 4.60 logX
Drinking (log) [a]	2.25	1,41	NS	3.0	
Belly nosing (log) [a]	0.85	1,41	NS	0.0	
Fighting (log) [a]	17.04	1,41	****	28.21	= - 0.25 + 3.09 logX
Chewing (log) [a]	2.33	1,41	NS	3.2	

*P<0.05, **P<0.01, ****P<0.0001

[a] The data treated using $\log_{10}$ transformation in order to become normally distributed.

After applying all the recordings summarised in Table 2.28 to a multiple regression analysis in order to explain which factors influenced the LW of the piglets at 6 weeks of age, it was concluded that the equation that could express better this relationship was the following:

LW at 6 weeks (kg) = 5.60 + 0.956 LW week3 - 0.811 weaning age (1=3w; 2=4w, 3=5w) + 0.494 WW (F=63.55, d.f.=3,38, P<0.0001, R^2_{adj}=82.1%) (Equation 2.9)

The above equation suggests that the body weight of the piglets at 6 weeks of age was primarily explained by their weight at 3 weeks of age (90.8% of the variation), their weaning weight (7.2%) and their weaning age (2%). The results of the linear and multiple regression analyses suggest that the live-weight of the piglets from birth to weaning were the most crucial factors which could influence their LW at six weeks of age.

2.4 Discussion

In nature weaning is a gradual process that has been observed to be completed when piglets become 10 weeks of age (Brooks and Tsourgiannis 2003) or even in some cases at 17 weeks of age (Jensen and Recen 1989; Boe 1991). The economic constraints of management systems mean that it is usually a rapid process on commercial farms, which takes place at a much younger age at around 18 to 24 days of age, which is the average weaning age in many countries (King and Pluske 2003). The young piglets are expected to make an abrupt change from a warm liquid milk, delivered at approximately 50 minute intervals (Wechsler and Brodman 1996) from the sow's udder, to a dry diet and water, which is available at all times in an unfamiliar environment and a new social order. At weaning, the young piglets have to use their pre-weaning experiences to locate the creep feed and the drinkers. These may differ in design from those that they have been exposed to before weaning and the piglets may also have to compete with new penmates. Other piglets have to rely on their survival instinct as they have limited or no experience at all of eating and drinking, which can also be due to limited or no provision of creep feed and water pre-weaning (Fraser *et al.*, 1993). There is a dramatic reduction in dry matter intake following weaning and it does not recover to the pre-weaning level until the second week post weaning (Brooks and Tsourgiannis 2003).

Although it has been identified that there is great variability in feed intake both before and after weaning (Aumaitre 1972; Algers *et al.*, 1990; Pajor *et al.*, 1991), there are no studies to demonstrate a linkage between the pre- and post-weaning feeding behaviour of individuals. This is primarily because pigs have been treated as groups (litters) and the average performance and response have been measured (Pajor *et al.*, 1991). For example, the teat that the piglets occupy at suckling (teat order) (Fraser 1980) on the same sow may differ in milk production terms by as much as 200% or more (Algers *et al.*, 1990). So, it may be that different piglets within the same litter will be affected quite differently by the nutritional change.

This study focused on gaining information about the pre-weaning behaviour of individual piglets, which were classified according to their weaning weight (heavy, medium and light) and their teat preference (anterior, middle and posterior) at three different weaning ages (3, 4 and 5 weeks of age) and relating this to their behaviour and ability to make a successful transition to solid feed post-weaning.

2.4.1 The effect of weaning age on piglets' live-weight at 6 weeks of age.

It was found that there was a significant effect (Table 2.28) of weaning age on the final weight of the piglets at 6 weeks of age. Piglets weaned at three weeks of age were 2 and 1.5 kg heavier (Table 2.25) than piglets weaned at four and five weeks of age respectively. From their first week post-weaning 3W piglets gained on average 51g day^{-1} more weight than 4W piglets, which had to remain with the sow for another week. The difference was becoming even greater between 3W piglets and those weaned last in this experiment (139 g day^{-1}). Overall, in that short period of 3 weeks (from week 3 that they have been weaned to week 6 of their life) 3W piglets gain significantly more weight than piglets kept with their dams for one (1.3 kg heavier, Table 2.24) or two more weeks (2.6 kg heavier, Table 2.24). The results of this study show that the piglets had the potential to grow quicker when they were away from the sow, than staying for one or two more weeks with her and fed exclusively on milk. These findings are re-enforced by the findings of Harrel *et al.*,

(1993) who states that the sow is not capable of producing vast amounts of milk that will fully satisfy the needs of the piglets and Martin (1984) identifies that this occurs after the eighth day of lactation. That was also illustrated in a regression analysis which showed that as the piglets remain longer with their mother to suckle her udder, this significantly, negatively, affected their LW at 6 weeks of age by 0.9 kg/week (Table 2.29). The fact that milk production was becoming a limiting resource for the piglets' increasing hunger (as they were growing older), is also re-enforced by the finding of the total amount of time that piglets spent in suckling their 'home' teat (Table 2.8). It was recorded that piglets during the fourth and fifth week of lactation spent significantly less time on suckling their 'home' teat in comparison with the total time recorded manipulating the sow's udder. Their willingness to invest more time on stimulating other parts of the udder, which were not suckled primarily by them, shows their increased need to get more milk in order to satisfy their hunger. So, instead of withdrawing from the udder after draining their share from it and concentrating their efforts on exploring other possible resources to satisfy their hunger (creep-feed, water or sow's feed), they showed a preference to suckle other teats that have been previously emptied from their littermates. It was suggested by Boe and Jensen (1995) that this is happening because the presence of the sow acts as a destractor to the piglets as they concentrate their efforts on stimulating the sow to suckle more frequently and provide more milk, instead of utilising other available resources (creep-feed and water) of nutrients to maximise their feed intake. This conclusion has also been demonstrated from the observational recordings of feeding and drinking behaviour of the piglets while they were at different stages of their pre-weaning life (Tables 2.8 and 2.11). It was recorded that the piglets had a constant low interest in creep feed during the fourth and fifth week of lactation as they were engaging only 0.2 to 0.3% of their total weekly time in feeding in relation to the already weaned 3W piglets which were committing 6.6% of their total weekly time in this behaviour.

The restricted milk production during the fourth and fifth week of lactation in combination with the limited feed and water intake as well as with the increased delay of weaning, led to significantly lower LWGs for piglets of 4W and 5W treatment during the period 3 to 6 weeks of age and subsequently to significant lower LWs at 6 weeks of age. This study shows that WW is not the only precursor of heavier LW of piglets' post-weaning. Other factors were also identified that could significantly influence the LW of the piglets at 6 weeks of age. It was shown that the superior pre-weaning LW of the piglets (Table 2.29) and more specifically those which were heavier at an age closer to that of weaning (e.g LW week 3), had significantly more chances to become heavier at 6 weeks of their life. The above results come to an agreement with the findings of McConnell *et al.*, (1987), Orihuela and Solano (1995) and Lawlor *et al.*, (2002) who observed that the heavier piglets at weaning can also be the heavier at slaughter.

2.4.2 Post-weaning feed intake and the importance of water.

Even though the piglets of the three treatments were not consuming significantly different amounts of feed during the first four days after weaning (Figure 2.18), on a weekly basis during the first week post-weaning, piglets of the two older weaning ages managed to consume significantly greater amounts of feed (Table 2.22) than 3W piglets. The above results suggest that piglets of the older weaning ages (4 and 5 weeks of age) were gastro-intestinally more mature in order to consume higher creep feed amounts post-weaning (Aumaitre 1972). 3W piglets were not only consuming significantly less amounts of feed during the first week post-weaning, but they were also spending significantly lower periods of time on feeding during the first two days post-weaning. It was suggested that a consequence of weaning at an early age (12 and 21 days of age) can cause a slight delay in the development of eating behaviour post-weaning (Gonyou *et al.*, 1998; Song and

McGlone 1998). This delay can also be the response of the more immature hindgut of the 3W piglets, which need extra time to develop and function due to its even more limited utility pre-weaning (Bolduan *et al.*, 1988) as opposed to that of 4W and 5W piglets, which had an extra one or two more weeks to adapt. For this reason it was suggested that the transition from a milk based – high fat diet to a cereal/soya diet should be gradual and progressive to allow time for the immature digestive tract to adapt (Fowler 1985b). According to the data in Table 2.19, 3W piglets needed one or two days more as a transition period in comparison with pigs on the 5W and 4W treatments respectively, in order to establish a feeding-drinking behavioural pattern which would have the same proportional characteristics to the average weekly performance of their first week post-weaning.

In many cases the piglets were described by their observers as having the 'knowledge' to decide what is best for them from a nutritional point of view (Kyriazakis *et al.*, 1990; Dalby *et al.*, 1995). The higher inclusions of water in the daily-weekly ration of the 3W and 4W piglets (lower feed:water ratio) during the first week post-weaning in relation to 5W piglets, can be described as a coping mechanism that was employed by them in order to ease the transition from feeding exclusively on milk pre-weaning to creep feed and water after weaning. This is in agreement with the earlier findings of Brooks *et al.*, (1984) who demonstrated that in the immediate post-weaning period, piglets consumed water rather than eating food. So, the feed:water ratio (Table 2.22) for 3W piglets (1:10) had to be highly significant lower than 4W (1:5) and 5W (1:3.3) piglets in order to cope with the abrupt change of weaning. A similar case was observed between piglets of 4W and 5W treatment. Also, the piglets were observed to be able to locate the drinkers more quickly than the feeders (Table 2.17) even though the feed was presented in a wide area from where its familiar essence (as it was the same feed during the pre- and post-weaning period) could attract them much quicker than the odourless and colourless water. Their effectiveness in locating the water resources makes them less vulnerable to dehydration (Gill 1989). According to the above observations it can be speculated that the piglets had a stronger drive to locate the water than the feed in a new environment, despite the fact that during the 3rd and 5th week of lactation, they were engaging in significantly longer periods of time in feeding than drinking (Table 2.10) if not equal (4th week).

Ravindram and Kornegay (1993) suggested that the post-weaning lag is a complex phenomenon and available evidence suggests that it may be related, in part, to the inability of the early weaned pig to secrete sufficient quantities of hydrochloric acid within the stomach and to cause optimal enzyme activation in order to achieve efficient digestion of the diets. The same authors' suggest that insufficient acid secretion, together with the stress of weaning, may also disturb the balance of the intestinal flora and allow the proliferation of coliforms resulting in scours and poor performance. The more efficient FCR levels (0.61) recorded on piglets weaned at three weeks of age in relation to 4W (1.21) and 5W (1.34) piglets, shows that their transition period, was more optimal from a feed absorption point of view, as lower feed intake levels during the first week post-weaning positively influenced the gastrointestinal tract to accept the radical change of the feed's form (from milk to creep feed), and the gastrointestinal tract of these piglets speculated to be in a non-unfavourable position as the villi length of the SI is directly proportional to the intensity of absorption of water and minerals (Miller and Skadhauge 1997). Also, the significantly higher proportions of water to feed levels that were calculated to be present in the stomach of the 3W piglets according to their feed and water intakes in relation to 4W and 5W treatment helped them to achieve an initial hydration and hydrolysis of the feed components (NRC. 1998) in their stomach for a more complete absorption of the nutrients. Some others could argue that high water intake levels were the result of increased incidences of diarrhoea, but in that case average DLWG and FCR levels should be depleted.

After the third day post-weaning, 3W piglets started spending more time at the feeders while consuming less feed. It can be concluded that piglets weaned at four and five weeks of age had either more frequent bouts or greater mouthfuls of feed than 3W piglets for the week post-weaning as they were consuming greater amounts of feed in shorter periods of time. Bigelow and Houpt (1988) observed that, higher frequency of feeding bouts was a characteristic of the older and more experienced pigs during the fattening period (10 to 30 kg LW) in comparison with newly weaned piglets. Also, Fowler and Gill (1989) state that the low level of feed intake is an effective defence strategy by the piglet to cope with its new circumstances and try to maintain physiological homeostasis. According to van Beers-Schreurs and Bruininx (2002) this action will also prohibit pathogenic bacteria passing the stomach and entering the small intestine. The longer periods of time that piglets of 3W treatment spent in order to consume significantly less amount of feed, could also be another defence mechanism against feed pathogens and feed malabsorption, as they provided the stomach with more time in proportion to feed intake levels, to secrete sufficient quantities of hydrochloric acid in order to digest the feed.

2.4.2.1 'Feeding for age'.

Even though 3W piglets appeared to need more time to adapt to feeding on creep-feed, a comparison of 'feeding for age' activities between the three treatments provides a new aspect to the interpretation of these results. 3W piglets had become 4 weeks old by the time they reached the seventh day post-weaning. At that stage, they were eating significantly more feed than piglets weaned at four or five weeks of age. The same observations were made for day 2 post-weaning. Piglets of the older ages needed four days in order to reach the feeding levels that they should have had for their age according to the performance of 3W piglets on day 7. Piglets of the older weaning ages were lacking the capacity to eat as much feed for their age as the 3W piglets. The initial extra week that 3W piglets had in order to acclimatise to weaning, makes them equivalent to the 'experienced' group of pigs described by Gonyou (1987) and Morgan *et al.*, (2001). The experience that they gained helped them not only to consume greater amounts of feed and water by the sixth week of their life but also to establish a stronger digestive system which enable them to obtain significantly higher LWGs (6.614 ± 0.346 kg; Table 2.24) from weaning (week 3) to the end of the experimental period (week 6) than 4W (5.343 ± 0.302 kg) and 5W piglets (3.985 ± 0.316 kg).

2.4.3 Suckling behaviour: which piglets suckle the most and when?

It has been shown by other scientists, that milk let-down occurs for only 20 seconds every hour (Fraser, 1980). Pre- and post-massaging of a specific part of the udder by a piglet occurs in order to stimulate the manipulated teat and exercise the local muscle, so an increase of milk production could occur locally in the following active sucklings. It was decided to compare the suckling behaviour that occurred in the week pre-weaning between the three treatments as an expression of total teat manipulation, because this value could reveal the personal investment of the piglets to the teat and show how much they depend on this resource.

It was calculated for piglets on 3W and 4W treatment that the biggest proportion of the observed sucking duration was spent manipulating their 'home' teat (90.6 and 83% respectively). In both treatments, the heaviest piglets of the litters spent more time manipulating the udder. This action was reported to stimulate the particular teat and increase the local milk production (Jensen *et al.*, 1998; Bruckmeier 2001). Spinka and Algers (1995) reported that young animals in lower condition begged more and in response parents provided more food in response to increased begging. In contrast to Spinka and Algers's (1995) theory, this study shows that the heavy piglets of the litters, which were suckling the anterior and more productive teats of the udder, spent larger periods of time on begging behaviour than piglets of the medium and light weight classification. The difference between the findings of the two studies, from a methodology point of view, can probably be attributed to the fact that they were observing only the sucking incidences between 0900 and 1600 hours for the first three days of lactation. On the other hand, if the piglets that beg the most are those that are in poorer condition, and according to this study the heaviest piglets are these which fulfil their theory, then it can be concluded that the heavy piglets of the litters are those which suffer the most from the inadequate milk production of the sow during the 3rd and 4th week of lactation, as they were spending extra time stimulating the udder in order to produce more milk in the following milk let-downs. Exactly the opposite pattern was found during week 5 of lactation, as smaller piglets invested more time in begging behaviour than piglets of medium and large size. The udder at this time was not occupied that often by the heavier piglets (heavy and medium size) as they were more keen to spend their time on feeding and drinking activities. So, the lighter piglets had the opportunity to suckle any part of the udder as much as possible with the hope of getting more milk. They managed to increase their LWG in comparison to the previous week gains, as they were probably drinking the share of the MTS-piglets, which had reduced sucking durations and reduced LWG. The MTS-piglets had extended periods of pre-weaning feeding behaviour, which paid off later as they performed significantly better during the first day after-weaning, as they had longer feeding duration activities than piglets sucking other parts of the udder.

2.4.4 The effect of weaning age on post-weaning stress.

Early weaning may increase aberrant behaviours such as belly nosing and flank biting, which can be important indicators of stress (Metz and Gonyou 1990; Boe 1993). This study shows that piglets weaned at 4 weeks of age were more vulnerable to the weaning procedure as they expressed significantly more fighting, chewing and belly-nosing behaviours than piglets weaned at three and five weeks of age respectively. Piglets perform behaviours such as rooting, biting objects, chewing, sniffing at substrate and walking/standing during the first days post partum and their combination with the manipulation of the udder, are the activities that are performed more frequently by free-range domestic pigs during the first 4 weeks of their life and it is assumed that piglets familiarise themselves with their surrounding during this period (Petersen 1994). So, the longer periods of time spent by 4W piglets during the post-weaning week shows that these piglets require more time to familiarise themselves with a new environment, in which they were away from the sow's udder and had to feed exclusively on creep feed and water.

2.4.5.1 The case of belly nosing.

It was observed that during the post-weaning period, 4W piglets were performing significantly more belly nosing than 3W and 5W piglets. In order to understand the difference in the expression of this behaviour, the pre-weaning activities of the piglets have to be considered. Belly-nosing involves the repetitive rooting behaviour on the belly of another piglet, similar to massaging the sow's udder (Fraser 1978), and can result in the development of lesions on the recipient piglet. Because this behaviour pattern resembles massaging the udder and sucking, it may be associated with hunger. Approximately 3 weeks after farrowing, milk yield of sows becomes insufficient to support maximal pig weight gain (Zijlstra *et al.*, 1996). Piglets weaned at three weeks of age, left the sow at a point that she was at the peak of the milk supply curve (Whittemore 1998) and the piglets had higher energy reserves for their age during the first days post-weaning as they had not significantly different WWs than piglets weaned at four and five weeks of age (Table 2.7). So, it can be assumed that 3W piglets were more satisfied sucking the udder in the week pre-weaning, as they had drunk, proportionally to their body-weight, more milk than 4W and 5W piglets. At 3 weeks of age, piglets were observed to have established a feeding behaviour pattern similar to that observed on weeks 4 and 5 of lactation. At the same time, fighting behaviour was at its peak, and it is proposed that this resulted from the introduction of the feeders and the access to the feeding resources due to the positive correlation between feeding and fighting (Figure 2.10). So, it was interpreted that 3W piglets did not express an enormous burst of belly-nosing behaviour during the week post-weaning for the following reasons:

i) they achieved satiety from sucking milk during the pre-weaning period as they were observed to have a consistency on suckling their 'home' teat,

ii) they had developed an interest on creep feed pre-weaning, which was still at its peak around weaning,

iii) they had probably re-established a rank order after the introduction of the feeders, which was chronologically very close to weaning date, and that could help them to be more settled and less competitive for the resources even though there were plenty of spaces at the feeder for all the piglets to feed simultaneously and avoid conflicts (Hughes 1976),

iv) they were including, on average, significantly greater amounts of water in their daily ration during the post-weaning week which helped them to achieve some sense of satiety, as their feed intake was low (Maenz *et al.*, 1994) and also

v) they were gaining more weight than piglets that had to remain with their sow for another week, as that shows their successive adaptation to the new feeding and drinking resources.

For all the above reasons, it can be speculated that 3W piglets were less stressed and managed to adapt more easily to their new post-weaning environment and perform less belly nosing on their pen-mates as a sign of their discomfort (Metz and Gonyou 1990; Boe 1993).

On the other hand, piglets weaned at four weeks of age, spent the same amount of time at the udder in the week pre-weaning as 3W piglets, having to drink though less amount of milk (Martin 1984; Harrel *et al.*, 1993), as milk production had already decreased even more after the 3rd week of lactation (Whittemore 1998) and for this reason they had to suckle for significantly more time the teats of the udder that were not occupied earlier by them. Even though they had greater nutritional requirements for their age, which could not be satisfied from milk, they were not using the feeders for longer according to their needs. The fact that i) they did not reach satiety from milk intake pre-weaning, hence they were extensively hungry from the pre-weaning period, ii) they were not visiting more often the feeder neither increased their presence at the feeders in relation to the previous week's performance (Table 2.11) and iii) the fact that belly nosing was found to be highly correlated with diminished suckling behaviour and teat order (PTS-piglets, hence less milk intake (Pluske and Williams 1996b); see Figure 2.11); led them to carry through the belly-nosing behaviour as a replacement of the suckling behaviour (Gardner *et al.*, 2001). This was instinctively used in order to satisfy their hunger pre-weaning: stimulate the udder of the sow, suckle the milk and fulfil their hunger and thirst.

5W piglets, during the fifth week of lactation were suckling the sow less often and for shorter periods of time than during a week earlier. They had to do so, because the sow was becoming less willing to lay down and expose her udder to the litter, and also at the same time the piglets were experiencing the milk supply becoming limited for their increased needs and they had to go through extensive fights in order to keep suckling, as the competition at the udder was becoming stronger due to the break down of the teat-order. This process helped them to become less dependent on the sow's udder in a way which was more of a natural progression and less of an abrupt change. Also, 5W piglets did not express as much belly-nosing as 4W piglets after weaning, because instead of belly nosing, PTS-piglets (which have been shown to be more susceptible to the vice) had the chance to compensate for the previous weeks' depressed suckling duration by manipulating the sow's udder for longer (Table 2.8, 'light' piglets, that according to Table 2.9 are more likely to suckle the posterior teats) in comparison to the their littermates. In this way, they had depressed their 'drive' to suckle their pen-mates post-weaning as they had become more familiar with the creep feed and water; which is shown by the longer periods of time that they spent on feeding and drinking during the first day after weaning (Figure 2.12). Their extensive pre-weaning feeding and drinking behaviour is identified to be an important factor in their ability to adapt to the post-weaning environment (Cox and Cooper 2000) because domestic pigs have well-developed spatial memory abilities (Mendl *et al.*, 1997) which would be of value to pigs in a number of contexts including relocating feed (Wood-Gush *et al.*, 1990).

Also the significantly lower fighting behaviour observed during the 5th week of lactation on comparison to the 4th week, suggests that it could be the result of a more stable social hierarchy (Worobec and Duncan 1997) formed after prolonging weaning for another week (4W *vs.* 5W).

This study shows that weaning at an early age (3 weeks instead of four weeks) does not stimulate piglets to perform more belly nosing as previously stated by Dybkjaer (1992). Also, Amaral *et al.*, (2003) identified that factors such as weaning weight lower than 6.3 kg and unfamiliarity with post-weaning drinkers to those been available pre-weaning could amplify the behaviour of belly nosing post-weaning. The factors mentioned above were shown not to have influenced the performance of belly nosing as 2/3 of the 3W population were below that weight (Table 2.7), and even though the post-weaning drinkers were not familiar to piglets of all treatments, 4W piglets (which scored the most incidences of belly nosing) managed to locate them more quickly than 3W piglets which needed more time.

The results of this study are in agreement with the findings of other authors (Gonyou *et al.*, 1998; Worobec *et al.*, 1999; Orgeur *et al.*, 2001) who observed the onset of belly nosing to coincide with the establishment of feeding behaviour. The difference between this study and the findings of the other workers is that the establishment of feeding behaviour for 4W piglets observed to take place on the second day post-weaning and not on the fourth, as they suggested.

2.5 Conclusion

This study showed that piglets of 3, 4 and 5 weeks of age have the potential to grow faster when removed from the sow. Piglets weaned at 3 weeks of age had the ability to grow faster and became significantly heavier at six weeks of age than piglets that had to extend their stay for one or two more weeks with the sow. It was identified that from the 3W piglets those which favoured the most to perform closer to their growth potential were the medium and light weight piglets of the litter. It has been identified that the depressed growth rates were due to the limited resources of milk provided by the sow after the third week of lactation and the voluntary neglecting of creep feed and water by the piglets, as they were trying to increase the teat-productivity with extended periods of non-nutritive sucklings. Finally, piglets weaned at four weeks (4W) of age had the greatest difficulty adapting to their new environment in comparison to 3W and 5W piglets, as they had greater scores on aggressive and abnormal behaviour (fighting, chewing and belly-nosing) during the week post-weaning. This increased difficulty in adapting to the post-weaning environment in combination with the reduced presence of the PTS-piglets at the udder, led them to carry through the belly-nosing behaviour in order to satiate their depressed pre-weaning udder manipulation.

Chapter 3

The effect of feeder familiarity on post-weaning feeding behaviour and immune response in pigs weaned at 4 weeks of age.

The protocols for all animal experiments were approved by the University of Plymouth Animal Ethics Committee.

3.1 Introduction

Weaning can be a traumatic event for pigs as it involves changes in diet and in the social and physical environment (Fraser *et al.*, 1998). Increased stress in the post-weaning period is associated with a reduced immune capacity (Metz and Gonyou 1990). Feed intake is an important determinant of performance that may also reflect the health status of weanling pigs (Pluske and Williams 1996). In the recent past, problems of enteric diseases in weaned pigs have been overcome by the use of antibiotic growth promoters (AGP's) and mineral antimicrobials namely copper sulphate and zinc oxide (Wenk 2000). A major factor contributing to this problem of enteric disease is the disruption of feed intake post-weaning. Some pigs fail to eat for 24-56 h post-weaning and as a result are more vulnerable to enteric diseases (Brooks and Tsourgiannis, 2003). It is important to develop management strategies that will maintain continuity of feed intake following weaning.

In previous studies, it was identified that there were piglets that fail to sample the feed in the first 6-12 hours post-weaning, and that it took them 48 hours to establish a feeding pattern. All piglets that were involved in the previous experiment had been observed to visit the creep feeder while they were in the farrowing crate. Therefore, it is postulated that the presence of a familiar creep-feeder immediately after weaning, will increase the 'confidence' of the piglets to start sampling the feed quicker, minimise the 'feeding stasis', and hence, to establish a successful feeding pattern soon after weaning. Bruininx *et al.*, (2002) have shown that consumption of a high quality diet during the suckling period stimulates early post-weaning feed intake, and Phillips and Phillips (1999) observed that familiarity with the drinker minimised the time to the first drinking event. It is speculated that familiarity with the feed (Bruininx *et al.*, 2002) and the feeder will cause the weanling pig to focus more on feed intake and less on exploratory behaviour. All previous studies based their results on the average performance of the litter and did not distinguish how piglets that differed in size (large, medium and small) or had been suckling different teats (suckling the anterior, middle or posterior teats of the udder) performed post-weaning and how these differences in feeding behaviour and motivation could lead to a successful post-weaning feeding performance.

Weaning has been described as a very stressful period for piglets (Weary and Fraser 1997) and it may also adversely affect pig behaviour as it can lead to persistent belly nosing and chewing of penmates (Gonyou *et al.*, 1998). This kind of behaviour has been termed 'harmful social behaviour', as it can cause injury in conspecifics (Beattie *et al.*, 1995). In addition, it may lead to greater levels of restlessness and aggression within the groups of pigs (Fraser 1978). Social stress from mixing, fighting and crowding are some of the post-weaning factors that can trigger the release of cortisol, depressing the immune response to bacterial infection (Hopwood and Hampson 2003). It would be interesting to understand how *E.coli* bacteria counts are correlated with piglets' pre-weaning feeding behaviour pattern, and to obtain information about the relationship between the flourishing of these bacteria and the latency to first feed sampling, establishment of feeding pattern and growth performance at the end of the trial period. Barnett *et al.*, (1989) and other scientists (Pluske *et al.*, 1996a; Pluske *et al.*, 1996b) described the effect that pre- and/or post-weaning feeding behaviour has on the gut health of the piglet, but there are no studies which describe how the gut health of individual piglets in a litter (with respect to their LW or teat-suckling orientation), is affected by their pre-weaning feeding experience and their post-weaning motivation.

The aim of this study was to examine how the familiarity that the piglets gained with the feeder during the pre-weaning period can affect the feeding behaviour post-weaning during the first week post-weaning.

The principal objectives of this study were to:

- Describe the pre- and post-weaning feeding behaviour of individual pigs weaned at 28 days of age.
- Examine the relationship between pre-weaning feeding behaviour and latency to first feed post-weaning and feeding behaviour during the first 7 days post-weaning with or without the influence of the familiar troughs, which had been provided during the pre-weaning period and 'transferred' with the piglets to the weaning accommodation.
- Obtain information on total feed intake and growth performance of pigs weaned at 4 weeks of age.
- Obtain information about the bacteria flourishing in the large intestine of the piglet during the first 24 and 72 hours after weaning (assessed by LAB: *E.coli* ratios), due to

limited feed intake and stress, and examine the differences between successful (piglets that were observed to spend more time feeding post-weaning) and not successful eaters at the end of the trial (7 days).

3.2 Materials and methods.

3.2.1. Experimental animals

The experiment took place on a commercial farm (Adrian Shute, Hallworthy), which was located in the NE of the County of Cornwall. The experiment was conducted according to a randomised block design, with two replicates and two treatments. The treatments were as follows:

i) all of the experimental litters had the opportunity to be fed from a feeder pre-weaning. The same feeder (FF) was carried with the piglets to the weaning accommodation in addition to the post-weaning trough (NF) which was already present in the pen, and

ii) the rest of the litters weaned into pens that were only provided with the post-weaning trough (non-familiar feeder: NF).

Sixteen sows of various parity numbers (Hermitage Seaborough, F1 Hybrid Gilt) and their litters (Hermitage Seaborough, F1 Hybrid Gilt crossed with Hermitage Seaborough, Hylean L.W. Boar) were used in the experiment. A replicate comprised eight litters weaned at 4 weeks of age which were selected randomly for pre- and post-weaning observations. From each litter, six piglets were selected (8 litters for each replicate, n=96 piglets). All the piglets in the litter were observed from the 21st day of their life until weaning at 28 days and for a week post-weaning. As the weight of piglets is often inversely related to their previous pre-weaning experience of feed (Algers *et al.*, 1990), the 2 heaviest (H), the 2 lightest (L) and the 2 piglets closest to the median (M) weight of the litter at weaning were selected to provide a uniform sized group for study in the post weaning period. The experiment was divided into two phases: i) farrowing and pre-weaning period and ii) post-weaning period.

3.2.2 First phase: farrowing and pre-weaning period

3.2.2.1 Sow's management and accommodation

In gestation, the sows were loose-housed in large groups and they were provided with deep-straw bedding, which was used as comfort material and a rooting substrate. The sows were moved to the farrowing crates ((0.60 x 2.45 m), total pen 2.31 x 2.45 m) 4 days prior to their anticipated delivery date (see Figure 3.1) and were given 2.5 kg DM of diet in a liquid form (1: 2.5 feed: water), twice daily.

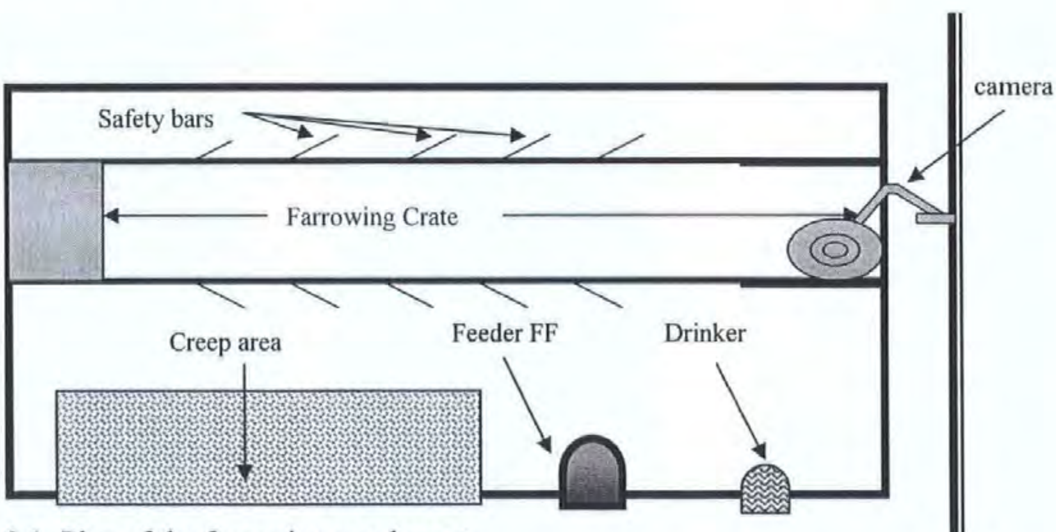


Figure 3.1 Plan of the farrowing pen layout.

The farrowing rooms were maintained at 20°C. A plastic heating mat, which was part of the pen's floor, was provided as a creep area and raised the temperature locally to about 30°C. The farrowing crates had a perforated floor and sows were provided with water *ad libitum* and were fed, twice daily, on a restricted feed ration (5 kg DM day^{-1}). The feed was formulated by the farm owner and had a specification designed to meet the nutritional requirements of the gestating and lactating gilts in order to maintain a good health status and vigour (diet specification in Table 3.1).

Table 3.1 Declared composition of the experimental diet for gilts (gestation/lactation).

Ingredient	Inclusion g kg^{-1} DM
Oil	54.5
Protein	175.8
Fibre	24.5
Ash	56
Lysine	10
Moisture	130
Copper	20.86 mg kg^{-1}
Sodium selenite-selenium	0.4 mg kg^{-1}
Vitamin A –retinol	10,000 iu
Vitamin D3 –cholecalciferol	2,000 iu
Vitamin E α-tocopherol	52.15 iu
Digestible energy (DE)	14.49 MJ kg^{-1}

3.2.2.2 Pre-weaning piglet's management

Piglets had their teeth and tails clipped and were given an iron injection at birth. The piglets were weighed at birth and every seven days until weaning. The piglets were weighed for last time during lactation one day before weaning in order to minimise the handling and stress on the piglets on the following day, when they had to be moved from the farm to the University's weaning accommodation. A high quality commercial creep feed (2mm Tuck Firstlite, Clark & Butcher Ltd, Lion Mills, Cambs) was provided *ad libitum* and the daily intake of the litter was recorded from the 14^{th} day of lactation (diet specification in Table 3.2). Feed was added twice daily (0900 and 1500 hours) in order to ensure that fresh feed was always present. Every afternoon, before the scheduled feeding at 1500 hours, the amount of feed present in the feeding trough was deducted from the total amount of feed that had been provided the previous day in order to keep a record of the amount of feed usage of the litter for that day. Water was also provided daily from bowl drinkers (Alvin piglet bowl drinker, Fisher Founderies Ltd., Birmingham) which were thoroughly cleaned every day. The location of the feeders and drinkers is shown in Figure 3.1. Weaning and transfer of the pigs to the weaning accommodation was completed at approximately 1500 hours.

Table 3.2 Declared composition of the experimental creep feed diet for piglets (2-6 weeks of age).

