# Improving udder quality traits in sows to aid survival and performance of piglets

**By**

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# Abstract

Survival and growth of the piglet is determined by its ability to suckle rapidly after birth, which can be influenced by sow udder morphology. The initial aims of this research were to define a methodology to describe udder morphology (1), to study the sources of variation in the morphology (2) and its relationship with piglet teat preferences (3). A further aim was to assess colostrum quality (IgG) using a quick on-farm method (4), and the final objective was to estimate the heritability ($h^2$) of udder morphology and colostrum traits (5). A methodology to describe a sow udder was developed from review of udder morphology literature and a pilot experiment assessed effects of sow posture, laterality and day on six udder traits, with good repeatability. Methodology was then applied and showed that sows parity number, breed, and teat pair position (anterior, middle, posterior) were significant sources of variation in udder traits. A study on newborn piglet suckling behaviour showed that piglet characteristics such as vitality score and birth weight did not affect teat preference or the latency from birth to first suckling. The majority of siblings suckled for the first time from a previously used teat, mostly located in the posterior part of the udder, though late born piglets preferred teats located in the anterior part. The evaluation of Brix refractometer percentage to assess IgG showed a positive correlation with laboratory Radial immunodiffusion results. Therefore this tool was adopted to investigate the genetic potential of colostrum IgG concentration. All udder morphology and colostrum traits measured in this study were moderate to highly hereditable, with some important correlations with reproductive and productive traits. These udder traits should be included in the breeding goal and weighed appropriately with other important traits in the breeding objectives to enhance optimal genetic progress.

# Dedication

I dedicate this PhD thesis to my little brother Luciano, who always made me proud of him. Since we were children I have always acted thinking about him, a big sister must give a good example. I hope I did. Without his love and support many of the milestone in my life would have been very difficult, if not impossible, to achieve.

I wish this work will be an encouragement to him to seek his educational and professional goals, despite difficulties and failures.

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# Lists of publications

## Peer-reviewed publications

1. A. Balzani, H.J. Cordell, S.A Edwards (submitted, 2015). Does sow udder conformation influence teat access by newborn piglets? *Theriogenology*.
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## Conference and abstracts

1. A. Balzani, H.J. Cordell, E. Sutcliffe and S.A Edwards. Heritability study on sow udder morphology traits. Genetic Society spring meeting. Edinburgh 16-17 April 2015. Poster presentation.
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5. A. Balzani, H.J. Cordell, S.A Edwards. Evaluation of an on-farm method to assess colostrum quality in sows. Proc. 65th Annual Meeting of the European Federation of Animal Science, Copenhagen 25-29 August 2014. Poster presentation.
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# Chapter 1. Introduction

## 1.1 Research context

With the intensification of agriculture, the goal of guaranteeing enough affordable food has been achieved in developed countries. Over the recent decades, most research in agriculture has emphasized the need to rethink common production practices in term of ethics and resources (Bawden, 1991). In his book, Douglas (1984) stated that agricultural practices should be focused on “meeting the needs of the present without compromising the ability of future generations to meet their own needs”. A lot has been done to achieve this aim, but there is still more to do in order to accomplish societal needs, such as mitigation of both the causes and consequences of climate change, ensuring food safety, enhancing product quality, and improving animal welfare. In the livestock sector, one way to contribute to these aims is to decrease the existing losses caused by mortality. The most crucial period in the cycle life of a mammal is the neonatal period (Nowak *et al.*, 2000). Pre-weaning mortality rates vary a lot between farms, but are high among all species: 10% to 25% in lambs, 7% to 50% in kids, 0% to 50% in calves, 0% to 35% in foals, 5% to 35% in pigs (Mellor and Stafford, 2004)

## 1.2 Outline of the problem

Piglet mortality is a major source of financial loss to the British pig industry. The causes are numerous and currently ~1.5 million liveborn piglets annually do not survive until weaning. Maximising the numbers of piglets reared per sow per annum is a major goal of pig industry. Since the overhead cost of sow feeding and maintenance is essentially unchanged by litter size, the more piglets that are reared the greater the biological and financial efficiency of the enterprise, and the lower the environmental footprint of pig meat production (BPEX, 2009). Litter size in the Top 10% of UK herds now averages 13.4 piglets, compared with 12.4 piglets ten years ago, and this trend is likely to escalate with the ongoing efforts of UK-based and international breeding companies. However the increase in sow prolificacy which has occurred over the last decade as a result of genetic selection strategies in specialised damlines has a negative impact on piglet survival. The sow prolificacy issue has received considerable critical attention regarding the threat to the animal welfare.

The importance of the acquisition of passive immunity in the first 24 hours of life for subsequent lifetime health and performance makes this a major contributory factor to raising the health status of the pig herd. It has been demonstrated that the time taken to find a teat and suckle after birth is a key determinant of piglet survival (Baxter *et al.*, 2008), and that a delay in suckling reduces both the level of passive immunity (Bland *et al.*, 2003) and the weight gain achieved by the piglet (Vasdal and Andersen, 2012). In the light of these considerations, developing strategies to improve teat access and adequate colostrum intake will positively impact piglet performance and survival. Many years ago, English *et al.* (1977) highlighted the problem of older sows who failed to adequately expose a proportion of the lower row of teats. More recently it has been shown that teat accessibility decreases with the increment of sow parity number, as animals become larger and teats become higher from the floor or less well exposed (Vasdal and Andersen, 2012). The sow's udder plays a very important role, as colostrum and milk are the main source of energy and passive immune protection for piglets, and access to an early and plentiful supply of these are therefore essential for their growth and health. The necessity to investigate the linkage between udder morphology and teat access, and to determine how udder morphology traits vary between animals and how they change during the sow's life cycle, is compelling in order to understand and mitigate the effects of the past decade of selection for increased litter size, fast growth and lean meat (Vasdal and Andersen, 2012).

## 1.3 Aim of the thesis

This thesis seeks to generate new knowledge on sow udder morphology traits, their relationship with piglet teat seeking behaviour and their genetics in order to improve piglet survival and performance. The specific objectives are to:

I. Develop an evaluation method to define udder morphology traits
II. Investigate the main causes of variation in udder traits during the sow life cycle.
III. Study the relationship between udder morphology traits, ease of colostrum extraction and piglet suckling behaviour
IV. Evaluate an on-farm tool to analyse colostrum composition.
V. Report on the heritability of udder traits and the interaction with other important production traits.

# Chapter 2. Literature Review

Sow prolificacy has increased enormously over the past two decades; the highest rate has been achieved by the Danish pig industry (+3.0 Yorkshire piglets and +3.8 Landrace piglets per litter) with on average of 16.8 total born piglets per farrowing. This prolificacy has had negative repercussions on pre-weaning mortality. An important economic loss to the pig industry, all around the world, is in fact the mortality of piglets (Serenius and Muhonen, 2007; Quesnel, 2011). Losses of up to 20-25% of newborn piglets have been reported (Alonso-Spilsbury *et al.*, 2007). The recent pre-weaning mortality data show that the proportion of piglets failing to survive until weaning is 14% in France (Foisnet *et al.*, 2010a), 11.8% in Australia (APL, 2012), between 14% and 16% in Norway (Andersen *et al.*, 2007) and 16% in Denmark (DPCR, 2010). In England and Wales a study conducted in 2006 reported a pre-weaning mortality rate of 11% (O'Reilly *et al.*, 2006) which was slightly lower than the value of 12% documented in British pig herds six year later (Kilbride *et al.*, 2012). These rates indicate that currently pig production is facing important economic losses and, most importantly, that the general welfare status of piglets is threatened (Baxter *et al.*, 2009; Cabrera *et al.*, 2013). Mammalian species are characterized by females that nurse and care for their young. The neonates rely uniquely on their maternal nutrition. Piglet performance, immediate and long term survival depend on early and sufficient intake of good quality colostrum (Edwards, 2002). In this respect, to find a teat and suckle as soon as possible after birth is of vital importance for the survival of neonatal piglets (Andersen *et al.*, 2011). A state-of-art analysis of the causes that prevent early intake of good quality colostrum, and possible solutions, will aid improvement of piglet survival and identify gaps for possible investigation. This review aims first of all to identify what prevents teat access and to evaluate the consequences. The second part highlights the role of colostrum in preventing mortality and reviews the principal analytical procedures to evaluate colostrum composition. The third part gives coverage of the information about sow udder morphology and provides an overview of the current knowledge of udder morphology traits in other species. Finally productive and reproductive sow traits for genetic selection purposes are explored.

## 2.1 Teat access

Neonatal piglets die on about 80% of all mortality occasions as a result of crushing by the sow or of starvation (Morrison *et al.*, 1983; Svendsen *et al.*, 1986; Dyck and Swierstra, 1987; Alonso-Spilsbury *et al.*, 2007; Strange *et al.*, 2013). However, crushing episodes are often over-estimated by incorrect diagnosis. English (1969) advised that deaths by crushing were predisposed because the piglets did not receive enough food. To reinforce this statement, Weary *et al.* (1996) showed that starving piglets spend more time near the sow, seeking a way to feed themselves, and thus increase their risk to be crushed. Furthermore, starvation has been recorded in association with crushing by many authors (Svendsen *et al.*, 1986; Dyck and Swierstra, 1987; Alonso-Spilsbury *et al.*, 2007; Andersen *et al.*, 2011; Strange *et al.*, 2013). Moreover, a correlation has been found between mortality and hypoxia, indicating that prolonged farrowing increases risk of suckling delay (Zaleski and Hacker, 1993; Herpin *et al.*, 1996). There is compelling evidence that piglets that consume colostrum are vital and robust, and spend less time near the mother (Andersen *et al.*, 2011). There are consequently many good reasons to believe that the factors that increase the latency to find a teat and suckle negatively affect piglet survival (Tuchscherer *et al.*, 2000; Vasdal and Andersen, 2012).

### *2.1.1 The effect of piglet characteristics*

Like other mammals, neonatal piglets depend entirely upon the care and resources from their mother (Nowak *et al.*, 2000). The sow uterus differs from some other species in the nature of the placenta, which prevents the transfer of essential antibodies (Patten, 1948). Hence the neonatal piglet is born without passive immunity (Aumaitre and Seve, 1978; Mellor and Cockburn, 1986; Berthon *et al.*, 1996). Furthermore, piglets do not possess brown adipose tissues and therefore they are born with low energy reserves (Herpin *et al.*, 2002). Mammary secretions are the sole source of energy supply and maternal antibody for the neonate and contain cells, bioactive peptides such as growth factors, and cytokines (Schanbacher *et al.*, 1997) that contribute to neonatal immunity and thermoregulation (Wagstrom *et al.*, 2000). These substances are transferred by the maternal colostrum, and can cross the piglet's intestinal barrier due to a temporary permeability (Rooke and Bland, 2002; Salmon *et al.*, 2009). Although young mammals are dependent on maternal care, as soon as they are born they exhibit teat seeking and suckling behaviour (Nowak *et al.*, 2000). Immediately after birth, newborn piglets start searching via nose contact until they find a teat and start suckling from it (Randall, 1972). Despite the innate expression of teat-seeking behaviour, the latency to first suckling varies considerably between piglets (Rohde and Gonyou, 1987). A natural behaviour particular to the piglet is the competition between siblings over the nutrient resources. It has been suggested that offspring competition starts in the uterus and continues for access to the teats after birth (Drake *et al.*, 2008). Teat access by newborn piglets in the first hour of life has been well investigated in relation to the physical environment (Rohde Parfet and Gonyou, 1988), sow pre-partum activity (Špinka and Illmann, 2015), asphyxia at birth (Herpin *et al.*, 1996), rectal temperature, vitality and birth weight (Tuchscherer *et al.*, 2000; Baxter *et al.*, 2008; Baxter *et al.*, 2009), physiological variables (Casellas *et al.*, 2004) and the influence of management routines (Christison *et al.*, 1997; Vasdal *et al.*, 2011). To date, teat access has never been related in detail with the sow's udder morphology.

Collectively, these studies outline that teat access by newborn piglets in the first hour of life depends on many variables, some related to birth conditions (e.g. vitality, birth weight, birth order), with sow characteristics (e.g. parity number, behaviour, farrowing induction), and farrowing management and environment (e.g. environmental temperature, provision of assistance). How these variables influence piglet survival will be discussed in the following sections.

#### *2.1.1.1 Teat seeking behaviour*

Teat seeking behaviour, defined as the searching phase for the udder initially and for the location of the teat subsequently, has been widely studied to improve farrowing management to reduce piglet mortality (Hartsock and Graves, 1976; Rohde and Gonyou, 1987). Huddling of piglets near the mother in the first days after farrowing (Mount and Rowell, 1960; Curtis, 1970; Hrupka *et al.*, 2000; Andersen *et al.*, 2007; Vasdal *et al.*, 2009), udder massage (Jensen *et al.*, 1998) and teat order establishment (Fraser, 1977; De Passille *et al.*, 1988; Boe and Jensen, 1995; Mason *et al.*, 2003) are the behaviours most recorded. During the first hour of life, piglets spend more time close to the sow's udder (Vasdal *et al.*, 2010) to which they are attracted by the heat, the odor and the softness of the udder skin. De Passille and Rushen (1989b) described teat sampling behaviour for the first time. In her study she observed that, for the initial 8 hours postpartum, the neonatal piglet which has suckled for the first time on a teat then moves along the udder, sampling from different teats and biting or pushing littermates to obtain other teats. Teat preference has received great interest from scientists, as it is a peculiarity of piglet behaviour. It seems that colostrum outflow plays an important role (Fraser, 1976; Fraser, 1977; Jeppesen, 1981; Fraser, 1984; King *et al.*, 1997; Skok *et al.*, 2007). It has been stated that the anterior teats have more colostrum outflow (Pluske and Williams, 1996), and also are in a more comfortable and a safe position (English *et al.*, 1977). In contrast with this result, Skok and Škorjanc (2013) did not find a correlation between colostrum yield and teat position. Huddling of piglets at the anterior part of the udder could be explained by the sow's grunting, that draws the attention of the piglets (Jeppesen, 1981; Castren *et al.*, 1989; Kasanen and Algers, 2002; Skok and Škorjanc, 2013). Another reason that explains the order could be the mother's breath odor (Jeppesen, 1981). A more recent and scientific explanation comes from the study carried out by Skok and Škorjanc (2013), using a mid-domain effect (MDE) approach to better understand the order around the mother's udder. Skok and Škorjanc (2013), studied which factors determine the allocation to a specific teat in the first few days after farrowing, before teat order is established. The results of the study showed that anterior and posterior positions were easy to keep, so suckling position could be maintained more effectively. Piglets suckling behaviour was related to the geometric constraints of the shape of the mammary gland. MDE approaches showed that teat position did not depend on biological causes but from the limitations of the mammary complex. Contrary to previous findings, in this analysis, colostrum yield, piglet body weight and colostrum intakes were not correlated with teat position. The absence of relationship between suckling position and piglet body weight was demonstrated also by Hemsworth *et al.* (1976) and some years later confirmed by Fraser *et al.* (1979) and more recently by Kim *et al.* (2000).

#### *2.1.1.2 Birth condition*

Domestic pigs produce large litters and small young that rely completely on the maternal care during the first day of life (Fraser and Thompson, 1991). Higher mortality has been associated with breathing difficulty at birth (Scott *et al.*, 1976; Leenhouwers *et al.*, 2001; Devillers *et al.*, 2011) and umbilical cord rupture after parturition (Herpin *et al.*, 1996; Leenhouwers *et al.*, 2001; Devillers *et al.*, 2011). Splay-leg was also identified as a cause of mortality because it reduces piglet mobility, increasing the time to achieve udder contact and suckle (Devillers *et al.*, 2011). Attempts to quantify neonatal vitality have involved measurement of heart rate, respiration rate, muscle tone and rapidity of attempts to stand (Zaleski and Hacker, 1993). Also, vitality is associated with the neonatal behaviours which can predict piglet survival, including teat seeking (Hoy *et al.*, 1995). These neonatal behaviours have been defined as time to first upright standing, first udder contact and first colostrum uptake (Leenhouwers *et al.*, 2001). Tuchscherer *et al.* (2000), comparing surviving piglets with those that died before the first 10 days of life, demonstrated that the main factors that affect the survival at the time of birth were: birth weight (Sharpe, 1966; Vasdal *et al.*, 2011); birth order (Fraser and Thompson, 1991; Klobasa *et al.*, 2004) and rectal temperature. Several authors have reported the same results: low rectal temperature at a few hours after birth was correlated with piglet mortality (Herpin *et al.*, 1996; Vasdal *et al.*, 2010; Devillers *et al.*, 2011). In contrast, Leenhouwers *et al.* (2001) did not find a relationship between rectal temperature and survival rate. In other studies, it was pointed out that farrowing survival increases with increase in birth weight (Zaleski and Hacker, 1993; Leenhouwers *et al.*, 1999; Leenhouwers *et al.*, 2001). Hendrix *et al.* (1978) noted that birth weight was positively correlated with subsequent IgG content of piglet serum, and in addition Nguyen *et al.* (2013) discovered that more IgG intake had occurred in large piglets (>2.0 kg) at 3 days of age. A sow-offspring behaviour review reported that, due to behavioural competition, a low birth weight piglet has less chance to survive until weaning (Drake *et al.*, 2008). Furthermore, lower weight gain, or even weight loss, in the first days of life has been linked with mortality (Svendsen *et al.*, 1986; Dyck and Swierstra, 1987; De Passille and Rushen, 1989a; Devillers *et al.*, 2011).

Genetic selection for lean growth efficiency and sow prolificacy negatively affects neonatal survival. Newborn piglets selected for lean tissue growth rate are less physiologically mature and this affects their capacity to survive (Canario *et al.*, 2007). Besides, intense selection for increased litter size in the last decade is responsible simultaneously for the reduction in individual birth weight and a greater degree of competition for teat access (Dyck and Swierstra, 1987; Roehe and Kalm, 2000; Drake *et al.*, 2008; Campos *et al.*, 2012). Several studies have found that the average of 10-11 piglets across all parities is the natural number of piglets that a sow can rear in commercial conditions (Weber *et al.*, 2009; Andersen *et al.*, 2011; Vasdal *et al.*, 2011). Large litter size increases mortality by increasing sibling competition, resulting in failure to reach the teat and suckle (Milligan *et al.*, 2001; Andersen *et al.*, 2011). In addition Zindove *et al.* (2013) demonstrated that an increased number of piglets born alive has a negative impact on piglets survival rate at weaning and decreases mothering ability. Moreover, colostrum intake per piglet increases when litter size decreases (Parfet and Gonyou, 1988; Le Dividich *et al.*, 2005; Baxter *et al.*, 2008; Andersen *et al.*, 2011; Quesnel, 2011), and decreases when within-litter heterogeneity of birth weight increases (Quesnel, 2011; Nguyen *et al.*, 2013). For each additional piglet born, colostrum availability decreases by 22 to 42g (Devillers *et al.*, 2007; Baxter *et al.*, 2008). Low birth weight and weak neonatal condition have a negative effect on colostrum intake (Lecce, 1971; Hendrix *et al.*, 1978; Yaguchi *et al.*, 1980; De Passille *et al.*, 1988; Fraser and Thompson, 1991; Herpin *et al.*, 1996; Tuchscherer *et al.*, 2000; Devillers *et al.*, 2007; Vasdal *et al.*, 2011).

The evidence presented in this section suggests that piglet birth condition influences the latency to find a teat and suckle, preventing access to the vital resources necessary for the neonates to grow and survive. Piglets that cannot access a functional teat typically die in the first four day of life (English and Smith, 1975).

### *2.1.2 The effect of sow characteristics*

#### *2.1.2.1 Maternal behaviour*

Sow behaviour and nursing ability are the base to support economy and efficiency of pig husbandry (Špinka *et al.*, 2000; Kim *et al.*, 2001). For this reason, a large and growing body of literature has investigated sow maternal behaviour (Algers and Uvnäs-Moberg, 2007). A comparative study between domesticated pigs and non-domesticated wild boar, *Sus scrofa*, revealed no difference in most aspects of the maternal behaviour (Špinka *et al.*, 2000). A number of authors have considered that maternal infanticide and siblicide is an evolutionary behaviour adopted by the pig in order to maximize the outcomes from maternal investment (Fraser, 1990; Nowak *et al.*, 2000; Edwards, 2002; Drake *et al.*, 2008; Andersen *et al.*, 2011). This concept leads to the suggestion that maternal crushing, and maternal failure in general, might be a strategy to increase the resources available for the fitter survivors and therefore their survival prospects (Andersen *et al.*, 2011).

Maternal behaviour is commonly dived into three phases: pre-, during and post-farrowing. Pre-farrowing behaviour of sows is mainly characterized by nest-building (Wischner *et al.*, 2009). A few hours before the parturition, the sow starts to build the nest. The animals express this behaviour even when confined in crates, and it is exactly the same behaviour as shown by non-domesticated wild boar (Jensen, 1993; Gustafsson *et al.*, 1999; Špinka *et al.*, 2000).

The farrowing duration is on average 166 min (26–505), though this now varies more widely with breed and litter size, and during this period plasma oxytocin concentrations are elevated (Algers and Uvnäs-Moberg, 2007). Lewis and Hurnik (1985) described two sow nursing behaviour phases, an initial behaviour during colostrum letdown and a second, more complex, behaviour during milk production. For the entire duration of parturition colostrum is continuously available, with the sow for much of this time passively lying down on a flank and exposing the udder, allowing newborn piglets to access the teat and suckle (Špinka and Illmann, 2015). Jarvis *et al.* (1999) observed that, throughout farrowing, the sows that are less responsive towards their piglets have higher offspring survival rate. They also noticed that postural changes happen more in the initial stage of the parturition than in the later stage. During the entire farrowing process, sow behaviour of exposing the udder is fundamental for the survival of her offspring. Teat accessibility (Andersen *et al.*, 2011; Vasdal and Andersen, 2012) and number of functional teats (Vasdal and Andersen, 2012; Chalkias *et al.*, 2014) are important to achieve the maximum amount of colostrum transfer. Vasdal and Andersen (2012) noticed that the access to the lower teat row during nursing is always more limited than the upper row.

Post-farrowing behaviour is characterized by increased occurrence of postural changes (Špinka and Illmann, 2015). A considerable number of studies have focused on the sow behaviour before lying down (Clough and Baxter, 1984; Blackshaw and Hagelsø, 1990; Wischner *et al.*, 2009). The grade of carefulness when the sow lies down has been associated with crushing events (Marchant *et al.*, 2001). The type of pre-lying behaviour observed is characterized by seven actions: rooting (Blackshaw and Hagelsø, 1990; Špinka *et al.*, 2000; Marchant *et al.*, 2001; Wischner *et al.*, 2009; Valros, 2010) pawing (Marchant et al., 2001; Pokorná et al., 2008; Wischner et al., 2010)(Marchant *et al.*, 2001; Pokorná *et al.*, 2008; Wischner *et al.*, 2009), sniffing piglets (Valros et al., 2003; Pokorná et al., 2008; Wischner et al., 2010), nudging piglets (Marchant et al., 2001), looking around (Marchant et al., 2001; Wischner et al., 2010), turning around (Burri *et al.*, 2009) and descending vertically (Špinka et al., 2000). Overall, good mothering abilities are defined when her behaviour prevents crushing of piglets and allows teat access.

#### *2.1.2.2 Sow parity number*

Sow maternal ability is dependent on the number of litters she has produced in her life cycle. Moore *et al.* (2001) found that the progeny of gilts grow more slowly and have higher mortality. In contrast, Weber *et al.* (2009) reported that increasing the parity number increases piglet mortality rate. Andersen *et al.* (2011), during a study on litter size effects on piglet survival, established no correlation between parity number and mortality, but she noticed that sows in parity four had more piglet mortality. Vasdal and Andersen (2012) discovered that teat accessibility decreases in old sows, and this indirectly affects piglet survival. Has been demonstrated a positive correlation between piglet mortality and farrowing duration (Zaleski and Hacker, 1993), although the opposite result was found in the study of Leenhouwers *et al.* (2001). Moreover, it was reported that high parity sows have a higher rate of stillbirth (Kirkden *et al.*, 2013), which probably reflects a larger average litter size and longer farrowing duration.

Smaller udder size in gilts and second parity sows is correlated with lower colostrum and milk production (Eissen *et al.*, 2000). In accordance with these results, it was found that piglets of gilts and second parity sows had the highest drop in rectal temperature from birth to 2 hours, although there were no significant differences in litter size or latency to suckle (Vasdal *et al.*, 2010). Vasdal *et al.* (2010) hypothesized that the hypothermia was due to the lack of heat that the piglet should receive from the udder surface, since gilts have smaller mammary glands, and from less nutrient production as previously shown by Eissen *et al*. (2000). Considering all of this evidence, it seems that the maternal ability of the sow initially increases with parity number, but may then deteriorate at higher parities.

### *2.1.3. Farrowing management*

Pre-weaning mortality cannot be dissociated from the farrowing management and environment. In this regard, Kirkden *et al.* (2013) reviewed the most common management strategies applied to reduce piglet mortality, and concluded that focusing attention on the farrowing process and the first hour after birth is the best solution to prevent mortality. Farrowing assistance and special care for the weak piglets are the most recommended strategies to minimize piglet mortality. This review reported a list of good practices to assist the weak piglets, such as drying, providing extra heat, facilitating the teat seeking process by placing them in front of the udder, and feeding them artificially.

A survey focusing on the variability of piglet mortality around farrowing in relation to management practice was conducted by Andersen *et al.* (2009), who did not find any association between piglet survival rate and farrowing supervision and piglet care. However, it was found that there was a reduction in piglet mortality when the piglets were helped to obtain colostrum immediately after birth. Two years later, the same author designed an experimental study, focusing on each of the management factors that could influence piglet mortality at farrowing. The results of this study showed that drying piglets and placing them under the heat lamp in the creep area immediately after birth reduced mortality (Andersen *et al.*, 2009). Another detailed examination of different management routines at the time of farrowing by (Vasdal *et al.*, 2011) showed no difference in mortality between piglets not assisted and piglets that were both dried and placed under the heat lamp or in front of the udder. She found, nevertheless, a significant reduction in piglet mortality when the piglets were dried after birth, and recorded the highest postnatal mortality when the litters were placed at the udder without being dried first. Together these studies outline a critical, but complex, role for farrowing assistance and piglet care around farrowing.

## 2.2 Colostrum

Colostrum is the first secretion of the mammary gland and is a key contributor for piglet survival (De Passille and Rushen, 1989a; Fraser, 1990; Tuchscherer *et al.*, 2000; Milligan *et al.*, 2002; Andersen *et al.*, 2011; Devillers *et al.*, 2011; Vallet *et al.*, 2013). Early intake of colostrum is essential for piglet survival for several reasons; not only is it fundamental to develop immune protection (Porter, 1969; Bourne and Curtis, 1973; Klobasa *et al.*, 1981; Rooke and Bland, 2002; Rooke *et al.*, 2003; Le Dividich *et al.*, 2005; Quesnel *et al.*, 2012) but also to increase resistance to infection in the immediate postnatal period (Drew and Owen, 1988) and after weaning (Devillers *et al.*, 2011; Vallet *et al.*, 2013). Moreover, colostrum is an important source of energy for thermoregulation and body growth (Curtis, 1970; Ledividich and Noblet, 1981; Herpin and Le Dividich, 1993; Jensen *et al.*, 2001; Devillers *et al.*, 2004b; Le Dividich *et al.*, 2005; Quesnel *et al.*, 2012). It is also necessary for piglets at birth for the supply of growth factors that stimulate intestinal growth (Widdowson *et al.*, 1976; Xu *et al.*, 2002), and play a role in blood glucose regulation (Herpin and Le Dividich, 1993). Furthermore, it has been demonstrated that the weight increment at 12 hours is correlated with the later weight gain of a litter (Ledividich and Noblet, 1981; De Passille and Rushen, 1989a; Tuchscherer *et al.*, 2000). The high level of oxytocin in the blood associated with farrowing causes the release of colostrum ad libitum (Forsling *et al.*, 1979) and it then becomes phasic with time.

Fraser and Lin (1984) demonstrated by hand milking the sow that colostrum is available even before farrowing. On average, the duration of colostrum release is 12 to 48h after parturition (De Passille and Rushen, 1989; Fraser *et al.*, 1992; Devillers *et al.*, 2004). However recent study defined colostrum yield as occurring from 0 to 24 h after initiation of farrowing (Vadmand *et al.*, 2015). It is also well known that composition changes rapidly postpartum (Klobasa *et al.*, 1987, Bland *et al.*, 2003). For this reason, reducing the delay to find a teat and suckle is of fundamental importance for the health and growth of the neonatal piglets.

### *2.2.1 Colostrum yield*

Several authors have investigated the physiological role of colostrum and measured its yield over the first 24 hours. However colostrum yield is complicated to assess and it has never been possible to measure it directly (Farmer and Quesnel, 2009). Colostrum production was calculated on average to amount to 3.3-3.7 kg in the first 24h, with a range of 1.5 to 6kg (Foisnet *et al.*, 2010b; Quesnel, 2011). Devillers *et al.* (2004) reported that an average volume of 3.6 kg (range from 1.9 to 5.3 kg) of colostrum was produced by sow until 17 to 24 hours after birth of the first piglet. A recent study on one-hundred sows estimated colostrum yield by the weigh-suckle-weigh method (Declerck *et al.*, 2015). The average colostrum production per sow was 4.75kg (range from 0.65 to 9.42 kg). Colostrum production is very variable between sows and factors affecting this variability are not well understood (Farmer and Quesnel 2009). Fraser and Lin (1984) claimed that colostrum yield is related to udder stimulation. Similarly, Devillers *et al.* (2007) reported a positive correlation between colostrum production and litter weight. This hypothesis was confirmed also by Kim *et al.* (2000). Conversely, Le Dividich *et al.* (2005) reported no significant association between birth weight and colostrum yield. In their review of factors affecting colostrum yield, Farmer and Quesnel (2009) identified endocrine status and nutrition as main influencing variables. Prostaglandins play an important part in colostrogenesis and administration of prostaglandin to induce farrowing reduces colostrum yield (Devillers *et al.*, 2007). Nutrition remains the major factor studied to alter colostrum composition: the dietary lipid fraction has been largely exploited for its effect on the brain development and passive immunity; the amino acid fraction has been associated with increased protein content in colostrum but not with energy intake. Also, supplementation with yeast extract or fermented liquid feed has been related with increasing immunoglobulin in colostrum, as well as vitamin and minerals (Farmer and Quesnel 2009). Teat pair position has been associated with colostrum yield; anterior and middle teats seemed to have a larger production than posterior ones (Fraser and Lin, 1984; Fraser and Rushen, 1992). A more recent study confirmed this evidence, showing that anterior and middle glands produce more colostrum and milk than posterior glands (Kim *et al.,* 2000).

### *2.2.2 Colostrum composition*

Porter (1969) and Curtis (1970) quantified the immunoglobulin in sow colostrum, showing that 80% of the proteins in sow colostrum were immunoglobulin (Ig). There are three identified classes of Ig in swine, IgG, IgA, and IgM. Immunoglobulin G is the most abundant and most extensively studied immunoglobulin. Klobasa *et al.* (1987) showed that colostrum immunoglobulin G (IgG) concentration (in mg/ml) passed from 95.6 at the beginning of lactation to 64.8 after 6 hours, to 32.1 after 12 hours. After parturition, total solids and protein were higher, while fat and lactose were lower than in mature milk. During the first 6h, the content of IgG was greater than IgA. At 2 weeks of age, the composition changed with the concentration of IgG replaced with IgA (Klobasa *et al.*, 1987). Swine colostrum composition at farrowing contains 24–30% dry matter, 15–19% total proteins, 5–7% fat, 2–3% lactose and 0.63% ash (Klobasa *et al.*, 1987; Csapo *et al.*, 1996). Lactose concentration is very low prior to farrowing (Devillers *et al.*, 2007). However IgG concentration at parturition seems to vary from one study to another (Table 2.1); this can be related to the methodology used to analyse the composition. Other possible explanations arising from the literature review of colostrum yield and composition studies are related to the sow characteristics.

Table 2. 1 Variation in immunoglobulin G concentration at parturition according to the sampling time and analytical methodology used (ELISA: enzyme linked immune-sorbent assay; RID: radial immune diffusion)

| Author (year) | Method | SamplingTime (hours) | IgG (mg/ml) |
|---|---|---|---|
| Loisel *et al*. (2013) | ELISA | 0 | 52 |
| | ELISA | 24 | 11 |
| Quesnel (2011) | ELISA | 0 | 62 |
| | ELISA | 24 | 17 |
| Foisnet *et al*. (2011) | ELISA | 0 | 70 |
| | ELISA | 6 | 50 |
| | ELISA | 12 | 25 |
| | ELISA | 24 | 10 |
| Cabrera *et al*. (2012) | RID | 0 | 43 |
| Leonard *et al*. (2010) | ELISA | 1 | 63 |
| Foisnet *et al*. (2010b) | ELISA | 0 | 74 |
| Devillers *et al*., (2005) | ELISA | 2 | 62 |
| | ELISA | 24 | 15 |
| Voisin (2005) | ELISA | 0 | 78 |
| Devillers *et al*. (2004a) | ELISA | - 8 | 100 |
| | ELISA | 0 | 85 |
| | ELISA | 12 | 60 |
| Bland *et al*. (2003) | ELISA | 0 | 61 |
| | ELISA | 4 | 62 |
| | ELISA | 8 | 45 |
| | ELISA | 12 | 24 |
| | ELISA | 16 | 26 |
| | ELISA | 20 | 15 |
| | ELISA | 24 | 9 |
| Bland and Rooke (1998) | ELISA | 0 | 61 |
| | ELISA | 4 | 62 |
| | ELISA | 8 | 45 |
| | ELISA | 12 | 24 |
| Klobasa *et al*. (1987) | RID | 0 | 96 |
| | RID | 6 | 65 |
| | RID | 12 | 32 |
| | RID | 18 | 22 |
| Machadoneto *et al*. (1987) | RID | 0 | 73 |
| | RID | 24 | 22 |
| | RID | 48 | 13 |
| Curtis (1970) | RID | 0 | 61 |
| Porter (1969) | RID | 0 | 80 |

### *2.2.3 Principal analytical methods to assess colostrum quality*

Analysis of immunoglobulin G is most commonly used to determine the quality of colostrum. There are several methodologies applicable, which differ in terms of time, cost and efficacy.

#### *2.2.3.1 The Radial Immune Diffusion (RID)*

The golden standard RID was developed by Mancini *et al.* (1965) and since then has been used to quantify immunoglobulin first in serum, and later in colostrum (Kalff, 1970; Cabrera *et al.*, 2012). Radial immunodiffusion, an antibody-precipitant technique, is a simple procedure that requires a small amount of sample but needs overnight incubation. The quantification of antibody present in serum or colostrum is performed without any separation step (Guidry and Pearson, 1979). Serum or diluted colostrum, as well as the internal IgG standards of the kit, are placed in individual wells on the RID plate. The plates, that contain the antibody for the specific protein to be quantified, are incubated and at equilibrium an antigen-antibody precipitate ring is formed (Guidry and Pearson, 1979). After the recommended incubation period, the precipitin ring diameter is measured. The IgG concentrations of samples are determined by comparing the diameter of the precipitation ring with a standard curve generated by the internal standards of each kit. One of the problems in RID analysis is that discrepancies in IgG concentration can occur between RID kits made by different companies (Ameri and Wilkerson, 2008). The amount of immunoglobulin quantified can thus depend on the company that made the kit, and potential discrepancies could occur due to inaccuracies of the internal IgG standards that are provided (Gapper *et al.*, 2007; Morrill *et al.*, 2012).