Ingredient	Inclusion g kg^{-1} DM
Oil	90
Protein	220
Fibre	22
Ash	55
Lysine	16.5
Moisture	138
Copper (copper sulphate)	160 mg kg^{-1}
Sodium selenite-selenium	0.20 mg kg^{-1}
Vitamin A –retinol	15,000 iu
Vitamin D3 –cholecalciferol	2,000 iu
Vitamin E α-tocopherol	250 iu
Digestible energy (DE)	16 MJ kg^{-1}

*Feed supplied by BOCM (2mm Startercare Easywean Pellet, BOCM Pauls Ltd, Ipswich)

3.2.3. Second phase: post-weaning period

On the day of weaning, the piglets had to be moved from the commercial farm, which was located in Hallworthy (NE of Cornwall), to Newton Abbot (Mid. Devon) at the University's experimental unit. The piglets were transferred in a specially modified horse box, which could accommodate 8 deep-straw bedded pens (equals the number of pens per replicate). Each litter (6 piglets), was penned individually. The transfer was completed within an hour.

3.2.3.1 The weaning accommodation

After weaning, the piglets were housed in an environmentally controlled, flatdeck weaner house, comprising 10 pens. The layout of the building is illustrated in Figure 3.2. Each pen was 1.44 x 1.25 m in floor area giving a space allocation of 0.30 m^2 per pig when stocked at six pigs per pen. The pen floor was totally perforated (Cumfideck, Big Pig, Deeside, Clwyd) and beneath each pen was a stainless steel effluent tank that could be emptied *via* a valve outside the building.

Weaning took place in the afternoon (1400 hours) in order to minimise stress (Ogunbameru *et al.,* 1992). Uniform replicates were formed as piglets were retained in groups with their littermates to avoid problems that might be caused by stocking density or group size and also avoiding any effects that could arise from mixing unfamiliar piglets confounding the behavioural observations. Four out of eight pens of the weaning accommodation were in addition equipped with the same design of feeder that the piglets had used while they were with the sow (pens 1, 2, 3 and 4 in Figure 3.2). In the second replicate, pens 5, 6, 7 and 8 (Figure 3.2) were fitted with the familiar feeder in order to balance for the 'pen effect'. Electric heaters were used to raise the temperature and a ventilator distributed the warm air evenly in the unit. A thermostat was also installed in order to keep the temperature of the weaning accommodation at the desirable levels (28°C). A min-max thermometer was used for the daily recordings of the temperature.

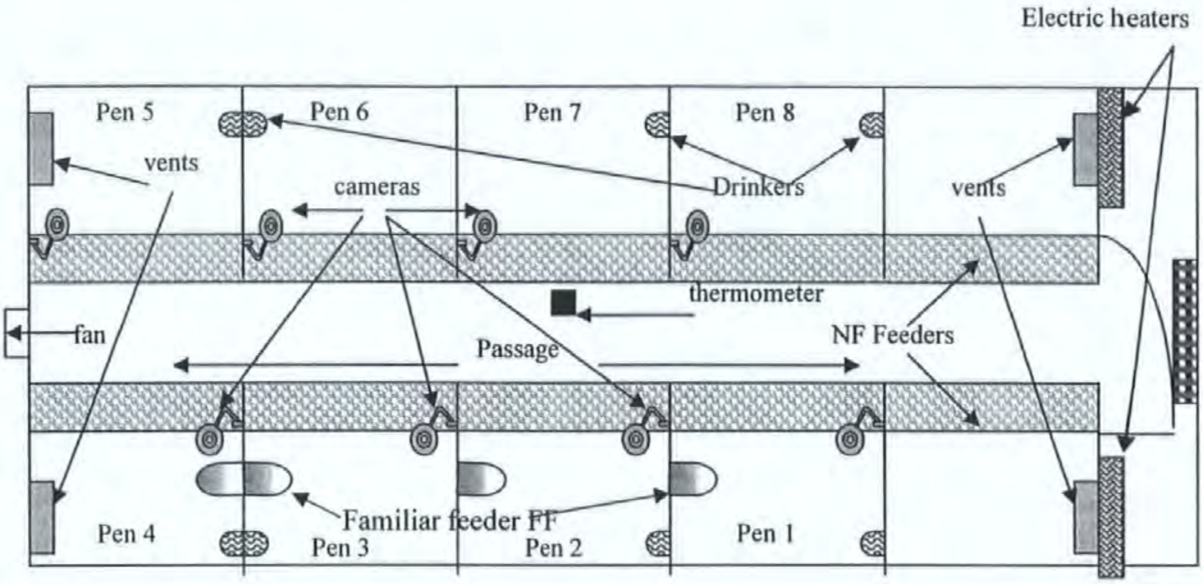


Figure 3.2 The flatdeck weaner accommodation.

3.2.3.2 Feeding and drinking management

The piglets were weighed at weaning and at 7 days post-weaning in order to minimise stress as much as possible. Following weaning, the piglets were offered, *ad libitum,* the diet on which they were fed pre-weaning. The feed continued to be provided according to the pre-weaning time-table (0900 and 1500 hours) in order not to disturb the feeding patterns that might have been established during the lactation period and also, not to influence their behaviour as anticipation of feeding routines could have a considerable negative impact on their behaviour (Waitt and Buchanan-Smith 2001). Adequate feed was given in the afternoon and additional feed was also provided the following morning in order to ensure the *ad libitum* status of the study and to avoid the sight of an empty feeder, which could discourage the piglets from eating. The feed was supplied in pelleted form in the familiar feeder (50% of the pens) and in a trough (all pens) that would enable all 6 pigs of the group to feed simultaneously (in order to minimise agonistic behaviour at the feeders). The feed usage was estimated daily at 1500 hours after thoroughly cleaning the feeding troughs and providing the piglets with fresh feed.

Each pen was provided with water from a bowl drinker (Alvin piglet bowl drinker, Fisher Founderies Ltd., Birmingham) positioned 20 cm above the floor, and supplied from a low pressure break tank system (ZercH_2Opipe, Carbro Consultants, Newton Abbot, Devon). The water delivery rate from the drinkers was adjusted to exceed 450 cm^3 min^{-1} as a flow rate below this has been shown to adversely affect the performance of weaner pigs (Barber 1992). Water intake was recorded using turbine flow water meters (PSM-L, Kent Meters, Luton, Bedfordshire) at 1500 hours daily after thoroughly cleaning the bowls and calculating in all cases the amount of water used for this action. The pigs were kept in the weaner accommodation until the 6th week of their life (35d).

3.2.4 Assessment of gut health.

The effect of the familiar feeder on the duration of 'feeding stasis' (from weaning until first successful sampling of feed) and on the establishment of a feeding pattern after weaning was determined from recordings of physical data (feed and water intake) and behavioural observations. In addition, gut health was assessed from rectal swabs. Rectal swabs were taken from all the experimental animals on the following dates: one day before weaning (while the piglets were in a familiar environment with their mother), 1 and 3 days post weaning and at the end of the trial (7 days post weaning). This sampling method was applied in order to provide a better view of the potential pathogens that were already present in the piglets' intestines (*E.coli*) and record how populations changed in relation to the piglets' feeding pattern. Maclean and Thomas (1974) have reported that *E.coli* counts increase in animals that are under stress.

The representative samples were serially diluted 10-fold in Maximum Recovery Diluent (MRD; 1 ml sample in 9 ml MRD). Relevant dilutions were plated out on selective media and plates were incubated at the recommended temperature. Namely, *Coliforms* were enumerated on VRBA agar using double-layered pour-plate technique and incubated aerobically for 24 hours at 37^{o}C. Lactic acid bacteria were enumerated on Rogosa agar and incubated anaerobically for 72 hours at 30^{o}C. All selective media used were obtained from Oxoid, Basingstoke, UK.

The ratio of Lactobacilli-*E.coli* was recorded in all cases in order to evaluate the gut health of the piglets. Reid and Hillman (1999) proposed that an assessment of a pig's capacity to resist pathogens could be based on the faecal ratio of lactobacilli:coliforms in the gut contents, since lactic-acid bacteria are known to inhibit the growth of enteroroxigenic *E.coli* (Hillman *et al.*, 1995). Reid and Hillman (1999) reported that although it could be argued that faecal populations and numbers do not represent those present in the small intestine (SI), where *E.coli* attach and causes disease, a larger population of lactic-acid bacteria relative to coliforms provides some indication that enhanced numbers of those strains that are capable of inhibiting coliforms, including pathogens, might be present.

3.2.5 Behavioural observations during the pre- and post-weaning period.

From the 14^{th} day of lactation, all the piglets in the litter were identified by means of a unique combination of coloured stripes on their backs. The piglets were monitored, using a time-lapse video recording device (VCR, Panasonic Time lapse video cassette recorder, AG-6730), 24 hours a day, from the 21^{st} day of lactation until weaning. Each camera (Sanyo VCC 6572) was fitted to the ceiling of the building, in order to get a panoramic view of the pen. The cameras were fitted with colour lenses in order to make it possible to distinguish the piglets of each litter, as a combination of different colours (Net Ex, Perkins Ltd, Ottery St Mary) was used on their backs (red, blue green and yellow stripes in three arrangements for each of the colours used: I, II and III stripes). A colour quad splitter (Panasonic Digital Field Switcher, WJ-FS20) had the ability to handle the signal of four different cameras, which were attached onto it and to record the four signals on a single tape through the VCR (see Figure 3.3). A videotape (S-VHS) was used for the recording of a 24 hour period and was replaced daily approximately at 1600 hours. Once the selection has been made at weaning, the feeding behaviour of the chosen piglets (n=96) was analysed from the videotapes using the *Observer 5.0* (Noldus, Tracksys Ltd, Nottingham) software. The piglets were also observed for suckling, fighting and drinking behaviour during the course of the day (see Table 3.3). Observations were also made for the teat preference of individual piglets e.g. if they were suckling the anterior (ATS), middle (MTS) or the posterior (PTS) teats of the sow's udder (see Plate 3.1). At the end of the pre-weaning period, each litter was observed for 168 hours (x 16 litters = 2,688 hours total observation time).

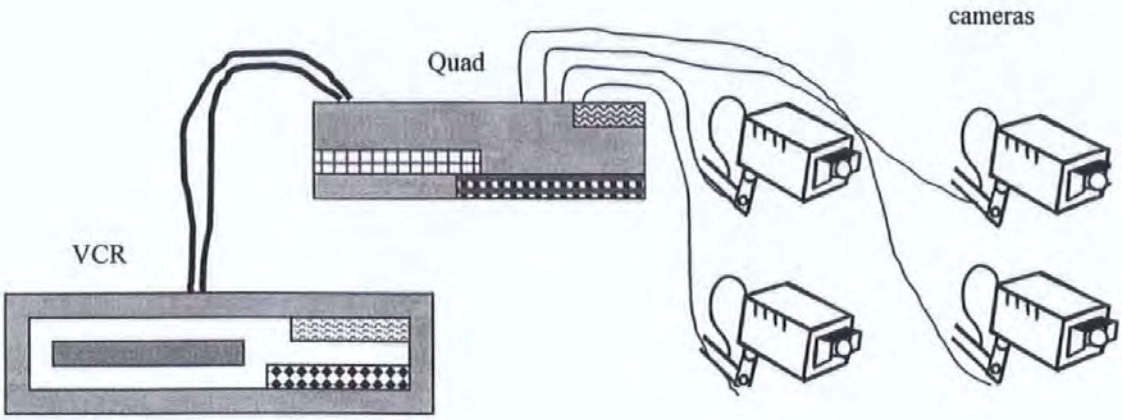


Figure 3.3 Representation of the hardware arrangement for the video recordings.

Table 3.3 Ethogram used for the identification of various pre-weaning behaviours.

Behaviour	Description
sucking	Focal pig had a teat in its mouth and performed a suckle
teat order	A teat characterised as anterior – middle – posterior, by its position on the sow's udder (it has been divided into three parts at proximity, Plate 3.1)
eating	Focal pig's head was in the feeder trough, and was in contact with the feed (Plate 3.2)
drinking	Focal pig's head was in the water bowl, and was in contact with the water (Plate 3.3)
fighting	Two or more pigs came to a violent contact to each other performing biting behaviour, or continuous displacement of their opponent (Plate 3.4). The location where the contact was initiated was also made: at the udder (while one of the actors was suckling), at the feeder (while one of the piglets was eating), and playing (at any other part of the farrowing pen).

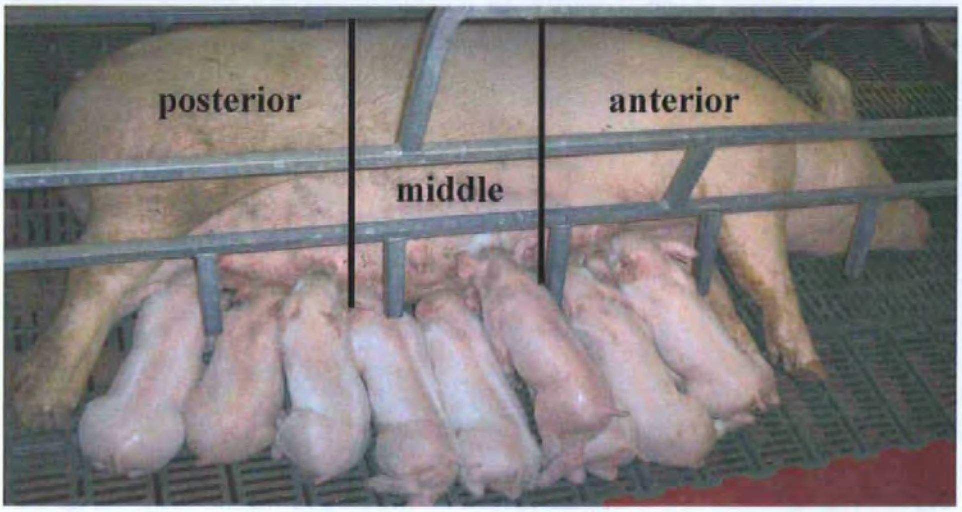


Plate 3.1 The teat-order identification on the sow's udder.

Plate 3.2 Illustration of pre-weaning feeding behaviour.

Plate 3.3 Illustration of pre-weaning drinking behaviour.

Plate 3.4 Illustration of pre-weaning fighting behaviour.

Weaning was completed by 1500 hours on the 28th day of their life. The cameras in the weaning accommodation had been set to recording mode before the piglets were moved into the pens, in order to make it possible later to estimate the latency to sample feed for first time for each piglet ('feeding stasis'). The piglets were re-marked at weaning with their individual colour stripes, in order to be identifiable clearly through the monitor in future observations of their behaviour. For the first day after weaning, the amount of feed offered to the piglets was pre-measured and it was given immediately after the introduction of each group into the pen (time 0). The procedure was necessary in order to ensure a more accurate calculation of the 'feeding stasis'. All piglets were re-marked daily so that an equal amount of handling was applied to all piglets on all treatments. The pigs were observed for the first 7 days post weaning (168 hours each pen x 16 pens = 2,688 hours total observational time). The behaviours that were recorded and the way that they were defined are presented in Table 3.4.

Table 3.4 Ethogram used for the identification of various post-weaning behaviours.

Behaviour	Description
feeding	Focal pig's head was in the feeder (Plate 3.5) or the familiar trough (Plate 3.6), and was in contact with feed. The piglets were also observed while they were feeding alone or in the presence of one or more of their penmates
drinking	Focal pig's head was in the drinker, and was in contact with the water (Plate 3.7). The piglets were also observed while they were drinking alone or in the presence of one or more of their penmates
belly nosing	Focal pig rubbing its nose in a rhythmic pattern on the belly (abdomen) of another pig. This behaviour identified in both states: active (sucking a piglet) and passive (sucked by a piglet)
fighting	Two or more pigs come to a violent contact performing biting behaviour or continuous displacement of their opponent
chewing	Focal pig manipulating the chain which were hanging from a pen-wall or chewing the boundaries of the pen (Plate 3.8)

Plate 3.5 Illustration of post-weaning feeding behaviour (from the NF feeder).

Plate 3.6 Illustration of post-weaning feeding behaviour (familiar feeder FF).

Plate 3.7 Illustration of post-weaning drinking behaviour.

Plate 3.8 Illustration of post-weaning chewing behaviour.

3.2.5.1 Observing the behaviours and logging them in through the Observer 5.0 software

The behavioural analysis took place at the very end of the experimental period and different actions were logged into the software while observing through a monitor the pre-recorded video tapes. The video player was linked to the PC so that after an observation was logged into the software the attached time code of each recorded activity could help the observer to identify the exact time an action took place. A colour-monitor (Panasonic video monitor, WV-CM11450/B), which was connected to the video, was used for behavioural observations of the piglets (Figure 3.4). Each tape contained the recordings of four different cameras (or pens). The splitter enabled the operator to 'switch' between the pre-recorded pictures from the four cameras and it made possible to observe one pen at a time. Any of the behaviours (Table 3.3 and 3.4) was determined from the moment a pig was observed to perform an action until the moment it stopped performing it for more than 5 seconds (simplifying the observation procedure as there was a chance for the piglet to come back and continue), or had started another behaviour. In any of these incidences, the videotape was paused, the behaviour was recorded to the program (typed in the Observer software spreadsheet), and then the tape was resumed for further behavioural observations.

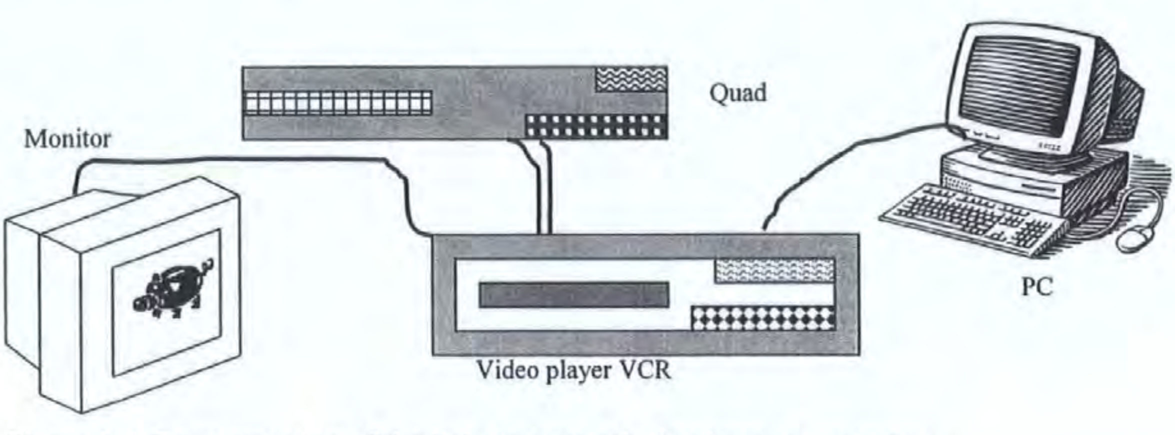


Figure 3.4 Representation of the links between the hardware components.

3.2.6 Animal growth performance

The piglets were weighed on day 1 post-partum and then subsequently every 7 days in order to calculate individual weekly live-weigh gain. The piglets were weighed again one day before weaning, and then after 7 days at 35 days of age.

3.1.1 Statistical analysis

The data analysis divided into two phases: a) pre-weaning and b) post weaning behaviour and performance.

For the pre-weaning period the following recordings were analysed:

i) Differences in suckling behaviour

ii) Feeding and drinking behaviour

iii) Piglets' aggressiveness during the week pre-weaning

iv) Daily live-weight gain (DLWG) performance and

v) Gut health response (faecal Lactobacilli *: E.coli* ratio)

The effect of body-size (heavy, medium, light piglets in the litter) and teat-order (ATS, MTS and PTS) classification of the piglets was also considered in the analysis in order to identify differences on the expression of the above behaviours between and within treatments.

For the post-weaning period the following recordings were analysed:

i) Feeding and drinking behaviour

ii) Belly-nosing behaviour

iii) Piglet aggressiveness during the week post-weaning

iv) The effect of pre-weaning feeding and drinking behaviour on post-weaning performance

v) DLWG performance and

vi) Gut health response (faecal Lactobacilli : *E.coli*- ratio)

All the statistical analysis was carried out in Minitab v. 13 for Windows (Minitab Inc., Pennsylvania, USA, 2000). All the statistical tests which have been employed for the analysis of the pre- and post-weaning behavioural and growth performance data are presented in Table 3.5. The data are tabulated in the sequence they are presented in the Results section.

Table 3.5 Statistical tests used for the analysis of pre- and post-weaning data.

Comparison	Data transformation applied	Covariates	Test used
Statistical analysis of biological performance data			
WW and DLWG *vs.* LW-classification and teat-order			GLM-Anova[a]
Post-weaning DLWG and LW *vs.* treatments*teat-order*classification		BW, WW LS, sex	Factorial analysis
Post-weaning DLWG , LW *vs.* teat order			GLM-Anova[a]
Post-weaning DLWG and LW *vs.* treatments, teat-order, classification, LS, WW, BW, total pre-weaning feeding-drinking-suckling-fighting behaviour, total post-weaning feeding-drinking-belly-nosing-chewing-fighting behaviours			Multiple Regression analysis[d]
Post-weaning DLWG, FCR *vs.* treatments		BW, WW	GLM-Anova[a]
Post-weaning DLWG , LW *vs.* classification			GLM-Anova[a]
DLWG at week 4 *vs.* DLWG at week 5 (within treatments)			T-test
DLWG and LW at 4 and 5 weeks of age *vs.* teat-order, LW-classification			GLM-Anova[a]
Daily feed intake *vs.* day			Linear Regression[d]

Daily water and feed intake from day one to day 7 post-weaning *vs.* day post-weaning		treatment	GLM-Anova[ax]
Daily water and feed intake *vs.* treatments		BW, WW, LS	GLM-Anova[a]
Daily feed:water ratio *vs.* treatments			GLM-Anova[a]
Pre-weaning statistical analysis of behavioural measurements			
Teat suckling preference *vs.* LW classification			Cross-tabulation[c]
Daily suckling duration *vs.* LW-classification		LW at 3 weeks, LWG on week 2, parity number of the sow, number of piglets	GLM-Anova[a]
Daily suckling duration *vs.* teat-order		LW at 3 weeks, LWG on week 2, parity number of the sow, number of piglets	GLM-Anova[a]
Weekly suckling duration *vs.* LW-classification			Kruskal-Wallis[e]
Weekly suckling duration *vs.* teat-order			Kruskal-Wallis[e]
Weekly feeding, drinking and fighting duration *vs.* teat order, LW classification, teat order*LW classification			Factorial Analysis
Daily drinking and fighting duration *vs.* LW-classification	Square root or $\log_{10}$ respectively[b]		GLM-Anova[a]

Daily feeding and fighting duration *vs.* teat-order	Square root and log_{10} respectively[b]		GLM-Anova[a]
Weekly feeding and drinking duration *vs.* LW-classification			GLM-Anova[a]
Weekly feeding and drinking duration *vs.* teat-order			GLM-Anova[a]
Weekly fighting duration *vs.* LW-classification	log_{10}[b]		GLM-Anova[a]
Weekly fighting duration *vs.* teat-order	log_{10}[b]		GLM-Anova[a]
Weekly LWG *vs.* teat-order			GLM-Anova[a]
LW classification change: Birth *vs.* weaning			Cross-tabulation[c]
Post-weaning statistical analysis of behavioural measurements			
Feeding stasis *vs.* treatment, LW classification, teat order		Total pre-weaning feeding, drinking, suckling and fighting duration, WW, sex	Factorial analysis
Feeding stasis *vs.* total pre-weaning feeding, drinking and suckling duration (within treatment)			Correlation
Feeding stasis *vs.* one day before weaning feeding, drinking and suckling duration (within treatment)			Correlation
Feeding stasis *vs.* LW classification (within and between treatments)			Kruskal-Wallis[c]

Feeding stasis *vs.* teat order (within and between treatments)			Kruskal-Wallis[e]
Total post-weaning feeding duration *vs.* treatment, LW classification, teat order		Total pre-weaning feeding, drinking, suckling and fighting duration, WW, sex	Factorial analysis
Day 1-5 post-weaning feeding duration *vs.* treatment, LW classification, teat order		Total pre-weaning feeding, drinking, suckling and fighting duration, WW, sex	Factorial analysis
Daily total feeding duration *vs.* treatments			Kruskal-Wallis[e]
Daily feeding duration from the unfamiliar trough *vs.* treatments			Kruskal-Wallis[e]
Daily feeding duration *vs.* total pre-weaning feeding, drinking and suckling duration (within treatments)			Correlation
Daily feeding duration (days 1, 2 and 3) *vs.* 1 day pre-weaning feeding, drinking and suckling duration (within treatments)			Correlation
Daily feeding duration (days 1, 2 and 3) from the familiar feeder *vs.* total pre-weaning feeding, drinking and suckling duration (within treatments)			Correlation
Daily feeding duration (days 1, 2 and 3) from the unfamiliar feeder *vs.* 1 day pre-weaning feeding, drinking and suckling duration (within treatments)			Correlation

Time spent feeding alone *vs.* treatment	Square root[b]		GLM-Anova[a]
'Social' feeding (not alone) *vs.* treatment	Square root[b]		GLM-Anova[a]
Time spent feeding alone *vs.* 'Social' feeding (within treatments)			Mann-Whitney
Time spent feeding alone *vs.* teat-order (within and between treatments)			Kruskal-Wallis[c]
Daily drinking duration *vs.* LW classification (within and between treatments)		WW, total pre-weaning feeding and suckling duration	GLM-Anova[a]
Daily drinking duration *vs.* teat-order (within and between treatments)		WW, total pre-weaning feeding and suckling duration	GLM-Anova[a]
Total post-weaning drinking duration *vs.* treatment, LW classification, teat order	square root[b]	Total pre-weaning feeding, drinking, suckling and fighting duration, WW, sex	Factorial analysis
Day 1-5 post-weaning drinking duration *vs.* treatment, LW classification, teat order	Log_{10}[b]	Total pre-weaning feeding, drinking, suckling and fighting duration, WW, sex	Factorial analysis
Daily drinking duration *vs.* treatments	Log_{10}[b]	Total pre-weaning feeding, drinking, suckling and fighting duration, WW, sex	GLM-Anova[a]

Day 2 drinking duration *vs.* LW classification*teat-order	Log_{10}[b]	Total pre-weaning feeding, drinking, suckling and fighting duration, WW	GLM-Anova[a]
Daily drinking duration *vs.* daily feeding duration (within treatments)	Log_{10}[b]		Correlation
Daily drinking duration *vs.* total pre-weaning feeding, drinking and suckling duration (within treatments)	Log_{10}, square root[b]		Correlation
Daily drinking duration (days 1, 2 and 3) *vs.* 1 day pre-weaning feeding, drinking and suckling duration (within treatments)	Log_{10}, square root[b]		Correlation
Daily drinking duration *vs.* LW classification (within treatments)	Log_{10}[b]	WW, total pre-weaning drinking and feeding duration	GLM-Anova[a]
Time spent drinking alone *vs.* treatment			Kruskal-Wallis[c]
'Social' drinking (not alone) *vs.* treatment			Kruskal-Wallis[c]
Time spent drinking alone *vs.* 'Social' drinking (within treatments)			Mann-Whitney
Time spent feeding alone *vs.* teat-order (within and between treatments)			Kruskal-Wallis[c]
Daily fighting, chewing and belly-nosing duration *vs.* treatments			Kruskal-Wallis[c]

Daily fighting, chewing and belly-nosing duration *vs.* total pre-weaning feeding, drinking and suckling duration (within treatment)	Log_{10}, square root[b]		Spearman rank correlation
Daily drinking, feeding, fighting, chewing and belly-nosing duration *vs.* daily drinking, feeding, fighting, chewing and belly-nosing duration (within treatment)	Log_{10}, square root[b]		Spearman rank correlation
Daily fighting duration *vs.* LW-classification (NF treatment)		WW	GLM-Anova[a]
Daily fighting duration *vs.* LW-classification (FF treatment)			Kruskal-Wallis[e]
Daily chewing and belly-nosing duration *vs.* LW classification (within treatments)			Kruskal-Wallis[e]
Daily fighting and belly-nosing *vs.* teat-order (within treatments)			Kruskal-Wallis[e]
Daily chewing duration *vs.* teat order (NF treatment)		WW, total pre-weaning fighting duration	GLM-Anova[a]
Daily chewing duration *vs.* teat order (FF treatment)			Kruskal-Wallis[e]
Daily fighting, chewing and belly-nosing duration *vs.* LW classification (between treatments)			Kruskal-Wallis[e]
Daily fighting and belly-nosing duration *vs.* teat-order (between treatments)			Kruskal-Wallis[e]
Daily chewing duration *vs.* teat-order (between treatments)			GLM-Anova[a]

Post-weaning behavioural durations *vs.* pre-weaning behavioural durations	Log_{10}, square root[b]		Spearman rank correlation
Post-weaning behavioural durations *vs.* post-weaning behavioural durations	Log_{10}, square root[b]		Spearman rank correlation
Post-weaning behaviours during different post-weaning periods *vs.* BW, LW week1 to week4, LWG week1 to week4, teat-order	Log_{10}, square root[b]		Spearman rank correlation
Monitoring of gut adaptation			
Pre-weaning faecal lactobacilli: E.coli ratios *vs.* LW-classification			Kruskal-Wallis[e]
Pre-weaning faecal lactobacilli: E.coli ratios *vs.* teat-order			Kruskal-Wallis[e]
Faecal lactobacilli:*E.coli* ratio difference day 1-weaning *vs.* treatments, teat-order, classification	Log_{10}, square root[b]	LS, BS, WW, day 1 post-weaning fighting-chewing-drinking-feeding-belly nosing duration, pre-weaning drinking-feeding-fighting-suckling duration	Factorial analysis

Faecal lactobacilli:*E.coli* ratio difference day 1-weaning *vs.* treatments, teat-order, classification, LS, BS, WW, day 1 post-weaning fighting-chewing-drinking-feeding-belly nosing duration, pre-weaning drinking-feeding-fighting-suckling duration	Log_{10}, square root[b]		Multiple Regression analysis[d]
Faecal lactobacilli:*E.coli* ratio difference day 1-weaning *vs.* treatments	Log_{10},	Post-weaning day1 drinking duration, teat-order	GLM-Anova[a]
Faecal lactobacilli:*E.coli* ratio difference day 3-day1 *vs.* treatments, teat-order, classification	Log_{10}, square root[b]	LS, BS, WW, sum day1-3 post-weaning fighting-chewing-drinking-feeding-belly nosing duration, pre-weaning drinking-feeding-fighting-suckling duration	Factorial analysis
Faecal lactobacilli:*E.coli* ratio difference day 3-day1 *vs.* treatments, teat-order, classificationLS, BS, WW, sum day1-3 post-weaning fighting-chewing-drinking-feeding-belly nosing duration, pre-weaning drinking-feeding-fighting-suckling duration	Log_{10}, square root[b]		Multiple Regression analysis[d]
Faecal lactobacilli:*E.coli* ratio difference day 3-day1 *vs.* treatments*LW classification	Log_{10}, square root[b]	WW, pre-weaning total suckling and fighting duration	GLM-Anova[a]

Faecal lactobacilli:*E.coli* ratio difference day 3-day1 *vs.* treatments*teat-order	Log_{10}, square root[b]	WW, pre-weaning total suckling and fighting duration	GLM-Anova[a]
Faecal lactobacilli:*E.coli* ratio difference day 7-day3 *vs.* treatments, teat-order, classification	Log_{10}, square root[b]	LS, BS, WW, sum day1-7 post-weaning fighting-chewing-drinking-feeding-belly nosing duration, pre-weaning drinking-feeding-fighting-suckling duration	Factorial analysis
Faecal lactobacilli:*E.coli* ratio difference day 7-day3 *vs.* treatments, teat-order, classification, LS, BS, WW, sum day1-7 post-weaning fighting-chewing-drinking-feeding-belly nosing duration, pre-weaning drinking-feeding-fighting-suckling duration	Log_{10}, square root[b]		Multiple Regression analysis[d]
Faecal lactobacilli:*E.coli* ratio difference day 7-day3 *vs.* treatments,	Log_{10}, square root[b]	pre-weaning drinking duration	GLM-Anova[a]
Faecal lactobacilli:*E.coli* ratio difference day 7-weaning *vs.* treatments, teat-order, classification		LS, BS, WW, sum day1-7 post-weaning fighting-chewing-drinking-feeding-belly nosing duration, pre-weaning drinking-feeding-fighting-suckling duration	Factorial analysis

Faecal lactobacilli:*E.coli* ratio difference day 7-day3 *vs.* treatments, teat-order, classification, LS, BS, WW, sum day1-7 post-weaning fighting-chewing-drinking-feeding-belly nosing duration, pre-weaning drinking-feeding-fighting-suckling duration	Log_{10}, square root[b]		Multiple Regression analysis[d]
Faecal lactobacilli:*E.coli* ratio difference day 7-day3 *vs.* treatments,	Log_{10}, square root[b]	pre-weaning duration,	GLM-Anova[a]
Faecal lactobacilli:*E.coli* ratio differences between two sampling points *vs.* all pre- and post-weaning observational durations, BW, LW week1 to week4, LWG week1 to week4	Log_{10}, square root[b]		Spearman rank correlation

[a] Tukey test was employed every time a GLM-ANOVA analysis was carried out in order to determine the significance of the differences between the treatments.
[ax] GLM-Analysis of covariance with a subsequent comparison using Tukey test for multiple comparisons among slopes (Zar 1999).
[b] For clarity of the presentation, untransformed values are shown in the tables and text.
[c] There were no expected frequencies less than 5.
[d] For each case, a histogram of the residuals was plotted and it was checked that the data conformed to a normal distribution (Eddison 2000).
[e] The non-parametric Kruskal-Wallis test, can be applied instead of the parametric ANOVA test (Eddison, 2000). The non-parametric Q test is equivalent to the parametric Tukey test, which is used in the GLM-ANOVA analysis (Eddison, 2000).

3.3 Results

3.3.1 DLWG performance.

The LW of the piglets, according to which they had been classified at weaning, is presented in Table 3.6. The data in this table confirm that the LW of the piglets that were occupying different parts of the sow's udder did not differ significantly ($P>0.05$), but MTS piglets managed to gain significantly more weight than their PTS littermates ($P<0.01$). On the other hand, there was a distinct difference in the WW of the piglets which had a different LW classification at weaning ($P<0.001$). Also, highly significant differences recorded on the DLWG the week before weaning among piglets of different LW-classification, with piglets of heavier status gaining significantly more weight than the immediate lower LW-classification.