#### *2.2.3.2 The Enzyme Linked Immune-Sorbent Assay (ELISA)*

The enzyme linked immune-sorbent assay does not always require overnight incubation. It consists of adding sample to wells in a polystyrene plate precoated with antigen, incubated for 1 h and then washed. The colostrum or serum is added at different dilutions to the wells. A cycle of washing is then performed to allow the antibody to bind with the antigen, remove the un-bound material, and the protocol ends with the addition of an enzyme substrate to detect antigen-bound antibody. This leads to a colour change that is proportional to the amount of bound antibody. The colour intensity is determined by spectrophotometry. The quantification of immunoglobulin is made by creating a standard curve using commercially available Ig standards. This analysis is so far the most used to assess immunoglobulin G in swine colostrum, but is not suitable for on-farm use since it requires specialized laboratory equipment to perform the analysis (Bland *et al.*, 2003; Devillers *et al.*, 2004a; Foisnet *et al.*, 2010b; Leonard *et al.*, 2010; Foisnet *et al.*, 2011; Quesnel, 2011; Moreno-Indias *et al.*, 2012; Pausenberger *et al.*, 2012; Pribylova *et al.*, 2012; Loisel *et al.*, 2013).

#### *2.2.3.3 The Brix refractometer*

Refractometry measures the concentration of any solution of dissolved solids, based on the degree to which the light rays are bent (Chavatte *et al.*, 1998). The refractometer estimates colostrum IgG by reporting a Brix value (measure of refractive index), which is then correlated with colostrum IgG concentration. Brix is a rapid, accurate, and inexpensive method which has been used to evaluate colostrum quality in sheep (Harker, 1978), horses (Chavatte *et al.*, 1998; Cash, 1999) and dairy cattle (Morrill *et al.*, 2012; Quigley *et al.*, 2013; Bartier *et al.*, 2015), though not yet investigated for the pig. Bielmann *et al.* (2010) reported that optical and digital brix refractometer indexes were not affected by sample storage temperature (fresh or frozen). However the Brix refractometer does not allow for the variability of the non-antibody proteins in colostrum. As has already been mentioned, most of the proteins in colostrum are IgG (Klobasa *et al.*, 1987; Csapo *et al.*, 1996); thus, measuring total protein in colostrum may provide a value highly correlated with IgG concentration. The correlation coefficient for the Brix refractometer against RID in cows has been found to be lower than in horses, and this could be attributable in part to the composition and volume of colostrum (Bielmann 2010) and in part by the kit used (Gapper *et al.*, 2007).

### *2.2.4 Factors influencing colostrum yield and composition*

#### *2.2.4.1 Sow characteristics*

A proportion of sows fail to produce colostrum (Farmer and Quesnel 2009). The majority of variance in sow colostrum composition can be explained by the breed (Declerck *et al.*, 2015). It has been established that Duroc sows produce more IGF-I protein than Landrace (Simmen *et al.*, 1990; Farmer *et al.*, 2007) and Yorkshire. In contrast, lactose concentration is greater in Yorkshire than Duroc and Landrace/Pietrain (Farmer *et al.*, 2007). The Chinese Meishan breed produces more lipid (Le Dividich *et al.*, 1991), and more lactose (Zou *et al.*, 1992), than white breeds. Concentration of immunoglobulin IgA was greater in

Hampshire and Landrace x Yorkshire sows than in pure breeds (Inoue, 1981a; Inoue, 1981b). It remains to clarify the effect on colostrum production of sow age; in fact, some studies demonstrated that increasing the number of parities (three to six parities) increases colostrum production (Devillers *et al.*, 2007). In contrast with these results, a recent study recorded no significant effect on colostrum yield of parity, gestation length or parturition duration (Declerck, *et al.*, 2015). Fat concentration decreases with increasing parity number, the maximum difference was observed between the first and the second parity (Klobasa *et al.*, 1986), while the content of IgM and IgG was more concentrated in sows of more than 4 parities (Klobasa *et al.*, 1987). These results could be explained by the increased exposure to a wide range of pathogens in older sows (Farmer and Quesnel, 2009). Ambiguous results were found about the relationship between teat position and immunoglobulin content: anterior (Rooke *et al.*, 1998; Wu *et al.*, 2010), posterior (Klobasa *et al.*, 1987) and middle regions (Tuchscherer *et al.*, 2006) have all been reported to be richer in IgG concentration

#### *2.2.4.2 Litter characteristics*

Quesnel *et al.* (2011), for the first time, discovered that stillbirth rate was negatively related to colostrum yield. Furthermore, litter size positively affects colostrum production (Declerck, *et al.*, 2015). The piglet weight also plays a role; a positive association was observed between birth weight and colostrum yield (King *et al.*, 1997). Colostrum production is affected by suckling; the regression of unsuckled mammary glands in the lactating sow occurs rapidly after 7-10 days of lactation (Kim *et al.*, 2000), and even after 3 days the mammary gland involution process is irreversible, associated with changes in gene expression (Theil *et al.*, 2006). It has been demonstrated that a teat which is not suckled gives less milk in the subsequent lactations. This was demonstrated considering piglets' weight, behaviour and mammary gland composition (Farmer *et al.*, 2012). These considerations are related with the positive effect of piglet vitality on colostrum yield found in previous studies (Devillers *et al.*, 2007; Quesnel *et al.*, 2012; Fraser *et al.*, 1985). In fact, it has been well demonstrated that a piglet's stimulation of the mammary gland improves colostrum yield (King *et al.*, 1997).

#### *2.2.4.3 Hormone effects on colostrogenesis*

Several hormones are related with colostrogenesis (Dehoff *et al.*, 1986). Before lactation starts, oxytocin concentration increases in blood (Ellendorff *et al.*, 1979); it has been demonstrated that oxytocin allows lacteal secretion (Kensinger *et al.*, 1986; Xu *et al.*, 2003). Progesterone has a negative influence on lactose secretion; a lower concentration of progesterone in plasma is related with an increment of lactose concentration in milk (Holmes and Hartmann, 1993). De Passille *et al.* (1993) showed an association between piglet mortality and losses of weight in sows with high progesterone concentration in blood after farrowing. Abnormalities in endocrine status are related with reduced colostrum production (Quesnel *et al.,* 2011; Foisnet *et al.,* 2010). The artificial administration of oxytocin to facilitate farrowing has been shown to have some hazards, such as increased number of stillborn piglets, piglets of low vitality and increased dystocia (Alonso-Spilsbury *et al.*, 2004; Mota-Rojas *et al.*, 2005). The utilization of hormones to induce farrowing can also have some negative effects on colostrum production if done before 112 days of gestation (Devillers *et al.*, 2005). It can additionally change the composition, giving fat concentration increment and decrease of protein (King *et al.*, 1996). Kirkden *et al.* (2013) pointed out that induced farrowing, even after 113 days of gestation, requires a mindful supervision to decrease piglet mortality.

## 2.3 Sow udder morphology

The word mammal is derived from the Latin *mamma* ("udder"), and research about the udder has a long history related to nursing and milking abilities. With regard to the sow mammary gland, investigation has been more focused on the physiology in order to improve milk production (Fraser *et al.,* 1985; Kim *et al.,* 2001; Farmer, 2013), and the anatomy to determine the genetic and phenotypic variation in functional teat number (Pumfrey *et al.,* 1980; Chalkias, *et al.,* 2013).

The ability of a sow to rear piglets depends on the accessibility of a sufficient number of functional teats (Chalkias *et al.,* 2014). The sow’s udder usually has from 13 to 17 mammary glands with, on average, 15 functional teats (Vasdal *et al.*, 2010). In the young gilt it is possible to find teats which are less functional than others. The main reason is that some of the teats can be inverted, small or supernumerary (supernumerary teat may be without glands, others are orifices of small glands, and yet others may open into one of the normal glands, but are not functional) and these types of teat are not suitable for suckling (Chalkias *et al.,* 2013). A teat is defined as inverted when the top of the teat, or even the entire teat, is inverted to form a crater (Nordby, 1934). Jonas *et al.* (2008) demonstrated that inverted teats reduce the rearing capacity of the sow and increase mastitis risk.

Mammary growth occurs in three phases, namely from 90 d of age until puberty, during the last third of gestation (Sorensen *et al.*, 2002) and throughout lactation (Kim *et al.*, 1999). Kim *et al.* (2000) showed that middle mammary glands, 12 hours after parturition, were the biggest glands, and at 21 days post-partum he noticed a greater growth from the second to the fifth than in the first and the posterior glands. These results support that substantial mammary gland growth occurs during lactation. Kim *et al.* (2000) showed that the mammary glands have different shape; the anterior (first and second pairs) and middle (third, fourth and fifth pairs) of mammary glands grow laterally and medially, while the posterior glands (sixth, seventh and eighth) expand elliptically in a longitudinal manner due to the space that they have to expand.

### *2.3.1 Udder traits and neonatal performance*

Sows with high teat number (range: 15-16) have bigger litters at weaning compared with sow with 14 teats (Rekiel *et al.*, 2014). Milk production depends on the number of alveolar cells present in mammary glands at the onset of lactation, and in particular on mammary gland composition in late lactation (Farmer *et al.*, 2010). It has been established that there is a correlation between weight gain of individual piglets and mammary DNA and RNA content (Nielsen *et al.*, 2001; Farmer *et al.*, 2010). Kim *et al.* (2000) also reported a relationship between protein and DNA content of the mammary gland and single piglet weight. Controversially, Nielsen *et al.* (2001) did not find any correlation between piglet ADG and mammary gland traits, considering as traits DNA and RNA of the gland tissue. However the studies presented thus far provide evidence that only teat pair position and mammary gland composition have been investigated in relationship with piglet performance, whereas in other species the udder morphology has received great attention focussed on the nursing and milking ability of the mother. A description of the morphological traits studied will be discussed in the following section.

### *2.3.2 Udder morphology in other species*

There is a large volume of published studies describing the role of udder morphology traits in relation to offspring survival, milk yield and health in bovine and ovine species. Udder conformation has been defined using many criteria; a list of the main teat traits (Table 2.2) and udder traits (Table 2.3) evaluated, the species studied and the evaluation tools used. A number of authors have demonstrated that udder morphology affects the calf’s ability to nurse and therefore to survive (Wythe, 1970; Edwards and Broom, 1982; Ventorp and Michanek, 1992). Huntley et al. (2012) studied the morphology of the sheep udder and its correlation with lamb performance. He carried out a combined study with linear scores and metric measurements. Higher weight was shown in lambs that suckled teats categorized with a score between 1 to 5, than in lambs reared by ewes with more medial or more lateral teat positions (6 to 9 point score). It has been demonstrated as well that there is a significant correlation between teat shape and milk flow in cows (Moore *et al.*, 1981; Kuczaj, 2003; Zwertvaegher *et al.*, 2011), goats (Jenness, 1980; Wang, 1989), and ewes (Labussiere *et al.*, 1981; Fernandez *et al.*, 1995; delaFuente *et al.*, 1996; Casu *et al.*, 2006). Moreover, there is a relationship between udder conformation traits and udder health status. The incidence of mastitis is associated with udder morphology (Seykora and McDaniel, 1985) and teat lesion prevalence is associated with teat position (Cooper *et al.*, 2013). This evidence formed the basis to investigate the heritability of the udder morphological traits in the pig in order to improve the offspring survival, increase the production and ensure health conditions in this species by selecting for the optimal criteria.

Table 2. 2 Teat conformation traits in different species, evaluated with metric scale or linear scoring systems.

| Teat Traits | Species | Evaluation tool | Reference |
|---|---|---|---|
| length | Sheep | Metric scale | Labussiere *et al.* (1981); Fernandez *et al.* (1994); Huntley *et al.* (2012) |
| | Sheep | Linear scoring | De la Fuente *et al.* (1995) |
| | Cow | Metric scale | Seikora *et al.* (1985); Kuczaj *et al.* (2003); Zwertvaegher *et al.* (2011) |
| | Buffalo | Metric scale | Espinoza *et al.* (2011) |
| diameter | Sheep | Metric scale | Labussiere *et al.* (1981); Fernandez *et al.* (1994); Huntley *et al.* (2012) |
| | Cow | Metric scale | Moore *et al.* (1981); Seikora *et al.* (1985); Kuczaj *et al.* (2003); Riera Nieves *et al.* (2005); Zwertvaegher *et al.* (2011) |
| | Buffalo | Metric scale | Espinoza *et al.* (2011) |
| lesion | Sheep | Linear scoring | Huntley *et al.* (2012) |
| | Cow | Linear scoring | Seikora *et al.* (1985) |
| placement | Sheep | Linear scoring | Labussiere *et al.* (1981); Fernandez *et al.* (1994); De la Fuente *et al.* (1995); Casu *et al.* (2006); Huntley *et al.* (2012) |
| orientation | Sheep | Metric scale | Labussiere *et al.* (1981); Fernandez *et al.* (1994) |
| orifice | Cow | Radiography | Seikora *et al.* (1985) |
| | Cow | Score | Hickman, *et al.* (1964); Riera Nieves *et al.* (2005); Riera Nieves *et al.* (2006) |
| Teat end | Cow | Linear scoring | ; Seikora 1985; (Riera-Nieves *et al.*, 2006); |

Table 2. 3 Udder conformation traits in different species, evaluated with metric scale or linear scoring systems.

| Udder Traits | Species | Evaluation tool | Reference |
|---|---|---|---|
| Distance between teat | Goat | Metric scale | Wang *et al.* (1988) |
| | Cow | Metric scale | Kuczaj *et al.* (2003) |
| Udder drop | Sheep | Metric scale | Labussiere *et al.* (1981); Huntley *et al.* (2012) |
| | Cow | Metric scale | Moore  *et al.* (1981);Kuczaj *et al.* (2003) |
| Udder shape | Sheep | Metric scale | Labussiere *et al.* (1981) |
| | Sheep | Linear scoring | De la Fuente *et al.* (1995) |
| | Cow | Metric scale | Kuczaj *et al.* (2003) |
| Udder depth | Sheep | Metric scale | Labussiere *et al.* (1981); Fernandez *et al.* (1994) |
| | Sheep | Linear scoring | De la Fuente *et al.* (1995); Huntley *et al.* (2012) |
| | Cow | Metric scale | Seikora *et al.* (1985) |

## 2.4 Genetic selection

During the past decades, much more information has become available on genetic selection strategies. Genetic selection has greatly improved animal performance over the years, due to the introduction of sophisticated mathematic models (BLUP animal models). Traits considered beneficial for production and welfare are often similar across livestock species, although the most valuable traits vary depending on the intended use of the animal and the species in question. In swine, genetic selection is focused on improving production, by selecting for fast growing animals with improved lean content, and reproduction, by selecting for higher litter size. Unfortunately, these traits often have unfavourable genetic correlations with piglet mortality around farrowing (Canario *et al.*, 2007; Tribout *et al.*, 2010) and sow behaviour modification, with negative repercussions for their own and their offspring welfare (Rauw *et al.*, 1998; Rauw, 2007; Canario *et al.*, 2012; Canario *et al.*, 2014). Rauw *et al.* (1998) argued that intense selection for high production efficiency in previous years has had a negative effect on piglet life. Farrowing survival is affected by large differences in body composition and physiological maturity of lean and fat piglet genotypes (Herpin and Le Dividich, 1993; Leenhouwers *et al.*, 2001); Canario *et al.* (2007) claimed that neonatal piglet survival has decreased due to different maturity at birth consequent on the efforts of breeding companies to improve carcass lean and prolificacy in sows. Direct selection on piglet survival is difficult due to its low (0.03) heritability (Damgaard *et al.*, 2003; Arango *et al.*, 2006), but significant genetic variation exists that allows this to proceed (Cecchinato *et al.*, 2008). However, a number of authors have suggested that a strategy to improve welfare and reduce piglet mortality could be an improved breeding scheme including maternal ability (Kanis *et al.*, 2004, 2005; Baxter *et al.*, 2011; Rutherford *et al.*, 2013; Rydhmer *et al.*, 2012).

### *2.4.1 Sow traits*

Pig production parameters most often considered for genetic improvement are, lean growth (Ollivier, 1998), low back fat thickness, body size growth (Zhang *et al.*, 2000), sometime also piglets born alive (Zhang *et al.*, 2000; Dube *et al.*, 2012). However the latter is most often considered a reproductive trait. Productive traits have moderate to high heritability in European (Ferraz and Johnson, 1993; Roehe and Kennedy, 1995; Hanenberg *et al.*, 2001; Chimonyo *et al.*, 2006; Roehe *et al.*, 2009), Chinese (Zhang *et al.*, 2000), and also South African (Dube *et al.*, 2012) breeds. Selection for productive traits has had some negative consequences, such as the increasing size of adult sows (Herpin and Le Dividich, 1993; Whittemore, 1994; McGlone *et al.*, 2004), and there is also evidence of genetic antagonism with reproductive traits (Rauw *et al.*, 1998; Zhang *et al.*, 2013). It has been established that there is a low negative genetic correlation between production traits and teat number (Ligonesche *et al.*, 1995).

In commercial pig production, the role of the sow is to rear piglets and the number of weaned pigs is a key factor to increases profitability by reducing production cost per pig marketed (Irgang *et al.*, 1994). A hyperprolific sow line has been one of the most important goals of breeding companies (Nielsen *et al.*, 2013). In the past, sow productivity was the only factor to evaluate genetic merit in the herd (Bereskin, 1984); on-going research considers a greater range of sow reproduction genetic parameters, namely age at puberty, oestrus symptoms, ability to become pregnant, litter size, piglet survival and weight (Zhang *et al.*, 2000; Dube *et al.*, 2012). However, until recently, litter size was still the only reproduction trait used in many breeding programmes, despite the fact that it has been demonstrated that there are considerable problems associated with piglet survival (Canario *et al.,* 2007) and other maternal ability traits, like udder morphology as Vasdal *et al.* (2012) suggested. Many breeding companies apply threshold selection based on number of normal teats; 14 functional teats at least is the minimum requirement for selection. Teat number has been shown to be from low (Enfiled *et al.*,1961); (Smith *et al.*, 1986) to moderately (heritability of 0.2-0.4) (McKay and Rahnefeld, 1990; Hirooka *et al.*, 2001; Fernandez *et al.*, 2004; Chalkias *et al.*, 2013) heritable in the pig. All replacement gilts are checked for their number of functional teats, but other aspects of udder quality such as teat position, teat size and milk flow rate are largely uninvestigated. Furthermore, the actual selection for 14 functional teats has a very low impact on prevalence of pigs with non-functional teats and leads to loss of animals with good reproduction and production capacity (Chalkias *et al.*, 2013).

Udder conformation in sows has received very little attention in terms of genetic selection; there is only one study in which rear udder "firmness" was assessed as a possible determinant of piglet rearing capacity (Aziz *et al.*, 1995). Firmness was defined with three linear scores dependent on the degree of attachment of the rear udder. The firmness trait was studied to assess the effect of parity number, birth season and year. Results showed that year did not significantly influence the firmness but herd and parity had a significant effect. The percentage of sows with normal udder condition decreased with increasing parity number (Aziz, 1995). The significant effect of herd means that there were a number of environmental effects on the mammary gland firmness, such as management, housing conditions, nutrition. Heritability of rear udder attachment was moderate (0.19).

Collectively, these studies outline a critical role in piglet survival of the current breeding strategy. Nevertheless, considering the economic value (Smith *et al.*, 1983), it is important that selection for litter size, lean meat and fast growth traits continue, but other criteria must be included (Rydhmer *et al.,* 2000). Baxter et al. (2011) investigated genetic effects on maternal behaviour at farrowing and stated that good mothering ability shows genetic potential. Some years before, Knol et al. (2002) also suggested to include in the selection criteria sow nursing ability, milk and colostrum composition and yield, and maternal behaviour.

### *2. 4.3 Udder morphology traits in other species*

In other species, where udder conformation and milk flow rate are important characteristics for good dairy production, extensive studies on these traits have been carried out (Table 2.4). Udder conformation traits in the cow have heritabilities in the order of 0.2-0.3 (Rupp & Boichard, 1999), whilst milk flow rate or milkability traits have higher heritability (Gäde *et al.*, 2006). Similar results have also been obtained in sheep (Casu *et al.*, 2006), and in goats (Horak and Gerza, 1969; Wang, 1989; Gäde *et al.*, 2006).

Table 2. 4 Heritability estimates for udder traits in bovine and ovine species.

| Species | Teat Traits | $h^2$ | Author (Year) | Species | Measurement |
|---|---|---|---|---|---|
| cattle | length | 0.32 | Dal zotto (2007) | Brown Swiss | score |
| cattle | length | 0.44 | Higgins (1980) | Holstein | cm |
| cattle | length | 0.31 | Gengler (1997) | Jersey | score |
| cattle | size | 0.28 | Bradford (2015) | Herefords | score |
| cattle | size | 0.21 | Kirschten (2001) | Holstein | score |
| cattle | size | 0.27 | Sapp (2004) | Gelbvieh | score |
| cattle | size | 0.49 | Bunter (2014) | Brahman | score |
| cattle | size | 0.38 | Bunter (2014) | Brahman | score |
| sheep | length | 0.23 | Gootwine (1980) | Assaf | score |
| sheep | length | 0.64/0.70 | Mavrogenis (1988) | Chios | cm |
| cattle | diameter | 0.09 | Higgins (1980) | Holstein | cm |
| goat | diameter | 0.38 | Luo (1997) | - | score |
| sheep | diameter | 0.83/0.80 | Mavrogenis (1988) | Chios | cm |
| cattle | diameter | 0.39-0.37 | Seykora (1985) | Holstein | score |

## 2.5 Summary and conclusions

All of the studies reviewed here support the hypothesis that maternal ability traits should be included in the genetic selection criteria. Many studies have stated that it is of fundamental importance for the survival of the piglet to have access to a teat and suckle as soon as possible after birth. This literature review pointed out the role of the udder morphology in offspring performance and highlighted the need to improve the knowledge on this topic. By ensuring easy access to the teat and good quality colostrum to the piglet, the production goals of reducing losses, improving welfare and enhancing available resources will be accomplished. Genetic strategies applied in other species suggest the relevance to undertake investigation of udder morphology and colostrum composition as potential new traits to include in swine breeding programmes.

# Chapter 3. Development of a methodology to describe udder conformation in sows

## 3.1 Summary

The aim of this study was to develop a methodology to measure sow udder conformation to use in studying the correlation between udder traits and piglet survival, health and performance. The steps in the investigation were i) to assess the repeatability of measures, ii) to determine if there was an important difference between the two sides of the udder, iii) to assess the extent of variation between sows, and finally iv) to verify if the measures differ in a systematic way over the days shortly before farrowing. Twenty-four sows were scored for six conformation traits of the udder measured twice a day, every day from the sows' entrance into the farrowing crates until farrowing (1-4 days later). The data were recorded from both sides when the sow was lying and when she was standing. The measurements taken were: inter-teat distance within the same row (samer; mm between the adjacent teat bases); distance from the base of the teats to the abdominal mid-line, recorded only in a lying posture (aml); distance between the teat base and the adjacent teat on the opposite row, recorded only in a standing posture (OPR), distance from the base of the teats to the ground (flr); teat length (len) measured from the tip to the base, and diameter (dia) measured at the tip of the teat. Intraclass correlation coefficients (ICC) revealed that most udder conformation traits were highly repeatable (ICC > 0.8); only dia and floor had lower repeatability (ICC = 0.7). Measurements did not differ by side. In general the greatest proportion of variance occurred at the sow level. Traits changed little in the days before farrowing, except for a change prior to farrowing in dia, flr and OR. Measures which used anatomical landmarks as the reference point were more reliable than those using the floor of the pen. Udder conformation measures can be used as a reliable phenotype for further study. They can be collected on any day shortly before farrowing, and only from one side and in one posture to save time.

## 3.2 Introduction

Sow productivity and nursing ability are the base to support the economy and the efficiency of the pig industry (Kim *et al.*, 2001). Piglets are totally dependent on their mother when they are born, and adequate intake of good quality colostrum is fundamental for their immediate and longer term survival (Edwards, 2002). In this respect, a short latency to find a teat and suckle is vital for a newborn piglet (Andersen *et al.*, 2011). Udder conformation plays a role in this; modern sows have larger body size and sub-optimal udder conformation that affects the ability of the newborn piglets to find a teat and suckle (Vasdal and Andersen, 2012). Genetic selection for lean growth rate and prolificacy in swine has also had undesirable consequences for piglet survival (Canario *et al.*, 2007; Tribout *et al.*, 2010), reducing size and maturity of piglets at birth and increasing sibling competition. Rydhmer (2000) reviewed genetic selection in the pig, focussing on all aspects of the sow production cycle, and stated that the present genetic increase in number of piglets born will become meaningless without selecting also for maternal ability. Morphological and genetic studies on the sow udder are scarce and have focussed on functional teat number (Jonas *et al.*, 2008; Vasdal and Andersen, 2012; Chalkias *et al.*, 2014) and on mammary gland characteristics in terms of milk production (Farmer and Sorensen, 2001; Ford *et al.*, 2003; Theil *et al.*, 2006). In contrast, udder conformation traits have been well studied and included as selection criteria in other species, since these determine the suitability for mechanical milking in goats (Horak and Gerza, 1969; Wang, 1989), cows (Moore *et al.*, 1981) and sheep (Labussiere *et al.*, 1981; Casu *et al.*, 2010). In sows there is only one published study on udder conformation, which determined genetic parameters of mammary gland firmness in relation with milk production (Aziz *et al.*, 1995). To date, no study has been reported on the associations between udder conformation, milk production and piglet survival. Therefore, the aim of this project was to develop practical measures to describe udder conformation which can be used in studying the correlation between these traits and piglet survival, and in determining their potential use in sow selection programs.

## 3.3 Materials and Methods

### *3.3.1 Animals*

All procedures on animals were in accordance with institution guidelines and UK animal welfare regulations, and approved by the Animal Welfare and Ethics Review Body of Newcastle University. The experiment was performed at Cockle Park Farm, Newcastle University, Newcastle upon Tyne, UK. The trial was carried out on 24 sows of crossbred genotype (Large White X Landrace dam line), which had been inseminated with semen from a synthetic sire line (Hermitage Genetics, Kilkenny, Ireland). In accordance with normal commercial farm procedures, animals were moved from the group gestation house to the farrowing unit at 110 days post-insemination, where they were kept in individual crates equipped with a feeder and drinker. Ambient room temperature averaged 21$^{o}$C. Sows were allowed to farrow normally at term over a 4 days period (Monday to Thursday); sows that had not farrowed within this period were then induced on Thursday by injection of a

prostaglandin analogue. Sows were fed home-milled meal before and during lactation (18.5% CP, 13.98 MJ DE, and 0.95% total lysine); at a level of 2.0 kg per day from entry to the farrowing accommodation until parturition.

### *3.3.2 Udder measurements*

The sows were scored for six udder conformation traits measured twice a day on every day from the sows' entrance into the farrowing crates (Monday) until parturition. Trait definitions are given in Table 1. To evaluate the feasibility of the recording process, where it was possible measures were taken both when the sow was lying and when she was standing. Some traits were measured in both postures, but others only in one posture because the constraint of the anatomy and behaviour of the sows prevented measurements. The classification of the measurement for each posture is reported in Table 3.1. To assess the uniformity between sides, data were collected from both teat rows in each posture. Five traits were measured using a retractable flexible ruler. Initially a tailor's ruler was used and it was applied directly on the skin surface, but the reading was not possible all the time because of the sow's reaction and movement. For a single operator a flexible ruler measure facilitated the recording process. Teat diameter was measured using a calliper. All the measurements were reported in millimetres.

Table 3 1 Definition of measurement of sow udder conformation traits (mm). Measures were taken for each teat with its teat pair and teat side noted.

| Traits | Definition |
|---|---|
| *Standing posture* | |
| len | Length of the teats from the base to the tip |
| dia | Diameter of the teat tip |
| samer | Inter-teat distance between adjacent teat bases in the same row |
| OPR | Distance between the adjacent teat base in the opposite row |
| flr | Distance between the teat tip and the pen floor |
| *Lying posture* | |
| samer ld | Inter-teat distance between adjacent teat bases in the same row |
| aml | Distance from the base of the teats in the upper row to the abdominal midline |
| flr ld | Distance from the base of the teats in the upper row to the pen floor |

### *3.3.3 Statistical Analysis*

Data were excluded from the analysis if they were incomplete due to missing repeated values. Descriptive statistics were performed, and data are reported as arithmetic mean and standard deviation (mean ± SD). Data repeatability, based on measurements of the same parameter at different time points (AM and PM), was assessed with the intra-class correlation coefficient (ICC package in R; Wolak *et al.* (2012)). Data are considered highly reproducible when ICC > 0.80. A linear model (lm function in R) was applied to evaluate the proportion of variance of each measured trait (considered as a continuous dependent variable) explained by the main and interaction effects of different factors (day when the measurement was recorded, sow and teat pair position, each considered as fixed effects). To test the significance of day, position and side, a mixed effects linear model (nlme package in R; Pinheiro *et al.* (2007)) was used to analyze the pseudoreplicated data (multiple observations of the same sow on the days prior to farrowing, on the two sides, and at different teat pair positions) considering sow as a random effect to correct for repeated measurements within sow. Specifically, the following statistical model with fixed and random effects was applied:

$$y_{ijk} = \mu_{0} + S_{i} + D_{j} + TPP_{k+} sow + \varepsilon_{ijk}$$

where: $y_{ijk}$ is the dependent variable studied, such as samer, len, dia, flr, aml, OPR; $\mu$ is the overall mean; $S_i$ is side (fixed effect with two levels); $D_j$ is day prior to farrowing (fixed effect with five levels); $TPP_k$ is teat pair position (fixed effect with eight levels); sow is the animal (random effect) and $\varepsilon_{ijk}$ is random error. Separate analyses were performed for each conformation trait. The level of significance was taken as $P < 0.05$. The statistical software R version 3.0.2 (2013-09-25) was used for all tests.

## 3.4 Results

In total 11436 scores were collected. Sows were sampled at different parities (first parity nine sows, five second, two third, one fourth, two eighth, two tenth and three eleventh parity). In total four sows farrowed on the sixth day from the entrance into the farrowing crate, ten sows farrowed on the fifth day, eight sows farrowed on the fourth day, one sow on the third day and one sow on the second day. In total 341 teats were measured (two sows had eight functional teats on both sides, six sows had eight functional teats on one side and seven on the other, twelve sows had seven functional teats on both sides, three sows had seven functional teats on one side and six on the other; one sow had six functional teats on both sides). To assess repeatability of measures only the sows and days with full data were kept; five sows were excluded from the analysis. The intraclass correlation coefficients of the repeated measures of the six udder characteristics are shown in Table 3.2.

Table 3 2 Repeatability (Intraclass correlation coefficient) of sow udder trait measures. Traits were measured in millimeters.

| Posture | *Standing* | | | | | *Lying* | | |
|---|---|---|---|---|---|---|---|---|
| Trait[1] | len | dia | samer | OPR | flr | samer | aml | flr |
| N | 960 | 960 | 960 | 960 | 960 | 960 | 960 | 960 |
| Repeatability | 0.82 | 0.70 | 0.90 | 0.97 | 0.92 | 0.93 | 0.94 | 0.71 |

[1] Udder trait measurement: len = teat length, dia = teat diameter, samer = inter-teat distance within the same row; OPR= distance from the teat base to the adjacent teat on the other row recorded in a standing posture; flr = distance from the teat base to the floor of the pen; aml = distance from the teat base to the abdominal mid line, recorded in a lying posture.

Descriptive statistics of each measured trait, classified by posture, side and repeated measurements (AM and PM) are presented in Table 3.3.

Table 3 3 Mean and (Standard Deviation) in millimeters of 6 sow udder traits.

| Trait[1] | First record (AM) | | | | Second record (PM) | | | |
|---|---|---|---|---|---|---|---|---|
| | Standing | | Lying | | Standing | | Lying | |
| | *Left* | *Right* | *Left* | *Right* | *Left* | *Right* | *Left* | *Right* |
| len | 17.98 | 17.58 | | | 17.18 | 17.03 | | |
| | (5.37) | (4.69) | | | (4.41) | (4.04) | | |
| dia | 10.83 | 11.04 | | | 10.52 | 10.62 | | |
| | (2.16) | (2.03) | | | (1.94) | (1.83) | | |
| samer | 100.63 | 100.49 | 106.25 | 106.61 | 100.22 | 100.78 | 102.5 | 101.07 |
| | (25.63) | (25.10) | (30.81) | (24.15) | (23.35) | (24.41) | (25.44) | (16.89) |
| OPR | 179.6 | | | | 171.38 | | | |
| | (43.08) | | | | (38.91) | | | |
| aml | | | 87.58 | 89.96 | | | 92.50 | 95.00 |
| | | | (20.38) | (27.92) | | | (33.03) | (12.24) |
| flr | 236.57 | 236.34 | 119.06 | 70.87 | 236.24 | 235.73 | 140 | 132.5 |
| | (42.35) | (42.21) | (67.63) | (69.29) | (38.90) | (38.94) | (67.69) | (51.92) |

[1] Udder trait measurement: len = teat length, dia = teat diameter, samer = inter-teat distance within the same row; OPR= distance from the teat base to the adjacent teat on the other row recorded in a standing posture; flr = distance from the teat base to the floor of the pen; aml = distance from the teat base to the abdominal mid line, recorded in a lying posture

The variance components for each of the six measured traits are presented in Table 3.4. The largest proportion of variation in teat dimensions (len = 51% and dia = 40%) was explained at the sow level. The variance in the distance from the teat base to the adjacent teat on the other row, recorded in a standing posture, and the distance from the teat base to the abdominal mid line, recorded in a lying posture, was highest at the teat pair position level (OPR = 53%; aml = 37%). These two dimensions were recorded differently according to the posture due to the practicality of measurement in a lying animal with sometimes only partial udder exposure. For the different samer dimensions, recorded in a standing or lying posture (samer = 35%; samer ld = 39%) the largest proportion of variance was explained by interaction between sow and teat pair position. Only a small part of the variation in the six udder conformation traits was explained at the day level.

Table 3 4. Percentage of variance explained by sow, teat pair position, the day of the recording, the interaction between the sow and the teat pair position and the interaction of the sow, the day and the teat pair position for 6 traits describing the udder conformation of 24 sows. For each trait, the value in bold indicates the factor that explains the largest proportion of variation.

| Factors | Trait[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | len | dia | samer | OPR | flr | aml | samer ld | flr ld |
| residual | 5.4 | 9.2 | 4.0 | 1.6 | 2.5 | 3.7 | 4.8 | 10.32 |
| sow | **51.3** | **40.6** | 16.1 | 17.3 | **44.2** | 25.8 | 23.4 | 27. |
| teat | 3.9 | 6.9 | 30.8 | **52.8** | 24.8 | **37.1** | 9.6 | 14.8 |
| day | 0.2 | 0.8 | 0.4 | 0.7 | 1.0 | 1.2 | 5.1 | 9.7 |
| sow:teat | 21.8 | 19.0 | **35.4** | 19.0 | 15.4 | 21.5 | **38.6** | **28.3** |
| sow:teat:day | 12.3 | 15.0 | 9.7 | 5.6 | 7.0 | 1.2 | 0.8 | 0.6 |

[1] Udder trait measurement: len = teat length, dia = teat diameter, samer = inter-teat distance within the same row; OPR = Distance from the teat base to the adjacent teat on the other row recorded in a standing posture; flr = Distance from the teat base to the floor of the pen; aml = distance from the teat base to the abdominal mid line, recorded in a lying posture; samer ld = inter-teat distance within the same row, recorded in a lying posture; flr ld = Distance from the teat base to the floor of the pen, recorded in a lying posture.

### *3.4.1 Factors associated with udder conformation trait variation*

The results of the mixed effects linear model are presented in Table 3.5, 3.6, 3.7, and Table 3.8. Side was not associated with any of the dependent variables, whereas teat pair position was significantly associated with all udder conformation traits measured. Only the measurements recorded immediately prior to farrowing were significantly different from the previous udder traits measurements. Generally teat diameter decreased prior to farrowing (day 5 = 11.23 mm vs day 0 = 10.68 mm; $P < 0.001$), whereas flr (day 5 = 218.64 mm vs day 0 = 261.81 mm; $P < 0.001$), len (day 5 = 16.84 mm vs day 0 = 18.65 mm; $P < 0.001$) and OR (day 5 = 170.71 mm vs day 0 = 184.12 mm; $P < 0.001$) dimension increased significantly between the entry into the farrowing crate and the parturition day.