Table 3.6 Weaning weight and DLWG for the week pre-weaning of piglets at different LW and teat-order classifications.

Classification of the piglets within their litter				SED		
n=16	Heavy (1)	Medium (2)	Light (3)	1-2	1-3	2-3
LW kg	10.08	8.44	6.66	0.259***	0.269***	0.263***
DLWG the week pre-weaning g/d	294.2	254.9	181.3	16.43*	16.43***	16.43***
	Anterior ATS (1)	Middle MTS (2)	Posterior PTS (3)			
LW kg	8.61	8.51	8.07	0.258	0.259	0.277
DLWG the week pre-weaning g/d	250	273	207	19.09	18.74	19.76**

***$P<0.001$

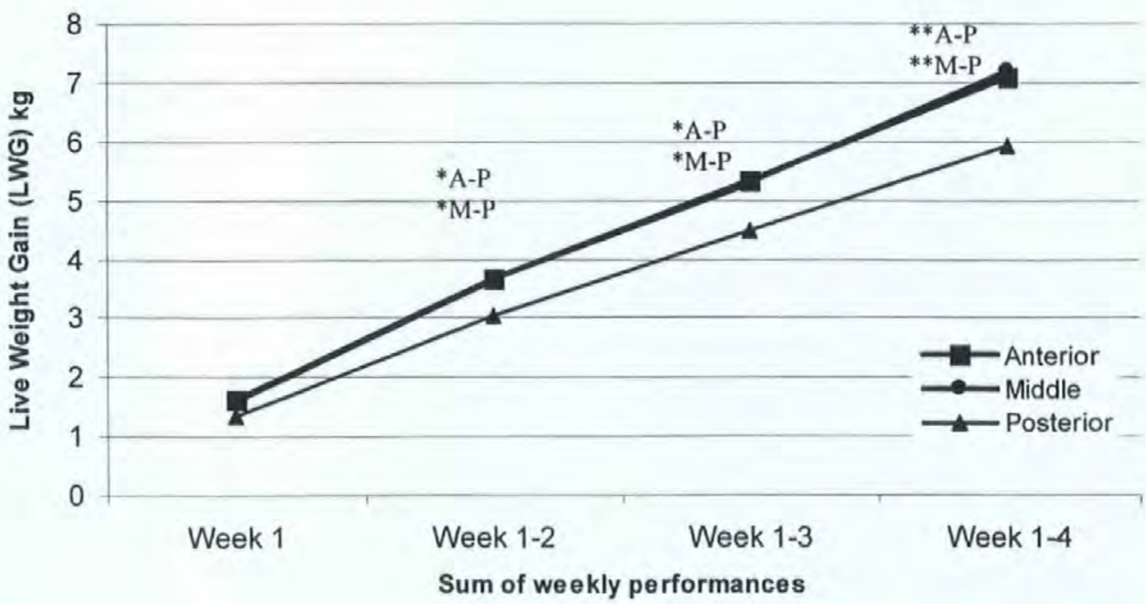
3.3.1.1 Pre-weaning growth performance according to teat order

LWGs of the ATS and MTS-piglets were found to be significantly greater than those recorded for PTS-piglets after the second week of lactation ($P<0.05$). The difference was increasing towards the weaning date ($P<0.01$) as it is shown in Figure 3.5. A cross-tabulation between LW-classification of the piglets at birth and later at weaning (Table 3.7) shows that:

i) the majority of the heavy piglets at birth maintained their LW superiority until weaning at 28 days of age ($P<0.05$),

ii) it was likely for medium weight piglets at birth to remain in this class or to become heavier until they reach 28 days of age, and finally

iii) the light weight piglets at birth remained the lightest until weaning ($P<0.01$).



*$P<0.05$, **$P<0.01$
P = Posterior, A = Anterior, M = Middle teats

Figure 3.5 Total LWG from birth to the week on question, achieved by piglets sucking different positions at the udder.

Table 3.7 Cross-tabulation between LW-classification at birth and at weaning.

	Piglet classification at 4 weeks of age		
Piglet classification at birth	% of agreement		
	Heavy	**Medium**	**Light**
Heavy	(+) 62.50*	(-) 28.13^{b}	(-) 9.38*
Medium	(+) 34.38^{b}	(+) 34.38^{b}	(-) 31.25^{b}
Light	(-) 3.13**	(+) 37.50^{a}	(+) 59.38**

Chi-square = 32.25, DF= 4, P= 0.0001
** = highly significant strong association ($P<0.01$), * = significantly strong association ($P<0.05$), ^{a} = medium strength of association ($0.1<P<0.05$), ^{b} = weak strength of association ($P>0.1$). The sign refers to the degree of association between categories: (+) likely to happen, (-) likely not to happen

3.3.1.2 Post-weaning growth performance of piglets.

A factorial analysis was performed in order to identify the main factors affecting the daily gain of the piglets during the first week after weaning. The results of the analysis showed that the interaction of treatment with teat-order could significantly affect the DLWG and LW of the piglets during the first week post-weaning ($P<0.05$). A further analysis identified that the only significant effect of treatment-teat order interaction was on ATS-piglets occurring between the two treatments, with piglets on the FF treatment growing significantly faster than piglets on the NF treatment ($P<0.05$; Table 3.8).

BW was identified to have a significant effect both on the LW and DLWG of the piglets ($P<0.05$). Also, WW showed to have a highly significant impact ($P<0.001$) on the LW obtained a week after weaning. DLWG and FCR performance were not significantly different between piglets of the two treatments after the first week post-weaning ($P>0.05$, Table 3.9).

Table 3.8 Average daily gain (g/d/piglet) one week post-weaning, between piglets of the two treatments having the same classification at weaning.

	NF	FF	s.e.d.		NF	FF	s.e.d.
Heavy	15.81	19.15	3.915	*Anterior*	13.35	20.26	3.493*
Medium	14.58	18.38	3.454	*Middle*	18.76	18.62	3.683
Light	19.19	18.57	4.001	*Posterior*	19.58	16.46	3.927

*$P<0.05$

A multiple regression analysis showed that WW (86.76%, $P<0.001$), BW (1%, $P<0.05$), weekly chewing duration (0.8%, $P<0.01$) and weekly fighting duration (0.5%, $P<0.05$) were the only variables which had a significant influence on the LW of the piglets recorded a week post-weaning and could predict 89.06% of the variation:

LW @ 5 weeks (kg) = -2.58 + 0.870WW + 0.731BW + 0.627 x $\log_{10}$weekly chewing duration + 0.329 x $\log_{10}$weekly fighting duration (F=172.69, d.f.=5,90, R^2=89.06%, $P<0.001$). (Equation 3.1)

After eliminating all the other variables except for WW, a linear regression analysis showed that 87.3% of the variation for the LW of the piglets at 5 weeks of age could be estimated using the following equation:

LW at 5 weeks (kg) = 1.60 + 0.958WW (F=646.43, d.f.=1,94, R^2=87.3%, $P<0.001$)

(Equation 3.2)

A multiple regression analysis showed that WW (9.3%, $P<0.001$), weekly chewing duration (8.4%, $P<0.01$), LS (5.3%, $P<0.01$), weekly fighting duration (3%, $P<0.05$) and

BW (0.6%, $P<0.05$) were the only variables which could predict 26.6% of the variation on LWG of the piglets the week after weaning:

LWG @ 5 weeks (kg) = -1.63 – 0.145WW – 0.0720LS +0.669 x $\log_{10}$weekly chewing duration +0.353 x $\log_{10}$weekly fighting duration + 0.643BW (F=6.53, d.f.=5,90, R^2=26.6%, $P<0.001$) (Equation 3.3)

DLWG and FCR levels were not significantly different ($P>0.05$) between the two treatments (Table 3.9).

Table 3.9 DLWG and FCR performance recorded for piglets on each treatment for the week post weaning.

	NF	FF	s.e.d.
DLWG (g/d)	168.2	186.6	18.65
FCR	1.576	1.572	0.3405

3.3.1.3 Post-weaning growth performance according to LW-classification within treatments.

There was a tendency for piglets of the lightest weight at weaning to perform better after weaning as they managed to maintain equal average daily live-weight gains (DLWGs) to those achieved pre-weaning (NF treatment), or even to grow faster after their separation from the sow (FF treatment, 24% higher DLWG, $P>0.05$; Table 3.10). Even though ATS and MTS-piglets on both treatments had the luxury to suckle the more productive parts of the udder pre-weaning, they gain significantly less weight after weaning in comparison to their pre-weaning performance ($P<0.05$). On the other hand, PTS-piglets that were suckling the less productive teats of the sow managed to maintain their DLWG performance a week post-weaning at similar levels to that obtained before weaning (DLWG week 4 *vs.* week 5, Table 3.11).

Table 3.10 Average daily live-weight gain (g/d) performance of piglets with different LW-classification at weaning.

	Week 4	Week 5	s.e.d.	% change in growth performance wk5-wk4
			NF treatment	
Heavy	295.5	147.3	31.1***	-50.17
Medium	241.1	151.8	20.9***	-36.99
Light	203.6	196.4	35.7	-3.5
			FF treatment	
Heavy	292.9	184.8	34.3**	-36.88
Medium	268.7	186.6	27.2**	-30.57
Light	158.9	197.3	27.7	+24.08

*P<0.05, **P<0.01, ***P<0.001

Table 3.11 Average daily live-weight gain (g/d) performance of piglets with different teat-order classification.

	Week 4	Week 5	s.e.d.	% change in growth performance wk5-wk4
			NF treatment	
Anterior	248.1	132.3	28.4***	-46.69
Middle	272.4	176.5	32.6*	-35.19
Posterior	221.0	196.2	35.1	-11.25
			FF treatment	
Anterior	252.9	200.8	34.0	-20.61
Middle	274.3	191.4	37.4*	-30.21
Posterior	194.6	175.9	28.9	-9.62

*P<0.05, ***P<0.001

A within treatment analysis showed that there was no significant difference in DLWG between piglets of different LW-classification or teat-order a week after weaning (Table 3.12). Piglets of heavy LW-classification on the FF treatment, managed to conserve their LW status after weaning as they were still heavier a week after weaning than the medium ($P<0.001$) and light ($P<0.001$) piglets of the litter. On the other hand, only the heavy piglets on the NF treatment managed to preserve their significant heavier ($P<0.001$) LW status at five weeks of age than medium and light piglets of the litter (Table 3.12). The 37% reduction in LWG (Table 3.11), which was recorded for piglets of the medium weight classification ($P<0.001$) the week after weaning, resulted in them not having a significant different LW in comparison with their lighter weaned littermates at five weeks ($P>0.05$, Table 3.12).

Table 3.12 LW and DLWG ± SEM's comparison between piglets of different LW-classification at 4 and 5 weeks of age within treatments.

Classification of the piglets within their litter						
	Heavy	Medium	Light	Anterior	Middle	Posterior
			NF treatment			
LW @ 4 weeks (kg)	10.081 ± 0.3713 [a]	8.469 ± 0.3713 [a,e]	7.250 ± 0.3713 [a,e]	8.726 ± 0.3569	8.936 ± 0.4158	8.127 ± 0.4017
DLWG 4 weeks (kg)	295.5 ± 18.17 [c,e]	241.1 ± 18.17 [c]	203.6 ± 18.17 [e]	248.1 ± 18.31	272.4 ± 21.33	221.0 ± 20.61
LW @ 5 weeks (kg)	11.113 ± 0.2842 [a,b]	9.531 ± 0.2842 [a]	8.625 ±0.2842 [b]	9.563 ± 0.3509	10.171 ± 0.4088	9.500 ± 0.3949
DLWG 5 weeks (kg)	147.3 ± 22.89	151.8 ± 22.89	196.4 ± 22.89	132.3 ± 20.63	176.5 ± 24.04	196.2 ± 23.22
			FF treatment			
LW @ 4 weeks (kg)	10.231 ± 0.2299 [a]	8.469 ± 0.2299 [a]	5.919 ± 0.2299 [a]	8.782 ± 0.4424 [c]	8.907 ± 0.4710 [d]	6.938 ± 0.4560 [c,d]
DLWG 4 weeks (kg)	292.9 ± 14.05 [a]	268.7 ± 14.05 [b]	158.9 ± 14.05 [a,b]	252.9 ± 18.14	274.3 ± 19.31 [b]	194.6 ± 18.70 [b]
LW @ 5 weeks (kg)	11.525 ± 0.3065 [a]	9.775 ± 0.3065 [a]	7.300 ± 0.3065 [a]	10.188 ± 0.4674 [c]	10.247 ± 0.4976 [d]	8.169 ± 0.4818 [c,d]
DLWG 5 weeks (kg)	184.8 ± 24.40	186.6 ± 24.40	197.3 ± 24.40	200.8 ± 23.57	191.4 ± 25.09	175.9 ± 24.29

Values with the same superscript are significant different ([a,b] = $P<0.001$, [e] = $P<0.01$, [c, d] = $P<0.05$)

3.3.2 Feed and water consumption.

3.3.2.1 Pre-weaning feed consumption.

Pre-weaning feed intake between litters, which were chosen randomly to comprise one of the two treatments is illustrated in Figure 3.6. Daily feed intake was not significantly different between treatments during the pre-weaning week.

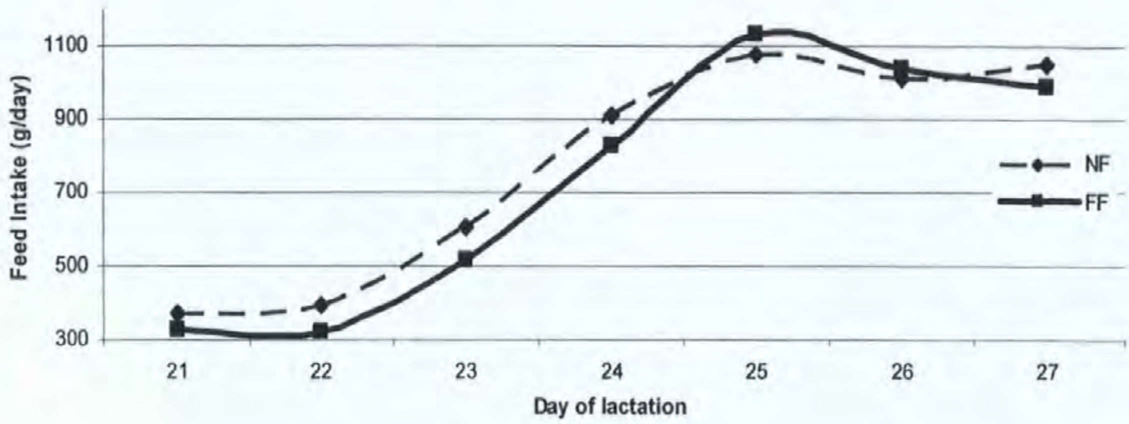


Figure 3.6 Daily pre-weaning feed intake between litters which were chosen randomly to comprise one of the two post-weaning treatments (average relationship FI (g) = 138.83x + 199.83; litter size: NF=13.125±0.368; FF=12.750±0.316).

3.3.2.2 Daily feed and water intake for the week post-weaning

Regression lines were fitted to daily feed intake of piglets on the two treatments (Figure 3.7), and subsequently a comparison between the slopes of the two lines took place. The analysis among the slopes of each line suggests that treatment had no significant effect on daily creep feed intake ($P>0.05$) during the first week post-weaning. The data in Figure 3.8 illustrates that piglets of the FF treatment were consuming significantly less amount of feed from the familiar feeder at the end of the post-weaning week (D33=2.446 ± 0.068 kg; D34= 2.496 ± 0.068 kg) in comparison with feed intake recorded on day 2 after weaning (2.811 ± 0.068 kg; $P<0.05$).

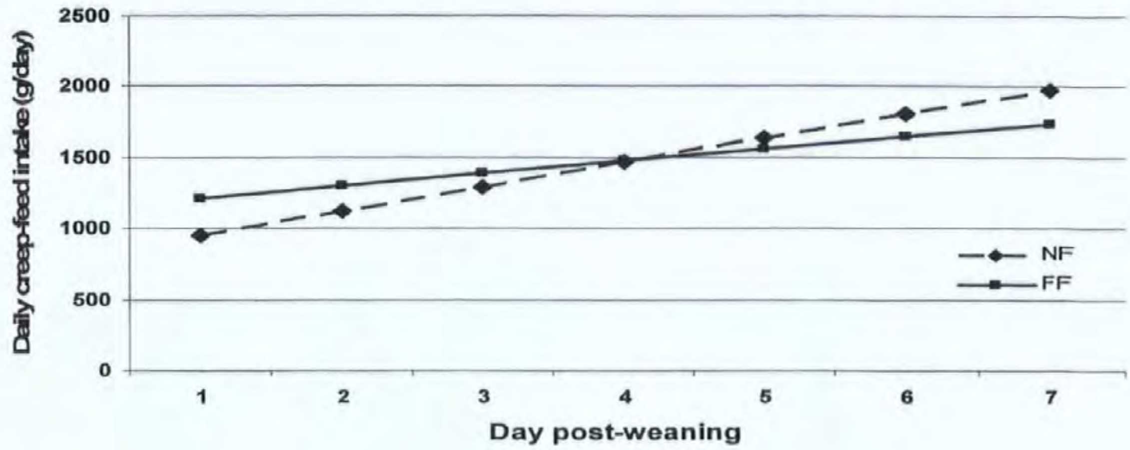
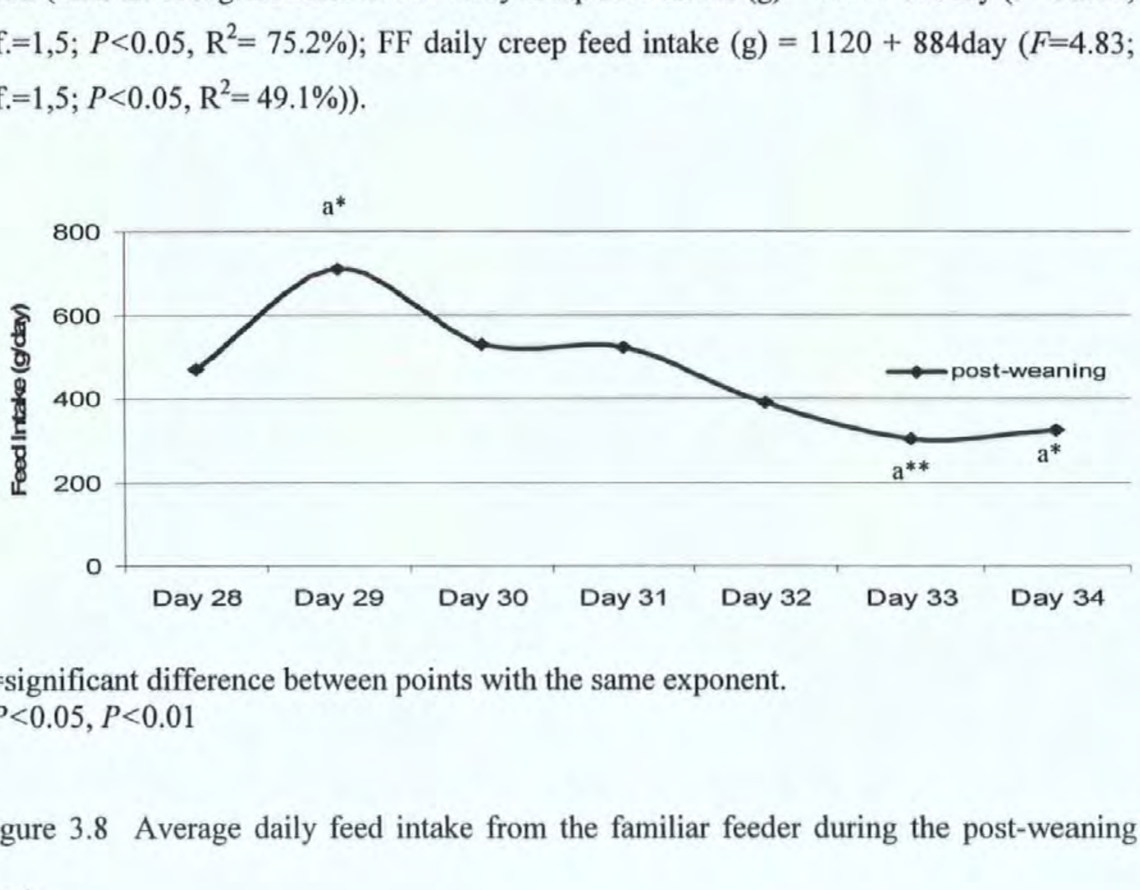


Figure 3.7 Average daily feed intake per group of 6 piglets (pen) during the post-weaning week (after fit of regression line: NF daily creep feed intake (g) = 780 + 171day (F=15.17; d.f.=1,5; P<0.05, R^2= 75.2%); FF daily creep feed intake (g) = 1120 + 884day (F=4.83; d.f.=1,5; P<0.05, R^2= 49.1%)).



a=significant difference between points with the same exponent.
*P<0.05, P<0.01

Figure 3.8 Average daily feed intake from the familiar feeder during the post-weaning week.

During the first day after weaning, piglets of the NF treatment consumed significantly more water (P<0.05, Table 3.13) than piglets of the FF treatment. That difference also led to a significantly lower feed:water ratio (P<0.05 Table 3.14) performance recorded for piglets of the NF treatment on the same day. For the rest of the post-weaning week, there was no significant difference in daily water consumption or daily feed:water ratio between litters of the two treatments ($P>0.05$; Tables 3.13 and 3.14).

Table 3.13 Average daily water intake during the post-weaning week (L day^{-1}).

Day post-weaning	NF treatment	FF treatment	s.e.d.
1	4.047	3.153	0.364*
2	4.618	4.032	0.591
3	3.911	4.051	0.585
4	4.035	3.727	0.657
5	4.057	3.656	0.588
6	3.745	3.668	0.620
7	4.240	4.060	0.684

*$P<0.05$

Table 3.14 Average daily feed:water ratio during the post-weaning week.

Day post-weaning	NF treatment	FF treatment	s.e.d.
1	0.1679	0.2885	0.0465*
2	0.3088	0.3960	0.0515
3	0.3812	0.3603	0.0370
4	0.3842	0.4302	0.0566
5	0.3866	0.4075	0.0321
6	0.4369	0.4107	0.0584
7	0.4987	0.4898	0.0925

*$P<0.05$

3.3.3 Behavioural recording during the pre-weaning period.

3.3.3.1 Suckling performance

There was a great variation in suckling duration between all experimental piglets during the last week of lactation (Figure 3.9). It was calculated that the average suckling duration of the piglets varied significantly between each day of observation ($P<0.0001$).

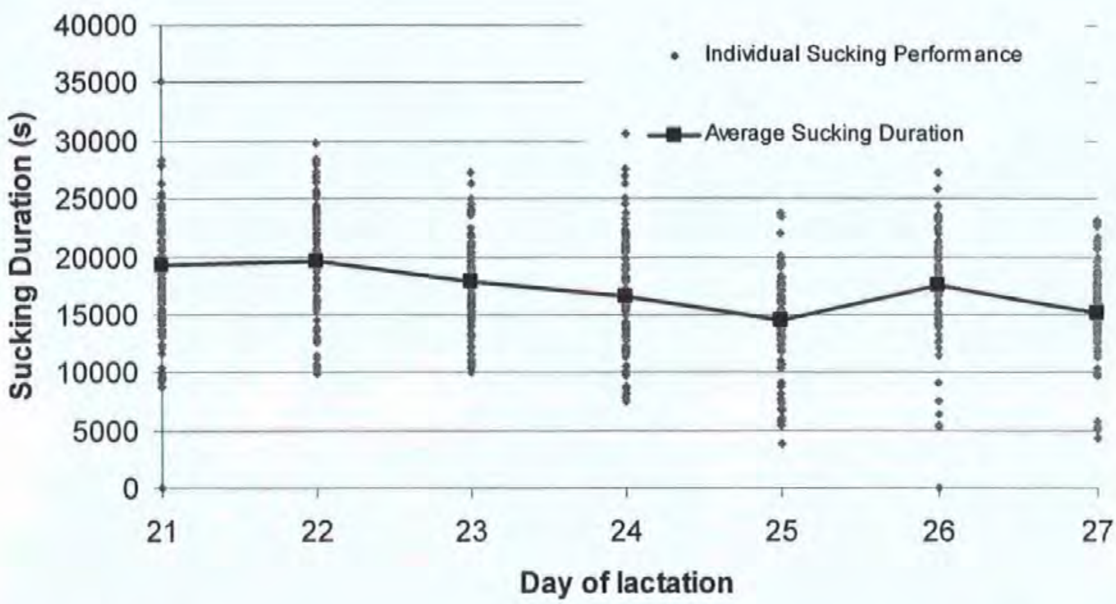


Figure 3.9 Individual and estimated average sucking performance (average s day^{-1} $piglet^{-1}$) of all piglets during the week pre-weaning (n=16).

A cross-tabulation between teat-preference and LW-classification of all piglets is presented in Table 3.15. It was observed that there was no clear pattern between heavy and medium weight class piglets and their teat-order ($P>0.05$) as they were almost spread evenly between the front and middle parts of the udder. For this reason it was decided to combine the two further anterior teat-sections of the udder (anterior and middle parts) in order to identify the LW classes which were suckling the posterior or the further middle-anterior teats of the udder. The new cross-tabulation showed (Table 3.16) that it was more likely for heavy and medium piglets of the litter to occupy the anterior and middle teats of the udder and for light piglets to inherit the posterior and less productive glands ($P<0.05$).

Table 3.15 Teat preference according to piglet size.

Teat suckled	Piglet classification % of attendance		
	Heavy	**Medium**	**Light**
Anterior	(+) 36.11	(+) 44.83	(-) 19.35
Middle	(+) 36.11	(+) 34.48	(-) 29.03
Posterior	(-) 27.78	(-) 20.69	(+) 51.61

Chi-square = 8.148, DF=4, P=0.086

Table 3.16 Teat preference according to piglet size (anterior and middle combined).

Teat suckled	Piglet classification % of attendance		
	Heavy	**Medium**	**Light**
Anterior - Middle	(+) 40.00[b]	(+) 35.38[b]	(-) 24.62[b]
Posterior	(-) 19.35[b]	(-) 29.03[b]	(+) 51.61[a]

Chi-square = 7.258, DF=2, $P<0.05$
[a] = medium strength of association ($0.1<P<0.05$), [b] = weak strength of association ($P>0.1$)
The sign refers to the degree of association between categories: (+) likely to happen, (-) likely not to happen

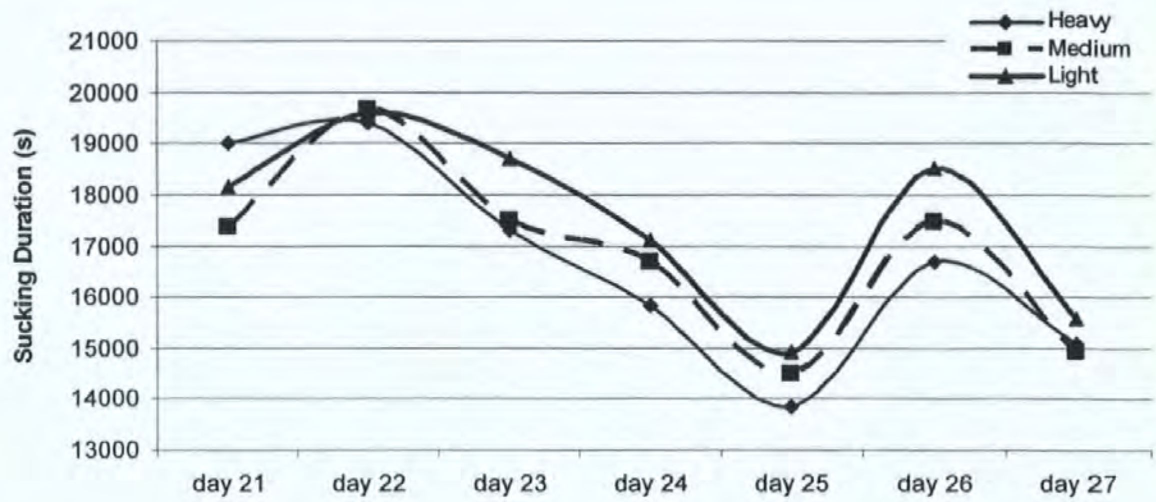


Figure 3.10 Piglets' sucking duration (mean day^{-1} piglet^{-1}) according to LW-classification (n=16).

The sucking behaviour data were also analysed according to the LW-classification of the piglets at weaning (heavy, medium and light) without noticing any significant difference between classes (Figure 3.10). The same conclusion was also drawn from the comparison of sucking behaviour between piglets engaging different parts of the udder (anterior, middle and posterior teats; Figure 3.11).

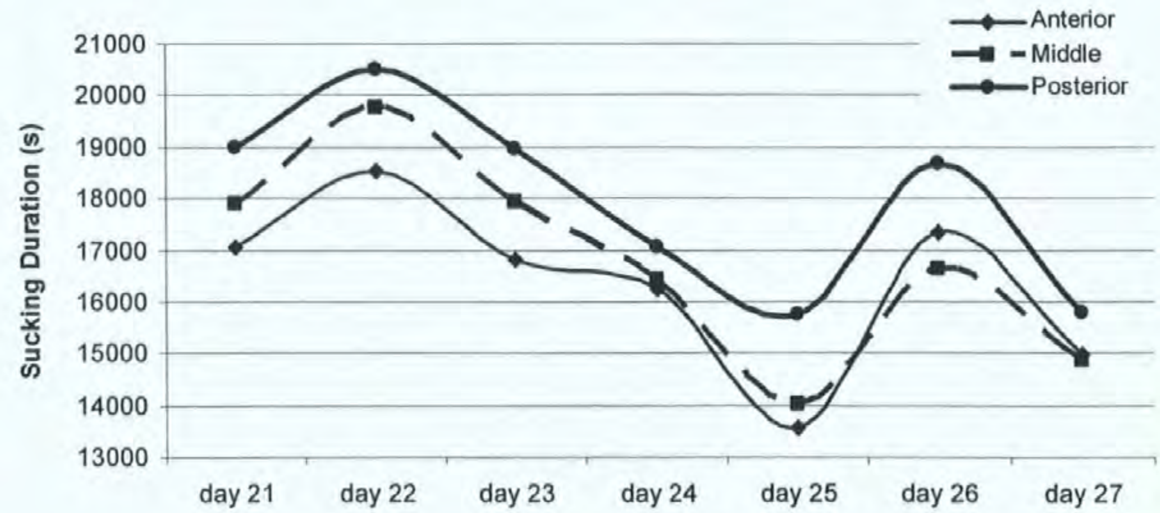


Figure 3.11 Representation of piglets' sucking performance (mean s day^{-1} piglet^{-1}) according to their teat preference classification pre-weaning (n=16).

Even though total sucking behaviour for the week pre-weaning was not significantly different between piglets of different LW-classification, the data in Table 3.18 indicate that the further back on the udder the piglets were suckling the more time they engaged in that activity ($P<0.05$).

Table 3.17 Total teat manipulation (s week^{-1}) for the week pre-weaning between piglets of different classes (medians).

Classification of the piglets within their litter			Q value		
Heavy (1)	Medium (2)	Light (3)	1-2	1-3	2-3
118918	118205	126733	1.723	4.882	3.159
Anterior (1)	Middle (2)	Posterior (3)			
115960	122922	128889	-2.58*	-9.47*	6.89*

Q value must be over 2.394 for significant difference (Eddison, 2000).
*$P<0.05$

3.3.3.2 Pre-weaning feeding behaviour

There was no significant difference ($P>0.05$) in daily feeder usage (s day^{-1}) between different days of lactation during the pre-weaning week (Figure 3.12).

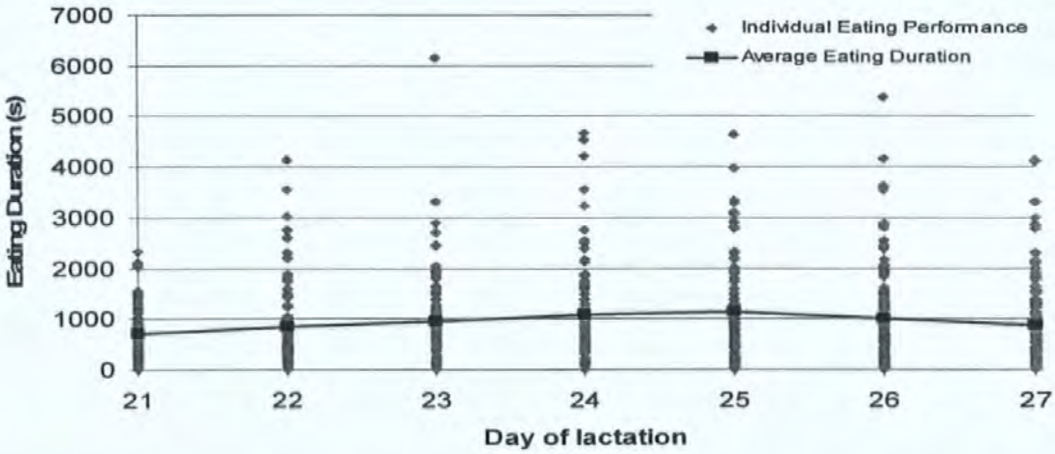


Figure 3.12 Individual and average feeding performance (s day^{-1} piglet^{-1}) of all piglets during the week pre-weaning (n=16).

The results of the factorial analysis showed that on a weekly basis, feeding duration was only affected by the teat order of the piglets and not from their LW-classification.

After identifying the main effects on feeding duration, a GLM analysis was employed in order to estimate differences in daily and weekly feeding duration between piglets of different teat-order classification (Table 3.18).

Table 3.18 Mean daily feeding duration (s day^{-1} $piglet^{-1}$) according to teat-order (n=16).

Day pre-weaning	Anterior (1)	Middle (2)	Posterior (3)	s.e.d. 1-2	s.e.d. 1-3	s.e.d. 2-3
21	729.0	770.5	637.5	2.357	2.314	2.440
22	723.1	846.6	974.3	3.282	3.222	3.398
23	837.1	992.3	1077.4	3.317	3.257	3.434
24	892.4	1116.1	1324.7	3.727	3.660	3.859
25	821.0	1221.4	1414.7	3.628	3.562*	3.756
26	761.2	1130.7	1170.7	3.821	3.752*	3.956
27	714.7	1017.1	950.2	3.661	3.595	3.791
total	5295	7059	7795	1060	1041*	1098

The s.e.d. refers to the analysis of the data after been treated using square root transformations
*P<0.05

It was observed that PTS-piglets were spending significantly more time feeding than ATS-piglets during the second and third day before weaning (P<0.05). Also, on a weekly basis, PTS and ATS-piglets were the only classes which differed significantly in feeding duration with the latter spending significantly less time (P<0.05).