Table 3.5 Mixed effects linear model describing the factors associated with teat diameter (dia) and length (len) measured in a standing posture on 24 sows.

| *Independent variable* | len | | | | | dia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | β[1] | SE | N | Estimate | P-value | β | SE | N | Estimate | P-value |
| Constant | 18.37 | 0.76 | | | _ | 10.29 | 0.29 | | | _ |
| *Side* | | | | | 0.14 | | | | | 0.06 |
| Left | Ref.[2] | | 1024 | 17.66 | | Ref. | | 982 | 10.72 | |
| Right | -0.19 | 0.14 | 1051 | 17.39 | | 0.15 | 0.07 | 1033 | 10.89 | |
| *Teat pair position* | | | | | <0.001 | | | | | <0.001 |
| Teat 1 | Ref. | | 290 | 17.23 | | Ref. | | 281 | 10.08 | |
| Teat 2 | 0.88 | 0.26 | 295 | 18.06 | | 0.07 | 0.12 | 286 | 10.15 | |
| Teat 3 | 1.29 | 0.26 | 294 | 18.45 | | 0.76 | 0.12 | 286 | 10.85 | |
| Teat 4 | 0.81 | 0.26 | 277 | 17.95 | | 1.44 | 0.13 | 270 | 11.64 | |
| Teat 5 | 0.43 | 0.26 | 294 | 17.63 | | 1.1 | 0.12 | 287 | 11.19 | |
| Teat 6 | 0.65 | 0.26 | 293 | 17.86 | | 1.21 | 0.12 | 284 | 11.3 | |
| Teat 7 | -1.47 | 0.27 | 271 | 15.97 | | 0.51 | 0.13 | 263 | 10.63 | |
| Teat 8 | -1.38 | 0.46 | 61 | 14.63 | | 0.31 | 0.22 | 58 | 9.88 | |
| *Day prior to farrowing* | | | | | <0.001 | | | | | <0.001 |
| day 0 | Ref. | | 371 | 18.65 | | Ref. | | 361 | 10.68 | |
| day 1 | -1.19 | 0.22 | 482 | 17.67 | | -0.05 | 0.11 | 462 | 10.77 | |
| day 2 | -1.08 | 0.25 | 377 | 17.18 | | -0.13 | 0.12 | 370 | 10.48 | |
| day 3 | -1.51 | 0.24 | 421 | 16.96 | | 0.27 | 0.11 | 413 | 11.01 | |
| day 4 | -0.6 | 0.26 | 308 | 17.39 | | 0.45 | 0.13 | 293 | 10.97 | |
| day 5 | -1.42 | 0.39 | 116 | 16.84 | | 0.3 | 0.18 | 116 | 11.23 | |

[1] Linear regression coefficient.; [2] Reference

Table 3.6 Mixed effects linear model describing the factors associated with the teat distance from the teat base to the floor of the pen recorded in a standing (flr) and lying (flr ld) posture, in 24 sows.

| *Independent variable* | flr | | | | | flr ld | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | β[1] | SE | N | Estimate μ | *P*-value | β | SE | N | Estimate μ | *P*-value |
| Constant | 245.52 | 6.71 | | | _ | 146.8 | 18.1 | | | _ |
| Side | | | | | 0.64 | | | | | 0.65 |
| Left | Ref.[2] | | 949 | 236.5 | | Ref. | | 137 | 148.14 | |
| Right | 0.53 | 1.12 | 959 | 236.18 | | -4.91 | 5.1 | 152 | 154.44 | |
| *Teat pair position* | | | | | <0.001 | | | | | 0.05 |
| Teat 1 | Ref. | | 270 | 253.39 | | Ref. | | 42 | 144.88 | |
| Teat 2 | -28.66 | 2.1 | 270 | 224.73 | | -1.47 | 8.29 | 44 | 143.75 | |
| Teat 3 | -41.94 | 2.1 | 269 | 211.73 | | 24.94 | 8.34 | 43 | 170.53 | |
| Teat 4 | -38.16 | 2.13 | 254 | 214.79 | | 30.88 | 8.44 | 41 | 177.56 | |
| Teat 5 | -20.57 | 2.1 | 270 | 232.82 | | 17.39 | 8.44 | 41 | 163.66 | |
| Teat 6 | -4.79 | 2.1 | 269 | 248.65 | | -4.15 | 8.39 | 42 | 141.55 | |
| Teat 7 | 5.14 | 2.14 | 250 | 258.22 | | -28.74 | 9.17 | 31 | 118.63 | |
| Teat 8 | 26.44 | 3.69 | 56 | 286.25 | | -50.52 | 18.6 | 5 | 83 | |
| *Day prior to farrowing* | | | | | <0.001 | | | | | 0.034 |
| day 0 | Ref. | | 255 | 261.81 | | Ref. | | 205 | 152.12 | |
| day 1 | -28.52 | 1.96 | 440 | 226.84 | | -19.35 | 7.89 | 57 | 161.67 | |
| day 2 | -24.02 | 2.02 | 374 | 238.08 | | 22.81 | 14.24 | 14 | 113.57 | |
| day 3 | -23.29 | 1.96 | 408 | 231.61 | | 9.65 | 13.71 | 13 | 136.92 | |
| day 4 | -20.51 | 2.13 | 315 | 239.58 | | | | 0 | | |
| day 5 | -24.11 | 3.04 | 116 | 218.64 | | | | 0 | | |

[1] Linear regression coefficient.; [2] Reference

Table 3.7 Mixed effects linear model describing the factors associated with distance from the teat base to the adjacent teat in the opposite row recorded in a standing up posture (OPR) and from the abdominal mid line recorded in a lying down posture (aml) in 24 sows.

[1]Linear regression coefficient; [2] Reference

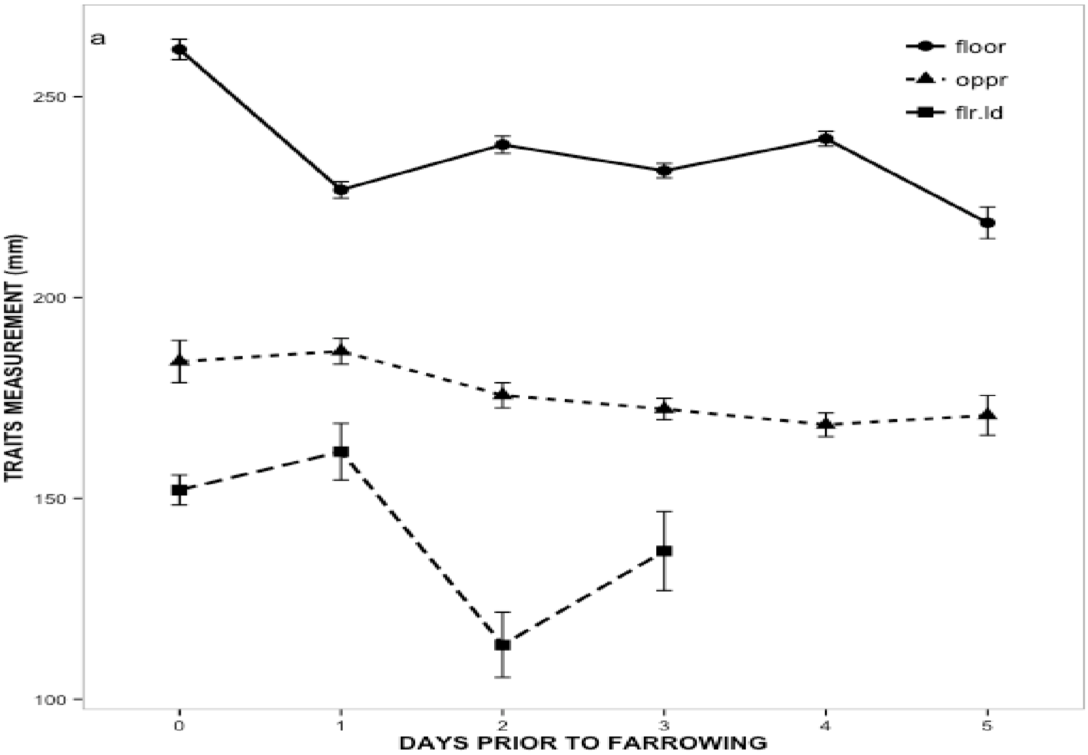
| *Independent variable* | OPR | | | | | aml | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | β [1] | SE | N | Estimate μ | *P*-value | β | SE | N | Estimate μ | *P*-value |
| Constant | 137.69 | 4.41 | | | | 64.04 | 8.13 | | | _ |
| Side | | | | | | | | | | 0.82 |
| Left | Ref.[2] | | | | | Ref. | | 147 | 90.96 | |
| Right | 0.6 | 8.17 | | | | -0.52 | 2.34 | 157 | 92.92 | |
| *Teat pair position* | | | | | <0.001 | | | | | <0.001 |
| Teat 1 | Ref. | | 135 | 138.76 | | Ref. | | 46 | 71.9 | |
| Teat 2 | 12.82 | 3.01 | 118 | 152.1 | | 5.42 | 3.73 | 47 | 77.73 | |
| Teat 3 | 53.35 | 3.1 | 108 | 191.44 | | 30.39 | 3.75 | 46 | 103.15 | |
| Teat 4 | 74.39 | 2.97 | 125 | 213.06 | | 38.94 | 3.79 | 44 | 111.77 | |
| Teat 5 | 72.65 | 2.96 | 126 | 211.39 | | 36.62 | 3.8 | 44 | 109.15 | |
| Teat 6 | 55.48 | 2.97 | 124 | 194.01 | | 28.1 | 3.85 | 42 | 100.65 | |
| Teat 7 | 13.4 | 3.07 | 111 | 149.79 | | -1.33 | 4.31 | 29 | 70.86 | |
| Teat 8 | -18.59 | 4.88 | 31 | 119.03 | | -28.8 | 7.96 | 6 | 41.75 | |
| *Day prior to farrowing* | | | | | <0.001 | | | | | 0.01 |
| day 0 | Ref. | | 89 | 184.12 | | Ref. | | 211 | 92.46 | |
| day 1 | -0.09 | 3.26 | 187 | 186.66 | | -3.56 | 3.23 | 66 | 90.91 | |
| day 2 | -3.99 | 3.31 | 190 | 175.71 | | 18.11 | 6.43 | 15 | 86 | |
| day 3 | -9.45 | 3.19 | 210 | 172.27 | | -5.09 | 6.52 | 12 | 96.67 | |
| day 4 | -13.16 | 3.46 | 146 | 168.37 | | | | 0 | | |
| day 5 | -11.56 | 4.62 | 56 | 170.71 | | | | 0 | | |

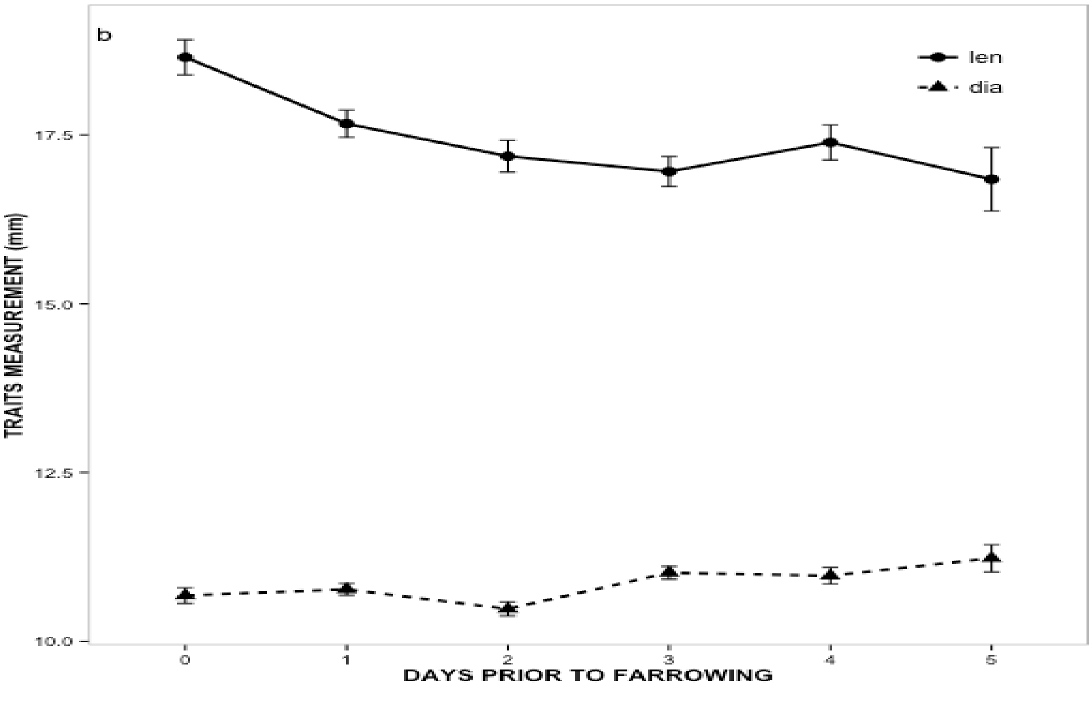
Table 3. 8 Mixed effects linear model describing the factors associated with inter-teat distance within the same row, recorded in a standing up (samer) and in a lying (samer ld) posture, in 24 sows.

| *Independent variable* | samer[3] | | | | | samer ld[3] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | β | SE | N | Estimate μ | P-value | β | SE | N | Estimate μ | P-value |
| Constant | 108.81 | 2.5 | | | _ | 108.39 | 12 | | 237 | _ |
| *Side* | | | | | 0.98 | | | | | 0.27 |
| Left | Ref. | | 814 | 100.49 | | Ref. | | 130 | 121 | |
| Right | 0.06 | 0.9 | 832 | 100.62 | | -12.39 | 3.99 | 135 | 117.96 | |
| *Teat pair position* | | | | | <0.001 | | | | | 0.024 |
| Teat 1 | Ref. | | 268 | 107 | | Ref. | | 44 | 121.36 | |
| Teat 2 | -4.71 | 1.58 | 267 | 102.26 | | -6.79 | 6.14 | 44 | 114.32 | |
| Teat 3 | -6.4 | 1.59 | 265 | 100.58 | | -8.37 | 6.21 | 42 | 113.1 | |
| Teat 4 | -19.11 | 1.58 | 267 | 87.86 | | -16.75 | 6.26 | 41 | 103.66 | |
| Teat 5 | -25.1 | 1.58 | 267 | 81.87 | | -13.14 | 6.22 | 42 | 108.33 | |
| Teat 6 | 12.97 | 1.61 | 253 | 119.63 | | 2.17 | 6.49 | 36 | 123.75 | |
| Teat 7 | 27.67 | 2.72 | 59 | 123.67 | | -4.16 | 9.63 | 12 | 128.33 | |
| Teat 8 | | | 0 | - | | -38.22 | 15.5 | 4 | 97.5 | |
| *Day prior to farrowing* | | | | | 0.06 | | | | | 0.023 |
| day 0 | Ref. | | 220 | 96.37 | | Ref. | | 187 | 111.82 | |
| day 1 | 5.94 | 1.65 | 365 | 103.36 | | 11.78 | 6.15 | 50 | 120.9 | |
| day 2 | 3.95 | 1.69 | 327 | 98.57 | | -4.31 | 10.2 | 15 | 120 | |
| day 3 | 4.96 | 1.64 | 360 | 101.44 | | -24.81 | 10.1 | 13 | 119.23 | |
| day 4 | 5.06 | 1.78 | 274 | 100.37 | | | | 0 | | |
| day 5 | 4.88 | 2.55 | 100 | 103.34 | | | | 0 | | |

[1]Linear regression coefficient.; [2] Reference

Figure 3.1 shows the mean values of the six udder conformation traits according to the day prior to farrowing. The lying posture measurements were recorded for only three days prior to farrowing because the sows did not lie laterally to expose the udder during the first days in the farrowing crate, preventing collection of these data.


a
floor
oppr
flr.ld
TRAITS MEASUREMENT (mm)
100
150
200
250
0
1
2
3
4
5
DAYS PRIOR TO FARROWING


b
len
dia
TRAITS MEASUREMENT (mm)
10.0
12.5
15.0
17.5
0
1
2
3
4
5
DAYS PRIOR TO FARROWING

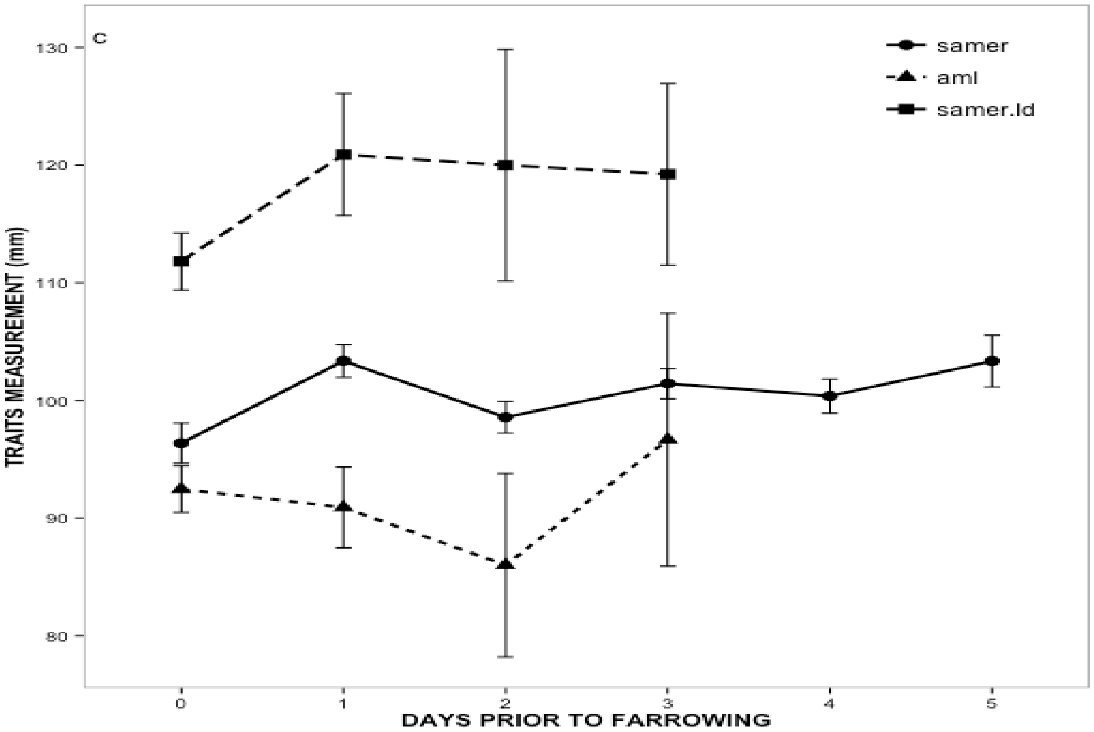


Figure3. 1 Mean and standard error of 6 udder conformation traits of 24 sows, recorded in millimetres in a standing or lying posture during the days prior to farrowing. 1a: (flr = Distance from the teat base to the floor of the pen recorded in a standing posture; OPR = Distance from the teat base to the adjacent teat on the other row recorded in a standing posture; and flr ld = Distance from the teat base to the floor of the pen recorded in a lying posture). 1b. (len = teat length; dia = teat diameter) 1c: (samer = inter-teat distance within the same row, recorded in a standing posture; aml = distance from the teat base to the abdominal mid line, recorded in a lying down posture; and samer ld = inter-teat distance within the same row, recorded in a lying posture).