3.3.3.3 Pre-weaning drinking behaviour

There was no significant difference ($P>0.05$) in daily drinker usage between different days of lactation during the pre-weaning week (Figure 3.13).

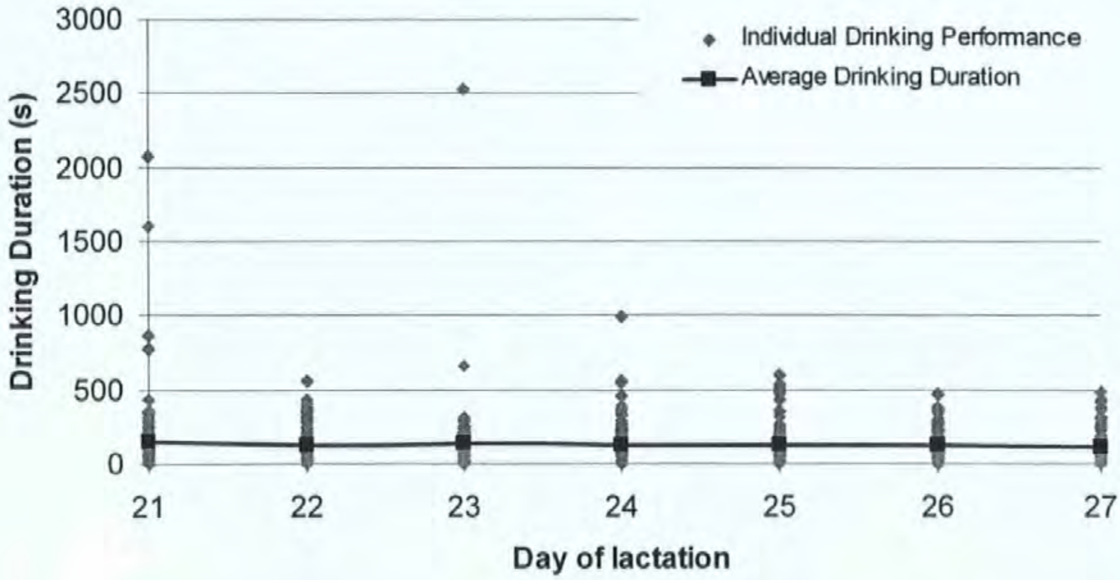


Figure 3.13 Individual and average drinking behaviour (s day^{-1} $piglet^{-1}$) of all piglets during the week pre-weaning (n=16).

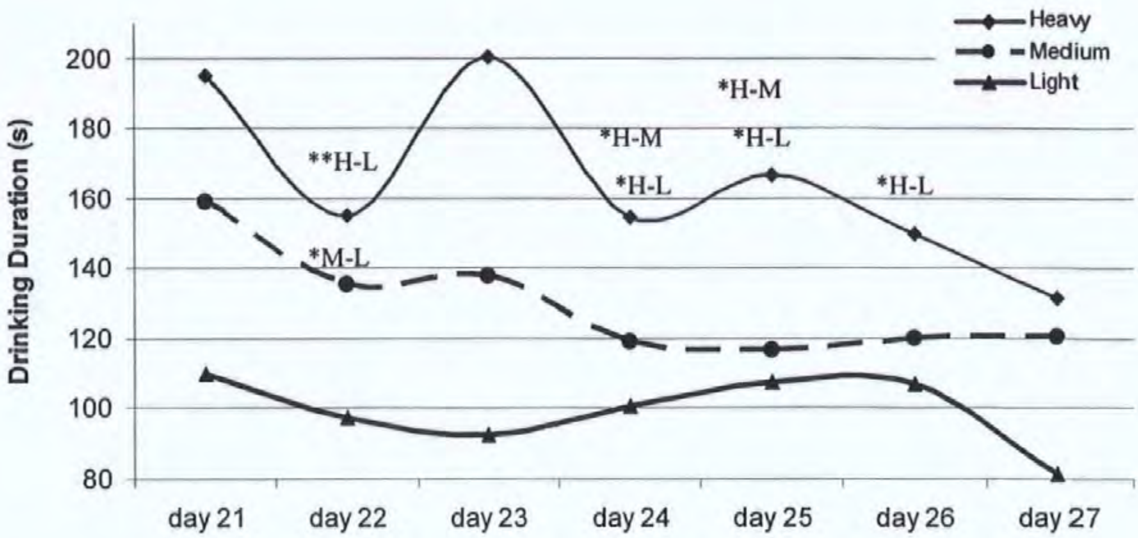
A factorial analysis was employed in order to identify the main effects on weekly drinking duration of the piglets during the week pre-weaning. The analysis showed that only piglets of different LW-classification were spending significantly different periods of time at the drinkers ($P<0.05$) and there was no other factor or a combination of factors which could explain any other differences between piglets (Table 3.19).

Table 3.19 Total drinking duration for the week pre-weaning between piglets of different classes.

Behavioural Duration (s)	Classification of the piglets within their litter			s.e.d.		
	Heavy (1)	Medium (2)	Light (3)	1-2	1-3	2-3
Drinking	1153	909	695	145.3	145.3***	145.3
	Anterior (1)	Middle (2)	Posterior (3)	1-2	1-3	2-3
Drinking	968	966	819	151.5	148.8	156.9

*P<0.05

A more detailed analysis of the daily pre-weaning drinking duration between piglets of different LW-classification is illustrated in Figure 3.14. On a weekly basis, the heavier the piglets, the more time they were observed to spend at the drinkers (P<0.001, Table 3.22). The difference was significant on days 22, 24, 25 and 26 of lactation. More specifically, on day 22 of lactation heavy and medium weight piglets were observed to spend significantly more time at the drinkers than their lighter littermates (155 *vs.* 98 (s.e.d. = 2.219) s; P<0.001) and (135 s *vs.* 98 s (s.e.d. = 1.594); P<0.05) respectively. On day 24 and 25, the heaviest piglets in the litter continued to spend significantly more time at the drinkers than the medium (D24: 155 s *vs.* 119 s (s.e.d. = 1.687); P<0.05, D25: 167 s *vs.* 117 s (s.e.d. = 1.741); P<0.05) and lightest (D24: 155 s *vs.* 101 s (s.e.d. = 2.318); P<0.05, D25: 167 s *vs.* 108 s (s.e.d. = 2.392); P<0.05) piglets of the trial. On Day 26, the small reduction in the average time spent at the drinkers by the heaviest piglets in comparison with the similar levels which were kept by the medium and light piglets of the litter had as a result the difference to be significant only between the heaviest and the lightest piglets of the litter (150 s *vs.* 107 s (s.e.d. = 1.974); P<0.05).



*P<0.05, **P<0.01
H = Heavy, M = Medium, L = Light weight piglets

Figure 3.14 Illustration of piglets' drinking performance (average s day^{-1} $piglet^{-1}$) according to their LW-classification at weaning (n=16).

3.3.3.4 Pre-weaning fighting behaviour

Daily fighting behaviour was significantly different from day to day (P<0.01) during the pre-weaning week. It can be observed from the data in Figure 3.15 that individual fighting performance of the piglets became more widely distributed towards the weaning date.

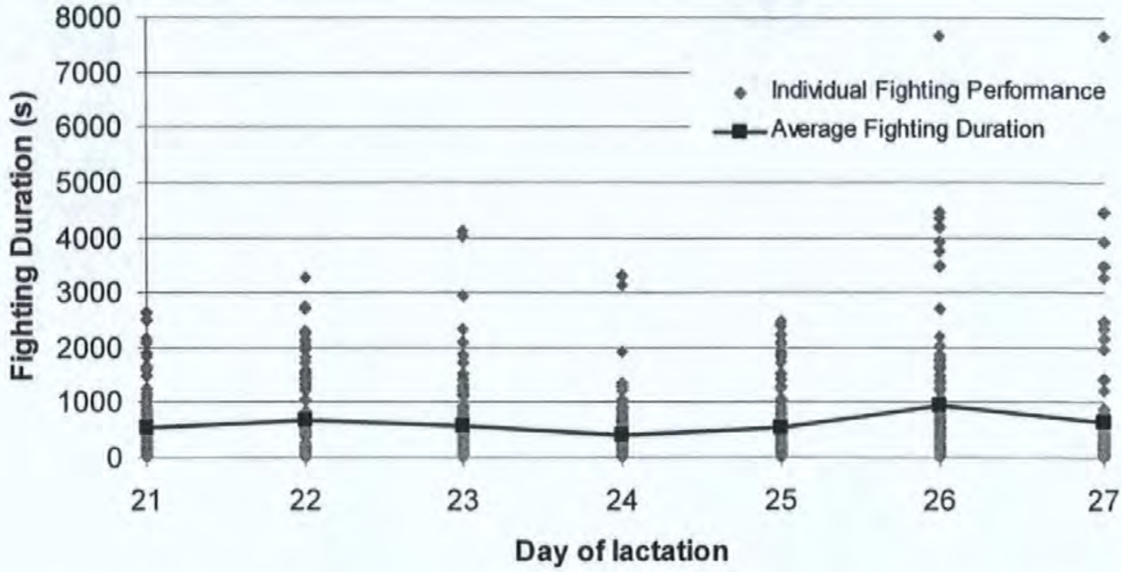


Figure 3.15 Individual and average fighting performance (s day^{-1} $piglet^{-1}$) of all piglets during the week pre-weaning (n=16).

A factorial analysis was employed in order to identify the main effects on weekly fighting duration on the week pre-weaning. The analysis showed that there was no significant effect of teat-order and LW-classification on the weekly fighting behaviour of the piglets (Table 3.20).

Table 3.20 Total fighting duration for the week pre-weaning between piglets of different classes.

Behavioural Duration (s)	Classification of the piglets within their litter			s.e.d.		
	Heavy (1)	Medium (2)	Light (3)	1-2	1-3	2-3
Fighting	4809	4553	3803	0.101	0.101	0.101
	Anterior (1)	Middle (2)	Posterior (3)	1-2	1-3	2-3
Fighting	4055	4532	4642	0.101	0.099	0.1048

Classifying piglets according to LW (Figure 3.16) or teat-order (Figure 3.17) did not show any significant difference in daily fighting duration ($P<0.05$).

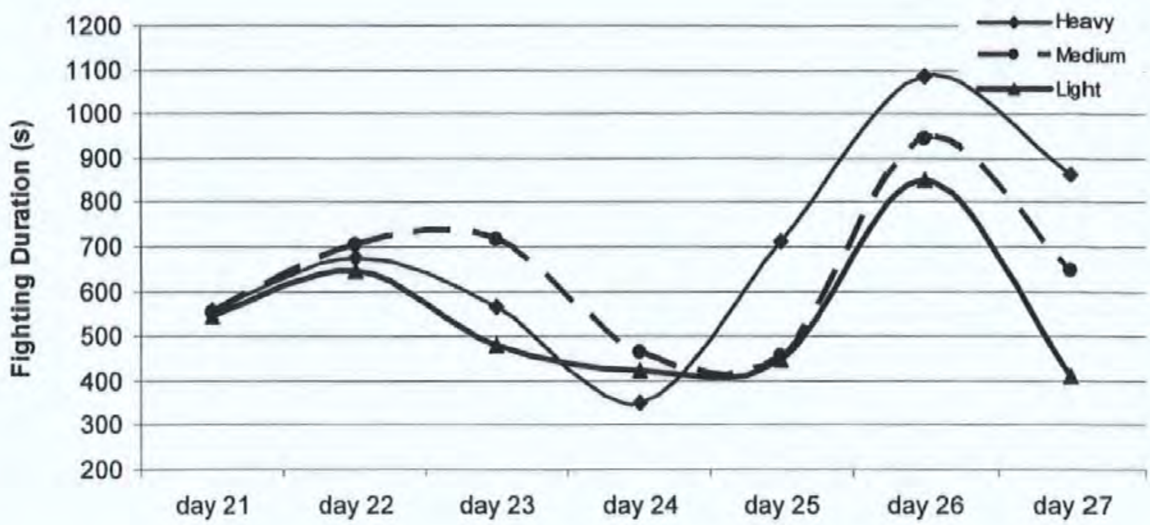


Figure 3.16 Representation of piglets' fighting duration (average s day^{-1} $piglet^{-1}$) according to their LW-classification at weaning (n=16).

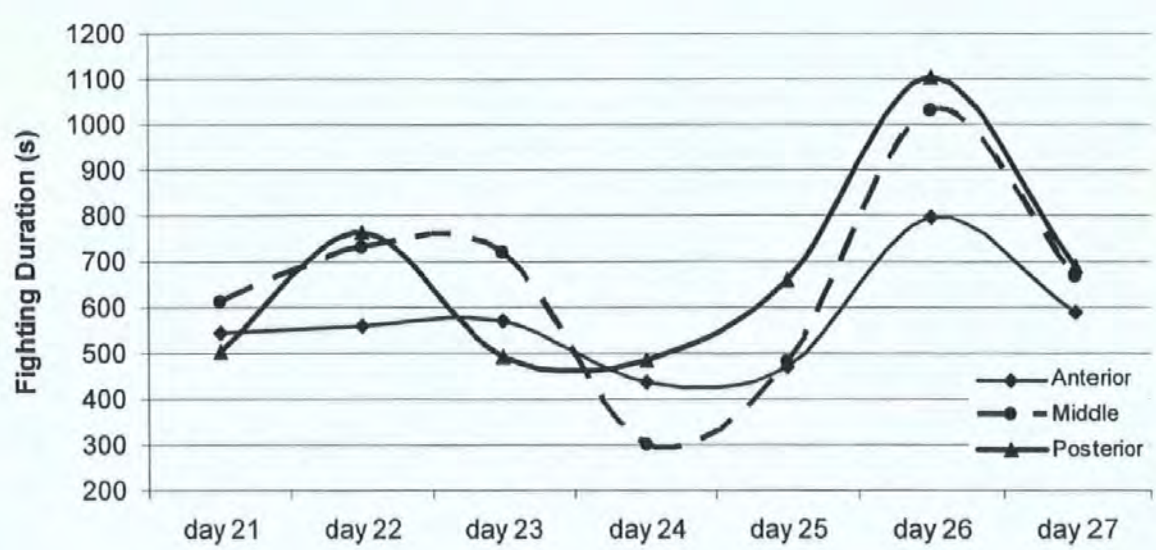


Figure 3.17 Representation of piglets' fighting duration (average day^{-1} $piglet^{-1}$) according to their teat-order classification pre-weaning (n=16).

There was no correlation between weekly feeding, drinking and suckling duration with fighting duration (P>0.05) for the week pre-weaning. A weak correlation was only identified between total feeding and drinking duration during the week pre-weaning (r=0.232, d.f.=94, P<0.05).

3.3.4 Behavioural recordings during the post-weaning period.

3.3.4.1 Latency to first feeding: Feeding 'stasis'

According to the results of the factorial analysis, piglets of both treatments faced the same difficulty in reaching the feed for the first time with or without the presence of the familiar feeder (P>0.05, Table 3.21). Factors such as total pre-weaning feeding and suckling duration, WW and sex had no significant effect on latency to first feeding. The same factorial analysis showed no significant effect of LW, teat-order classifications, or the interaction of treatment with any of the two classifications (LW-classification, teat-order) on latency to feed (P>0.05, Table 3.22). There was no correlation between total pre-weaning feeding experiences and latency to feed for each treatment (P>0.05).

Even though it was identified from the factorial analysis that the pre-weaning fighting and drinking duration significantly affected the feeding stasis, they expressed a very small part of the variation (F=4.72; d.f.=2,93; R^2_{adj}=7.3%; P<0.05).

Table 3.21 Average 'feeding stasis' ± SEM's between the two treatments.

Measurements in seconds	'feeding stasis' NF	'feeding stasis' FF	Main effect mean
Latency to feed (s)	1840 ± 555 (31 min ± 9 min)	2595 ± 638 (43 min ± 11 min)	2249 ± 338

Table 3.22 Latency to feed ± SEM's between and within treatments according to LW and teat-order classification (measurements in s).

	Classification of the piglets according to LW				Classification of the piglets according to teat-order			
Treatment	Heavy	Medium	Light	Main effect mean	Anterior	Middle	Posterior	Main effect mean
NF	2418 ± 1150	1653 ± 1034	1448 ± 1001	1859 ± 395	2166 ± 894	1602 ± 1100	1751 ±968	1859 ± 395
FF	3191 ± 1183	3130 ± 962	1464 ± 1554	2639 ± 548	2743 ± 874	1982 ± 1344	3060 ± 1051	2639 ± 548
Main effect mean	1987 ± 537	2484 ± 628	2276 ± 605		2361 ± 574	2052 ± 621	2303 ± 581	

3.3.4.2 Post-weaning feeding behaviour

It was calculated that there was no significant effect of treatment, teat-order and LW classification or any combination of treatment with any of the two classifications (LW-classification, teat-order) on total post-weaning feeding duration ($P>0.05$).

Factorial analysis was also carried out in order to identify the main factors that could influence the daily post-weaning feeding duration. It was identified that during the first two days, treatment was not influencing the feeding duration of the piglets ($P>0.05$). WW ($P<0.05$) and the combined effect of treatment with teat-order ($P<0.01$) were the main factors that could influence feeding duration during the first day post-weaning. After the third day post-weaning, feeder-treatment was the only factor which could affect the feeding duration of the piglets ($P<0.05$).

The results of the Kruskal-Wallis analysis which undertaken to identify differences in total feeding duration between piglets of different teat-order classification on the NF treatment are presented in Table 3.23. On day one post-weaning, MTS and PTS-piglets were spending significantly more time feeding ($P<0.01$) than ATS-piglets. ATS-piglets continued spending significantly less time than MTS-piglets on days 2 ($P<0.05$) and 3 ($P<0.05$) post-weaning, with the latter spending significantly more time at the feeder than PTS-piglets on day 3 post-weaning ($P<0.05$). After that day, there was no significant difference in time spent feeding between piglets of the NF treatment. Non significant differences were also observed in feeding duration between piglets of the FF treatment which had different teat-order classification (Figure 3.18).

Table 3.23 Mean feeding duration (s day^{-1} $piglet^{-1}$) recorded on NF piglets according to their teat-order classification (table presents medians).

Day post-weaning	Anterior (1)	Middle (2)	Posterior (3)	Q 1-2 [a]	Q 1-3 [a]	Q 2-3 [a]
1	2345	3285	4099	-3.183**	-4.393**	0.936
2	4699	6769	6175	-3.906*	-2.166	-1.637
3	3976	5870	4799	-4.282*	-1.625	-2.443*
4	4974	5466	4612	-1.649	0.060	-1.533
5	4767	5225	5638	-2.314	-1.805	-0.519
6	4491	5201	5488	-2.748	-2.256	-0.519
7	5208	5510	6305	-1.359	-1.986	0.494

*$P<0.05$, **$P<0.01$

[a] = statistics performed with non-parametric Kruskal-Wallis (for 3 treatments the estimated Q value must be over 2.394 for significant difference (Eddison, 2000)).

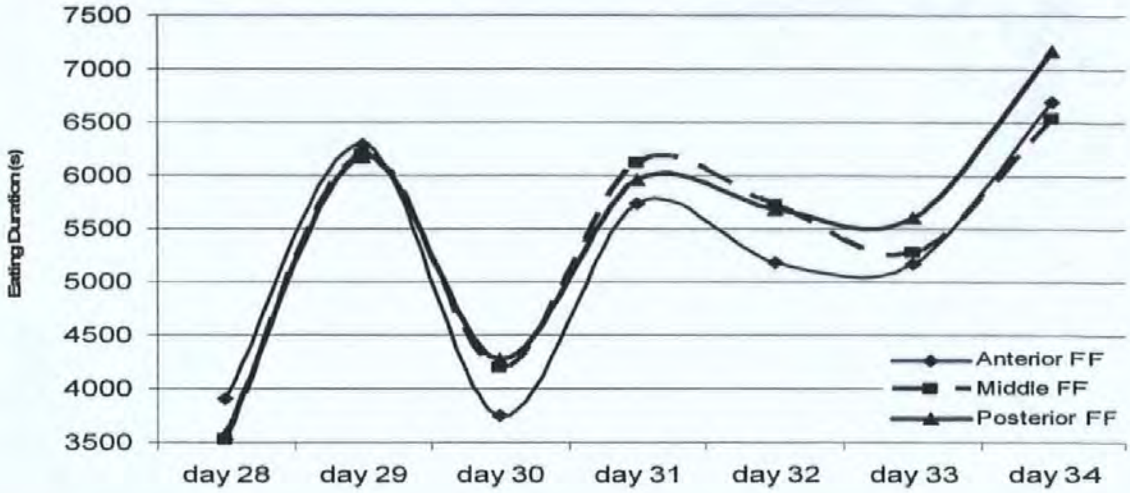


Figure 3.18 Mean feeding duration (s day^{-1} piglet^{-1}) recorded on FF piglets according to their teat-order preference.

Comparisons were also made between piglets of the two treatments having the same teat-order classification (Table 3.24). The results of the GLM-Analysis showed non significant differences between piglets of the two treatments. The combined effect of LW classification and treatment was the only effect on feeding duration during the 2nd day post-weaning (P<0.05) and the results are presented in Figures 3.19 and 3.20.

Table 3.24 Mean feeding duration (s day^{-1} piglet^{-1}) between piglets of the two treatments having the same teat-order classification.

Day post-weaning	Anterior NF	Anterior FF	s.e.d	Middle NF	Middle FF	s.e.d.	Posterior NF	Posterior FF	s.e.d.
1	2443	3968	563.1*	4389	3485	778.7	4636	3461	852.2
2	5332	6290	839.8	6942	6139	566.2	6427	5982	922.3
3	4001	3730	460.8	5881	4167	635.5*	5005	4426	977.2
4	4789	5786	570.4	5614	6050	567.5	4986	5852	986.1
5	4983	5242	832.0	5519	5687	634.8	5229	5573	706.1
6	4170	5225	465.8*	5254	5200	542.4	4832	5739	661.8
7	5472	6794	803.6	6109	6480	805.7	7119	7116	1500

*P<0.05

A within treatment analysis showed that the feeding duration between piglets of different LW classification was not significantly different on any of the post-weaning days (Figure 3.19 and 3.20). Only on day 2 post-weaning for the FF treatment, did piglets in the heavy at weaning group (5030 s) spend significantly less time feeding than piglets of medium (7302 s, Q= 3.273, $P<0.05$) or light weight classification (6451 s, Q= 2.613, $P<0.05$) (Figure 3.20).

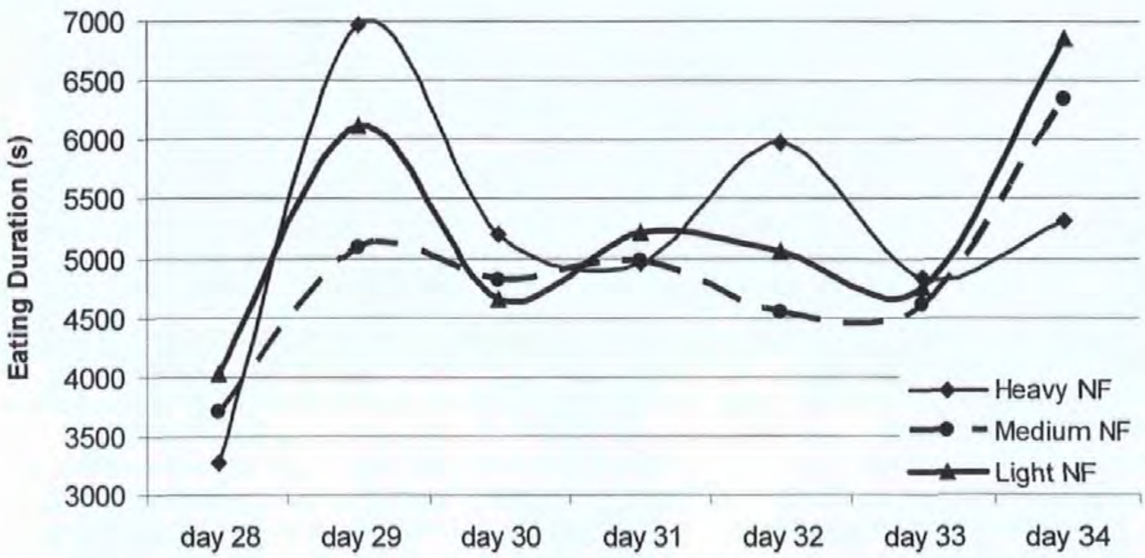
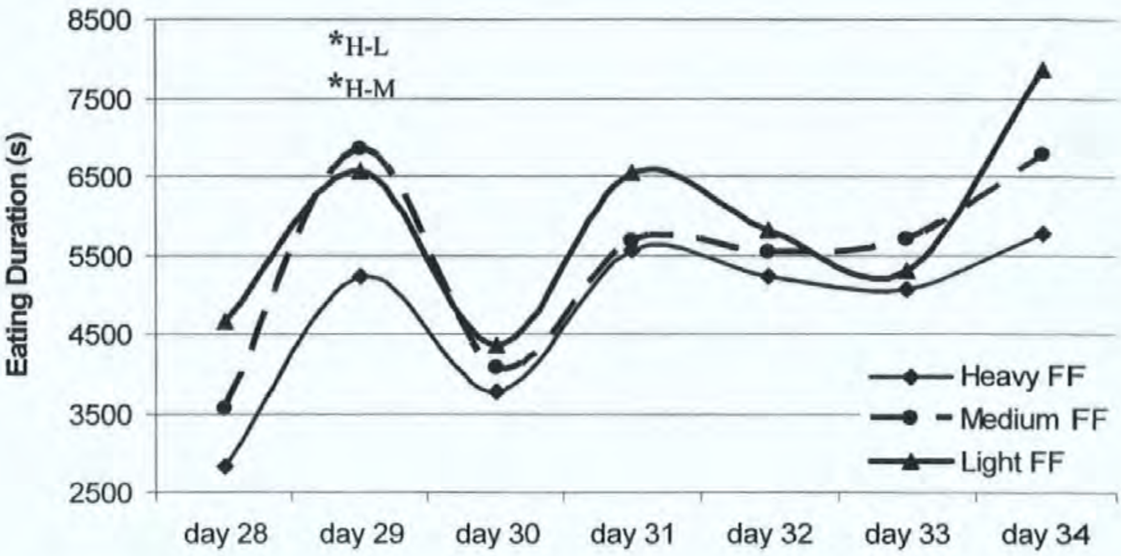


Figure 3.19 Mean feeding duration (s day^{-1} $piglet^{-1}$) recorded for NF piglets according to their LW-classification.



*P<0.05, H= Heavy, M=Medium and L=Light weight piglets.

Figure 3.20 Mean feeding duration (s day^{-1} $piglet^{-1}$) recorded for FF piglets according to their LW-classification.

A GLM analysis identified that there were no significant differences in daily feeding duration for the largest proportion of the post-weaning week between piglets of the same LW classification (P>0.05, Table 3.25).

Table 3.25 Mean feeding duration (s day^{-1} $piglet^{-1}$) between piglets of the same LW-classification.

Day post-weaning	Heavy NF	Heavy FF	s.e.d	Medium NF	Medium FF	s.e.d.	Light NF	Light FF	s.e.d.
1	3213	2877	546.7	3738	3525	715.7	4578	4100	1191
2	7094	5108	870.0*	5054	6892	713.2*	6325	6378	934.2
3	5060	3915	988.2	4879	4019	583.4	4782	4231	547.3
4	4969	5557	727.0	4951	5695	598.0	5548	6225	974.9
5	6074	5112	1026	4559	5518	570.7	5355	5504	601.5
6	4875	5017	648.8	4618	5686	557.6	4801	5248	597.7
7	5355	5743	777.7	6337	6791	689.8	6390	8311	1671

*P<0.05

Observations were also made on the total daily feeding duration as well as the time spent feeding from the unfamiliar feeder during the first week post-weaning (Table 3.26). For the majority of the post-weaning period, the total time spent feeding from the unfamiliar feeders was not significantly different between the two treatments (*P*>0.05). Only on the third day after weaning did the piglets of the NF treatment spent significantly more time feeding from the unfamiliar feeder than FF piglets (*P*<0.05). That time spent was also significantly higher than the total amount of time that the FF piglets spent feeding (*P*<0.05). Piglets of the FF treatment were engaged in feeding for significantly more time during the fourth and seventh day post-weaning (*P*<0.05).

Table 3.26 Total feeding duration and time spent feeding from the unfamiliar feeders (s day^{-1} $piglet^{-1}$) were recorded for piglets of the two treatments (medians).

Day post-weaning	NF total feeding duration	FF total feeding duration	Q [a]	NF feeding duration (unfamiliar feeder)	FF feeding duration (unfamiliar feeder)	Q [a]
1	3118	3101	-0.517	2870	2398	2.929
2	6125	6171	-2.757	5662	4782	3.963
3	4475	3976	10.338*	4238	2732	16.197***
4	5009	5665	-9.994*	4629	4936	-5.341
5	4923	5553	-8.788	4678	4893	-6.030
6	4905	5284	-9.305	4690	4407	-0.862
7	5669	6405	-10.51*	5174	5911	-10.511*

**P*<0.05, ****P*<0.001
[a] = statistics performed with non-parametric Kruskal-Wallis (for 2 treatments the estimated Q value must be over 1.960 for significant difference (Eddison, 2000)).

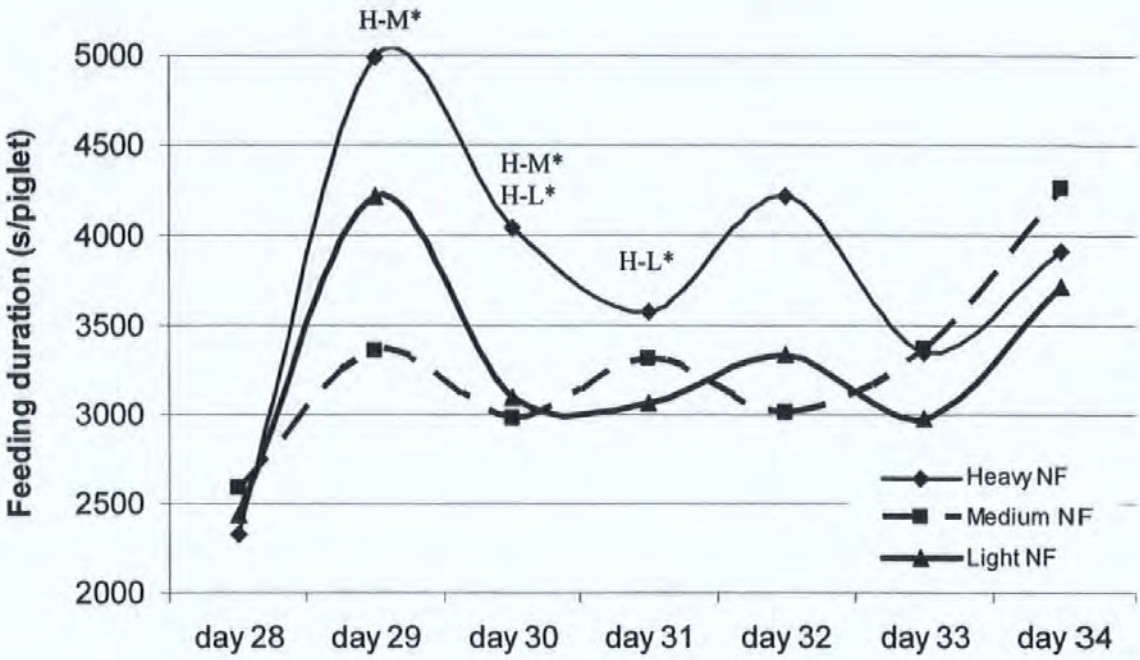
Correlation coefficients were calculated to identify relationships between total feeding, drinking and sucking experience during the week pre-weaning as well as the day before weaning with feeding duration recorded for day 1, 2 and 3 post-weaning for both treatments. There was a strong relationship between pre-weaning feeding duration the day before weaning and post-weaning feeding duration the day after weaning for piglets on the NF treatment (r = 0.494, $P<0.001$). There was no correlation between total pre-weaning feeding behaviour and total feeding duration (sum of duration from both feeders) for the first three days post-weaning for piglets on the FF treatment ($P>0.05$). On the other hand, piglets that were observed to spend more time at the udder during lactation had a low attendance duration at the familiar feeder during day 1 post-weaning (r=-0.429, P=0.002) as they showed a preference for the unfamiliar feeder (r=0.389, $P<0.01$). Also, there was a significant correlation between pre-weaning feeding experience and usage of the unfamiliar trough during Day 1 after weaning (r=0.316, $P<0.05$) for piglets on the FF treatment.

In order to identify the imitation effect in feeding behaviour between piglets of the two treatments (with or without the presence of the familiar feeder) that Appleby *et al.*, (1991) recorded during the first days after weaning, the piglets were observed while they fed alone, or at the presence of one or more of their littermates (Table 3.27). It was found that piglets that were provided with a familiar feeder spent significantly more time feeding alone (on both feeders) throughout the post-weaning week than piglets of the NF treatment. Social feeding was not significantly different between the two treatments except on day 3 that the NF piglets showed an increased tendency to feed simultaneously with their littermates in contrast to piglets of the FF treatment ($P<0.05$). Overall, piglets of both treatments showed a highly significant preference to feed simultaneously with one or more of their littermates than feeding alone ($P<0.001$; Table 3.27). More specifically, it was observed that the heavy piglets on the NF treatment had the tendency to feed simultaneously with one or more of their littermates throughout the post-weaning week (Figure 3.21) but the difference was only significant during the first four days post-weaning ($P<0.05$). The significantly higher tendency of the Heavy NF piglets to feed simultaneously with one or more of their littermates was drawn from their incapability to approach the feeder alone (due to limited pre-weaning feeding experience) in comparison to their littermates ($P<0.05$, Table 3.28). On the other hand, the provision of the familiar feeder, helped the piglets of all classes to approach the feed individually and spent non-significantly different periods of time in feeding ($P>0.05$, Table 3.28) than their littermates irrespective of their pre-weaning feeding experiences. The difference in 'feeding alone duration' between piglets of the two treatments which belonged to the less pre-weaning feeding experienced class (ATS piglets), was highly significant between them, with piglets that provided with a familiar feeder to spent significantly more time feeding alone ($P<0.01$, Table 3.28). The provision of the familiar feeder was also favoured by the more experienced piglets (PTS; regarding their pre-weaning feeding behaviour) to feed for significantly more time ($P<0.05$, Table 3.28) in comparison with the equivalent piglets of the NF treatment.

Table 3.27 Feeding duration (s piglet^{-1}) alone or with the presence of one or more of their littermates ('social feeding'), between piglets of the two treatments.

Day post-weaning	NF Feeding alone	FF Feeding alone	s.e.d.	NF Social feeding	FF Social feeding	s.e.d.
1	1215 ^{a}	1299 ^{b}	240.3	2450 ^{a}	2380 ^{b}	350.2
2	1875 ^{a}	2473 ^{b}	286.6*	4191 ^{a}	3747 ^{b}	383.5
3	1523 ^{a}	1608 ^{b}	194.7	3375 ^{a}	2461 ^{b}	368.0*
4	1728 ^{a}	2513 ^{b}	283.9**	3322 ^{a}	3418 ^{b}	280.2
5	1667 ^{a}	2001 ^{b}	152.5*	3521 ^{a}	3518 ^{b}	374.0
6	1506 ^{a}	1949 ^{b}	195.0*	3234 ^{a}	3470 ^{b}	254.6
7	2189 ^{a}	2254 ^{b}	516.9	3963 ^{a}	4552 ^{b}	373.1

(in the comparison between social and non-social feeding within treatments, values with the same superscript in a row differ accordingly: ^{a} $P<0.001$, ^{b} $P<0.001$)
*$P<0.05$, **$P<0.01$



*$P<0.05$ (significant difference between two classes), H=Heavy, M=Medium and L=Light

Figure 3.21 Feeding duration (s piglet^{-1}) of the NF piglets with the presence of one or more of their littermates according to their LW-classification.

Table 3.28 Total duration of feeding 'alone' (s piglet^{-1}) during the week post-weaning according to the teat-classification of the piglets (within and between treatments comparison of medians).

	ATS (1)	MTS (2)	PTS (3)	Q 1-2	Q 1-3	Q 2-3
NF	7363	16125	9706	-8.118*	-4.371*	-3.517*
FF	13366	11583	14244	0.284	-1.884	2.046
NF *vs.* FF	-8.856**	1.786	-3.832*			

[a] = statistics performed with non-parametric Kruskal-Wallis (for 2 treatments the estimated Q value must be over 1.960 for significant difference; for 3 treatments the estimated Q value must be over 2.394 for significant difference (Eddison, 2000)).
*$P<0.05$,**$P<0.01$

3.3.4.3 Post-weaning drinking behaviour

Factorial analysis was employed in order to identify the main factors which could influence the total drinking duration of the piglets post-weaning. It was identified that there was no significant effect of any of the three main factors (treatment, teat-order and LW classification) or a combination of those on total post-weaning feeding duration (P>0.05). Only total pre-weaning drinking duration had an effect on total post-weaning drinking behaviour expressing though a very small percentage of the variation (F=7.26; d.f.=1,94; R^2_{adj}=6.2%; P<0.01).

Factorial analysis was also carried out in order to identify the main effects which could influence the daily post-weaning drinking duration. There was no significant effect of any of the main factors (treatment, LW classification and teat-order) on drinking duration recorded on day one after weaning (P>0.05). Regression analysis showed a significant positive effect of pre-weaning suckling duration on post-weaning drinking duration having though a very small prediction power (F= 4.40; d.f.=1,94; R^2_{adj}=3.5%; P<0.05). The results of a GLM-Anova test showed that light piglets that were suckling the posterior teats of the udder spent significantly more time at the drinkers (175 s) than heavy piglets that were suckling the anterior (175 s *vs.* 148 s, s.e.d = 0.1654, P<0.05) and middle (175 s *vs.* 165 s, s.e.d = 0.1645, P<0.05) teats of the udder (the s.e.d refers to the comparisons which employed after treating the data using $\log_{10}$ transformation). After day four post-weaning, treatment was the only factor which could influence significantly the daily drinking duration of the piglets. A more detailed analysis is presented in Table 3.29.

Drinking duration was not significantly different between piglets on the two treatments for the largest proportion of the post-weaning week, except on days four and seven that piglets of the FF treatment spent significantly more time at the drinkers ($P<0.05$, Table 3.29). Drinking duration recorded on day one post-weaning for piglets on both treatments was not correlated with total pre-weaning feeding, drinking and suckling duration or any behavioural durations for the day before weaning. For piglets of the FF treatment there was a positive correlation between feeding and drinking duration during the day before weaning with drinking duration on day 2 post-weaning ($r= 0.337$, $P<0.05$ and $r= 0.335$, $P<0.05$ respectively).

Table 3.29 Main daily drinking duration (day^{-1} $piglet^{-1}$) ± SEM's between piglets of the two treatments.

Day post-weaning	NF treatment	FF treatment	s.e.d.[a]
1	600 ± 72.79	717 ± 72.79	0.051
2	781 ± 116.71	572 ± 116.71	0.066
3	351.6 ± 44.66	365.7 ± 44.66	0.059
4	388.5 ± 125.67	733.5 ± 125.67	0.067*
5	370.8 ± 57.69	413.1 ± 57.69	0.063
6	344.6 ± 48.82	469.1 ± 48.82	0.057
7	312.0 ± 72.84	522.6 ± 72.84	0.063*

[a] the s.e.d refers to the comparisons which employed after treating the data using $\log_{10}$ transformation
*$P<0.05$

There was no correlation between daily feeding and drinking duration during the post-weaning week for piglets of both treatments. A within treatment analysis showed that during day 1 post-weaning the heaviest piglets on the NF treatment were spending more time at the drinkers than their medium and lightest littermates ($P<0.05$, Table 3.30). The heaviest piglets were also observed to occupy the drinkers for longer than their medium-weight pen-mates during the sixth day post-weaning ($P<0.05$). There was no significant difference in drinker occupation time between piglets of different LW-classification on the FF treatment (Figure 3.22).

Table 3.30 Mean daily drinking duration (day^{-1} piglet^{-1}) between piglets of different BW-classification (NF treatment).

Day post-weaning	Heavy (1)	Medium (2)	Light (3)	s.e.d 1-2	s.e.d. 1-3	s.e.d. 2-3
1	995	474	411	0.097*	0.124*	0.099
2	216	659	1432	0.141	0.181	0.145
3	263	371	434	0.098	0.125	0.101
4	130	415	761	0.132	0.168	0.134
5	547	194	401	0.133	0.170	0.136
6	555	191	310	0.097*	0.125	0.099
7	344	297	327	0.127	0.163	0.130

[a] the s.e.d refers to the comparisons which employed after treating the data using $\log_{10}$ transformation
*P<0.05

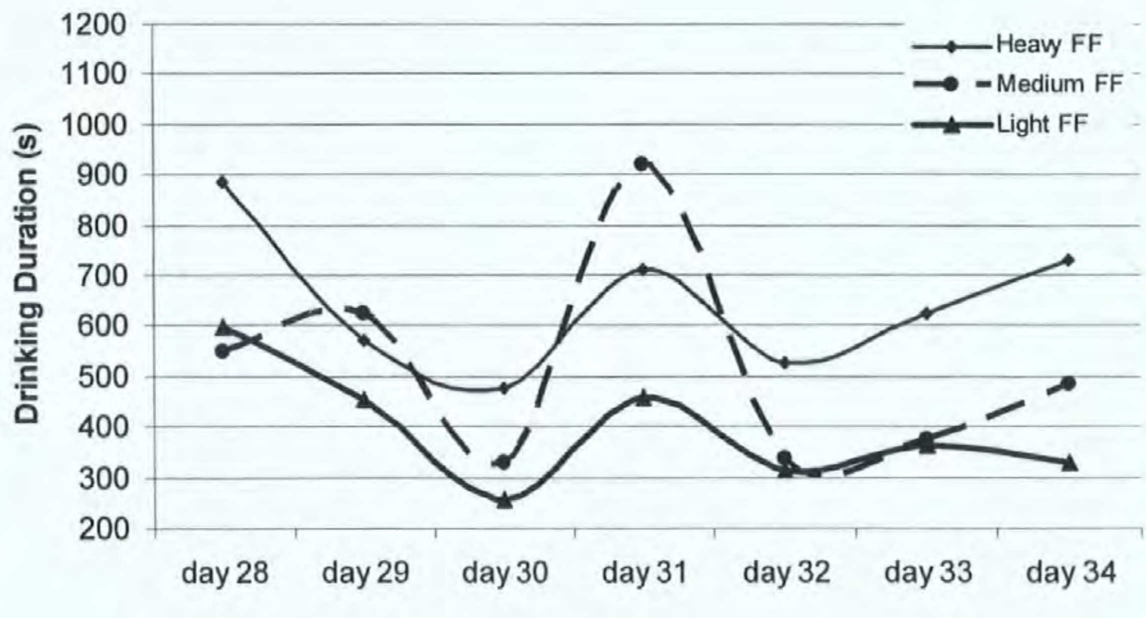


Figure 3.22 Mean drinking duration (day^{-1} piglet^{-1}) between piglets of different LW-classification of the FF treatment.

There were no significant differences in daily drinking duration between piglets of the two treatments which had the same LW and teat-order classification ($P>0.05$). The piglets of both treatments were also observed while they were drinking alone or at the presence of one or more of their littermates (Table 3.31). It was found that piglets of both treatments showed a preference for using the drinkers individually rather than with the presence of one or more of their pen-mates ($P<0.001$). Piglets of the FF treatment spent significantly more time drinking alone after the fourth day after weaning than piglets of the NF treatment ($P<0.05$), because the latter showed a tendency to spend significantly more time drinking with the presence of one or more of their littermates throughout the post-weaning week than piglets of the FF treatment ($P<0.05$). On a weekly basis, NF piglets of all classes (regarding their teat-position) were engaged for significantly more time in 'social' drinking than equivalent piglets of the FF treatment ($P<0.05$, Table 3.32).

Table 3.31 Drinking duration (s piglet^{-1}) alone or with the presence of one or more of their littermates (social drinking), between piglets of the two treatments (medians).

Day post-weaning	NF Drinking alone	FF Drinking alone	Q^a	NF Social Drinking	FF Social Drinking	Q^a
1	424^b	442^c	-4.652	99^b	48^c	11.038*
2	432^b	365^c	3.618	57^b	32^c	23.682***
3	270^b	222^c	6.721	47^b	16^c	12.161*
4	288^b	389^c	-11.899*	23^b	13^c	3.142
5	227^b	279^c	-8.615	38^b	22^c	16.578***
6	241^b	329^c	-12.578**	34^b	8^c	19.099***
7	233^b	334^c	-15.356**	16^b	9^c	7.935

*$P<0.05$, **$P<0.01$, ***$P<0.001$

^{a} = statistics performed with non-parametric Kruskal-Wallis (for 2 treatments the estimated Q value must be over 1.960 for significant difference (Eddison, 2000)).

(in the comparison between social and non-social feeding within treatments, values with the same superscript in a row differ accordingly: ^{b} $P<0.001$, ^{c} $P<0.001$)

Table 3.32 Total duration of 'social' drinking (s piglet^{-1}) during the week post-weaning according to the teat-classification of the piglets (within and between treatments comparison of medians).

	ATS (1)	MTS (2)	PTS (3)	Q^a 1-2	Q^a 1-3	Q^a 2-3
NF	628	424	459	3.397	3.951	-0.362
FF	362	148	147	3.244	4.592	-1.161
NF *vs.* FF	7.068*	-3.317*	6.131*			

[a] = statistics performed with non-parametric Kruskal-Wallis (for 2 treatments the estimated Q value must be over 1.960 for significant difference; for 3 treatments the estimated Q value must be over 2.394 for significant difference (Eddison, 2000)).
*P<0.05

3.3.4.4 Fighting, chewing and belly-nosing behaviour during the week post-weaning

Factorial analysis could not be employed to identify the effect of variable factors on total post-weaning fighting, belly-nosing and chewing behaviour because the data did not conform to a normal distribution (Hair *et al.*, 1998). Daily observations for the above behaviours were tested using the non-parametric Kruskal-Wallis test (Table 3.33). It was observed that fighting duration was not significantly different between the two treatments on a daily (P>0.05) as well as on a weekly basis (P>0.05). Piglets of the NF treatment were engaged for significantly more time in belly nosing behaviour during the first two days post-weaning than piglets of the FF treatment (P<0.05). Even though piglets of the FF treatment were only spending significantly more time in chewing behaviour in few occasions (days 2 and 4 post-weaning P<0.05), on a weekly basis they were engaged for significantly more time in chewing the chains and the surroundings of the pen than piglets of the NF treatment (P<0.05).

Table 3.33 Daily fighting, belly-nosing and chewing duration (average s day^{-1} $piglet^{-1}$) between piglets of the two treatments (table presents medians).

Day	Fighting Duration			Belly-nosing Duration			Chewing Duration		
	NF	FF	Q	NF	FF	Q	NF	FF	Q
1	302	302	-3.618	16	2	13.131**	1084	1313	8.271
2	992	981	1.723	49	0	11.418*	1620	2032	-12.062*
3	475	466	-1.378	24	20	-1.303	1030	1125	-3.963
4	403	570	6.720	0.0	0.0	-1.926	734	1544	-12.234*
5	357	616	-12.493*	0.0	0.0	2.798	681	712	-4.652
6	447	319	4.307	0.0	0.0	3.697	847	814	-3.102
7	700	454	9.649*	0.0	0.0	-2.838	1503	1436	2.067
Total	4662	4656	1.895	64	101	-4.164	8473	11871	10.683*

*$P<0.05$, **$P<0.01$

Tables 3.34 and 3.35 present the results of the correlation tests which were undertaken to identify relationships between post-weaning fighting and agonistic activities with pre-weaning recorded behaviours as well as with any of the behaviours observed during the post-weaning period respectively. Pre-weaning feeding experience was positively correlated with fighting duration on day 1 post-weaning for piglets of the NF treatment ($P<0.01$). Also, for piglets of the FF treatment extensive pre-weaning fighting duration was positively correlated with longer fighting duration on day 1 post-weaning ($P<0.05$) and longer periods of chewing behaviour ($P<0.01$) for piglets of the NF treatment. On the second and third day after weaning, extensive pre-weaning suckling duration was positively correlated with fighting duration for piglets of the FF treatment ($P<0.05$ and $P<0.01$ respectively).

Belly-nosing during the first day after weaning was not correlated with pre-weaning feeding, drinking and suckling duration for both treatments. Only on the second day post-weaning, was pre-weaning feeding and drinking duration positively correlated with belly nosing for piglets of the FF treatment ($P<0.001$ and $P<0.05$ respectively). After the third day post-weaning NF piglets that expressed extensive pre-weaning feeding duration were also engaged in longer periods of post-weaning belly-nosing until the end of the week ($P<0.05$). On the other hand, extensive pre-weaning feeding and drinking duration for piglets of the FF treatment were correlated negatively with daily belly-nosing duration for the period commencing day 4 to day 7 post-weaning ($P<0.001$). Extensive pre-weaning feeding behaviour of FF piglets was also correlated positively with chewing duration during the last two days of the post-weaning week ($P<0.05$).

A comparison between daily post-weaning behaviours showed that fighting duration for day one post weaning was positively correlated with chewing duration for FF piglets ($P<0.01$) and negatively for NF piglets ($P<0.01$). After the third day post-weaning, increased presence of the FF piglets at the drinkers was positively correlated with fighting duration ($P<0.05$). For the first two days post-weaning there was no correlation between feeding and drinking duration for piglets of both treatments ($P>0.05$). Chewing duration was positively correlated with drinking behaviour during most of the post-weaning period ($P<0.05$) for FF piglets. Finally, belly-nosing duration was highly negatively correlated with chewing behaviour ($P<0.001$) during the fourth and fifth day after weaning for NF piglets.

Table 3.34 Correlation between variable daily post-weaning behavioural observations within treatments

Day	Fighting	Chewing	Drinking
28	NF Chewing (-0.375**) FF Chewing (0.414**)		
29	FF Drinking (0.458***)		
30	FF Drinking (0.316*) FF Feeding (0.487***)		FF Feeding (0.473***) FF Chewing (0.335*)
31	FF Drinking (0.291*)	NF Belly-nosing (-0.491***) FF Feeding (0.344*)	FF Feeding (-0.320*) FF Chewing (-0.345*)
32	FF Chewing (0.515***) FF Belly-nosing (0.945***) FF Drinking (0.456***)	NF Belly-nosing (-0.468***) FF Belly-nosing (0.532***)	NF Belly-nosing (-0.347*) FF Belly-nosing (0.534***) FF Chewing (0.440**)
33	NF Belly-nosing (0.457***) NF Drinking (-0.294*)	NF Belly-nosing (0.319*)	FF Chewing (0.359*)
34	FF Chewing (0.491***)	FF Belly-nosing (-0.417**)	

*$P<0.05$, **$P<0.01$, ***$P<0.001$
Number in brackets = r of the Spearman rank correlation

Table 3.35 Correlations between variable pre-weaning behaviours and daily post-weaning aggressive and abnormal interactions for each treatment.

Post-weaning daily Fighting duration (s) *vs.* pre-weaning				
Day	**Fighting duration**	**Drinking duration**	**Feeding duration**	**Suckling duration**
28	FF (0.324*)		NF (0.385**)	
29				FF (0.283*)
30				FF (0.398**)
32			NF (-0.312*)	
33			NF (0.468***)	

Post-weaning daily belly-nosing duration (s) *vs.* pre-weaning				
Day	**Fighting duration**	**Drinking duration**	**Feeding duration**	**Suckling duration**
28	NF (-0.363*)			
29		FF (0.363*)	FF (0.447***)	
30	NF (0.360*)		NF (0.360*)	
31			NF (0.410**) FF (-0.462***)	
32			NF (0.279*)	
33		FF (-0.365*)	NF (0.341*) FF (-0.422**)	FF (0.421**)
34		FF (-0.315*)	NF (0.350*) FF(-0.566***)	

Post-weaning daily Chewing duration (s) *vs.* pre-weaning				
Day	**Fighting duration**	**Drinking duration**	**Feeding duration**	**Suckling duration**
28	NF (0.370**)			
29	NF (0.358*)		NF (0.358*)	
33		NF (-0.288*)	FF (0.304*)	
34			FF (0.362*)	

*P<0.05, **P<0.01, ***P<0.001
Number in brackets = r of the Spearman rank correlation

Comparisons were also made between piglets of the same treatment. There was no significant difference in fighting duration between piglets of different LW-classification on the NF treatment during the first 3 days after weaning (Figure 3.23). Piglets of medium weight were more aggressive after the 3rd day post weaning and the difference became significant with the light weight piglets only on day 4 (D32: 711 *vs.* 30 (s.e.d. = 306.6) s; $P<0.05$ respectively). On the other hand, fighting behaviour patterns were more distinct between piglets of the FF treatment (Figure 3.24). Heavy and medium weight piglets were significantly more aggressive during the first two days post-weaning than the lightest piglets of the litter (Day 28: H=601 *vs.* L=243 (Q=6.742) s; $P<0.05$, M=481 *vs.* L=243 (Q=-5.6) s; $P<0.05$, Day 29: H=1709 *vs.* L=751 (Q=7.65) s; ($P<0.05$), M=1425 *vs.* L=751 (Q=7.65) s; $P<0.05$ respectively).

Chewing behaviour had also no distinct pattern for piglets of the NF treatment throughout the week post-weaning except on day 1 after weaning when MTS-piglets were engaged for less time on chewing than PTS ($P>0.05$) and ATS-piglets of the litter (1002 *vs.* 2654 (s.e.d.=693.3) s; $P<0.05$) (Figure 3.25). On the other hand, ATS and PTS-piglets of the FF treatment were spending more time chewing on day 2 post-weaning than MTS-piglets (ATS=4438 *vs.* MTS=2153 (Q=3.825) s; $P<0.05$, (PTS=2671 *vs.* MTS=2153 (Q=-3.37) s; $P<0.05$, ATS *vs.* PTS (Q=3.825) s; $P<0.05$ respectively). On day 31, ATS- piglets continued to express significantly more chewing behaviour than MTS (3218 *vs.* 1914 (Q=4.38) s; $P<0.05$) and PTS (3218 *vs.* 1326 (Q=6.829) s; $P<0.05$) piglets. There were no significant differences in belly-nosing behaviour between piglets of different teat-order classification within each treatment ($P>0.05$, Figures 3.27 and 3.28)

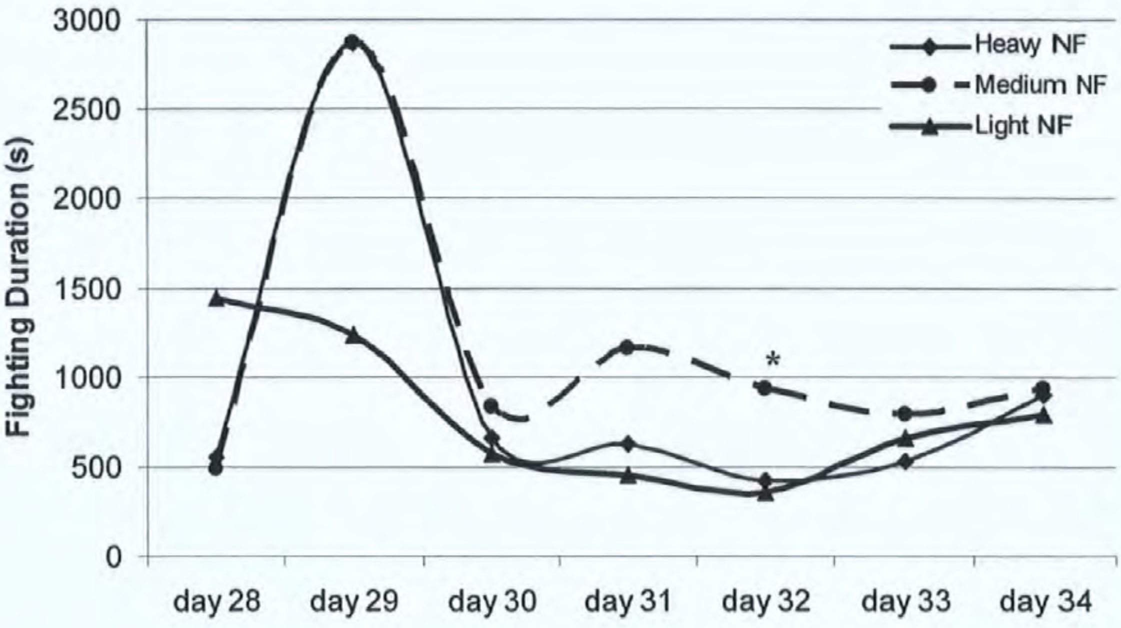


Figure 3.23 Mean fighting duration (s day^{-1} $piglet^{-1}$) between piglets of different LW-classification within NF treatment.

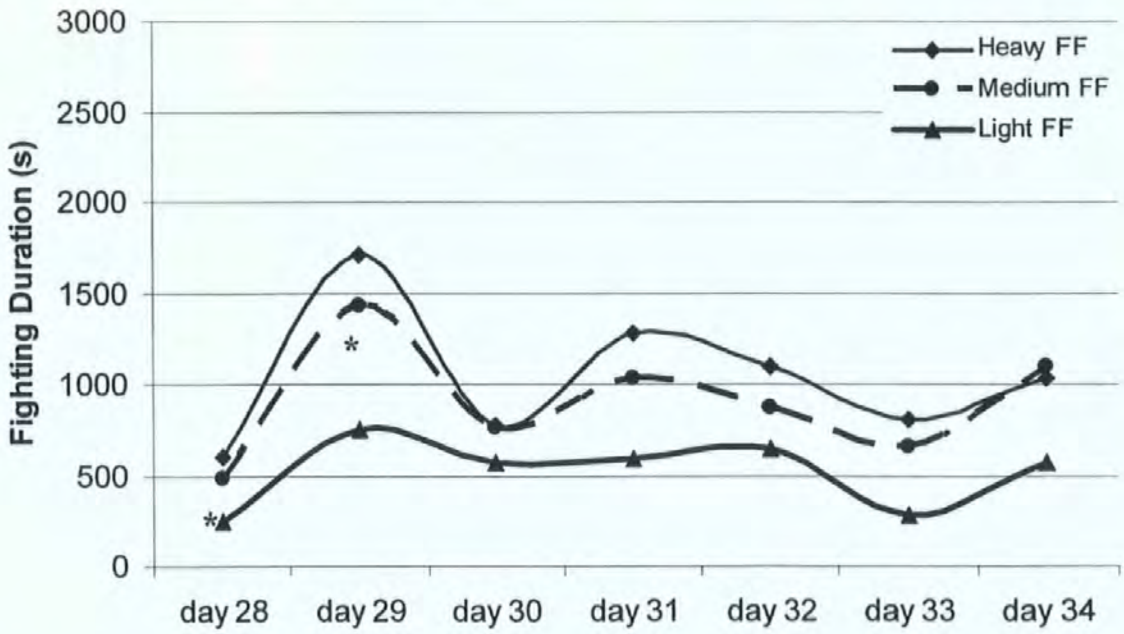


Figure 3.24 Mean fighting duration (s day^{-1} $piglet^{-1}$) between piglets of different LW-classification within FF treatment.

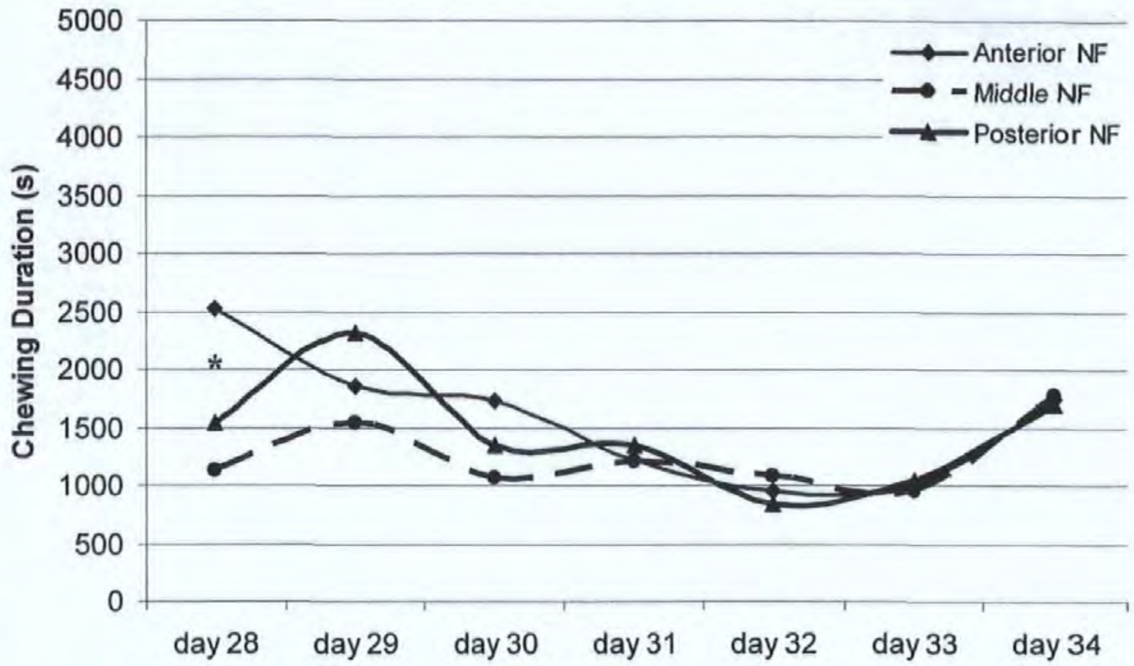


Figure 3.25 Mean chewing duration (s day^{-1} piglet^{-1}) between piglets of different teat-order classification within NF treatment.

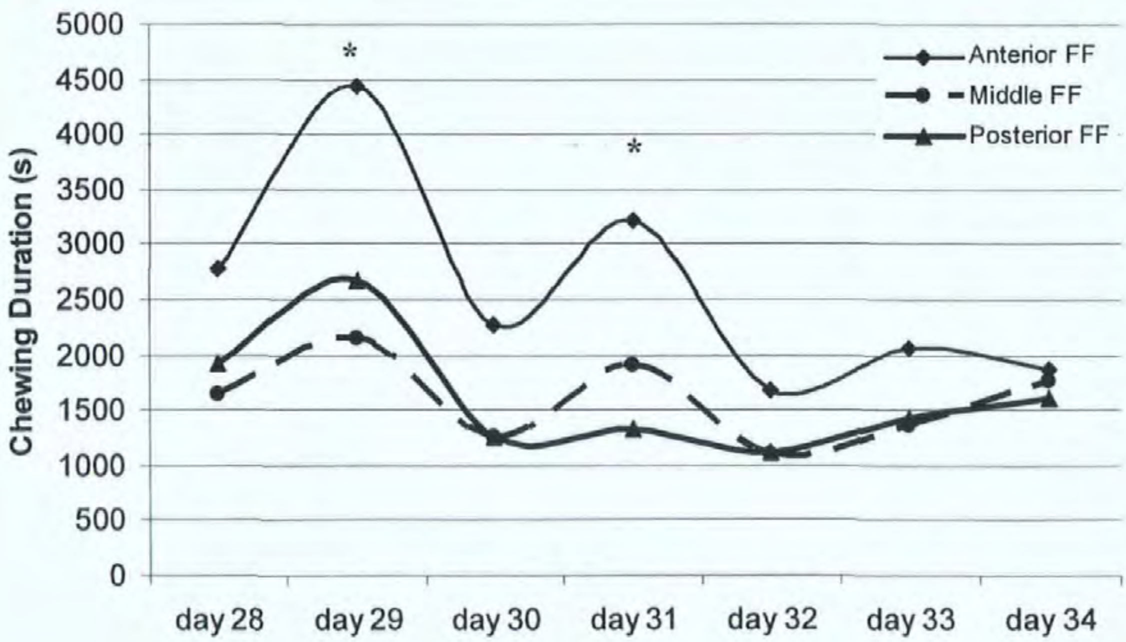


Figure 3.26 Mean chewing duration (day^{-1} piglet^{-1}) between piglets of different teat-order classification within FF treatment.

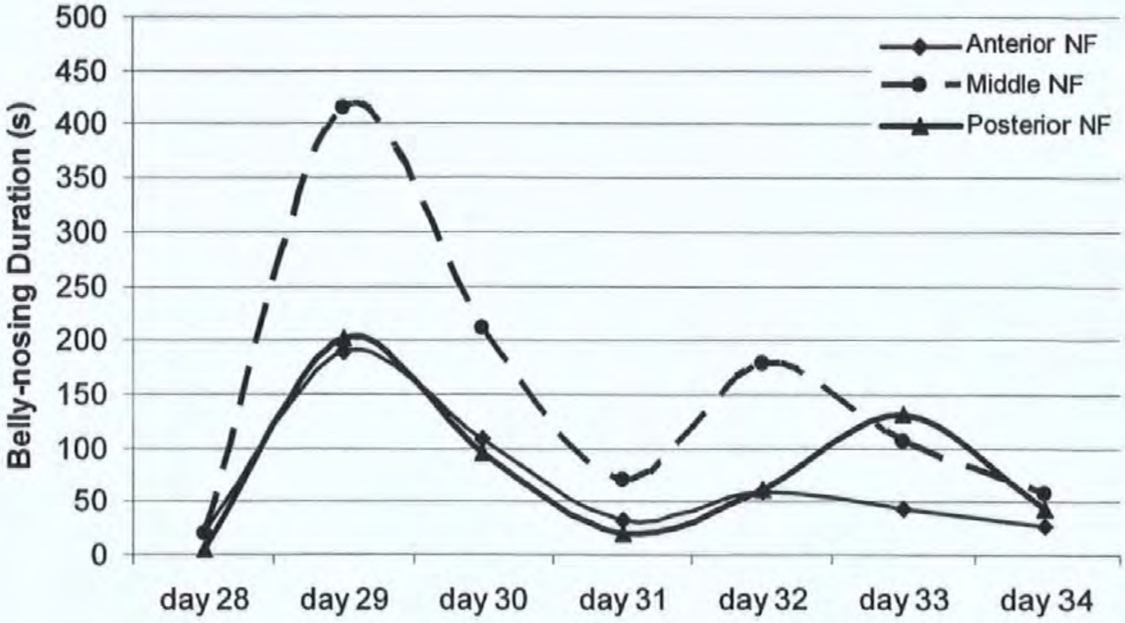


Figure 3.27 Mean belly-nosing duration (day^{-1} $piglet^{-1}$) between piglets of different teat-order classification within NF treatment.

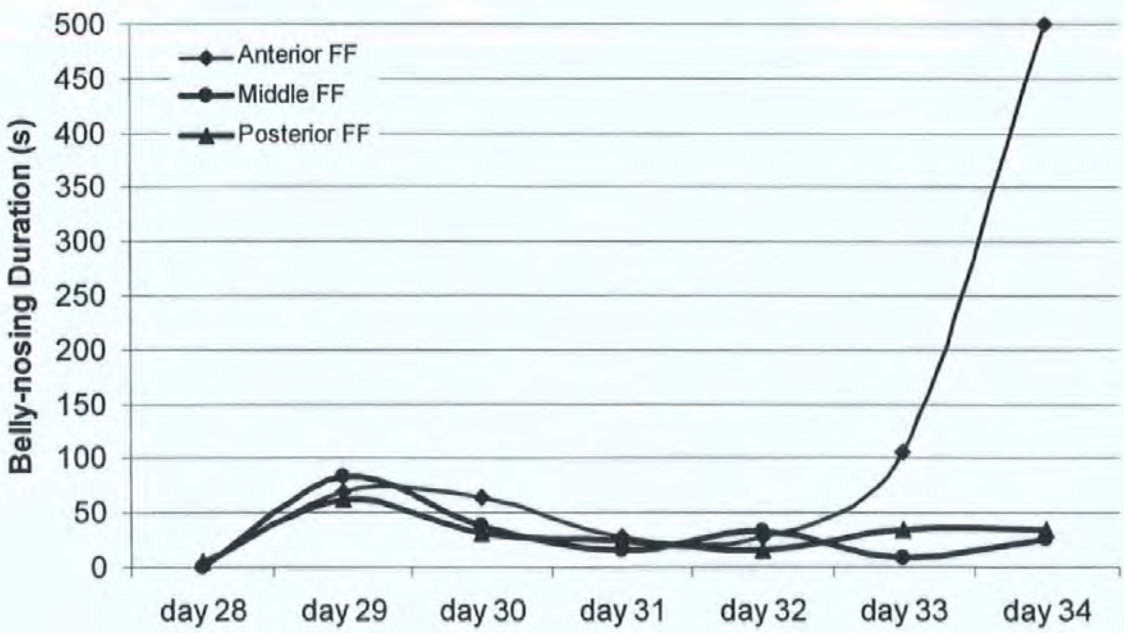


Figure 3.28 Mean belly-nosing duration (day^{-1} $piglet^{-1}$) between piglets of different teat-order classification within FF treatment.