### 3.5 Discussion

To characterise udder conformation, two series of measurements were performed by one operator every day from the entrance of a sow into the farrowing house until farrowing, with six traits recorded on each occasion. The evaluation method proposed is based on traits previously used to define udder conformation in the description of cows (Higgins *et al.*, 1980; Moore *et al.*, 1981), sheep (Labussiere *et al.*, 1981; Makovicky *et al.*, 2013) and goats (Wang, 1989). These measurements were adapted due to the different morphology of the sow udder, principally the lack of a milk cistern, the greater number of teats, and the small nipple dimension. Linear scores were not adopted, as often done in other species, since this was the first attempt to evaluate sow udder conformation, and the knowledge and experience of the classifier was not sufficient to transform the biological descriptive traits into a linear scale.

With respect to the first research question, it was found that measures that adopted anatomical land-marks as a reference point were highly repeatable. In contrast, measures which relied on distance relative to the floor were less so, since these were more affected by sow posture or motion at the time of measurement. The same repeatability of udder traits was found in the sheep for ranking ewes with a single score per lactation for selection purposes (Casu *et al.*, 2006).

The second question in this study sought to determine the effect of side and posture on udder morphological measurements. Results showed that on average records were not significantly different on the two sides of the same sow, indicating a lack of significant asymmetry which would invalidate single side assessment. The effect of posture was not assessed statistically, since the same traits were recorded in different ways dictated by practicality of measurement in a lying animal with sometimes only partial udder exposure. The repeatability of the measurements was high in both postures. However data collected in a lying down posture were less feasible on the first day after entry into the farrowing crate because the sows were more agitated. The trait flr taken in a lying posture showed the highest within-sow variability and the smallest repeatability. This trait when taken standing was considered reliable  to define udder conformation in ruminants (Moore et al., 1981, Labussiere *et al.*, 1981), but in sows it cannot be reliably measured in either standing or, above all, lying posture, where the sows do not always lie in full lateral extension and expose the bottom row of teats (Fraser, 1976).

The third question in this study was to assess the main sources of variability of udder conformation trait measures. Results indicated significant variation at sow level. Such variation can be explained by the same factors that affect morphology in other species: parity number, breed, anatomical characterisation (sheep: Fernandez *et al.*, 1995; Makovicky *et al.*, 2013),  but further studies are needed to determine the influence of these factors in the sow.

The trait flr recorded in a lying posture and the teat diameter were the measurements that varied more within the same sow, moreover their lower repeatability reflected the same trends. Diameter results could be explained by the methods used to record the data. The calliper slightly pressed the teat during the measurement, and the degree of pressure could bias the repeatability. However, Zwertvaegher *et al.* (2012) recorded 8,678 cow teat diameters using a more accurate technique, a 2-dimensional-vision-based camera, and they described the same diameter variability within animal.

With respect to the fourth research question, it was found that measurements were not significantly different according to the day of collection for almost all of the traits, the exceptions being flr, OR and dia which showed significant changes mostly prior farrowing. This suggests that most of the variables measured were not greatly affected over this period by growth of mammary glands due to colostrogenesis (Kim *et al.*, 1999). The increased distance between the teat bases in opposite rows on the parturition day might be explained by the onset of colostrogenesis. Overall, results for all the variables analysed indicated that the measurements taken with an anatomical landmark as a reference point are more reliable than those recorded using pen floor as a reference point. Teat diameter and distance from the adjacent teat in the opposite row measurements have to be corrected for the effect of day relative to farrowing.

## 3.6 Conclusion

This preliminary study showed that measures of udder conformation are repeatable within sow. Because they do not differ significantly between sides, in either standing or lying posture, they can be collected only from one side. The results show significant variability between sows and most do not change markedly in the days shortly prior to farrowing. Measures which use anatomical landmarks as the reference point are more reliable than those using the floor of the pen. Taken together, these results suggest that this methodology can be used to describe sow udder conformation in a quick and efficient way. This research will serve as a base for future studies focused on understanding the main sources of variation in udder morphology traits between sows. Further studies are also necessary to define how these udder conformation traits influence piglet suckling behaviour, survival and performance. Likewise it would be interesting to improve measurement methodology in order to assess mammary gland size variation. Moreover, in order to assess the feasibility of incorporating such traits into selection programmes, it is essential to investigate whether these traits are heritable and if they are correlated with other important production traits such as prolificacy and milk production.

# Chapter 4. Sources of variation in udder morphology of sows

## 4.1 Summary

This experiment investigated the sources of variation in sow udder morphology. A cross-sectional study of 218 sows (109 Large White × Landrace (LWL) and 109 Meidam (MDM)) of different parities was conducted using a combination of scores and metric measurements. For each teat 4 measures were taken: inter-teat distance within the same row (samer); distance from the base of the teat in the upper row to the abdominal mid-line (aml); length (len) from the tip to the base and diameter (dia) at the tip of the teat. Scores were adopted to define teat orientation (0 teat not orientated perpendicular to the mammary gland; 1 teat orientated perpendicular to the mammary gland), teat functionality (1 milk channel not working, including teats which were blind, inverted, or very damaged, 2 reduced availability of colostrum, 3 perfectly functional),and udder development (1 not developed to 3 fully developed). A longitudinal study on a subset of sows (N = 70) investigated how udder morphology changed in consecutive parities. Meidam had shorter teats, which were closer to the abdominal mid line than LWL (len: $P < 0.001$; aml: $P < 0.001$). In both studies, first and second parity sows had smaller teats (len: $P < 0.001$; dia: $P < 0.001$) than older multiparous sows. Teat position had a significant ($P < 0.001$) effect on samer in both breeds, with less distance between middle teat pairs. The distance from the base of the teats in the upper row to the abdominal mid-line was shorter in the anterior and posterior teats compared to the middle teat pairs. Teat length was greater in the anterior and middle teats than in the posterior ones, whereas dia was greater in the middle teats.  Teat pair position was associated with teat orientation ($P < 0.001$) and teat functionality ($P < 0.001$). Parity was associated with udder development ($P < 0.001$). Breed, parity and teat pair position were all significant sources of variation in udder morphology in sows.

## 4.2 Introduction

Pig breeding selection criteria have mainly focused on increasing litter size, obtaining fast and efficient growth, and improving carcass lean content. These goals have been set to improve the profitability of the sector, but this selection also brings some undesired side effects, such as; decreased heterogeneous piglet birth weight, increased sibling competition (Drake *et al.*, 2008; Vasdal and Andersen, 2012), and increased sow body size (O'Connell *et al.*, 2007; Moustsen *et al.*, 2011). These consequences might reduce teat accessibility, while increasing piglet competition for teats. Moreover, teat accessibility decreases with the increment of sow parity number, as animals become larger and teats become higher from the floor or less well exposed (Vasdal and Andersen, 2012). It has been established that latency for piglets to reach the udder, find a teat and suckle colostrum are important survival indicators in conventional farrowing crate systems (Baxter *et al.*, 2008). Nonetheless udder morphology characteristics which might influence this vary significantly between animals (Balzani *et al.*, 2015a). The anatomy of the sow udder has been studied to improve milk production (Fraser *et al.*, 1985; Kim *et al.*, 2001; Farmer, 2013), and the morphology to determine the genetic and phenotypic variation in functional teat number (Pumfrey *et al.*, 1980; Chalkias *et al.*, 2014). Since udder conformation in sows can influence latency to first suckling, and thus neonatal mortality, understanding the causes of variation in morphology might allow improvement in relation to the characteristics that promote good piglet performance. This knowledge will also be applicable for selection purposes in this species. However, before sow udder morphology can be incorporated into the selection criteria list, anatomical variation needs to be understood. Therefore, the aim of this experiment was to investigate the sources of variation in sow udder morphology and highlight the associated aspects of anatomical variation in sow udder morphology.

## 4.3 Material and methods

### *4.3.1 Cross-Sectional Study*

#### *4.3.1.1 Animals*

The experiment was conducted at Cockle Park Farm, Newcastle University, Newcastle upon Tyne, UK, and at three farms (Upton, Breamar, and Fox Cover) of the ACMC breeding company (Beeford, UK). It was approved by the Animal Welfare and Ethics Review Body at Newcastle University. Udder morphology trait measurements were collected between November 2012 and February 2015 from a population of 110 Meidam (Large White × Meishan MDM) at ACMC farms and 110 Large White × Landrace sows (LWL) at the Newcastle University farm. In total, 218 sows of different parities were sampled (19 sows at first parity for both breeds; 20 sows at second parity for both breeds; 16 LWL and 17 MDM at third; 16 LWL and 20 MDM at fourth; 16 LWL and five MDM at fifth; 12 LWL and 18 MDM at sixth; ten animals at more than sixth parity for each breed). Animals were moved from the group gestation house to the farrowing unit at 110 d post-insemination, where they were kept in individual crates equipped with a feeder and drinker. Ambient room temperature averaged 21$^{o}$C. No specific procedures were imposed in the study; feed, environment and management were maintained as standard commercial practice.

#### *4.3.1.2 Udder Traits*

Measurements of morphological traits were performed when the sow was in a lying posture in days one to three prior to farrowing. The same operator evaluated udder conformation using both score systems and metric measurements. The methodology used for measuring morphological parameters was that described and evaluated by Balzani *et al.* (2015a). Measurements were made using a ruler and a calliper (diameter) and were taken to the nearest millimeter (Figure 4.1). The following parameters were recorded for each animal: sow identity, breed (two levels), parity number (seven levels, from 1 to >6), teat pair position (I: the teat located most anterior, to VIII the teat located most posterior), and litter size (1 to 20). For each teat four measurements were taken: inter-teat distance within the same row (samer); distance from the base of the teat in the upper row to the abdominal mid-line (aml); length (len) from the tip to the base and diameter (dia) at the tip of the teat. Scores were adopted to define teat orientation (score from 1 to 5, where 1/5 was defined as: teat orientated towards/away from the midline; 2: teat orientated perpendicular to the gland, 3/4:teat orientated towards the cranial/caudal direction). Because of small numbers of observations in non-perpendicular categories, the teat orientation scores were subsequently combined in two categories (OR category 0: teat not orientated perpendicular to the mammary gland; and category 1: teat orientated perpendicular to the mammary gland). Udder development (dev score from 1 to 3, where 1 was defined as: udder is not developed and individual mammary glands are not defined; 2: udder is well developed but the mammary glands are not clearly distinct; and 3: udder well developed and individual mammary glands are clearly distinct); and teat functionality (fnct score from 1 to 3, where 1 was defined as: non-functional teat, milk channel not working, including teats which were blind: teats that were impaired early in the life of the pig, and remain as a small protuberance; inverted: the top of the teat, or even the entire teat, is inverted to form a crater; very damaged: teat injured such that milk ejection is not possible; or supernumery: small teats in-between two normal teats; 2:

reduced availability of colostrum, milk channel only partially working; and 3:teat perfectly functional). Non-functional teats were scored in the same way as in a Swedish study (Chalkias *et al.*, 2013).

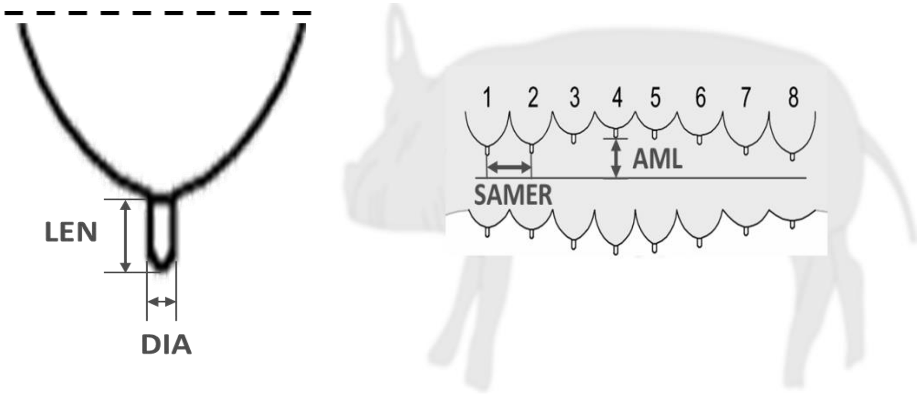


Figure 4. 1. Description of four udder traits measured in millimetres: (samer: inter-teat distance within the same row; aml: distance from the base of the teat in the upper row to the abdominal mid-line; len: teat length from the tip to the base; and dia: teat diameter at the tip of the teat).

### *4.3.1.3 Statistical Analysis*

Descriptive statistics were calculated, and data are reported as arithmetic mean and standard error of the mean (mean ± SEM). Data were analyzed using a mixed effects linear model (nlme package in R; Pinheiro *et al.* (2007)) with breed type, parity, teat pair position, and litter size as fixed effects and sow as a random effect. Initially the categorical nature of the score measurements was ignored (all traits were considered as continuous as has been adopted in previous research (Casu *et al.*, 2006)); the analysis was subsequently repeated for orientation and functionality scores using mixed-effects multinomial regression as implemented using the gsem function in Stata 14.0 (Stata Corporation, Texas, USA), which gave similar results to those obtained using nlme. The mixed-effects multinomial model failed to converge when modelling the udder development score as an outcome. For continuous outcomes the following statistical model with fixed and random effects was applied:

$$y_{ijkl} = \mu + B_i + P_j + TPP_k + LS_l + sow + e_{ijkl}$$

where: $\mu$ is the overall mean, $y_{ijkl}$ is the dependent variable studied (samer, len, dia, aml, OR, fnct, dev), $B_i$ is breed group (fixed effect with two levels), Pj is parity (fixed effect with seven levels), $TPP_k$is teat pair position (fixed effect with eight levels, not included when modelling udder development as there is no variation in udder development according to teat pair position), $LS_l$is litter size(fixed effect), and sow is the animal (random effect),$e_{ijkl}$ is random error. Differences were considered significant at $P < 0.05$.The statistical software R version 3.0.2 (2013-09-25) was used for all tests.

### *4.3.2 Longitudinal Study*

#### *4.3.2.1 Animals*

A longitudinal study was conducted on a subset of 58 Meidam (Large White × Meishan) at ACMC farms and 12 Large White × Landrace from the Newcastle University farm for which data were available in consecutive parities. The same sows were included in the cross-sectional study using data from only one occasion.

#### *4.3.2.2 Udder Traits*

All measurements were performed as reported previously. Scores were not recorded in this study.

#### *4.3.2.3 Statistical Analysis*

Sows were grouped considering only consecutive parity levels (five groups: first-second; second-third; third-fourth; fourth-fifth; and fifth-sixth consecutive parity groups) and analysis was carried out within each group separately. Data were analyzed using mixed effects linear model with the outcome (samer, aml, len, dia) modelled as a function of parity (considered as a fixed effect). Owing to the complete pairwise matching of observations by teat pair position and breed group, we did not consider it necessary to include these as fixed effects in the analysis. Sow was included as a random effect in the analysis. A linear model (lm function in R) was applied to evaluate the proportion of variance of each measured trait (considered as a continuous dependent variable) explained by the main effects of different factors (sow, consecutive parity group and teat pair position, each considered as fixed effects).

## 4.4 Results

### *4.4.1 Cross-Sectional Study*

Litter size was 12.66 ± 3.5 (mean ± SEM) for LWL and 12.19 ± 2.9 for MDM. Table 4.1 presents the descriptive statistics of udder morphology dimensions. Coefficients of variation were medium to high (16.5% to 30.4%) for all dimensions; dia and len were the more uniform dimensions, whereas aml and samer had greater variability across sows in both breeds. Standard deviations were significantly smaller in MDM for almost all the measured traits (len: $F_{1, 216} = 8.96$, $P = 0.003$; dia: $F_{1, 216} = 12.64$, $P = 0.0005$; aml: $F_{1, 216} = 5.40$, $P = 0.02$), except samer ($F_{1, 216} = 1.13$, $P = 0.29$), therefore udder morphology traits were more uniform in this breed compared with the LWL except for the inter-teat distance within the same row. Teat orientation scores were grouped into two categories because there were few scores different from score 1 (teat oriented perpendicular to the udder, 80.0%). Teat functionality scores were 4.9% non-functional (score 1), 23.4% partially functional (score 2), and 71.8% functional (score 3). Sow udder development scores, on the day shortly prior to farrowing when the measurement was recorded, were 5.2% poorly developed (score 1), 68.0% partially developed (score 2) and 26.8% fully developed (score 3).

Table 4. 1 Descriptive statistics of 4 udder morphological traits in sows of different parities from two sow breeds: Meidam (MDM; N= 110) and Large White × Landrace (LWL; N = 110); N: number of units measured; SD: standard deviation; CV: coefficient of variability.

| Breed | Udder Trait[1] | N | Mean | SD | CV | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
| LWL | len | 775 | 17.9 | 3.93 | 22.0 | 2 | 30 |
|  | dia | 776 | 10.7 | 1.96 | 18.5 | 5 | 18.5 |
|  | aml | 779 | 78 | 23.7 | 30.4 | 30 | 140 |
|  | samer | 674 | 108.1 | 24.79 | 22.9 | 45 | 210 |
| MDM | len | 817 | 16.4 | 3.68 | 22.4 | 3 | 28 |
|  | dia | 817 | 10.7 | 1.77 | 16.5 | 6 | 19 |
|  | aml | 829 | 72 | 21.03 | 29.2 | 30 | 150 |
|  | samer | 722 | 107.5 | 26.21 | 24.4 | 40 | 220 |

[1] samer: inter-teat distance within the same row; aml: distance from the base of the teats in the upper row to the abdominal mid-line; len: teat length from the tip to the base; dia: teat diameter at the tip of the teat; all measures in millimetres.