Spearman rank correlations were calculated within each treatment in order to identify relationships between various post-weaning behaviours (sum for each period) with weekly LW, LWG performance and teat-order (Tables 3.36 and 3.37). It was identified that for NF piglets (Table 3.36) there was a negative relationship between LWG for the first week post-partum and drinking behaviour for the period day1 to day3 post-weaning ($P<0.05$) as well as with belly-nosing duration for the period commencing day3 to day7 post-weaning ($P<0.05$). Also, NF piglets, which gained less weight during the 3rd week of lactation, were more aggressive during the post-weaning week ($P<0.05$). Finally, PTS piglets had more chances of spending more time feeding during the first three days post-weaning ($P<0.05$), while ATS-piglets expressed longer fighting behaviour during the second part of the post-weaning week ($P<0.05$) and occupied the drinkers for longer periods of time during the post-weaning week ($P<0.05$).

Table 3.36 Spearman rank correlations for various post-weaning behaviours (sum for each period) with weekly LW - LWG performance and teat-order (NF treatment).

	Period day1-day3	**Period day3-day7**	**Period day1-day7**
BW			
LW week1	Drinking (-0.318*)		
LW week2			
LW week3			
WW			
LWG week1	Drinking (-0.296*)	Belly-nosing (-0.302*)	
LWG week2			
LWG week3			Fighting (-0.315*)
LWG week4			
Teat-order 1=ATS, 2=MTS, 3=PTS	Feeding (0.368*)	Fighting (-0.314*)	Drinking (-0.333*)

*$P<0.05$

On the other hand, FF piglets of heavier LWs from birth to weaning had more chances to be involved in more fighting and drinking behaviour during most of the post-weaning period ($P<0.05$). FF piglets which were scoring lower LWGs during the first and fourth week post-partum had more chances of spending extra time at the feeders during the post-weaning week ($P<0.05$).

Table 3.37 Spearman rank correlations for various post-weaning behaviours (sum for each period) with weekly LW - LWG performance and teat-order (FF treatment).

	Period day1-day3	**Period day3-day7**	**Period day1-day7**
BW	Drinking (0.329*)	Fighting (0.325*) Drinking (0.475***)	Fighting (0.300*)
LW week1	Fighting (0.356*) Chewing (0.316*) Belly-nosing (0.325*)	Drinking (0.316*)	Fighting (0.300*)
LW week2	Fighting (0.388*)	Drinking (0.378*)	Fighting (0.300*)
LW week3	Fighting (0.420**) Drinking (0.351*)	Drinking (0.383*)	Fighting (0.352*)
WW	Fighting (0.415**) Drinking (0.338*)	Drinking (0.386*)	Fighting (0.401**)
LWG week1	Fighting (0.364*) Chewing (0.307*) Feeding (-0.299*) Belly-nosing (0.325*)		
LWG week2	Fighting (0.364*)	Drinking (0.391**)	Fighting (0.356*)
LWG week3		Drinking (0.313*)	Fighting (0.319*)
LWG week4			Fighting (0.322*) Feeding (-0.315*)
Teat-order 1=ATS, 2=MTS, 3=PTS	Chewing (-0.299*)		Chewing (0.322*)

*$P<0.05$, **$P<0.01$

The various correlations that were examined in order to identify relationships between pre- and post-weaning behaviour within each treatment (Table 3.38) showed that extensive pre-weaning drinking and feeding duration had a positive effect on NF piglets so as spent more time manipulating the chains of the pen (P<0.05). Post-weaning fighting duration was correlated negatively with pre-weaning feeding duration (P<0.05) and positively with suckling duration for NF piglets. The more aggressive piglets of the pre-weaning period had more chances of spending longer periods of time in belly-nosing post-weaning (P<0.01). Also, piglets that performed belly-nosing had low interest in chain manipulation (P<0.05).

Piglets of the FF treatment that had spent longer time drinking pre-weaning continued to spending more time at the drinkers post-weaning (P<0.01; Table 3.38) and they also became more aggressive (P<0.05). Drinking and fighting behaviour continued having a positive relationship post-weaning (P<0.05). Those piglets that had limited access to the udder pre-weaning showed an increased tendency to play with the chains (P<0.05). Chewing behaviour was also highly positively correlated with fighting duration (P<0.01).

Table 3.38 Spearman rank correlations for various post-weaning behaviours (sum for each period) with pre-weaning behavioural durations as well as with behaviours recorded during the post-weaning period (within treatments).

	NF treatment	FF treatment
Total pre-weaning period	***vs.* total post-weaning behaviour**	
Drinking	Chewing (0.311*)	Fighting (0.390*)
		Drinking (0.450**)
Feeding	Fighting (-0.343*)	
	Chewing (0.364*)	
Suckling	Fighting (0.495***)	Chewing (-0.326*)
Fighting	Chewing (-0.302*)	
	Belly-nosing (0.413**)	
Total post-weaning period	***vs.* total post-weaning behaviour**	
Fighting		Chewing (0.413**)
Chewing		
Drinking		Fighting (0.407**)
Feeding		
Belly-nosing	Chewing (-0.314*)	

*P<0.05, **P<0.01, ***P<0.001

A between treatment comparison showed that, independent of any LW-classification, piglets on the NF treatment had a tendency to perform more fighting and belly-nosing behaviour during the first two days after weaning and most of the days during the first week post-weaning (Figure 3.29 a-f). An exception was noticed for heavy piglets of the FF treatment which scored significantly more fighting behaviour during the second half of the post-weaning week (P<0.05; Figure 3.29a). Chewing behaviour was performed more often by heavy and light piglets of the FF treatment in comparison to medium weight piglets of the NF treatment, which had a tendency to engage more of their time on manipulating the chains (P<0.05) (Figure 3.29 h-j).

ATS and PTS-piglets of the NF treatment and MTS piglets of the FF treatment were observed to be more aggressive after weaning (Figure 3.30 a-c). On the other hand, chewing behaviour performed by ATS and MTS-piglets was observed to be significantly or numerically higher in FF treatment except PTS piglets of both treatments which were engaging almost identical periods of time manipulating the chain throughout the week post-weaning (Figure 3.30 g-i). MTS and PTS piglets of the NF treatment were also tending to be engaged for longer periods of time in belly-nosing behaviour during the post-weaning week (Figure 3.30 e-f).

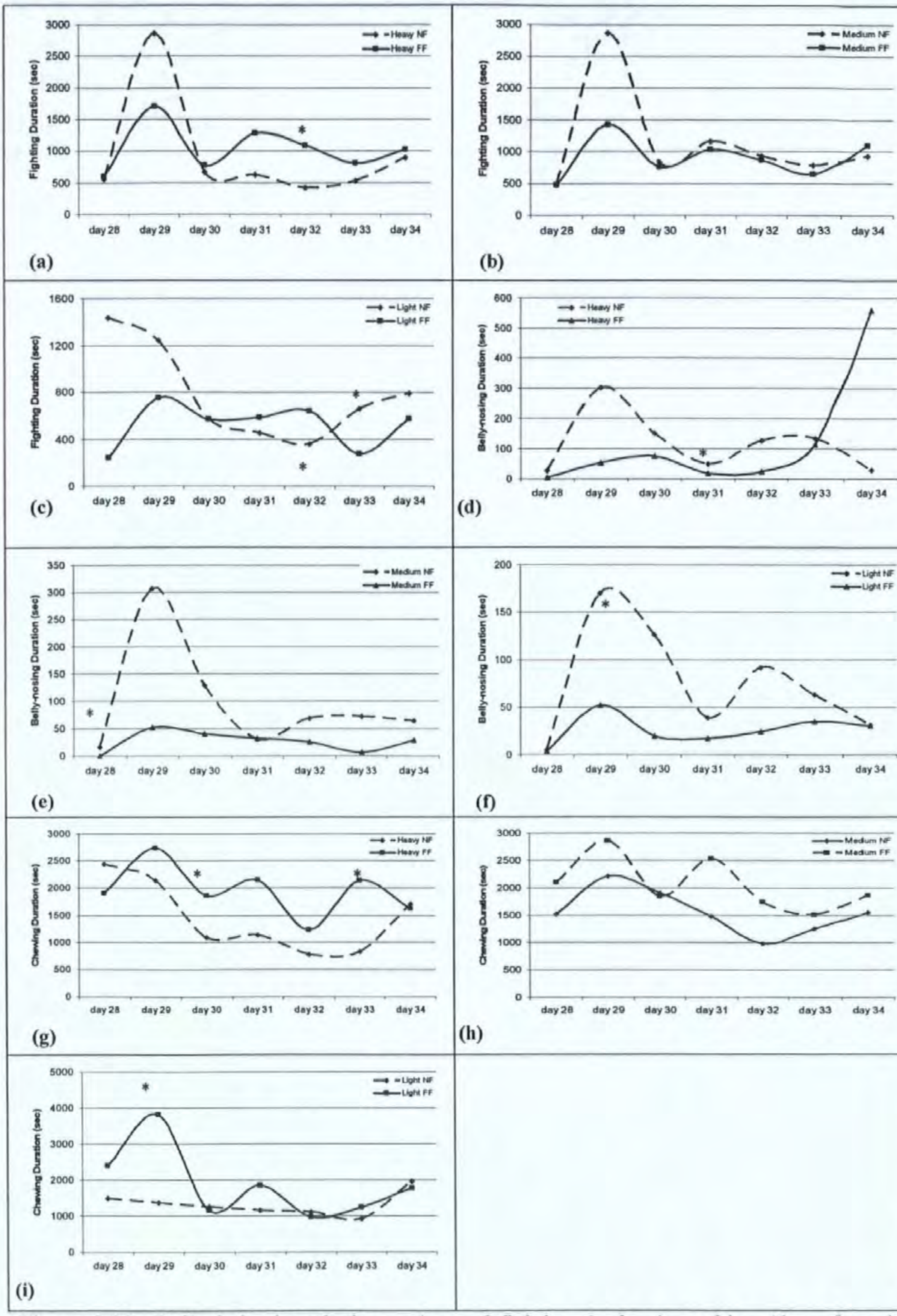


Figure 3.29 Daily behavioural observations of fighting (a, b, c), sucking (d, e, f) and chewing (g, h, i) activities between piglets of the same LW-classification from different treatments.

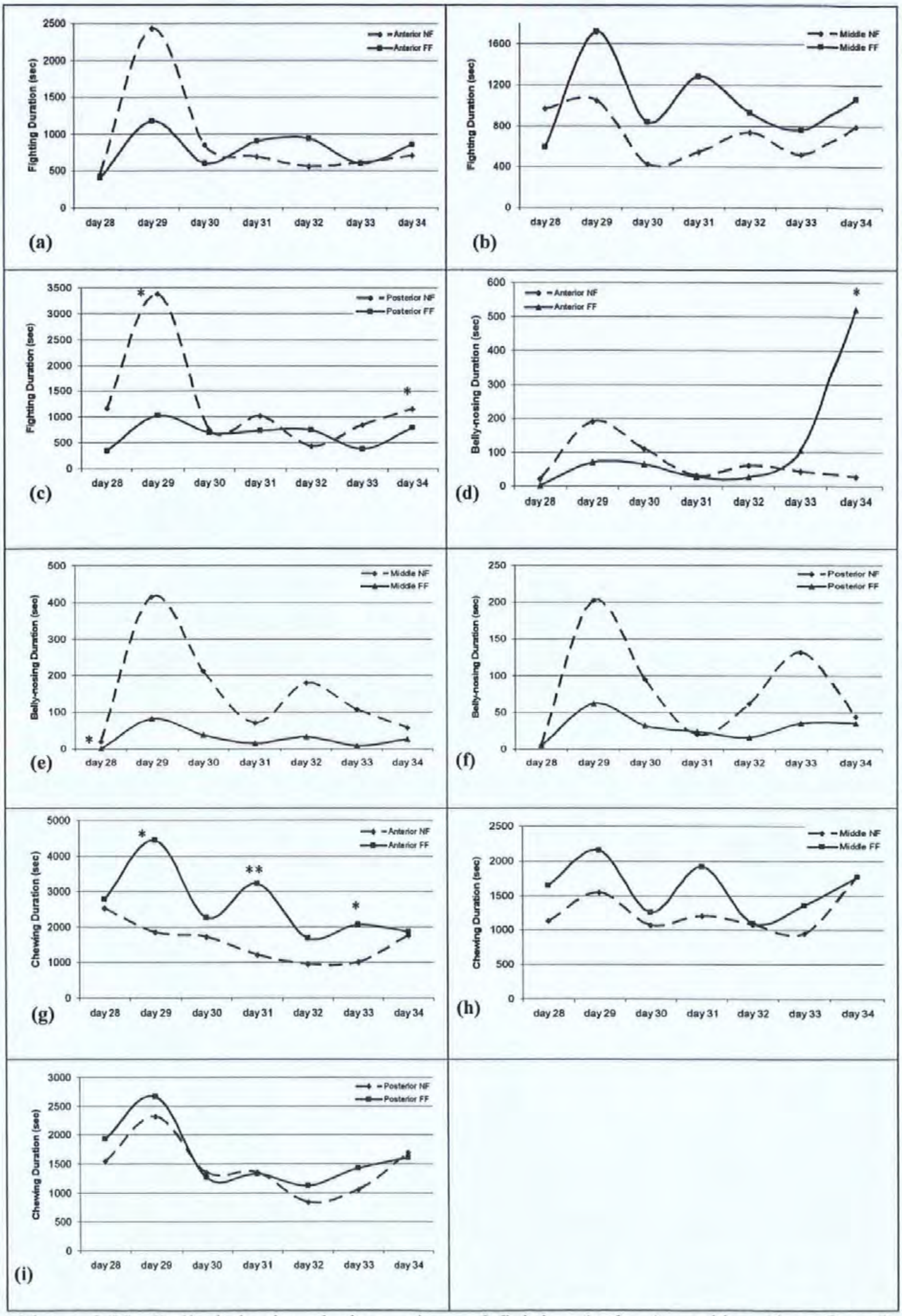


Figure 3.30 Daily behavioural observations of fighting (a, b, c), sucking (d, e, f) and chewing (g, h, i) activities between piglets of the same teat-sucking orientation from different treatments.

3.3.5 Assessment of gut health.

3.3.5.1 Pre-weaning lactobacilli:E.coli ratio.

Comparisons of faecal lactobacilli:*E.coli* ratios, which were sampled one day before weaning (D-1) between piglets of different LW and teat order classification are illustrated in Table 3.39. D-1 faecal lactobacilli:*E.coli* ratio was significantly higher for medium weight piglets than their lighter and heavier littermates ($P<0.05$). Also, the lighter piglets of the litter had significantly higher ratios of lactobacilli:*E.coli* at D-1 than the heaviest piglets of the litter ($P<0.05$). No significant difference in lactobacilli:*E.coli* ratio at D-1 was identified between piglets sucking different parts of the sow's udder.

Table 3.39 Faecal lactobacilli : *E.coli* ratios sampled one day before weaning between piglets of different classes (LW and teat order).

Classification of the piglets within their litter			Q value		
Heavy (1)	Medium (2)	Light (3)	1-2	1-3	2-3
0.2271	1.7415	0.4583	-9.822*	-3.102*	-6.72*
Anterior (1)	Middle (2)	Posterior (3)	1-2	1-3	2-3
0.508	0.789	0.550	-3.171	2.691	-5.378

*$P<0.05$

A regression analysis showed that there is a weak relationship between extensive presence at the feeders (7.7%) and faecal lactobacilli:*E.coli* ratios at D-1. Their relationship expressed by the following equation:

log D-1 faecal lactobacilli:*E.coli* ratios = -1.67 + 0.0173 (square root of tot. pre-weaning feeding duration) (F=6.84; d.f.=1,83; R^2_{adj}=7.7%; $P<0.05$) (Equation 3.4)

3.3.5.2 Post-weaning assessment of gut adaptation.

Factorial analyses were also employed in order to identify the main factors influencing the faecal lactobacilli:*E.coli* ratio differences between two sampling points. It was found that there was no difference in faecal lactobacilli:*E.coli* ratio between day 1 post-weaning and weaning (D1 faecal lactobacilli:*E.coli* ratio) for the two treatments ($P>0.05$, Table 3.40) and was not affected by the teat-order or LW-classification of the piglets ($P>0.05$, Table 3.41). Correlation analysis showed that for FF piglets (Table 3.41) the D1 faecal lactobacilli:*E.coli* ratio had a negative relationship with total pre-weaning drinking duration ($P<0.05$) and a positive one with feeding duration on day 1 after weaning ($P<0.05$). D1 faecal lactobacilli:*E.coli* ratio was negatively correlated with LWG the week pre-weaning ($P<0.05$) for NF piglets. A multiple regression analysis showed that 7.2% ($P<0.05$) of the variation on D1 faecal lactobacilli:*E.coli* ratio was attributed to teat-order of the piglets and 4.6% ($P<0.05$) to their drinking behaviour on day 1 post-weaning ($F=5.42$; d.f.=2,81; $R^2=11.8\%$; $P<0.01$).

For the period commencing day 1 to day 3 post-weaning, the faecal lactobacilli:*E.coli* ratio difference between those two sampling dates (D3 faecal lactobacilli:*E.coli* ratio) was significantly affected by the WW ($P<0.01$) and the total pre-weaning suckling ($P<0.01$) and fighting ($P<0.01$) duration. The treatment had no effect on D3 faecal lactobacilli:*E.coli* ratio (Table 3.40) and the effect of LW-classification refers to the higher D3 faecal lactobacilli:*E.coli* ratio ($\log_{10}$) recorded for light weight piglets on the NF treatment (1.67420 ± 0.4140) in relation to medium (-0.02795 ± 0.3778, $P<0.05$) and heavy (0.5609 ± 0.4482, $P>0.05$) piglets on the same treatment (values for the other classes = Heavy FF: -0.05537 ± 0.4623; Medium FF: 0.70254 ± 0.3737; Light FF: 0.94705 ± 0.5826). It was also showed that MTS-piglets of the NF treatment (1.8320 ± 0.4114) were scoring significantly higher D3 faecal lactobacilli:*E.coli* ratio ($\log_{10}$) than ATS-piglets of the same treatment (0.1500 ± 0.3198, $P<0.05$) and PTS-piglets of the FF treatment (-0.3610 ± 0.4128, $P<0.01$) (values for the other classes = PTS NF: 0.7585 ± 0.3807; ATS FF: 1.1540 ± 0.3605; MTS FF: 0.4920 ± 0.3597). The use of the non-parametric Kruskal-Wallis test identified also that the difference of the feacal ratio between ATS piglets of the two treatment was highly significant different (medians of ratios; NF= 0.075 *vs.* FF=0.610; Q= -7.446; $P<0.01$). The negative correlation between D3 faecal lactobacilli:*E.coli* ratio ($\log_{10}$) and teat-order ($P<0.05$) for FF piglets, shows that piglets suckling the further anterior teats had more chances of having higher lactobacilli counts in their faeces. There was a negative correlation between D3 faecal lactobacilli:*E.coli* ratio and chewing duration the day before sampling ($P<0.05$) and a positive relationship with active belly-nosing ($P<0.05$, Table 3.41). A multiple regression analysis attributed a very low value to the variation of D3 faecal lactobacilli:*E.coli* ratio on feeding duration for the period commencing day1 to day 3 post-weaning (F= 5.14; d.f.=1.82; R^2=5.9%, $P<0.05$).

For the periods commencing day 3 to day 7 post-weaning (D7 faecal lactobacilli:*E.coli* ratio) and from weaning to day 7 after weaning (D7-0 faecal lactobacilli:*E.coli* ratio), total pre-weaning drinking duration had a significant impact on faecal lactobacilli:*E.coli* ratio ($P<0.01$) and it was also highly negatively correlated with those two readings for FF piglets ($P<0.01$, Table 3.41). During these periods, NF piglets had significantly higher faecal lactobacilli:*E.coli* ratios than FF piglets ($P<0.001$, Table 3.40). A further statistical analysis using the non-parametric Kruskal-Wallis test to identify differences between piglets of the same classification, showed that the general difference of feacal D7 was attributed mainly on the significant difference which was recorded only between medium piglets of the two treatments ($P<0.05$, Table 3.42). Also, in the same way, the general difference of feacal D7-0 was attributed mainly on the significant difference which was recorded only between MTS piglets of the two treatments (medians of ratios: NF=171.400 *vs.* FF=-6.600; Q= 3.758; $P<0.05$). Both faecal lactobacilli:*E.coli* ratios were negatively correlated with post-weaning fighting and drinking duration for FF piglets ($P<0.05$) and were positively correlated with any form of belly-nosing (active, passive and sum of the two) for NF piglets ($P<0.05$, Table 3.49). Also, NF piglets with increased LWG performance the week pre-weaning had a tendency to score higher D7 and D7-0 faecal lactobacilli:*E.coli* ratios ($P<0.05$). A multiple regression analysis attributed 27.3% of the variation of D7 faecal lactobacilli:*E.coli* ratio on total pre-weaning drinking duration (4.3%, $P<0.01$), treatment (12%, $P<0.001$), LW classification (6.1%, $P<0.001$) and BW (4.8%, $P<0.05$) of the piglets and their relationship is provided by the following equation:

D7 faecal lactobacilli:*E.coli* ratio = 10.6 – 0.0735pre-weaning drinking duration – 1.65 treatment (NF=1; FF=2) – 1.04 LW classification (heavy=1; medium=2; light=3) – 1.81BW. (F= 7.42; d.f.=4,79; R^2=27.3%, $P<0.001$) (Equation 3.5)

On the other hand, 29.3% of the variation on D7-0 faecal lactobacilli:*E.coli* ratio was attributed to total pre-weaning drinking duration (13.9%, $P<0.001$), treatment (11.5%, $P<0.001$) and LW classification (3.9%, $P<0.001$) of the piglets and their relationship is provided by the following equation:

D7-0 faecal lactobacilli:*E.coli* ratio = 8.57 – 0.118pre-weaning drinking duration – 1.69 treatment (NF=1; FF=2) – 0.590 LW classification (heavy=1; medium=2; light=3) (F= 11.4; d.f.=3,80; R^2=29.3%, $P<0.001$) (Equation 3.6)

Table 3.40 Differences on Faecal lactobacilli:*E.coli* ratios between treatments.

Faecal lactobacilli:*E.coli* log_{10} ratio differences between two sampling points	NF	FF	s.e.d.
Day 1 post-weaning – weaning	-0.2761	0.0862	0.2601
Day 3 post-weaning -Day 1 post-weaning	0.9135	0.4283	0.3051
Day 7 post-weaning - Day 3 post-weaning	1.7615	0.2108	0.4536***
Day 7 post-weaning - weaning	2.3183	0.7074	0.4555***

****P*<0.001

Table 3.41 Correlations between pre- and post-weaning activities with lactobacilli:*Ecoli* ratio differences between two sampling points.

		Faecal lactobacilli:*E.coli* ratio differences between two sampling points							
Behavioural observations		day1-weaning		day3-day1		day7-day3		day7-weaning	
		NF	FF	NF	FF	NF	FF	NF	FF
BW		-0.057	-0.041	-0.159	0.146	0.211	-0.251	0.181	-0.213
LW week1		-0.003	-0.109	-0.285	-0.089	0.165	0.176	0.061	0.086
LW week2		-0.005	-0.174	-0.272	-0.028	0.231	0.120	0.120	0.024
LW week3		0.017	-0.127	-0.279	-0.076	0.182	0.123	0.092	0.015
LWG week1		0.028	-0.169	**-0.316***	-0.015	0.115	0.064	-0.017	-0.025
LWG week2		-0.006	-0.122	-0.196	-0.209	0.269	**0.389***	0.173	0.244
LWG week3		0.071	0.071	-0.146	-0.165	-0.058	0.064	-0.039	-0.019
LWG week4		**-0.342***	-0.26	0.013	0.153	**0.329***	-0.113	**0.298***	-0.128
Teat-order 1=ATS, 2=MTS, 3=PTS		0.195	0.176	0.241	**-0.296***	0.087	-0.004	0.188	-0.049
LS		0.029	0.175	0.015	-0.101	-0.035	0.177	-0.055	0.194
WW		-0.120	-0.169	-0.232	-0.015	0.285	0.064	0.196	-0.025
Total pre-weaning	Drink	0.006	**-0.367***	-0.156	0.056	-0.153	**-0.437****	-0.128	**-0.526*****
	Eat	0.076	-0.228	0.034	0.196	-0.198	-0.166	-0.182	-0.152
	Suckle	-0.085	0.035	0.073	0.009	0.173	**-0.375***	0.197	**-0.353***
	Fight	0.001	0.095	0.102	0.009	-0.003	0.173	0.089	0.230
1day before sampling	Fight	-0.018	-0.023	-0.027	0.078	**0.295***	-0.197	0.203	-0.350*
	Chew	-0.019	0.008	0.017	**-0.311***	0.021	-0.129	-0.009	**-0.297***
	Drink	-0.228	-0.164	-0.126	0.065	-0.060	-0.231	-0.087	**-0.312***
	Eat	**0.323***	-0.088	0.155	0.246	0.242	-0.071	**0.346***	-0.115
Belly nosing	Suck[a]	-0.220	0.233	0.038	**0.296***	0.284	0.241	0.265	0.241
	Sucked[b]	-0.014	-0.110	-0.023	-0.025	0.097	0.145	0.167	0.212
	Tot suck[c]	-0.210	0.132	-0.010	0.202	0.173	0.144	0.197	0.178

Total post-	Fight	-0.031	0.068	0.249	**-0.321***	0.191	**-0.418****
weaning	Chew	-0.058	-0.266	-0.096	0.086	-0.088	-0.097
period before	Drink	-0.097	0.042	0.144	**-0.379***	0.117	**-0.410****
sampling	Eat	0.206	0.293	0.029	-0.265	0.195	-0.181
Belly nosing	Suck[a]	-0.013	0.039	**0.394****	0.171	**0.378***	0.213
	Sucked[b]	-0.007	-0.060	**0.297***	**0.309***	0.202	0.269
	Tot suck[c]	0.028	0.066	**0.409****	0.227	**0.358***	0.207
Post-weaning	Fight			0.269	**-0.398****	0.141	**-0.519*****
period before	Chew			-0.192	-0.168	-0.192	-0.315*
sampling (d3-	Drink			0.094	**-0.372***	0.113	**-0.411****
7)	Eat			0.161	0.045	0.274	0.066
Belly nosing	Suck[a]			**0.429***	0.194	**0.377***	0.226
	Sucked[b]			0.268	0.280	0.210	0.264
	Tot suck[c]			**0.453****	0.263	**0.384***	0.238

*P<0.05, **P<0.01, ***P<0.001

Numbers = r and r_S of the correlation

Identification of belly-nosing behaviour: a= active sucking behaviour, b= passive sucking behaviour, c= sum of a + b

Table 3.42 Differences on D7 faecal lactobacilli:*E.coli* ratios within each treatments according to the LW-classification of the piglets (table presents medians of untransformed data).

	Heavy (1)	Medium (2)	Light (3)	Q1-2	Q1-3	Q2-3
NF	77.15	141.80	14.20	0.456	3.537	-3.081
FF	9.00	-0.95	-0.10	4.073	2.043	1.813
NF *vs.* FF Q=	3.912	6.576*	0.949			

[a] = statistics performed with non-parametric Kruskal-Wallis (for 2 treatments the estimated Q value must be over 1.960 for significant difference; for 3 treatments the estimated Q value must be over 2.394 for significant difference (Eddison, 2000)).

*P<0.05

3.4 Discussion

Natural weaning involves a gradual and long transition period from suckling to feeding (15-17 weeks Jensen and Recen (1989; 1991) during which piglets spend increasing amounts of time away from the sow, play and mix with piglets from other litters. In contrast, weaning in the farming industry (at 28d) is one of the most stressful events in the life of a pig as it involves abrupt and complete separation from the sow, a sudden switch from sucking the sow's milk to eating solid feed, and transfer to a complete new social environment with which the piglet has to cope and learn to defend itself alone. Hence, their pre-weaning experiences are likely to be important factors in their ability to adapt to the post-weaning environment (Cox and Cooper 2000). So, piglets weaned in commercial farms have to take advantage of the 'knowledge' they gained while they were with the sow (sampling and eating creep-feed, drinking water when available) in order to identify the feeding and drinking resources quickly and maintain a level of metabolisable energy intake similar to that achieved pre-weaning; they must also, avoid a slow gut transit time immediately after weaning that would give bacteria the opportunity to attach and the time to multiply (Pluske *et al.*, 2002). In order to do that, piglets have at least to be provided with drinking and feeding facilities as well as with creep feed of already 'known' properties – used during the pre-weaning period. It was shown previously that familiarity with the drinkers minimized the time to the first drinking event (Phillips and Phillips 1999). In a similar way, increased creep-feed consumption during lactation stimulated early post-weaning feed intake (Bruininx *et al.*, 2002). Therefore, it was speculated that pre-weaning familiarity with the feed and the feeder would cause the weaner pig to re-locate the feed more quickly, focus on feed intake more and, as a consequence, be less stressed by the weaning process. This study demonstrated that the provision of the familiar feeder i) allowed all piglets, irrespective of their pre-weaning feeding behaviour, the ability to allocate the feeding resources and spent more time feeding independent of their littermates, ii) helped the less experienced piglets of the litter to have an easier gastrointestinal adaptation to the new feeding regime by maintaining an adequate feed:energy intake immediately after weaning and consequently becoming heavier at the end of the first week and iii) improved the welfare of the piglets soon after weaning as they were more settled and performing significantly less belly-nosing. Finally, it was identified that extensive pre-weaning feeding behaviour can help piglets develop a more robust gastrointestinal ecosystem by the end of lactation independent of their weight.

3.4.1 The effect of feeder familiarity on post-weaning feeding behaviour and DLWG performance.

This study demonstrated that although the presence of the familiar feeder had no significant effect on latency to first feed, it gave the opportunity to the less experienced piglets (regarding their pre-weaning feeding behaviour) to spend more time feeding during the first days after weaning, and obtain in this way significantly greater growth levels by the end of the first week post-weaning. It was shown that PTS piglets were those with the higher pre-weaning feeding experience among all their littermates especially compared with those suckling the anterior teats of the udder (Table 3.18). After weaning, PTS and MTS piglets of the NF treatment continued to be engaged for significantly more time with the feeder than ATS piglets during the first three days post-weaning. On the other hand, the provision of a familiar feeder helped ATS piglets to spend identical periods of time at the feeder with their littermates. So, the presence of the familiar feeder helped vulnerable classes of piglets with less pre-weaning feeding experience to have access to the feeders for the same periods of time as their most experienced littermates and consume or forage the feed for longer than piglets with the same pre-weaning feeding experience (ATS piglets) on the NF treatment.

It could be argued that the increased feeding time of the ATS piglets on the FF treatment could be the result of an extra feeding space in the pen (6+1) (as it was noticed during the pre-weaning period by Appleby *et al.*, (1991)) rather than the positive effect of familiarity with the feeder. Lindemann *et al.*, (1987) opposed this view and demonstrated, that feeder space allowance (2 to 12 spaces at 15.2 cm sections) had no significant effect on post-weaning feed/gain ratio and had generally no effect on feed intake and daily gain of piglets weaned at 4weeks of age on 122x122 or 91x122 cm nursery pens. They concluded that when feed was supplied *ad libitum*, pigs were not required to eat as a group and thus trough space was not needed to accommodate all pigs at the same time. The set-up of this study is consistent with the recommendations of Lindemann and his co-workers: the piglets were fed *ad libitum* at all times, the pen had similar properties to those described by them (144 x 125 cm), and the feeder was divided to 6 sections of 18 cm diameter. Even though it was not required for piglets to eat as a group (Lindemann *et al.*, 1987), this study showed that piglets significantly preferred to feed simultaneously with one or more of their littermates irrespective of their treatment. The presence of the familiar feeder was the means for the less feed-experienced piglets (ATS piglets) to come in contact with the feed for longer period of time than equivalent piglets from the NF treatment. The presence of the familiar feeder was shown to be mostly of use for the less experienced piglets of the litter, as the more experienced piglets of the FF treatment showed a preference to feed from the unfamiliar feeder.

It was also shown that the presence of the familiar feeder significantly affected all piglets to visit the feeders and feed alone for longer periods of time than NF piglets (Table 3.27).

On the other hand, the less informed NF piglets (Heavy piglets) had to depend on their littermates during the first days after weaning in order to be 'guided' by their littermates to the feeders and imitate them in sampling and eating the feed. That was concluded from the fact that the heavier piglets of the litter have shown a significant preference for social feeding among all their other littermates (Figure 3.21). The preference for social feeding is also thought to be the development of a feeding strategy by the heavy NF piglets which had the lower pre-weaning feeding experience and increased scores of social feeding (Figure 3.21). This speculation comes to an agreement with previous observations of other workers (Held *et al.,* 2000; Morgan *et al.,* 2001) who reported that pigs were able to exploit successfully the knowledge of others by switching foraging tactics, with the dominant non-informed pigs following and displacing their informed, subordinate littermates in pair trials (Held *et al.*, 2000).

3.4.2 The effect of creep feed on the gastrointestinal maturation of the suckling piglet.

Fraser (1984) reported that anterior teats give 3 to 5 times more colostrum during the initial minutes of milking, with a nearly monotonic decline from front to rear. Sows milk provides not only nutrients, but also immunoglobulins, bioactive proteins and peptides, which stimulate and modulate the development of the gut (Zabielski 1998). This study demonstrated the benefit of the piglet developing a more stable gastrointestinal ecosystem while only suckling milk can be lost by the end of lactation (day 27). Reid and Hillman (1999) proposed that an assessment of a pig's capacity to resist pathogens could be based on the faecal ratio of lactobacilli:coliforms in the gut contents, since lactic-acid bacteria are known to inhibit the growth of enteroroxigenic *E.coli* (Hillman *et al.*, 1995).

Measurement of lactobacilli:*E.coli* ratio one day before weaning (day 27) showed that medium and light piglets at weaning had developed a more robust gastrointestinal ecosystem with greater capacity to resist pathogens (Reid and Hillman 1999) as well as being less stressed (Hendrickson *et al.*, 1999; Pluske *et al.*, 2002) as they had higher lactobacilli:*E.coli* ratio than the heavier piglets of the litter that were mostly suckling the anterior or middle teats of the udder (Table 3.16).