In the mixed effects model for the continuous dependent variables, teat pair position was associated with all the measured traits, breed was associated with len and aml, parity was associated with all except aml, and litter size was not associated with any variable (Table 4.2). Teat length was significantly smaller in Meidam sows compared with Large White × Landrace ($P < 0.001$). Furthermore, MDM had teats closer to the abdominal mid line ($P = 0.006$). Parity had a significant effect on the teat length, teat diameter and the inter-teat distance within the same row. First parity sows had smaller teats (len: $P < 0.001$; dia: $P < 0.001$) than multiparous sows. The inter-teat distance within the same row was shorter in first and second parity sows (samer: $P < 0.004$). The third factor tested to assess sources of udder morphology variation was teat pair position. Teat characteristics were related to position on the udder according to three sectors (MDM in brackets had greater teat number): pairs 1-2 anterior, 3-5(6) middle and 6(7)-7(8) posterior in both breeds. Teat position had a significant ($P < 0.001$) effect on samer, with less distance between middle teat pairs. Distance between the teat base and abdominal mid line was shorter in the anterior and posterior teats compared to the middle teat pairs. Teat length was greater in the anterior and middle teats than in the posterior ones, whereas dia was greater in the middle teats.

Table 4. 2 Population marginal mean and standard error of 4 udder traits of 110 LWL (Large White × Landrace) and 110 MDM (Meidam) sows, according to breed (two levels), parity number (seven levels, from 1 to >6), and teat pair position (I: the teats located most anterior , to VIII the teats located most posterior).

| | Sources of Variation | Udder trait[1] | | | |
|---|---|---|---|---|---|
| | | len | dia | aml | samer |
| **Breed** | LWL | 17.8 ± 0.15 | 10.7 ± 0.07 | 78.0 ± 0.81 | 108.1 ± 0.99 |
| | MDM | 15.9 ± 0.14 | 10.5 ± 0.07 | 71.3 ± 0.78 | 107.2 ± 0.95 |
| | P-*value* | < 0.0001 | 0.62 | 0.006 | 0.42 |
| **Parity** | 1 | 14.2 ± 0.24$^{a}$ | 9.4 ± 0.12$^{a}$ | 71.7±1.36 | 100.1 ± 2.22$^{a}$ |
| | 2 | 16.2 ± 0.23$^{b}$ | 10.1 ± 0.12$^{b}$ | 72.8±1.31 | 105.4 ± 1.56$^{a}$ |
| | 3 | 17.2 ± 0.26$^{b}$ | 10.8 ± 0.12$^{b}$ | 75.5±1.47 | 111.6 ± 1.76$^{b}$ |
| | 4 | 18.2 ± 0.25$^{b}$ | 10.9 ± 0.12$^{b}$ | 74.2±1.38 | 106.9 ± 1.64$^{b}$ |
| | 5 | 17.7 ± 0.32$^{b}$ | 10.7 ± 0.16$^{b}$ | 82.2±1.82 | 108.3 ± 2.1$^{b}$ |
| | 6 | 17.7 ± 0.27$^{b}$ | 11.1 ± 0.14$^{b}$ | 75.4±1.53 | 110.9 ± 1.83$^{b}$ |
| | >6 | 18.4 ± 0.33$^{c}$ | 11.6 ± 0.17$^{c}$ | 73.2±1.86 | 115.5 ± 2.22$^{c}$ |
| | P-*value* | < 0.0001 | < 0.0001 | 0.16 | 0.004 |
| **Teat pair position** | I | 17.9 ± 0.27$^{a}$ | 9.9 ± 0.10$^{a}$ | 57.5 ± 0.80$^{a}$ | 116 ± 2.02$^{a}$ |
| | II | 17.5 ± 0.28$^{ab}$ | 9.7 ± 0.11$^{a}$ | 63.5 ± 0.82$^{b}$ | 112.6 ± 1.42$^{ab}$ |
| | III | 17.6 ± 0.27$^{abc}$ | 10.5 ± 0.11$^{b}$ | 81.2 ± 1.17$^{c}$ | 107.3 ± 1.31$^{bc}$ |
| | IV | 17.8 ± 0.26$^{a}$ | 11.1 ± 0.12$^{c}$ | 94.5 ± 1.23$^{d}$ | 100.1 ± 1.26$^{cd}$ |
| | V | 17.1 ± 0.25$^{bd}$ | 11.4 ± 0.12$^{cd}$ | 93.2 ± 1.23$^{d}$ | 94.5 ± 1.55$^{d}$ |
| | VI | 16.7 ± 0.25$^{cde}$ | 11.4 ± 0.13$^{d}$ | 82.1 ± 1.23$^{c}$ | 110.1 ± 2.05$^{bc}$ |
| | VII | 16.3 ± 0.24$^{ef}$ | 11.0 ± 0.15$^{c}$ | 63.8 ± 1.47$^{e}$ | 120.7 ± 2.83$^{a}$ |
| | VIII | 15.33 ± 0.39$^{f}$ | 10.48 ± 0.20$^{e}$ | 49.0 ± 1.51$^{b}$ | - |
| | *P-value* | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 |

$^{a,b,c,d,e,f}$ Means with different superscripts within the same column are significantly different

[1] len: teat length from the tip to the base; dia: teat diameter at the tip of the teat; all measured in millimetres; aml: distance from the base of the teats in the upper row to the abdominal mid-line; samer: inter-teat distance within the same row; all measured in millimetres.

In the mixed effects model for the Scores, teat pair position was associated with teat orientation score ($P < 0.001$) and teat functionality ($P < 0.001$). Teats that were not perpendicular tended to come from the anterior part of the udder (21.3% first most anterior teat, 17.5% second most anterior teat, < 13% for the rest of the teats in the udder, Table 4.3) whereas teats that were perpendicular generally came from the middle. Teats with a score for functionality equal to1 (teat not functional) were most often recorded in the second most anterior teat (29.7% second most anterior teat, 16.2% the sixth and seventh posterior teats, < 8.5% for the rest of the teats in the udder, Table 3). In contrast, teats that were partially or fully functional were generally located in the rear or middle portion of the udder. Parity was associated with udder development score ($P < 0.001$) and teat orientation score ($P < 0.001$), but not with functional score ($P > 0.05$). First parity sows had poorly developed udders and individual mammary glands were not clearly defined (40% of sows with udder development score 1 were in their first parity, 20% second parity, 10% third parity, 30% fourth parity, 0% sows with more than five parities) compared to sows with udder development score 2 or 3, which tended to be multiparous. Litter size was marginally associated with teat functionality ($P_{nlme} = 0.06$, $P_{gsem} = 0.006$) and orientation score ($P_{nlme} = 0.01$, $P_{gsem} = 0.02$) and highly associated with udder development score ($P < 0.001$), however this significance seemed largely due to a few animals with small litter size and disappeared when these animals were excluded from the analysis.

Table 4. 3.Percentage of teats with different scores by orientation and functionality which occurred at each teat pair. The values in bold are the greatest percentage.

| Teat | OR[1] | | fnct [2] | | |
|---|---|---|---|---|---|
| | 1 | 0 | 1 | 2 | 3 |
| I | 11.8 | **21.3** | 8.1 | 3.4 | **17.6** |
| II | 12.0 | 17.5 | **29.7** | 9.6 | 15.4 |
| III | 13.7 | 12.8 | 8.1 | 11.8 | 14.4 |
| IV | **14.3** | 10.6 | 8.1 | 10.1 | 15.5 |
| V | **14.3** | 9.1 | 8.1 | 18.5 | 12.8 |
| VI | 13.8 | 12.5 | 16.2 | **21.4** | 11.2 |
| VII | 13.0 | 12.8 | 16.2 | 20.8 | 10.1 |
| VIII | 7.2 | 3.4 | 5.4 | 4.5 | 3.1 |
| Total[3] | 100 | 100 | 100 | 100 | 100 |
| Prop[4] | 80 | 20 | 4.9 | 23.4 | 71.8 |

[1] teat orientation score 0: teat orientated towards the cranial\caudal direction, or laterally.1: teat orientated perpendicular to the gland. [2] Teat functionality score from 1 to 3, where 1 was defined as: non-functional teat; 2: reduced availability of colostrum; and 3: teat perfectly functional. [3] Total of the percentages of teats at the different positions, by orientation or functionality score. [4]Proportion of all teats in the different orientation or functionality score categories.

### *4.4.2 Longitudinal Study*

In the mixed effects model of animals measured at consecutive parities, parity change was associated with all dependent variables to some extent (Table 4.4). Inter-teat distance within the same row and teat diameter increased significantly only between first and second parities. Teat length increased significantly between sows of first and second consecutive parities and in sows of third and fourth consecutive parities. The distance between the teat base and the abdominal midline was not significantly different by parity in the cross sectional study, whereas considering the same sow across two consecutives parities showed that this dimension decreased significantly between third and fourth parity. The variance components for each udder morphology trait are presented in Table 4.5. The largest proportion of variation in the measurements was associated with the residual, with 22-25% explained by the sow. Only a small part of variation was explained by the consecutives parity group.

Table 4. 4. Mixed effects models of data from a longitudinal study describing the effect of parity (two levels, measured within a specific consecutive parity group (5 groups)) on 4 udder traits of 70 sows (12 Large White × Landrace and 58 Meidam); N: number of units measured; SE: standard error.

| Parities | N | len[1] | | | samer [1] | | | dia [1] | | | aml [1] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Estimate | SEM | *P* -value | Estimate | SEM | *P*-value | Estimate | SEM | *P*-value | Estimate | SEM | *P* -value |
| first- | 16 | 14.38 | 0.55 | | 98.11 | 3.26 | | 9.36 | 0.21 | | 71.74 | 3.41 | |
| second | | 17.42 | 0.30 | 0.00 | 103.55 | 2.66 | 0.04 | 10.06 | 0.17 | 0.00 | 67.38 | 2.51 | 0.08 |
| second- | 11 | 17.25 | 0.80 | | 108.79 | 5.25 | | 10.57 | 0.32 | | 78.21 | 3.36 | |
| third | | 17.06 | 0.55 | 0.72 | 110.53 | 3.80 | 0.65 | 10.62 | 0.30 | 0.87 | 77.17 | 3.15 | 0.74 |
| third- | 21 | 17.80 | 0.47 | | 107.70 | 3.26 | | 10.64 | 0.29 | | 77.36 | 2.44 | |
| fourth | | 16.86 | 0.38 | 0.02 | 108.87 | 2.78 | 0.67 | 10.44 | 0.21 | 0.35 | 64.09 | 2.32 | 0.00 |
| fourth- | 10 | 18.87 | 0.68 | | 115.14 | 3.89 | | 11.04 | 0.41 | | 75.48 | 4.27 | |
| fifth | | 18.98 | 0.58 | 0.85 | 113.10 | 4.36 | 0.64 | 11.17 | 0.31 | 0.67 | 69.36 | 3.51 | 0.08 |
| fifth- | 6 | 88.47 | 4.99 | | 108.54 | 4.32 | | 10.85 | 0.44 | | 88.47 | 4.99 | |
| sixth | | 80.33 | 5.33 | 0.13 | 114.75 | 6.14 | 0.31 | 10.37 | 0.41 | 0.24 | 80.33 | 5.33 | 0.13 |

[1] len: teat length from the tip to the base; dia: teat diameter at the tip of the teat; all measured in millimetres; aml: distance from the base of the teats in the upper row to the abdominal mid-line; samer: inter-teat distance within the same row; all measured in millimetres.

Table 4. 5. Percentage of variance explained by sow, teat pair position and consecutive parities. For each trait, the value in bold indicates the factor that explains the largest proportion of variation.

[1]len: teat length from the tip to the base; dia: teat diameter at the tip of the teat; all measured in millimetres;

| Factors | Udder trait[1] | | | |
|---|---|---|---|---|
| | len | dia | aml | samer |
| Residual | **58.2** | **57.6** | **37.6** | **61.0** |
| Sow | 26.4 | 25.6 | 25.7 | 22.1 |
| Teat | 4.2 | 9.4 | 33.9 | 12.0 |
| Parity | 11.0 | 7.2 | 2.6 | 4.9 |

aml: distance from the base of the teats in the upper row to the abdominal mid-line; samer: inter-teat distance within the same row; all measured in millimetres.

## 4.5 Discussion

The present study was designed to determine the main causes of variation in sow udder morphology. The results indicate that breed type, parity number and teat pair position all have a significant relationship with udder morphology variation. Meidam sows had smaller and more uniform teats compared to Large White × Landrace. To our knowledge this is the first study to focus on udder morphology in sows, although in sheep a previous investigation of udder morphology observed consistent association between breed and morphology variation (Makovicky *et al.*, 2013). These results provide further support for the possibility of improving udder quality by genetic selection in sows, to generate animals with better nursing capacity.

First and second parity sows had smaller teats and less developed udders compared with older multiparous animals. A change in the distance between the teats and the abdominal midline according to the sow parity was not observed in the cross-sectional study, but was apparent in the longitudinal study, a result potentially attributable to the high variation between animals. Results indicated that around a quarter of the variation in the measurements was explained by the sow identity, much more than by the parity group, suggesting that one measurement in the life cycle of the sow might be adequate to describe the phenotypic trait. However, the majority of variance remained unexplained by the model. Increased udder morphology dimensions in multiparous sows are to be expected, since selection has led to faster growing animals with greater mature body size. Recent studies found that, compared to older measurements, sows have become larger and their body size increases with each lactation (O'Connell *et al.*, 2007; Moustsen *et al.,* 2011). An effect associated with udder growth might be a reduction in teat accessibility, due to greater height from the floor of the upper teat row and poorer exposure of the lower row. Vasdal and Andersen (2012) observed that in old sows teat access was impaired compared with younger animals, and related this to an increment in piglet mortality. There are other important aspects associated with reduced teat accessibility. First of all, it has been demonstrated that a teat which is not suckled gives less milk in the subsequent lactations. This was demonstrated considering piglets' weight, behaviour and mammary gland characteristics (Pedersen *et al.*, 2011; Farmer *et al.*, 2012). These considerations are related with the positive effect of piglet's vitality on colostrum yield found in previous studies (Edwards, 2002). Reduced functional teat number might then impact piglet performance and survival. In relation to these parity effects on sow udder morphology, all reported studies in other species have also found a significant association (sheep: Fernandez *et al.*, 1995; delaFuente *et al.,* 1996; Casu *et al.,* 2006; Zwertvaegher *et al.*, 2012; Cow: Kuczaj, 2003).

Another important result was the difference in morphology according to teat pair position on the udder. In both breeds the anatomy of the teat was characteristic for a specific position in accordance with Kim *et al.* (2000). The data indicated that 3 regions could be defined: anterior (the two most cranial teat pairs), posterior (the two most caudal teat pairs) and the middle teat pairs. Inter-teat distance within the same row was shorter in the middle part of the udder compared with the anterior and posterior part, whereas teat distance from the abdominal mid line was shorter in the anterior and posterior part of the udder compared with the middle. Average teat lengths were decreased in the posterior part of the udder, whereas diameters were decreased in the teats located on the anterior part and increased in the middle part. These results were in agreement with those obtained by Fraser *et al.* (1985) in a study in which a milking machine was developed to compare the yield of different teats. Teat length and diameter were measured in twelve sows and no relationship was found between teat dimension and milk yield.

In association with teat pair position effect, Puppe and Tuchscherer (1999) observed that piglets that used the teat pairs positioned on the middle section of the udder suckled with significantly less stability than piglets using the anterior or posterior teats. Skok and Škorjanc (2013) used a mid-domain effect (MDE) approach to better understand the teat order around the mother’s udder. Their results pointed out those anterior and posterior positions are easy to keep, so suckling position is maintained more effectively. Piglets’ suckling behaviour was related to the geometric constraints of the shape of the udder. The MDE approaches showed that teat position does not depend on milk productivity of the mammary gland but from the limitations of the mammary complex.

Teat pair position also had an effect on teat orientation and teat functionality. Teat functionality is a criteria already considered in some countries for gilt selection (Chalkias *et al.*, 2013), however no previous data were found related to Meidam and Large White x Landrace cross breed, or in relation to parity and teat pair position. The greatest proportions of teats not perpendicular to the udder and less functional were recorded in the anterior section of the udder, but overall the proportion of teat functionality did not follow any specific pattern. There was no association between teat functionality and parity, which might have been expected if teat damage progressively increases with age. Nonetheless, more research on this topic needs to be undertaken before the association between teat functionality and teat pair position is more clearly understood. To develop a full picture of the importance of udder morphology additional studies will be needed that examine the association with teat accessibility.

## 4.6 Conclusion

The present study was designed to determine the effect of breed, parity, teat pair position and litter size on udder morphology. One of the most significant findings to emerge from this study was that udder conformation varies according to the sow breed. This result should be a basis to carry out further investigation on the heritability of these traits and their contribution to improving sow nursing capacity. First parity sows had smaller udder and teat dimensions; these results were concordant in both a cross-sectional and longitudinal study. According to the teat pair position three categories of teat and udder region could be created. Anterior-posteriors teat were closer to the abdominal mid-line, more distant from each other, allowing more space between piglets, and with teat length and diameter smaller than the middle teat pairs. To conclude, the sow udder has a characteristic morphology influenced by the breed and parity number of the animal. Further investigation should study the relationship between these morphology traits and the piglets’ suckling behaviour and performance.