This study suggests that extensive pre-weaning feeding behaviour can significantly help (Table 3.48) the piglets that receive milk of low quantity to build a more resilient gastrointestinal ecosystem at the end of lactation rather than piglets that receive excessive amounts of milk and have little creep-feeding experience (Equation 3.4; heavy pigs which were mainly suckling the anterior or middle teats of the udder, Table 3.15). The combined effect of both good teat position (anterior or middle teats) and high creep feed intakes was shown to be a better combination that could build a more resilient gastrointestinal ecosystem from the suckling pigs (medium weight piglets suckling anterior or middle teats). This can be attributed to the following factors. Even though heavy pigs were gaining significantly more weight during the week pre-weaning than the other two classes (Table 3.6), they were probably not expressing their full growth potential (Williams 2003) as milk production became limited from the 8th day of lactation onwards (Martin 1984). So, according to the theory of Tuchscherer *et al.*, (1998) medium and light piglets were less stressed because they had alternative ways to maximise their nutrient intake and satisfy their hunger by not relying exclusively on sow's milk and using instead the creep-feeders extensively. Bolduan and co-workers (1988) concluded that the creep feed should always be perceived both as a nutrient supply and as a bacterial substrate. Miller *et al.*, (1984a) and Miller *et al.*, (1984b) suggest that either no creep feed or adequate creep feed intake will produce immunity in the piglets, hence a more robust gastrointestinal ecosystem. So, the increased pre-weaning feeding experience of the lighter piglets armed them with a more resilient gastrointestinal ecosystem than heavy piglets which were growing faster and were feeding exclusively on milk. Bruininx *et al.*, (2004) suggested that the consumption of creep feed could not affect the morphology of the SI or the microbial activity in the colon during lactation (d 28). In contrast to the earlier finding of Bruininx *et al.*, (2004), this study shows that the combination of high milk intakes with extensive feeding duration (medium LW-piglets) can develop a more resilient gastrointestinal ecosystem which was less susceptible against the feed and its natural antigens by the time of weaning (day 27).

3.4.3 The effect of the familiar feeder on the time needed for the gastrointestinal tract to adapt to the new feed-regime after weaning.

Weaning creates an environment suitable for the proliferation of *E.coli* in the small intestine. During this period, the numbers of lactobacilli dropped dramatically, while the numbers of *E.coli* increased far above the numbers of lactobacilli. This change in microflora could lead to an overgrowth by enteropathogenic *E.coli* (Hampson *et al.*, 1985). This study demonstrated that the pre-weaning feeding experience of the piglets could seriously affect their gastrointestinal ecosystem during the first three days after weaning when they are not provided with a familiar feeder (piglets of NF treatment). It was shown that the prolonged pre-weaning feeding experience of the light piglets helped them to maintain a more stable gastrointestinal ecosystem (higher D3 faecal lactobacilli:*E.coli* ratios) than medium and heavy piglets of the litter (having though half the lactobacilli population of that recorded for light piglets). The same effect was also recorded with creep-feed experienced MTS piglets and less experienced ATS piglets of the NF treatment, with the latter scoring significantly lower faecal lactobacilli:*E.coli* ratios. Bolduan *et al.*, (1988) state that nearly all non infectious pig diseases and most depressions of performance are caused by intestinal microbes and since the piglet is able to adapt its enzymes and mucosa (immune response, morphology) to solid feed, the issue of microbiological adaptation remains uncertain. They concluded that most dangers to the health and life of weaner piglets do not result from a temporary nutritional deficiency but from the gut flora and their feed should always be perceived both as a nutrient supply and as a bacterial substrate. So, lower faecal lactobacilli:*E.coli* ratios can also be attributed to the fact that ATS piglets of the NF treatment i) had limited creep-feed intake after weaning and that limited the growth of the appropriate gut flora and also ii) they had highly significant lower post-weaning weight gains in comparison with their immediate pre-weaning performance (47% reduction, Table 3.11). So, they were under more stress as they were lacking the experience to locate the feeders alone (Table 3.28), and feed for longer (Table 3.23) in order to achieve satiety. Also, stress it self could trigger cortisol release, depressing in this way the immune response to bacterial infection (Pluske *et al.*, 2002).

The maintenance of a feed:energy intake soon after weaning by ATS-piglets of the FF treatment, could influence the pH of the stomach to remain as low as possible and minimize in this way the amount of harmful bacteria which can pass the stomach and enter the small intestine (van Beers-Schreurs and Bruininx 2002). It was also suggested by Miller *et al.*,(1984a; 1984b) that piglets with limited pre-weaning feeding experience did not have the digestive capacity to absorb the nutrients and resist the natural feed antigens. So, the provision of a familiar feeder, gave the opportunity to the piglets to become more familiar with the feed post-weaning and maintain a higher level of feed intake post-weaning, helping them in this way to preserve a more favorable gastrointestinal ecosystem soon after weaning independent of their pre-weaning feeding experience.

3.4.4 The influence of the familiar feeder on post-weaning agonistic behaviour.

Amaral *et al.*, (2003) identified that one of the main risk factors associated with suckling vices after weaning (d 30) was unfamiliarity with post-weaning drinkers as opposed to familiarity with the drinkers available pre-weaning. This study demonstrated that in addition to drinker familiarity, early familiarity with the post-weaning feeder can also suppress the performance of the suckling vices post-weaning. The presence of the familiar feeder helped all piglets of the litter to gain access to the feed alone and not been 'guided' by a litter-mate and hence, to become more independent from day 1 post-weaning, in comparison with the NF treatment where only the experienced piglets managed to have access to the resources unaided (Table 3.28). Their independence on locating and using the feeding resources for longer during the first days after weaning makes them less vulnerable to the weaning procedure and hence less stressed as they manage to maintain an intake of nutrients as stress can also be a triggering factor of belly-nosing (Metz and Gonyou 1990). So, according to Carson and Wood-Gush (1983), the depressed performance of belly-nosing immediately after weaning by the FF piglets, can be an indicator of less distressed animals as suckling is also employed by the piglets to satisfy emotional needs after the removal of the sow which can cause a broad spectrum of various psychological stresses (Algers *et al.*, 1990; Widowski and Torrey 2005).

3.5 Conclusion

Weaning is one of the most stressful events of the pig's life as it involves several social, environmental and nutritional changes which can seriously affect its behaviour and health status while at the same time lacking active immunity. It was shown that the consumption of creep-feed during late lactation can boost the health status of the piglets, having a greater impact on medium-weight piglets that were suckling on the more productive teats. Only piglets with prolonged pre-weaning feeding experience had a better immune response soon after weaning (day 3). On the other hand, the provision of a familiar feeder i) allowed piglets with limited pre-weaning feeding experience the ability to visit the feeders autonomously for the same period of time as their more experienced littermates and ii) helped them to gain more weight and obtain a stronger immune response by day 3 after weaning in comparison with equivalent piglets that were not suited with a familiar feeder. In this way, the provision of the familiar feeder minimizes the implications of weaning which characterized by reduced feed intakes and depressed growth rates which are more prominent on piglets with suppressed pre-weaning feeding experience. Finally, the provision of the familiar feeder allowed all piglets to have equal access to the feeding resources, improved the welfare status of the piglets as they performed significantly less belly-nosing behaviour during the first days after weaning.

Chapter 4

The effect of various time-sampling techniques on the outcome of a behavioural study.

4.1 Introduction.

There are several studies in the literature that fail to come to agreement on the behavioural response of the piglets despite the fact that they observed them in similar situations. Hohenshell *et al.*, (2000a) concluded that different experimental designs used in various studies, including the use of different genetic lines of pigs, confinement, housing, weaning time (Ogunbameru *et al.*, 1992), feeding time (Waitt and Buchanan-Smith 2001) and feeding facilities (Patience 1998), complexity of diet (Fraser *et al.*, 1994), lighting pattern (Lay *et al.*, 1999; Bruininx *et al.*, 2002b), were all likely to be responsible for the different results between them. Another factor that might influence the outcome of a behavioural study is the recording rules which specify how the behaviour is recorded. According to Martin and Bateson (1986), this covers the distinction between continuous recording and time sampling (which, in turn, is divided into instantaneous sampling and one-zero sampling). With instantaneous sampling the observation session is divided into short sample intervals. On the instant of each sample point the observer records whether or not the behaviour pattern is occurred and the score obtained is expressed as the proportion of all sample points on which the behaviour pattern was occurring. In one-zero sampling, the observer records whether or not the behaviour pattern has occurred during the preceding sample interval and this is done irrespective of how often, or how long, the behaviour pattern has occurred during the sample interval. The score obtained by one-zero sampling is expressed as the proportion of all sample intervals during which the behaviour pattern occurred. Continuous recording aims to provide an exact and faithful record of the behaviour as contrasted with time sampling methods where the behaviour is sampled periodically, having as a result less information and the lack of an exact record of the behaviour. These limitations showed time sampling methods to be imperfect (Martin and Bateson 1986) and led Altmann (1974) to argue that one-zero sampling should never be used as it does not give unbiased estimates of frequency or duration. However, several empirical studies have shown that time sampling can in practice give quite good estimates of durations or frequencies (Leger 1977; Tyler 1979; Rhine and Linville 1980).

In Table 1.14, a number of studies were presented which even though they addressed the same behavioural questions (e.g. post-weaning feeding behaviour), had completely different methodological approaches on a number of factors (such as number of animals used, age of the experimental animals, focal animals selected). They also applied recording rules which varied from 5 minute scan samplings during a 6 hour (Gonyou *et al.*, 1998) and 10 hour period day^{-1} (Merlot *et al.*, 2004) for the first 2 and 3 days post-weaning, to 4 sessions of 10 minutes continuous observations for the first 4 days post-weaning (Hohenshell *et al.*, 2000a). Very few studies used continuous recordings for extended periods of time (Boe 1991; Lay *et al.*, 1999; Tsourgiannis *et al.*, 2003a; Tsourgiannis *et al.*, 2003c; Tsourgiannis *et al.*, 2003b; Tsourgiannis *et al.*, 2005). The aim of the present study was to 'test' some of the most 'popular' time-sampling regime applied to similar behavioural studies using various continuous recording methods and to examine the level of association of the results obtained from such time-sampling strategies with the 'true' behavioural durations (24 h day^{-1} for 7 days week^{-1}). Also, to identify an optimum time sampling technique for this study, which could give a reasonable approximation to continuous recording in order to balance the theoretical accuracy of measurements against ease and reliability of measurement.

The principal objectives of this study were to:

- Compare the association between proportion of duration of behavioural measurements taken during the day (8:00 to 17:00h) and night hours (17:00 to 8:00h) using a continuous recording method for the week before and after weaning at 28 days.
- Examine the levels of association between measurements obtained using an extended continuous recording method ('true' duration of the behaviours: 24 hours day^{-1} x 7 days $week^{-1}$) and a time sampling method (continuous recordings during the day or night hours).
- Identify the level of association between 'true' duration of the behavioural measurements (24 hours day^{-1} x 7 days $week^{-1}$) and measurements taken using other time-sampling methods (during a 40, 20, 15 and 5 min of continuous recording method every hour of the day period (8:00 to 17:00h)).
- Identify an optimum time sampling technique that could give a reasonable approximation to continuous recording for each behaviour observed in this study (fighting, chewing, eating, drinking, belly-nosing and milk suckling) for the week pre- and post-weaning.

4.2 Materials and methods.

Information about the experimental animals, the type of their accommodation and the way behaviour was recorded was presented in the materials and methods section of the previous chapter (Chapter 3). The experimental animals were exposed to 24:00, light:dark cycle in order to allow the observer to record the behaviour of the piglets continuously, due to the lack of infrared technology. It could be argued that the continuous lighting pattern applied in order to observe the piglets could influence their daily behaviour and hence jeopardise the reliability of the measurements taken. However it is common commercial practice to give 24h light in the post-weaning period to encourage feed intake. Also, piglets have generally been exposed to 24h light pre-weaning through the use of infra-red light heater. Earlier work done by Lay and co-workers (1999) observed that the daily behaviour of the piglets weaned at 24±0.94 days of age, (5.58±0.18kg) exposed to continuous illumination, was not significantly different from that of pigs that were given 12 h darkness (46% *vs.* 32%, $P>0.05$). They found that more 24:0 piglets were active compared with 12:12 pigs (between 1830 and 0630) during only two specific periods of the day: 18:30 to 21:30 and 3:30 to 6:30 ($P<0.001$ respectively). Their results indicated that the pigs maintained a circadian rhythm during constant illumination and they eventually rested during the night in harmony with their circadian rhythm. Lay and co-workers (1999) concluded that when a continuous illumination photoperiod has to be applied, observations should be made during the day. Their conclusions are based only on observations describing the number of animals been active without relating the type of behaviours recorded (standing, eating, drinking, not sleeping etc.) neither their frequency nor their duration. Even though their methodological approach is not considered to be sound, it was decided for the sake of argument to discuss the results obtained using only the time-sampling regimes which were referring to the day hours (8:00 to 17:00h) and examine their association level with the 'true' behaviour of the piglets for the week pre- and post-weaning.

4.2.1. Time sampling intervals.

It was decided to divide each observational day into two time periods, day hours (8:00 to 17:00) and night hours (17:00 to 8:00), on the basis that the period between 8:00 and 17:00h was the most commonly used period during which observations reported in the literature (Delumeau and Meunier-Salaun 1995; Gonyou *et al.*, 1998; Spinka *et al.*, 2002; Schroder-Petersen *et al.*, 2003; Widowski *et al.*, 2003; Hotzel *et al.*, 2004; Merlot *et al.*, 2004; van de Weerd *et al.*, 2005). In recent work undertaken by van de Weerd and co-workers (2005) on biting behaviour the period between 14:00 and 17:00 was used as that was the most suitable time period when the pigs were most active. Therefore, an attempt to identify which of the two day *v.* night time periods would give a better representation of the 'true' proportional duration was undertaken for each of the behaviours.

Also, it would be very useful to identify an optimum time sampling interval that could give a reasonable approximation of continuous recording method (CRM) (24h day^{-1} x 7 days $week^{-1}$) in order to balance the theoretical accuracy of measurement against ease and reliability of measurement. The following observation periods were used in the current study: 40, 20, 15 and 5 min of continuous recordings every hour during the period between 8:00 to 17:00 h that most of the observers used for their behavioural observations. A single day's behavioural measurements for each of the sampling periods tested were also compared with the 'true' proportional duration of the behaviours.

4.2.2. Statistical analysis.

The observational measurements (duration) for all the recorded behaviours taken within each time-sampling period were transformed to proportions in order to express the time for which a given behaviour occurred, in relationship to the total recorded period of each regime. Pearson correlation analysis was carried out in order to identify the level of which the measurements of the extended continuous recording method (CRM) (24 hours x 7 days a week) were associated or vary together with the respective measurements derived from the various time-sampling regime, which were described earlier (Martin and Bateson 1986; Hair *et al.*, 1998; Eddison 2000). When the data did not conform to a normal distribution, the equivalent non-parametric Spearman rank correlation test was employed (Martin and Bateson 1986; Eddison 2000). The correlation coefficient of each test was characterised according to the interpretations suggested by Sprinthall (1982) for statistically significant Pearson correlations of various sizes. The interpretations presented in Table 4.1. For the purposes of this study, a time-sampling method was considered to be accepted, when the results obtained using such a method described by a 'high' or 'very high' correlation (>70%) with the 'true' proportional duration of the behaviours observed.

Table 4.1 Interpretations for statistically significant Pearson correlations of various sizes (quoted from Sprinthall (1982)).

Value of r	Interpretation
< 0.2	Slight; almost negligible relationship
0.2 - 0.4	Low correlation; definite but small relationship
0.4 - 0.7	Moderate correlation; substantial relationship
0.7 - 0.9	High correlation; marked relationship
0.9 - 1.0	Very high correlation; very dependable relationship

Comparison between correlations were carried out by using the square of the correlation coefficient (r^2), which is known as the coefficient of determination (Martin and Bateson 1986): r^2 expresses the proportion of the variation in one measure that is accounted for statistically by the variation in the other measure.

Kruskal-Wallis tests were carried out between duration of behaviours that were taken during the day and night hours in order to identify the period of day that the piglets were the most active performing a specific behaviour (eating, drinking, suckling and fighting).

4.3 Results.

4.3.1. Pre-weaning period.

For eating and fighting behaviour there was a high and very dependable correlation between either of the two time-sampling periods (day or night hours) with the 'true' duration of the behaviours after following an CRM technique (P<0.001, Table 4.2). Measurements obtained in drinking behaviour during the day hours had 1.5 times greater association with the 'true' duration of the specific behaviour in contrast with recordings performed during the night period. Recordings for suckling behaviour performed during the night hours showed 14% greater correlation with the 'true' duration of the behaviour than measurements obtained using a day sampling regime.

Table 4.2 Correlations between weekly behavioural measurements taken continuously 24 h day^{-1} x 7 days $week^{-1}$, with weekly observations recorded during the day and night hours.

Behaviour		*r and r^2* values for day hours (8:00 to 17:00 h)	*r and r^2* values for night hours (17:00 to 8:00 h)
Drinking	*r*	0.815***	0.659***
	r^2	0.664	0.434
Eating	*r*	0.932***	0.927***
	r^2	0.868	0.859
Suckling	*r*	0.751***	0.841***
	r^2	0.564	0.707
Fighting	*r*	0.851***	0.870***
	r^2	0.724	0.757

***P<0.001

It was also worth noting that piglets spent significantly more time in drinking (P<0.001) and feeding (P<0.001) behaviour during the period between 8:00 to 17:00 h than the rest period of the day (17:00 to 8:00 h, Table 4.3). Even though piglets were observed to spend equal periods of time in fighting behaviour between the day and night hours of the recordings (P>0.05), they used proportionally twice as much of their time in fighting during the day than during the night hours (P<0.001). Also, piglets were observed to spend identical proportions of their time (20%) in suckling behaviour during the day and night hours of the recordings (P>0.05, Table 4.3) for the week pre-weaning.

Table 4.3 Comparisons between weekly durations and proportional durations of behavioural observations recorded using two different time-sampling techniques for the week pre-weaning (medians).

Behaviour	Day hours (8:00 to 17:00 h)	Night hours (17:00 to 8:00 h)	Q [a]	Day hours (8:00 to 17:00 h) % of the time been observed	Night hours (17:00 to 8:00 h) % of the time been observed	Q [a]
Drinking	526 sec	200 sec	-42.325 ***	0.232	0.053	59.946***
Eating	4333 sec	1274 sec	-55.282 ***	1.910	0.337	68.584***
Suckling	44828 sec	75583 sec	73.766***	19.77	20.00	-10.883
Fighting	1533 sec	1239 sec	-10.365	0.676	0.327	30.405***

***P<0.001

[a] = statistics performed with non-parametric Kruskal-Wallis (for 2 treatments the estimated Q value must be over 1.960 for significant difference (Eddison, 2000)).

Using the results of Tables 4.2 and 4.3, it can be speculated that it was more efficient and less time consuming to perform recordings during the day hours (8:00 to 17:00h) of the week pre-weaning, on the grounds that:

- correlations between measurements taken using the day time-period with 'true' proportional duration of the behaviours were greater (if not equal) than correlations obtained between night and CRM time-sampling methods.
- the proportion of the behavioural durations were highly associated with the 'true' duration of the recordings.
- a day time-period is more than 50% shorter in length than a night time-period, hence it is easier and less time consuming to use.

In the previous chapter (Chapter 3) the exact period of time that the piglets spent in some particular behaviour was determined using a continuous weekly observational method (CRM) during the week pre- and post-weaning. So, it was thought to test several shorter time-sampling periods, some of which were previously used by other workers (e.g. 1 day $week^{-1}$ between 7:00 and 19:00 h (Schroder-Petersen *et al.*, 2003), 10min observations- 4 times a day (Hohenshell *et al.*, 2000a)) and estimate their level of association with the 'true' proportional duration of the behaviours (CST method). Therefore, it would be possible to reduce the work load of the behavioural study and identify an optimum time sampling technique that could give a reasonable approximation to results obtained using a continuous recording scheme. The following sampling periods were tested: 40, 20, 15 and 5 min of continuous recordings for every hour between 8:00 and 17:00h, daily for a week (Table 4.4). It was found that a single time-sampling method could not be applied in order to obtain statistically adequate information about the 'true' proportional duration of those behaviours (eating, drinking, fighting, chewing and belly-nosing) for the week pre-weaning. So, for drinking and eating behaviour a daily sampling period of 20 min continuous recordings for the week pre-weaning every hour between 8:00 and 17:00 h, produced a highly significant ($P<0.001$) and strong association with the 'true' duration of the behaviours as their between variation could be explained by 72 and 86% respectively (Table 4.4). Also, for observational measurements taken in eating behaviour, the shortest weekly time-period of 5 min continuous recordings every hour of the day sampling regime, also explained a very large proportion (77%) of the variation when compared with 'true' proportional duration of the behaviour ($P<0.001$). A sampling period of 40 min continuous recordings every hour between 8:00 and 17:00 h for the week pre-weaning was the most appropriate method to perform measurements of suckling behaviour. The use of this sampling period had an equal strength of association (equal value of the correlation coefficient) with measurements taken continuously between 8:00 and 17:00 h (Table 4.2) and could explain more than 74% of the variation ($P<0.001$) of the 'true' proportional duration of the behaviour. Moderate and low level of association ($P<0.001$), which could explain less than 70% of the variation of the 'true' proportional duration of the behaviour, was obtained when comparing measurements performed in fighting behaviour using any of the four time-sampling periods (40, 20, 15 and 5 min). It was concluded that weekly sampling periods shorter than 60 min of continuous observations during the day hours will not give a valid interpretation of the 'true' proportional duration of this behaviour.

Table 4.4 Correlations between behavioural measurements taken continuously 24 h day^{-1}, with observations recorded using the following time-sampling techniques: 40, 20, 15 and 5 minutes every hour between 8:00 and 17:00 h, daily for a week.

Behaviour		*r and r^2* values for 40 min	*r and r^2* values for 20 min	*r and r^2* values for 15 min	*r and r^2* values for 5 min
Drinking	r	0.611***	0.717***	0.483***	0.608***
	r^2	0.373	0.514	0.233	0.369
Eating	r	0.793***	0.863***	0.744***	0.772***
	r^2	0.629	0.745	0.553	0.596
Suckling	r	0.751***	0.576***	0.468***	0.508***
	r^2	0.564	0.332	0.219	0.258
Fighting	r	0.691***	0.605***	0.372***	0.318***
	r^2	0.477	0.366	0.138	0.101

***P<0.001

As stated earlier, there were many authors (Boe 1991; Boe and Jensen 1995; Auldist *et al.*, 2000) who observed the behaviour of the piglets and built their conclusions on observations performed after a single day's recordings. Table 4.5 illustrates the results obtained using such sampling methods in relation to the total and 'true' behaviour of the piglets during the week pre-weaning. It was found that using a single day's recordings of behavioural measurements in drinking and fighting behaviour gave results which were associated statistically significantly (P<0.001) but, according to Sprinthall (1982), very poorly (30 to 69%) with the 'true' proportional duration of the behaviour in the given week. Also, the daily correlations were varying from day to day. A marked relationship was only identified for daily measurements of eating and suckling behaviour of the piglets during the week pre-weaning (Table 4.5). It was calculated that measurements of eating behaviour taken on any of the last three days of lactation (weaning at 28 days) could give a marked relationship when compared with the 'true' behaviour of the piglets for the given week (P<0.001). Similar results were obtained for measurements of suckling behaviour undertaken during the first three days of the fourth week of lactation; which had high association with the 'true' duration of the behaviour (P<0.001).

Table 4.5 Correlations between daily behavioural measurements taken continuously 24 h day^{-1} with continuous weekly recordings for the week pre-weaning.

Behaviour		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Drinking	r	0.504***	0.515***	0.700***	0.556***	0.503***	0.348***	0.568***
	r^2	0.254	0.265	0:490	0.309	0.253	0.121	0.323
Eating	r	0.455***	0.627***	0.643***	0.684***	0.767***	0.708***	0.752***
	r^2	0.207	0.393	0.413	0.468	0.588	0.501	0.565
Suckling	r	0.737***	0.775***	0.754***	0.588***	0.638***	0.680***	0.570***
	r^2	0.543	0.600	0.568	0.346	0.407	0.462	0.325
Fighting	r	0.596***	0:693***	0.657***	0.388***	0.622***	0.694***	0.594***
	r^2	0.355	0.480	0.432	0.151	0.387	0.482	0.353

***P<0.001

A single day's observations performed continuously during the period between 8:00 and 17:00 h, gave a significant but very low level of association with the 'true' duration of each of the recorded behaviours (Table 4.6). Even lower levels of association were obtained using sampling periods of shorter recorded duration (a single day's recordings performed for 20 and 5 minutes every hour for the period between 8:00 and 17:00 h) which according to the results could be appointed as less appropriate to help the observer of this study to obtain a satisfactory level of information in order to draw proportionally the same conclusions (Tables 4.7 and 4.8).

Table 4.6 Correlations between weekly behavioural measurements taken continuously 24 h day^{-1} with a single day's recordings performed between 8:00 and 17:00 h.

Behaviour		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Drinking	r	0.455***	0.471***	0.533***	0.469***	0.365***	0.183	0.285**
	r^2	0.207	0.222	0.284	0.219	0.133	0.033	0.081
Eating	r	0.397***	0.630***	0.616***	0.687***	0.337**	0.581***	0.490***
	r^2	0.157	0.397	0.379	0.472	0.113	0.337	0.240
Suckling	r	0.628***	0.719***	0.558***	0.177	0.619***	0.482***	0.336**
	r^2	0.394	0.517	0.311	0.031	0.383	0.232	0.123
Fighting	r	0.548***	0.609***	0.584***	0.538***	0.513***	0.571***	0.302**
	r^2	0.300	0.371	0.341	0.289	0.263	0.326	0.091

**P<0.01, ***P<0.001

Table 4.7 Correlations between weekly behavioural measurements taken continuously 24 h day^{-1} with a single day's recordings performed for 20 minutes every hour for the period between 8:00 and 17:00 h.

Behaviour		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Drinking	r	0.326**	0.313**	0.483***	0.410***	0.270**	0.117	0.239*
	r^2	0.106	0.097	0.233	0.168	0.073	0.014	0.057
Eating	r	0.404***	0.508***	0.477***	0.611***	0.591***	0.460***	0.480***
	r^2	0.163	0.258	0.227	0.373	0.349	0.211	0.230
Suckling	r	0.532***	0.473***	0.390***	0.091	0.526***	0.206*	0.222*
	r^2	0.283	0.223	0.152	0.008	0.276	0.042	0.049
Fighting	r	0.165	0.434***	0.379***	0.398***	0.289**	0.282**	0.094
	r^2	0.027	0.188	0.144	0.158	0.083	0.079	0.008

*P<0.05, **P<0.01, ***P<0.001

Table 4.8 Correlations between weekly behavioural measurements taken continuously 24 h day^{-1} with a single day's recordings performed for 5 minutes every hour for the period between 8:00 and 17:00 h.

Behaviour		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Drinking	r	0.328**	0.129	0.236*	0.361***	0.158	0.081	0.236*
	r^2	0.107	0.016	0.055	0.130	0.025	0.006	0.056
Eating	r	0.318**	0.383***	0.448***	0.532***	0.456***	0.359***	0.428***
	r^2	0.101	0.146	0.200	0.283	0.208	0.129	0.183
Suckling	r	0.407***	0.529***	0.345**	0.098	0.351***	0.338**	0.023
	r^2	0.165	0.279	0.119	0.009	0.123	0.114	0.0005
Fighting	r	0.141	0.299**	0.336**	0.355***	0.179	0.162	0.068
	r^2	0.019	0.089	0.113	0.126	0.032	0.026	0.004

*P<0.05, **P<0.01, ***P<0.001

4.3.2. Post-weaning period.

Spearman and Pearson correlations showed that measurements taken of drinking, eating, chewing, belly-nosing and fighting behaviour continuously during the day or night hours for the week post-weaning had a high correlation with the 'true' values for duration of the behaviours after using the CRM method (P<0.001, Table 4.9). It was noticed though that for eating, belly-nosing and fighting behaviour measurements taken during the night hours shown 11, 33 and 24% greater correlation with the 'true' values of duration than recordings performed during the day hours.

Table 4.9 Correlations between behavioural measurements taken continuously 24 h day^{-1} x 7 days week^{-1}, with observations recorded during the day and night hours daily for a week.

Behaviour		*r and r^2* values for day hours (8:00 to 17:00 h)	*r and r^2* values for night hours (17:00 to 8:00 h)
Drinking	*r*	0.738***	0.742***
	r^2	0.544	0.550
Eating	*r*	0.726***	0.799***
	r^2	0.527	0.638
Belly-nosing	*r*	0.708***	0.913***
	r^2	0.501	0.833
Chewing	*r*	0.886***	0.843***
	r^2	0.785	0.710
Fighting	*r*	0.748***	0.896***
	r^2	0.559	0.803

***P<0.001

It is also worth noting that piglets performed more drinking, eating and chewing behaviour (P<0.001) and spent proportionally more than double their time (P<0.001) performing those activities during the day hours of the recordings, even though this period consists of almost 1/3 of their total daily time (Table 4.10). Even though belly-nosing behaviour was performed for twice as long a period of time during the night than the day hours of the recordings (P<0.05 and P<0.001 respectively), the piglets spent proportionally the same amount of their time performing this behaviour (0.023 *vs.* 0.027 % of the time been observed; P>0.05). The same observation applied for fighting behaviour (0.616 *vs.* 0.783 % of the time been observed; P>0.05, Table 4.10).

Table 4.10 Comparisons between weekly duration and proportional durations of behavioural observations recorded using two different time-sampling techniques (recordings during the day hours *vs.* night hours; medians).

Behaviour	Day hours (8:00 to 17:00 h)	Night hours (17:00 to 8:00 h)	Q[a]	Day hours (8:00 to 17:00 h) % of the time been observed	Night hours (17:00 to 8:00 h) % of the time been observed	Q[a]
Drinking	1652 sec	1184 sec	24.531 ***	0.728	0.313	83.959 ***
Eating	21848 sec	14923 sec	55.109 ***	9.633	3.948	79.813 ***
Belly-nosing	51.66 sec	103.96 sec	-18.980*	0.023	0.027	-7.895
Chewing	6015 sec	3828 sec	27.813 ***	2.652	1.013	53.381 ***
Fighting	1398 sec	2961 sec	-35.414 ***	0.616	0.783	-11.229

*P<0.05, ***P<0.001

[a] = statistics performed with non-parametric Kruskal-Wallis (for 2 treatments the estimated Q value must be over 1.960 for significant difference (Eddison, 2000)).

Even though it was calculated earlier (Table 4.9) that behavioural recordings performed using the night sampling regime could have a greater association with the 'true' value for duration of the behaviours than recordings made during the day period, several shorter time-sampling methods will be tested (during the day hours as most of the other workers used) and the association of those measurements with the 'true' proportional duration of the behaviours will be calculated. It was identified (Table 4.11) that for drinking, eating, belly-nosing and fighting behaviour the level of association of the behavioural durations derived using any of the shorter time-sampling regimes (40, 20, 15 and 5 min every hour during the day period for the week post-weaning) was characterised as moderate (P<0.001) with *r* values accounted for less than 70% of the variation with the 'true' proportional duration of the behaviours. Only measurements taken in chewing behaviour using sampling periods of 40, 20 and 15 min every hour during the day period for the week post-weaning, had a high correlation with the 'true' duration of the behaviours ($P<0.001$). Also, a sampling strategy of 40 min, could give 10 and 20% stronger associations with the 'true' proportional duration of chewing behaviour than observational periods of 20 and 15 min respectively (for every hour during the day sampling regime for the week post-weaning). Also, by extending the behavioural observations in chewing from 15 to 20 min every hour during the day recordings could increase by 10% the association of the results with the 'true' proportional duration of the behaviour.

Table 4.11 Correlations between behavioural measurements taken continuously 24 h day^{-1} week^{-1}, with observations recorded using the following time-sampling techniques: 40, 20, 15 and 5 minutes every hour between 8:00 and 17:00 h.

Behaviour		*r and r²* values for 40 min	*r and r²* values for 20 min	*r and r²* values for 15 min	*r and r²* values for 5 min
Drinking	*r*	0.638***	0.585***	0.579***	0.295**
	r²	0.407	0.342	0.335	0.087
Eating	*r*	0.583***	0.673***	0.603***	0.462***
	r²	0.339	0.453	0.364	0.213
Belly-nosing	*r*	0.664***	0.627***	0.570***	0.430***
	r²	0.441	0.393	0.325	0.185
Chewing	*r*	0.839***	0.777***	0.720***	0.523***
	r²	0.704	0.604	0.518	0.273
Fighting	*r*	0.656***	0.656***	0.604***	0.437***
	r²	0.430	0.430	0.365	0.191

**P<0.01, ***P<0.001

A single day's continuous recordings for 24 h (Table 4.12) or during the day hours (Table 4.13) had a variable and moderate level of correlation ($P<0.001$) with the 'true' duration value of the behaviours, expressing in this way very little of the variation between the two measurements. Behavioural measurements performed on any given day using shorter daily time-period of 20 (Table 4.14) and 5 min (Table 4.15) of continuous monitoring every hour for the period between 8:00 and 17:00 h, gave in their majority low level of correlation with the 'true' proportional duration of the behaviours. Correlations performed between a single day's recordings, after making use of a 5 min time-period every hour between 8:00 and 17:00 h with the 'true' proportional duration of the behaviours, were predominantly non-significant (Table 4.15).

Table 4.12 Correlations between daily behavioural measurements taken continuously 24 h day^{-1} with a day's continuous recordings for the period post-weaning.

Behaviour		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Drinking	r	0.406***	0.693***	0.574***	0.564***	0.621***	0.611***	0.475**
	r^2	0.165	0.480	0.329	0.318	0.385	0.373	0.225
Eating	r	0.550***	0.588***	0.633***	0.496***	0.684***	0.691***	0.636**
	r^2	0.302	0.346	0.400	0.246	0.468	0.477	0.404
Belly-nosing	r	0.118	0.528***	0.671***	0.713***	0.662***	0.712***	0.649**
	r^2	0.014	0.278	0.450	0.508	0.438	0.507	0.421
Chewing	r	0.642***	0.636***	0.702***	0.633***	0.625***	0.618***	0.578**
	r^2	0.412	0.404	0.493	0.400	0.391	0.382	0.334
Fighting	r	0.574***	0.747***	0.671***	0.581***	0.573***	0.670***	0.560**
	r^2	0.329	0.558	0.450	0.337	0.328	0.449	0.313

***P<0.001

Table 4.13 Correlations between weekly behavioural measurements taken continuously 24 h day^{-1} with a single day's continuous recordings performed between 8:00 and 17:00 h.

Behaviour		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Drinking	r	0.408***	0.511***	0.420***	0.480***	0.558***	0.376***	0.439**
	r^2	0.166	0.261	0.176	0.200	0.311	0.141	0.193
Eating	r	0.515***	0.515***	0.510***	0.307**	0.596***	0.606***	0.320**
	r^2	0.265	0.265	0.260	0.094	0.355	0.367	0.102
Belly-nosing	r	0.069	0.354***	0.421***	0.602***	0.416***	0.562***	0.498**
	r^2	0.004	0.125	0.177	0.362	0.173	0.316	0.248
Chewing	r	0.554***	0.551***	0.574***	0.577***	0.508***	0.464***	0.513**
	r^2	0.307	0.304	0.329	0.333	0.258	0.215	0.263
Fighting	r	0.508***	0.525***	0.441***	0.539***	0.520***	0.556***	0.488**
	r^2	0.258	0.276	0.194	0.291	0.270	0.309	0.238

**P<0.01, ***P<0.001

Table 4.14 Correlations between weekly behavioural measurements taken continuously 24 h day^{-1} with a single day's continuous recordings performed for 20 minutes every hour for the period between 8:00 and 17:00 h.

Behaviour		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Drinking	r	0.386***	0.419***	0.240*	0.339**	0.442***	0.121	0.215*
	r^2	0.149	0.175	0.057	0.115	0.195	0.014	0.046
Eating	r	0.339**	0.207*	0.365***	0.373***	0.428***	0.426***	0.430**
	r^2	0.115	0.043	0.133	0.139	0.183	0.181	0.185
Belly-nosing	r	0.121	0.333**	0.311**	0.434***	0.456***	0.394***	0.419**
	r^2	0.015	0.111	0.096	0.188	0.208	0.155	0.175
Chewing	r	0.435***	0.527***	0.461***	0.479***	0.261*	0.326***	0.431**
	r^2	0.189	0.277	0.212	0.229	0.068	0.106	0.186
Fighting	r	0.516***	0.495***	0.304**	0.397***	0.410***	0.383***	0.451**
	r^2	0.266	0.245	0.092	0.157	0.168	0.146	0.203

*P<0.05, **P<0.01, ***P<0.001

Table 4.15 Correlations between weekly behavioural measurements taken continuously 24 h day^{-1} with a single day's continuous recordings performed for 5 minutes every hour for the period between 8:00 and 17:00 h.

Behaviour		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Drinking	*r*	-0.246*	0.412***	0.042	0.234*	0.356***	0.172	-0.028
	r^2	0.060	0.169	0.001	0.054	0.126	0.029	0.001
Eating	*r*	0.046	0.263*	0.368***	0.098	0.324**	0.315**	0.291**
	r^2	0.00	0.069	0.135	0.009	0.105	0.099	0.084
Belly-nosing	*r*	0	0.128	0.169	0.160	0.208*	0.199	0.147
	r^2	0	0.016	0.028	0.025	0.043	0.039	0.021
Chewing	*r*	0.136	0.274**	0.410***	0.413***	0.259*	0.273**	0.210*
	r^2	0.018	0.075	0.168	0.170	0.067	0.074	0.044
Fighting	*r*	0.090	0.281**	0.142	0.276**	0.340**	0.331**	0.243*
	r^2	0.008	0.079	0.020	0.076	0.115	0.109	0.059

*P<0.05, **P<0.01, ***P<0.001

4.4 Discussion.

It has already been mentioned by Hohenshell and co-workers (2000a) that different experimental designs used in previous studies are all likely responsible for the different results between them. Another very important factor, as shown in this study, which can also affect the validity of the results obtained in a behavioural work and that was not given the appropriate attention so far, is the recording rules used and, more specifically, the amount of time over which a behaviour has to be recorded for at a given age of the piglets' in order to obtain 'true' and valid information of their activities. There would be no such problem if the researchers were performing their observations continuously, throughout the period of interest, in order to obtain the exact record of the behaviour. In many cases time sampling is used precisely because continuous recording is not practicable, and for this reason continuous recordings methods have been ruled out by the majority of the observers (Martin and Bateson 1986). According to the same authors, the use of very short time-sampling intervals or the application of instantaneous sampling techniques can compromise the accuracy of the measurements, since rare behaviour patterns would tend to be missed when the length of the sample interval is not appropriate. But, it may be possible to distinguish an obvious 'break-point', above which short time sampling periods are too inaccurate, but below which it gives a reasonable approximation to continuous recording. One problem with this whole process is the need to measure the behaviour using continuous recording initially in order to provide a true record for comparison. This study applied the suggested methodology of Martin and Bateson (1986) in order to identify an 'optimum' time-sampling period which could give a reasonable approximation to continuous recording in order to balance the theoretical accuracy of measurements against ease and reliability of measurement. Also, it attempted to examine the reliability of the measurements taken when using various shorter time-sampling periods of continuous recordings, most of which, had been applied in several other studies (Table 1.14).

In order to simplify the methodology of their behavioural study, some workers chose to use a single time-sampling method in order to perform observations on piglets during their pre- and post-weaning period of their life (Fraser 1978; Gonyou *et al.*, 1998; Widowski *et al.*, 2003; Hotzel *et al.*, 2004). It was found in this study that there was not a single time-sampling regime of the shorter periods (Tables 4.4 and 4.11) that could be applied to observe several different behaviours during the pre- and post-weaning period and allow the observer of this study to obtain measurements which were associated strongly enough with the 'true' duration of the behaviours. Only measurements taken using a continuous weekly recording method for the period between 8:00 to 17:00 h had a high statistically significant positive correlation with the 'true' duration of the behaviour. It was shown that a time-sampling period of 40 min continuous daily monitoring for the week pre-weaning during the day hours (8:00 to 17:00 h) could be sufficient to provide measurements in suckling and fighting behaviour sufficiently strongly associated with the 'true' proportional duration of the behaviours. A time-period of 5 and 20 min every hour during the day hours for the week pre-weaning was sufficient to obtain measurements in eating and drinking behaviour respectively, having a marked relationship with the 'true' proportional duration of the behaviours. On the other hand, in order to obtain valid measurements of a marked relationship for any of the post-weaning behaviours, a more intensive time-sampling period of daily continuous monitoring between 8:00 and 17:00h during the post-weaning week had to be applied (Table 4.9). Only weekly measurements taken in chewing behaviour in a period of 15 min continuous recording every hour between 8:00 and 17:00 h (Table 4.11), were proven to be sufficient to provide a valid and strong relationship (r>70%) with the 'true' proportional duration of the behaviour.

In their efforts to reduce the work-load of the observational study and maintain the accuracy of their recordings, researchers tended to use various extensive continuous time-sampling periods on a single day of a week and drew their conclusions from the measurements of that day (Laitat *et al.*, 1999b; Schroder-Petersen *et al.*, 2003). It was shown that a single day's observations using time-sampling periods of continuous monitoring between 8:00 and 17:00 h for the week pre- and post-weaning had a significant but low to moderate level of association which could explain less than 70% of the variation with the 'true' duration of the behaviours observed. Only for pre-weaning feeding and suckling behaviour, a single day's behavioural measurements could have a good approximation to the 'true' proportional duration of the behaviours (>70%). It was noticed that for eating behaviour, when only a single day had to be recorded continuously (24h), measurements taken on any of the last three days of lactation had a significantly high correlation with the 'true' recordings of the behaviour (Table 4.5). Similarly, for suckling behaviour, any of the first three days on the fourth week of lactation could present measurements of high correlation with the 'true' recordings of the behaviour. A single day's measurements taken using shorter sampling periods (20 and 5 min every hour for the period between 8:00 to 17:00 h) had even lower level of association with the 'true' proportional duration of the behaviours. So, using the current experimental set-up and taking measurements from 96 focal animals, a sampling period of 8h continuous recording (8:00 to 17:00 h) or shorter from only one day, was proven not to be sufficient to give a strong association with the 'true' duration of the behaviours observed (r<70%). It is also straightforward to understand by noticing the basic rules of statistics that the lower the number of focal animals used, the lower the statistical power and acceptability of the measurements (Martin and Bateson 1986; Eddison 2000). Also, according to Martin and Bateson (1986), using an instantaneous sampling method, which was used so freely previously by other workers instead of a continuous recording for the period between 8:00

and 17:00 h, could rather compromise the accuracy of the measurements in relation to the exact record of the behaviour even when a very short sample interval had to be used (sample interval should be as short as possible).

It was concluded that the observer had to be very careful when choosing to perform behavioural measurements on a single day or while using short sampling periods on a given day (for 40, 20, 15 and 5 min every hour between 8:00 and 17:00h). The recordings obtained using such sampling periods provided results that were not strongly associated with the 'true' duration of the behaviours. Martin and Bateson (1986) suggested that preliminary work has to be done before the initiation of the main study, in order to identify the appropriate time-sampling method which has to be applied to obtain valid measurements. While interpreting the results of the preliminary study the observer has to know that the amount of time that various behaviours have to be recorded for could not be decided by the proportion of time piglets spent performing them during the course of the day. This study showed that behaviours which had a longer duration through the course of the week (pre-weaning suckling behaviour and post-weaning eating behaviour), had to be observed for at least twice as long a time as other behaviours of a shorter duration in order to get a strong representation of their 'true' values (Tables 4.3 and 4.10). A different situation occurred in observations of pre-weaning eating and fighting behaviour. In that case, it was calculated that even though eating behaviour had at least three times longer duration than fighting behaviour (Table 4.3), it needed 1:8 of the amount of time spent observing the piglets for fighting in order to get a statistically strong association with the 'true' duration of the behaviours (Table 4.4). It was described by Martin and Bateson (1986) that it was due to the fact that some individuals or some behaviour patterns were more conspicuous than others. It was concluded that for some of the pre-weaning behaviours (drinking and fighting) and for all of the post-weaning ones (eating, drinking, chewing, belly-nosing and fighting) daily recordings during the course of the week had to be taken in order to get a very good correlation of these measurements with the 'true' duration of the behaviours. Following the basic rules of statistics described by Martin and Bateson (1986), Hair *et al.*,(1998) and Eddison (2000), it is well understood that if fewer animals were observed for the purposes of this study (<96 focal animals), a longer period of time would be needed to observe the piglets in order to achieve a strong level of association (r>70%) with the 'true' duration of their activities.

A survey of articles published in Applied Animal Behaviour Science since 2000, found that of the research conducted to determine the behaviour of the piglets during the pre- and post-weaning period of their life when weaned at around 28 days of age, 73% (Maletinska and Spinka 2001; D'Eath 2002; Donaldson *et al.*, 2002; Weary *et al.*, 2002; Breuer *et al.*, 2003; Mason *et al.*, 2003; Merlot *et al.*, 2004; O'Connell *et al.*, 2005) made use of such time-sampling regimes which could not provide results of sufficient statistical association with the 'true' duration of the behaviours under investigation when tested for the purposes of this study. It was noted that the sample size of the animals (focal animals) was almost similar in all studies (around 100 piglets). On the other hand, only 27% of the published work in Applied Animal Behaviour Science since 2000 (Valros *et al.*, 2002; van den Brand *et al.*, 2004; Wattanakul *et al.*, 2005), were found to have chosen time-periods which could provide results of sufficient statistical association with the 'true' duration of the behaviours under investigation when tested for the purposes of this study.

4.5 Conclusion.

It is quite clear now, that choosing to use a time-period which was previously applied by other researchers in a similar experimental set-up and in order to observe the same behaviour (Maletinska and Spinka 2001; Weary *et al.*, 2002) could lead most of the times to incorrect conclusions as these time-sampling strategies have been proven to be insufficient to provide strong or valid statistical associations with the 'true' duration of the behaviours under investigation ($r<70\%$). Continuous weekly recordings during the day hours (8:00 to 17:00h) were shown to be sufficient to provide measurements of strong association with the 'true' duration of the behaviours for the given week. Also, the use of such time-sampling strategies can reduce the work-load of the observer by 2/3 in relationship to continuous 24h day^{-1} weekly recordings. But, even this amount of time can be described as extensive and rejected as an option by some of the workers when the sample size of the animals is very large. Also, the application of extended recording methods, presuppose the use of very expensive equipments which most of the time is economically impossible for the researcher to get hold of such tools. For this reason, the large majority of the researchers chose to use shorter time-sampling methods so, compromising the association of their measurements with the 'true' behaviour of the piglets (Martin and Bateson 1986). But the convenience of the observer can not be used as an excuse if the results produced are invalid. It is very important to establish more accurate time-sampling recording methods with the guidance of preliminary observations when sufficient continuous recording periods or adequate number of focal animals can not be utilised.

Chapter 5

Concluding Discussion.

The studies reported in this thesis aimed to investigate the effect of pre-weaning feeding behaviour on post-weaning feeding behaviour in pigs weaned at various ages (3, 4 and 5 weeks of age) and identify factors that could influence the feeding behaviour and feed intake of the piglets during the first week after weaning. The studies were constructed using time extensive continuous recording methods in order to monitor the 'true' behaviour unbiased by sampling errors.

In wild or semi-natural conditions, weaning of piglets is a gradual process (15-17 weeks; Boe (1991)) involving a reduction in suckling frequency and a parallel increase in foraging activity and the ingestion of solid food (Jensen 1988). Piglets forage in family groups and can learn by imitation of their dam, older group members (Stolba and Wood-Gush 1989) or from their more 'experienced' littermates (Hutson 1989; Appleby *et al.*, 1991; Held *et al.*, 2000; Morgan *et al.*, 2001). In contrast, weaning in the farming industry (at 28d) is one of the most stressful events in the life of a pig as it involves an abrupt and complete separation from the sow, a sudden switch from sucking the sow's milk to eating solid feed, and transfer to a completely new social environment in which the piglet has to cope and learn to defend itself alone. Under these conditions, early weaning can be a traumatic process giving rise to an abrupt reduction in nutrient intake and associated detrimental consequences for growth and health because piglets have not fully adapted to ingestion of solid food while they have been with the sow (Pluske *et al.*, 1997).

Weaning age may also have a significant impact on the event of weaning and increase variability in the response, as pigs of the same social status can be affected differently depending on their age, size for age and nutritional background for age. This is explained by the fact that pigs are slow to develop normal levels of eating (Blackshaw 1981) and it is common for some piglets in a litter to take a few days to discover and accept solid food as a source of nutrients. This results in a loss of weight, described as 'the weaning growth lag' by Fraser (1984a). Therefore, this study examined the feeding behaviour of the piglets that had different weaning weight or teat-order classification and the influence of their pre-weaning behaviour on their post-weaning progress when weaned at various ages (3, 4 and 5 weeks of age).

The effects of weaning age on individual animal feed intake characteristics are still unknown. Although it has been identified that there is great variability in feed intake both before and after weaning (Aumaitre 1972; Algers *et al.*, 1990; Pajor *et al.*, 1991), there are no studies to demonstrate a linkage between the pre- and post-weaning feeding behaviour of individuals. This is primarily because pigs have been treated as groups (litters) and the average performance and response have been measured (Pajor *et al.*, 1991). In contrast to the previous works (Delumeau and Meunier-Salaun (1995): 3 pigs/litter those with high FI; Merlot *et al.*, (2004): only female piglets), the studies reported in this thesis were undertaken using observations from individual piglets (6 piglets from each litter; 50:50 male:female) that comprised a representative sample of their litter as:

i) they constituted at least 50% of the litter population,

ii) the piglets represented a broad spectrum of the litters' weaning weight range (the 2 heaviest, the 2 lightest and the 2 piglets closer to the median weight of the litter) and

iii) the piglets were observed continuously for 24 h/d, for at least 2 weeks of their life (depending on their weaning age) in order to obtain the 'true' record of their activities (Martin and Bateson 1986).

It was found that there was a significant effect of weaning age on the final weight of the piglets at 6 weeks of age. Piglets weaned at three weeks of age were 2 and 1.5 kg heavier than piglets weaned at four and five weeks of age respectively. The results of this study showed that the piglets had the potential to grow faster when they were away from the sow, rather than when they stay for one or two more weeks with their dam and fed exclusively on milk. The study reported in this thesis provides evidence that piglets during the fourth and fifth week of lactation spent significantly less time on suckling their 'home' teat in comparison with the total time recorded manipulating the sow's udder. Their willingness to invest more time on stimulating other parts of the udder, which were not suckled primarily by them, shows their increased need to get more milk in order to satisfy their hunger due to the limited supply of the sow's milk. These results are re-enforced by the findings of Harrel *et al.,* (1993) who stated that the sow is not capable of producing sufficient milk to fully satisfy the needs of the piglets after the eighth day of lactation (Martin 1984). The piglets, instead of withdrawing from the udder and concentrating on exploring other possible resources (creep-feed, water or sow's feed) they showed a preference to suckle other teats that were previously emptied by their littermates. It was suggested by Boe and Jensen (1995) that this is happening because the presence of the sow acts as a distractor as the piglets concentrated their efforts on stimulating the sow to suckle more frequently and provide more milk, instead of utilising other available sources (creep-feed and water) of nutrients to maximise their feed intake. The study reported in this thesis provides evidence that piglets had the capacity to ingest more feed during the fourth and fifth week of lactation as 3W piglets did at the end of their post-weaning week; at which point they became 4 weeks old. The delay of weaning for a further one or two more weeks marked another setback on the feeding performance of these piglets as it 'cost' them the first four days post-weaning in order to reach the feeding levels that they should have had for their age; according to the performance of 3W piglets on day 7.

According to the results of this study, delaying the weaning age for a week (weaning at 28d), not only had a significant impact on post-weaning growth performance of the 4W piglets but it also affected their behaviour. Boe (1993) agreed with Metz and Gonyou (1990) who stated that early weaning may increase aberrant behaviours such as belly nosing and flank biting, which can be important indicators of stress. The study reported in this thesis contradicts their findings, as it shows that piglets weaned at 4 weeks of age were more vulnerable to the weaning procedure. They expressed significantly more fighting, chewing and belly-nosing behaviours than piglets weaned at three and five weeks of age respectively. The results of this study also contrasts the recommendations of the Scientific Veterinary Committee for improving the welfare of the farm animals, which under the Commission Directive 2001/93/EC of the 9th November 2001, suggested that 'in the interest of their welfare, piglets should not be weaned from the sow aged less than 28 days, unless the health of either the sow or her piglets would otherwise be adversely affected or advantages for the health of the piglets justify an earlier weaning'.

The reasons behind those contradictions were identified to be both nutritional and behavioural. It was concluded that because 4W piglets:

i) did not reach satiety from milk intake pre-weaning as they had to drink proportionally less amount of milk (Martin 1984; Harrel *et al.*, 1993), hence they were extensively hungry during the pre-weaning period,

ii) they did not increase their nutrient intakes from creep feed as they were neither visiting the feeder more often nor increasing their presence at the feeders in relation to their previous week's performance and

iii) the fact that belly nosing was found to be highly correlated with diminished suckling behaviour and teat order (more pronounced on PTS-piglets, that according to Pluske and Williams (1996) had lower milk intakes);

led them to carry through the sucking activity post-weaning on their pen-mates as a replacement for the suckling behaviour (Gardner *et al.*, 2001) during the lactation period which was applied in order to stimulate the udder of the sow, suckle the milk and fulfil their hunger and thirst. On the other hand, 3W piglets appeared to be less stressed (performing less belly-nosing on their pen-mates (Metz and Gonyou 1990; Boe 1993)) and managed to adapt more easily to their new post-weaning environment (they were gaining more weight than piglets that had to remain with their sow for another week) as

i) they achieved satiety from sucking milk during the pre-weaning period (based on the consistency of suckling their 'home' teat),

ii) they had developed an interest in creep feed pre-weaning, which was still at its peak around weaning and

iii) they were smaller animals having lower energy requirements to maintain body weight during the first days post-weaning until they were able to adapt to their new environment.

Weaning at 5 weeks of age, appeared to be a more progressive process more like the weaning course in natural and in semi-natural environments (Fowler 1985; Jensen and Recen 1989; Boe 1991; Brooks and Tsourgiannis 2003). This was concluded from the fact that 5W piglets were suckling the sow less often and for shorter periods of time during the fifth week of lactation. According to Krebs and McCleery (1984) this can be described as the optimisation of the foraging behaviour by the piglets as participating in sucklings was one strategy, and to cease suckling was another. Also, prolonging weaning for an extra week gave the opportunity to some classes of piglets (piglets of diminished suckling behaviour) to manipulate the sow's udder for longer which appeared to be enough to depress the performance of belly-nosing behaviour as it was found that the vice was highly correlated with diminished suckling behaviour. Finally, depressed post-weaning fighting behaviour of the 5W piglets in comparison with 4W suggests that prolonging weaning for another week helped 5W piglets to form a more stable social hierarchy, which helped them to settle more easily during the immediate post-weaning period (Worobec and Duncan 1997).

According to Wattanakul *et al.*, (2005) the creep feeding activity of the piglets during the lactation period has an important role to play in reducing the growth check during the adaptation to early weaning. But even when creep food is offered from an early age, while the piglets are still with the sow, some piglets consume little or no solid food before weaning (Brooks and Tsourgiannis 2003) and, of those that do consume food, there is a large variation between piglets (Pajor *et al.*, 1991). That was due to the fact that the ingestion of solid feed during lactation can speed the induction of amylase and protease enzymes required to digest this food efficiently once milk is removed (Aumaitre 1972; de Passille *et al.*, 1989). This study demonstrated that extensive pre-weaning feeding behaviour can significantly help the piglets that receive lower levels of milk (PTS-piglets) (Pluske and Williams 1996) to build a more resilient gastrointestinal ecosystem at the end of lactation rather than piglets that receive excessive amounts of milk and have little creep-feeding experience (heavy pigs that were suckling equally anterior or middle teats of the udder). Bolduan *et al.*, (1988) state that feed should always be perceived both as a nutrient supply and as a bacterial substrate but Bruininx *et al.*, (2004) reported that the consumption of creep feed did not affect the morphology of the SI nor the microbial activity in the colon while the piglets were still suckling (d 28). It was concluded by Bolduan *et al.*, (1988) that most dangers to the health and life of weaner piglets do not result from a temporary nutritional deficiency but from the gut flora in the tract. This study supports the above views and provides evidence that the combined effect of both good teat position (anterior or middle teats) and high creep feed intakes was shown to be a better combination, which could trigger an even healthier gut ecosystem from the suckling pigs (medium weight piglets suckling anterior or middle teats). So, it was concluded that the benefit to the piglet of obtaining a more resilient gastrointestinal ecosystem while suckling the anterior teats of the udder (Fraser 1984b) can be lost by the end of lactation (day 27) and replaced by the beneficial, combined effect, of suckling milk and the consumption of creep feed as a compensation for nutrient intake to support their growth potential.

According to the results of this study, the inadequacy of the milk supply produced by the sow in late lactation (after the 3rd week post-partum) led piglets to focus more on stimulating the udder instead of searching for alternative ways to increase their nutrient intakes. In addition, the poor production practices followed by the farmers that did not provide sufficient aid and motivation to the piglets to enhance their pre-weaning feeding behaviour and enable them to establish quickly enough a post-weaning feeding pattern, were the main factors that resulted in the suppression of overall growth performance (pre and post-weaning) of the 4W piglets. From the relationship established in Equation 2.2 in Chapter 2, it was found that the LW of the piglets the week post-weaning was partially explained by the total pre-weaning feeding duration of the piglets. So, in order to increase the LW of the piglets post-weaning, it would be logical either to find ways to improve the pre-weaning feeding behaviour of the piglets, or to help them to 'make use' of the feeding experience that they have gained pre-weaning and let them use it after weaning. The provision of a familiar feeder in the post-weaning accommodation was considered to be a useful and low cost practice that could enable the less experienced piglets in the litter to gain equal access to the feed, gain significantly more weight and obtain a stronger immune system. It was shown by other workers (Kelly *et al.*, 1990; Pluske *et al.*, 1996) that encouraging a high level of intake in the immediate post-weaning period could help to maintain villus integrity and digestive function. Kim *et al.*, (2001) concluded that in sheep the acceptance of a new food is conditioned by familiarity with the food *per se* (Green *et al.*, 1984) or with the food container (Chapple *et al.*, 1987). Wood-Gush and co-workers (1990) observed that this was happening because the presence of a new object firstly causes avoidance, and then orientation, approach, and finally biting. The same was observed to happen in sheep (Chapple *et al.*, 1987). In addition, earlier work in rats demonstrated that experience with food container reduces aversions to new food (Braveman 1978). In the same way Phillips and Phillips (1999) observed that familiarity with the drinker minimised the time to the first drinking event; even though Delumeau and Meunier-Salaun (1995) found that early familiarity with the feeder had no effect on feed intake. The study reported in this thesis provides good evidence that the provision of the familiar feeder minimizes the reduction in feed intakes, expression of belly-nosing soon after weaning and depressed growth rates which are more prominent in piglets with lower pre-weaning feeding experience (Algers *et al.*, 1990).

It was identified that the piglets that were faced with the greatest difficulty in acclimatizing to weaning and establishing an adequate daily feed consumption were the piglets sucking the anterior teats (ATS-piglets). On the other hand, the provision of a familiar feeder helped ATS-piglets to spend identical periods of time at the feeder with their littermates. Bruininx *et al.*, (2001) states that identification of various determinants of individual feed intake characteristics, especially during the first days after weaning, could serve to improve health and performance of weanling pigs housed in groups. So, the provision of a familiar feeder not only allowed piglets with limited pre-weaning feeding experience the ability to visit the feeders autonomously for the same period of time as their more experienced littermates, but also helped their gastrointestinal tract to adapt quicker under the new feeding regime and in response gain more weight in comparison with equivalent piglets of the second treatment that were not provided with a familiar feeder.

Pajor *et al.*, (1991) and Delumeau and Meunier-Salaun (1995) did not observe any relationship between the teat order and the creep feeding activity. The lack of agreement of the studies reported in this thesis with their study can either be due

i) to the limited number of piglets selected from each litter (3 piglets/litter), as they selected subjects for study according to their feeding activity and not to their teat-order,

ii) they offered the creep feed for limited period of time (90 min/day),

iii) they observed the animals for limited period of time daily (90 min) for the period pre-weaning and also,

iv) they recorded their post-weaning feeding behaviour only during the first four days post-weaning.

Schnebel and Griswold (1983) observed that during periods of competition, the ability of certain individuals to access the resources may be compromised, as a result of their lower rank and poorer competitive ability. Consequently, Turner *et al.*, (2000) suggested that under commercial conditions, provision of resources to a group of pigs must be adequate to allow every individual sufficient access, regardless of social status or competitive advantage or disadvantage. Results obtained in the current experiment showed that the provision of adequate feeding space (post-weaning feeding troughs) was of most use for the more experienced piglets in the litters in respect of their pre-weaning feeding behaviour. Alternatively, providing piglets with an additional feeder which they were allowed to become accustomed to for at least two weeks pre-weaning, could allow the more vulnerable classes of piglet post-weaning (regarding their ability to reach and consume the feed) to locate the feed unaided and autonomously without having to rely on the feeding temperament of their more experienced littermates or having to imitate them eating (Held *et al.*, 2000; Morgan *et al.*, 2001). Wattanakul and co-workers (2005) observed that the method of creep feed presentation (between a tray and a hopper) is very important in the initiation of feeding behaviour. The study reported in this thesis suggests that familiarity with the post-weaning feeder is more important than the feeder presentation as it can increase the feeding performance of the less experienced piglets; given that the feeder used was chosen randomly and was not tested against other types of feeder in preference tests as described earlier by Wattanakul *et al.*, (2005).

According to Hohenshell *et al.*, (2000), different experimental designs used in various studies, including the use of different genetic lines of pigs, confinement, housing, weaning time (Ogunbameru *et al.*, 1992), feeding time (Waitt and Buchanan-Smith 2001) and feeding facilities (Patience 1998), complexity of diet (Fraser *et al.*, 1994), lighting pattern (Lay *et al.*, 1999; Bruininx *et al.*, 2002), were all likely to be responsible for the different results between them. The results of this study agree with the earlier suggestions of Martin and Bateson (1986), who demonstrated that the recording rules that specify how the behaviour is recorded and followed in each research might also be another factor that can influence the outcome of a behavioural study. More specifically, when the time sampling techniques applied by other workers (found in a survey of articles published in Applied Animal Behaviour Science since 2000), were used in the study reported in this thesis in order to determine the behaviour of the piglets during the pre- and post-weaning period of their life when weaned at around 28 days of age, 73% (Maletinska and Spinka 2001; D'Eath 2002; Donaldson *et al.*, 2002; Weary *et al.*, 2002; Breuer *et al.*, 2003; Mason *et al.*, 2003; Merlot *et al.*, 2004; O'Connell *et al.*, 2005) made use of such observation periods which could not provide results of sufficient statistical association with the true duration of the behaviours under investigation when tested for the purposes of the study reported in this thesis.

This study demonstrated that a single sampling regime shorter than 8h (between 8:00 to 17:00 h) could not give a marked relationship with the 'true' duration of the behaviours recorded when a broad spectrum of behaviours recorded (feeding, suckling, drinking, chewing, fighting, belly-nosing) during the pre- and post-weaning week as previously done by other researchers (Fraser 1978; Gonyou *et al.*, 1998; Widowski *et al.*, 2003; Hotzel *et al.*, 2004). Also, a single day's observations determined by continuous monitoring between 8:00 and 17:00 h for the week pre- and post-weaning used by some observers (Laitat *et al.*, 1999; Schroder-Petersen *et al.*, 2003) did not correlate strongly ($r<0.70$, Sprinthall (1982)) with the true duration of the behaviours observed. Only for the pre-weaning feeding and suckling behaviour was a single day's measurements (24h) during the last or first days of the 4th week of lactation respectively, significantly highly correlated with the 'true' recordings of the behaviour.

Phillips (2000) suggested that all research reports should be evaluated on the quality of the finding in relation to the robustness of the research methodology, acknowledging that no research technique is perfect. The application of extended recording methods presuppose the use of very expensive resources which many researchers can not access. For this reason, the large majority of the researchers chose to use shorter sampling periods. By so doing they have compromised the association of their measurements with the 'true' behaviour of the piglets (Martin and Bateson 1986). It is very important to establish more accurate time-sampling recording methods based on a robust examination of preliminary observations when sufficient continuous recording periods or adequate number of focal animals can not be utilised.

Future work

Despite the significant progress that has been made in the understanding of the microbial ecology of the lower gastrointestinal tract of the piglet during the pre- and post-weaning period, and even though this study identified the effect of the pre-weaning feeding behaviour in the ability of the gut to adapt under the new feeding regime soon after weaning, there is still lack of clear answers on questions such as: what is the effect of the pre-weaning feeding behaviour in the gut health of the individual piglet from birth to the period soon after weaning? It would be interesting to identify a relationship between the status of piglets' gut health and performance characteristics such as their BW, LW and teat-order during the course of this period. This is the next area in which knowledge has to be enhanced as ways of improving voluntary FI pre-weaning is a very important issue for both scientists and the producers.

Also, little work has been done on the underlying science behind the factors that influence the post-weaning feeding behaviour of individual piglets in relation to their pre-weaning feeding activities. It was observed in both studies described in Chapter 2 and Chapter 3 of this thesis, that piglets with limited pre-weaning feeding behaviour (3W piglets and ATS-piglets of the NF treatment) were including greater amounts of water in their daily ration during the week post-weaning which according to Maenz *et al.*,(1994) was a mechanism which helped the piglets to achieve a sense of satiety, when their feed intake is low. In view of the problems that the piglet has in discriminating between hunger and thirst (Brooks and Tsourgiannis, 2003) it might be anticipated that post-weaning performance would be improved by offering a liquid diet i) as it has a dry matter concentration similar to that of sow's milk which could encourage intake and maintain continuity of nutrient supply especially in the more vulnerable classes of piglets with less pre-weaning feeding experience and ii) it could help piglets to overcome the problem of satisfying their drives of hunger and thirst separately.

Another area that requires attention is the examination of FLF in protecting the GI-tract of the vulnerable classes of piglets (those with limited pre-weaning feeding experience) before and after weaning. Considering the beneficial effects that had on sows to overcome disorders due to the stress associated with farrowing, enhance immunity of newborn piglets through better immunological quality of colostrum and control pathogen challenge for both sows and their newborn piglets (Demeckova *et al.*, 2003b; Demeckova *et al.*, 2003a; Demeckova *et al.*, 2003c), it would be interesting to test if the use of the FLF both on sows and piglets could have beneficial effects most importantly on specific groups of piglets, characterised earlier as 'more vulnerable', to obtain a sound immune system and help them maintain it after weaning. It also has to be identified whether the favourable effect of the use of a familiar feeder and the antimicrobial performance of a FLF could combine together and integrate so as to help the weaned piglet to overcome more successfully the challenges that it faces (environmental, nutritional, social and psychological) soon after weaning.

Wattanakul and co-workers (2005) observed that the method of creep feed presentation (between a tray and a hopper) is very important in the initiation of feeding behaviour. So, it would be interesting to evaluate the existing pre-weaning feeder designs available in the market and identify the most suitable type which could help the piglets spend more time feeding or foraging pre-weaning and after they have been weaned to help them maintain high FI independent of their pre-weaning feeding experience.

Summary of main conclusions

- This study demonstrated that weaning at 3 weeks of age can help piglets to achieve heavier body-weight by week 6 of their life than piglets that had to remain with their dam for another week or two.

- Weaning at 4 weeks of age can compromise the weight and negatively affect the social behaviour of the piglets (more fighting and belly-nosing).

- The use of a familiar feeder can help piglets with less pre-weaning feeding experience to spend similar periods of time eating in comparison to their more experienced littermates (regarding their pre-weaning feeding behaviour) and achieve higher growth rates and healthier GI-tract soon after weaning than equivalent piglets that were not provided with a familiar feeder.

- Piglets that were provided with a familiar feeder appeared to be less stressed as they engaged in less belly-nosing behaviour soon after weaning.

- The use of short time-sampling regimes can not be adequate to provide a good estimate of the 'true' behaviour of the piglets for the week pre- and post-weaning (28 d).

- Continuous weekly recordings during the day hours (8:00 to 17:00h) were shown to be sufficient to provide measurements of strong association with the 'true' duration of the behaviours for the given week.

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