# Chapter 5. Does sow udder conformation influence teat access by newborn piglets?

## 5.1 Summary

The aim of this study was to investigate if there is a relationship between the latency to first suckling and udder and teat morphology, and to assess the extent to which piglet and sow characteristics influence teat pair position preference. Udder morphology trait measurements, piglet suckling behaviour and sow productive and behavioural traits were recorded from a population of 74 Large White X Landrace sows of different parities. The inter-teat distance within the same row was larger between the teats that were suckled on the first contact with the udder, compared with the un-suckled ($P = 0.04$). The latency from birth to suckling was shorter when the piglets were born later in the litter ($P < 0.001$), from a litter with a low incidence of stillborn piglets ($P = 0.001$) and from a sow with an induced farrowing ($P = 0.007$). The latency from first udder contact to suckling was similarly affected by the piglet birth order ($P = 0.03$) but not in a consistent pattern, incidence of stillborn piglets ($P < 0.001$) and farrowing induction ($P = 0.001$). Moreover there was a tendency for piglets born from a multiparous sow ($P = 0.06$) and in a large litter size ($P = 0.07$), to have a longer latency to find a teat and suckle once they had made the first contact with the udder. A high proportion of siblings (64%) suckled for the first time on a teat previously chosen by another piglet. The majority of the neonates suckled first from a teat located in the posterior part of the udder (41%) or in the anterior part (33%), rather than the middle section. The time from the first udder contact to locate a teat and suckle was not influenced by piglet vitality score at birth, weight or provision of human assistance to place it at the udder. Although suckling itself is clearly an instinctive behaviour, acquisition of colostrum depends on many variables, relative not only to piglet characteristics but to sow behavioural and morphological characteristics as well. Future studies on sow characteristics are therefore recommended.

## 5.2 Introduction

Immediately after birth newborn piglets start searching, using nose contact, until they find a teat and start suckling from it. This behaviour has been well studied in order to improve pig management and reduce piglet mortality (Hartsock and Graves, 1976; Rohde Parfet and Gonyou, 1988). After suckling, piglets tend to suckle many teats with frequent changes. This teat sampling behaviour lasts for about the first 8 h postpartum and facilitates colostrum consumption (De Passille and Rushen, 1989b). Sow nursing behaviour enables the offspring to sample all teats freely (Špinka and Illmann, 2015). Early teat suckling success determines early colostrum intake, which is essential for the piglet's immediate and long term survival and performance (Edwards, 2002). Colostrum provides energy (Herpin and Le Dividich, 1993), immune protection (Klobasa *et al.*, 1987; Rooke and Bland, 2002), as well as helping the gut to mature in the first few hours of life (Quesnel *et al.*, 2012). Colostrum ejection decreases quickly after parturition, and is gradually replaced by milk. Thus, it is essential that the piglet achieve its first colostrum intake as quickly as possible after birth. Despite the innate expression of teat-seeking behaviour, the latency to first suckling varies considerably between piglets (Rohde Parfet and Gonyou, 1988; Baxter *et al.*, 2008; Baxter *et al.*, 2009). Understanding the causes of this variation is therefore essential to improve piglet survival. Teat access by newborn piglets in the first hour of life has been well investigated in relation to the physical environment (Rohde Parfet and Gonyou, 1988), sow pre-partum activity (Špinka and Illmann, 2015), asphyxia at birth (Herpin *et al.*, 1996), rectal temperature, vitality and birth weight (Tuchscherer *et al.*, 2000; Baxter *et al.*, 2008; Baxter *et al.*, 2009), physiological variables (Casellas *et al.*, 2004) and the influence of management routines (Christison *et al.*, 1997; Vasdal *et al.*, 2011). To date, teat access has never been related in detail with the sow's udder morphology. Sows with high teat number (15-16) have bigger litters at weaning compared with sows with 14 teats (Rekiel, 2000; Rekiel *et al.*, 2014). Furthermore, it has been found that a sufficient number of functional teats in a sow is essential for the growth and development of the piglets (Chalkias *et al.*, 2014). The purpose of the current study was to better understand initial piglet suckling behaviour and its relationship with sow udder morphology. The main objective was to investigate if there is a relationship between the latency to first suckling and udder and teat morphology. Other possible causes of delay in successful suckling were studied including piglet characteristics, such as birth weight, vitality and birth order, sow characteristics, such as parity, behaviour, ease of colostrum extraction, and management around farrowing. A second objective was to assess the extent to which these factors determine teat pair position preference for first suckling. It was hypothesized that there would be an interaction between teat seeking success and udder traits.

## 5.3 Material and Methods

### *5.3.1 Animal.*

The experiment was conducted at Cockle Park Farm, Newcastle University, Newcastle upon Tyne, UK, following approval by the Animal Welfare and Ethics Review Body at Newcastle University. Udder morphology trait measurements and piglet suckling behaviour were recorded between November 2012 and November 2014 from a population of 74 Large White X Landrace sows of different parities (13 sows first parity, 11 sows second, 11 sows third, 13 sows fourth, 12 sows fifth, 7 sows sixth. Considering that there were few sows with more than six parities, a group of 6 sows with more than six parities was created). Animals were moved from the group gestation house to the farrowing unit at 110 days after final insemination, where they were kept in individual crates equipped with a feeder and drinker. Ambient room temperature averaged 21°C. No specific procedures were imposed in the study; feed, environment and management were maintained as standard commercial practice. The farmer was allowed to assist birth for sows having birth problems; however no cross-fostering of piglets occurred until after data collection was completed.

### *5.3.2 Piglet Characteristics*

Piglet observation started at birth. After each piglet was born, when an observer was present, it was lifted gently, marked with its birth order number on its back (BO), and weighed (BW). Considering that there were few litters recorded in which more than seven piglets were observed, due to observer availability, a category of piglet birth order of more than seventh piglet was created (the first newborn piglet was observed in 59 litters, the second born piglet was observed in 53 litters, the third piglet in 51 litters, the fourth in 46 litters, the fifth in 32 litters, the sixth in 29 litters, the seventh in 23 litters, and subsequent piglets born were observed in 40 litters). In order to assess the effect of different management routines, piglets were distributed into two treatments groups (control C and assisted A). The piglets in the Control group, after being weighed, were placed back where they were found. Piglets in the Assisted group, after being weighed, were dried, positioned under a heat lamp located behind and to one side of the sow and, when they had stood and started to move, the operator carefully placed them centrally in front of the udder. Video cameras equipped with wide-angle lenses were mounted at the back of each farrowing crate to record piglet behaviour out of working hours. Output from each camera was input into a Panasonic WJ-FS 416 16-camera multiplexer whose output was then recorded using a Panasonic AG-6040 time lapse video cassette recorder (VCR). The VCR was set to record for a 24-h period on a single 120-min tape; using this equipment, an image was captured from each camera at three seconds intervals. Data were collected from 7 farrowing batches over time; in total 74 litters were included in the experiment. All the observations occurred between eight am and midnight, seven of which were filmed.

Data collection was the same for both treatment groups. Immediately after birth, piglet vitality was recorded using a score (VITA: 1 to 4) based on movement during the first 15 seconds of life (Table 5.1). Continuous observations were made on all litters during parturition and until the last piglet born under study had suckled. To assess teat seeking success, latency to find a teat and suckle were recorded. Time from birth to suckling (TBS) and time from first udder contact to suckling (TUS) were recorded, with suckling defined as taking a teat into the mouth for a period of three seconds or longer and showing sucking and swallowing behaviour. In order to determine the relationship between udder morphology and teat success for each piglet, the first teat suckled was recorded by side (left or right), row (upper o lower) and defined as teat pair position suckled (TPS). The teat pairs were numbered in ascending order (1, 2, 3 to 7) from the most anterior to the most posterior ones.

Table 5. 1 Piglet birth vitality score (VITA) description

| *VITA Score* | *Description* |
|---|---|
| 1 | No movement, no breathing after 15 s |
| 2 | No body or leg movement after 15 s, piglet is breathing or attempting to breathe coughing, spluttering, clearing its lungs |
| 3 | Piglet shows some movement, breathing or attempting to breathe and rights itself onto its sternum within 15s |
| 4 | Good movement, good breathing, piglet attempts to stand within 15 s |

### *5.3.3 Sow Characteristics*

Sows were allowed to farrow normally at term over a four day period (Monday to Thursday); sows that had not farrowed within this period were then induced on Thursday by injection of a prostaglandin analogue. Any assistance given to a sow during farrowing was also recorded. Records were made of the litter size traits such as total born, the number of stillborn and mummified piglets. A stillborn piglet was defined as one that never started to breathe. Because of the small numbers of observations in some categories, litter size data were subsequently combined to give three categories (category one: from 2 to 11 piglets; category two: from 12 to 16 piglets; and category three: from 17 to 20 piglets). Teat measurements were made as described in Chapter 2; a summary is given in Table 5.2. In this experiment, a further evaluation was made of posterior udder damage condition. Udder damage score was recorded as a single value for each sow and evaluated on only the three last teats and mammary glands. The scoring system used to identify posterior udder damage was based on a modified version of the score system developed by Soede et al. (personal communication, Table 5.2). Sow behaviours recorded during farrowing were: teat exposure score ("Show", Table 5.2) and changing position (yes or no). Teat functionality and ease of colostrum sampling score were recorded when samples of colostrum were available immediately before the onset of parturition or during parturition. The operator quietly approached the sow and obtained a sample by using hand pressure, exerted approximately in the centre of the mammary gland to aid in making the colostrum flow more freely. Colostrum ease of extraction and teat functionality score definitions are reported in Table 5.2. Non-functional teats were scored in the same way as in a Swedish study (Chalkias *et al.*, 2013)

Table 5. 2 Sow farrowing behaviour and udder damage score descriptions.

| Traits | Description | Score |
|---|---|---|
| show | Show teat score evaluated the sow's propensity to expose the udder. This score was recorded at the beginning of farrowing | Score from 1 to 4; where 1 was defined as: teats were not shown; 2 sow showed only the teats in the upper row; 3sow showed the upper teat row and only the anterior teats of the bottom row; 4 sow showed both teat rows in full. |
| Position change | First posture change of the sow recorded from the beginning of the farrowing | Was defined as *YES* if the sow changed from a lying down posture on one flank to the other flank or she stood up, and *NO* if the sow remained lying down on the same flank for the entire length of the farrowing. |
| udder damage | The damage on the last three posterior teats and mammary glands was classified according to 3 categories. Each sow has a single score for each category. A and B were linear scores from absent (0) to severe (3) damage, coinciding with: **A** damage of mammary gland, and **B** teat. C classified the tissue and skin, determining if the tissue and skin were hard. | Category A: score from *0* to *3*; where *0* was defined as healthy mammary gland; 1one or two mammary glands affected with superficial wounds; *2* more mammary glands affected and one or two deep wounds ; *3* same as *2*, but wounds larger (>1 cm and deep).<br>Category B: score from *0* to *3*; where *0* was defined as healthy teats; *1* one teat damaged with wounds smaller than 1cm, milk channel is not affected; *2* two or three teats damaged or with wounds larger than 1cm, milk channel not affected; *3*more than three teats damaged and/or milk channel affected.<br>Category C: was defined with *YES* when the mammary gland tissue was hard, and *NO* when the mammary gland tissue was healthy |
| samer | Inter-teat distance within the same row | Millimetres recorded with ruler |
| len | Length of the teat | Millimetres recorded with ruler |
| dia | Diameter of the teat | Millimetres recorded with calliper |
| aml | Distance between teat base and the abdominal mid-line | Millimetres recorded with ruler |

| Traits | Description | Score |
|---|---|---|
| OR | Teat orientation with respect to the mammary gland | Score from *0* to *1*, where *0* was defined as: teat orientated towards/away from the midline or teat orientated towards the cranial/caudal direction; and *1* was defined as: teat orientated perpendicular to the mammary gland, |
| fnct | Teat functionality | Score from *1* to *3*, where *1* was defined as: non-functional teat, milk channel not working, including teats which were blind: teats that were impaired early in the life of the pig, and remain as a small protuberance; inverted: the top of the teat, or even the entire teat, is inverted to form a crater; very damaged: teat injured such that milk ejection is not possible; or supernumery: small teats in-between two normal teats; *2*: reduced availability of colostrum, milk channel only partially working; and *3*: teat perfectly functional; |
| ease of extraction | Colostrum ease of extraction | Score from *0* to *5*; where *0* was defined when no massage was needed and colostrum was freely ejected; *1* when colostrum expression was very easy by applying a stripping action to the teat with a thumb and one forefinger; *2* when a pressure with all the hand was exerted approximately in the centre of the mammary gland system and continued to the end of the teat; *3* when two forceful pressures with all the hand were exerted approximately in the centre of the mammary gland system and continued to the end of the teat; *4* when more than three forceful pressures with all the hand were exerted approximately in the centre of the mammary gland system and continued to the end of the teat; *5* no colostrum was ejected. |

### *5.3.4 Statistical Analysis*

Prior to statistical analysis, all data were checked for statistical outlier values. No data were excluded for this reason. Descriptive statistics were calculated, and data are reported as arithmetic mean and standard error. Normality was assessed by application of the Shapiro-Wilk test. Statistical differences in TBS and TUS between treatments were calculated with one-sample Wilcoxon tests; also known as Mann-Whitney test. Variation of TBS and TUS according with TPS was assessed using a mixed effects linear model (nlme package in R; Pinheiro *et al.* (2007)). The same model was used to compare the udder morphology traits between first suckled and un-suckled teats. The model included a binary dependent variable (suckled and un-suckled) and udder morphology traits (samer, len, dia, aml, OR, fnct, Ease of extraction) as independent variables, sow was included as a random effect. The categorical nature of some dependent variables was ignored since previous results showed no difference between using a mixed-effects multinomial regression or a mixed-effects multinomial model (Balzani *et al.*, 2015c)

To investigate what determined the variation of the dependent variables TBS, TUS and TPS, data were analyzed using a mixed effects linear model. Three models were created: the first considered piglet characteristics as independent variables: BO category (factor with eight levels), BW (continuous variable), treatment group (factor with two levels: control and assisted), and piglet vitality score (factor with four levels). The other models were created considering sow characteristics as independent variables grouped as productive and behaviour traits. In detail, the second model considered as independent variables the litter size category (factor with three levels), sow parity number (factor with seven levels), assisted farrowing (factor with two levels), induced farrowing (factor with two levels), number of stillborn and mummified piglets. The last model considered as independent variables the udder damage scores (two categories with four levels, and one category with two levels), the sow behaviour regarding udder exposure (factor with four levels) and the sow posture change (factor with two levels). Sow was considered as a random effect in all models. Differences were considered significant at $P < 0.05$. The statistical software R version 3.0.2 (2013-09-25) was used for all tests.

## 5.4 Results

### *5.4.1 First contact with the udder: suckled and un-suckled teat morphology*

In the mixed effects model for teat preference, inter-teat distance within the same row was larger between suckled teats compared with un-suckled teats ($P = 0.04$), whereas all the other morphology traits were not significantly different between the two groups. Results are shown in Table 5.3.

Table 5. 3Comparison between teat suckled during the first contact with the udder and un-suckled teat measurements (mean and standard errors in millimetres).

| Traits[1] | Teat | N | mean | se | F - value | P - value |
|---|---|---|---|---|---|---|
| samer | unsuckled | 274 | 108.1 | 1.51 | | |
| | suckled | 185 | 114.2 | 1.98 | 4.40 | 0.04 |
| len | unsuckled | 310 | 17.8 | 0.24 | | |
| | suckled | 218 | 17.8 | 0.22 | 0.30 | 0.58 |
| dia | unsuckled | 311 | 10.6 | 0.11 | | |
| | suckled | 218 | 10.4 | 0.12 | 1.91 | 0.17 |
| aml | unsuckled | 311 | 79.1 | 1.33 | | |
| | suckled | 218 | 75.5 | 1.65 | 0.26 | 0.61 |
| OR | unsuckled | 310 | 0.7 | 0.03 | | |
| | suckled | 218 | 0.7 | 0.03 | 0.01 | 0.92 |
| ease of extraction | unsuckled | 313 | 1.8 | 0.07 | | |
| | suckled | 216 | 1.6 | 0.07 | 1.55 | 0.21 |
| fnct | unsuckled | 296 | 1.2 | 0.03 | | |
| | suckled | 198 | 1.2 | 0.03 | 2.23 | 0.14 |

[1]Trait definition is reported in Table 5.2

### *5.4.2 Piglet characteristics*

In total, data were recorded for 371 piglets which were observed during farrowing (89% of the observations began at time zero, 11% within one hour after the first piglet was born, determined retrospectively from video), of which 155 were assigned in the control group and 216 in the assisted group. Due to farrowing synchronization and a limited number of operators, not all the piglets in a litter were observed. The number of piglets recorded per litter was, on average, 4 (min: 1, max: 15). Birth weight (BW) on average was 1.51 kg (min: 0.45 kg; max: 2.6 kg, Table 5.4). Piglet vitality score 4, was recorded for 34% of the piglets (N = 125), vitality score 3 for 34% (N = 124), and vitality score 2 for 32% (N = 119). Only 0.8% of the new-born piglets showed vitality score 1 (no movement and no breathing after 15 s, N = 3). There was no significant difference between treatment groups in vitality score and BW (Table 5.4).

Table 5. 4 Percentage of newborn piglets with different vitality scores and birth weight in kilograms (mean ± SD) in the two experimental groups: control and assisted.

| VITA score[1] | Treatment | |
|---|---|---|
| | Control (N=155) | Assisted (N=216) |
| 1 | 1 | 0 |
| 2 | 16 | 16 |
| 3 | 12 | 21 |
| 4 | 12 | 22 |
| Birth Weight | 1.5 (0.35 ) | 1.5 (0.35 ) |

[1] Vita score definition is reported in Table 5.1

#### *5.4.2.1 Latency to first suckle*

The time which elapsed from birth to suckling (TBS) on average was 00:29:35 minutes (min: 00:04:00 min; max: 3:28:00 h); in the control group it was 00:30:11 minutes (min: 00:04:00 min; max: 3:28:00 h) whereas in the assisted group it was 00:29:08 minutes (min: 00:04:00 min; max: 3:00:00 h). One-sample Wilcoxon test results showed no significant difference in TBS between treatments (P = 0.36). This time was shorter for piglets first suckling the anterior and posterior teats (28:03 se 3.01, and 26:31 se 3.93 min) than for mid-section teats (34:30 se 4.72, $F_{7,1} = 1.99$, $P < 0.05$). On average, time elapsed from the first udder contact to suckle (TUS) was 00:09:55 minutes (min.: 00:00:00; max.: 01:56:00 hours). Time elapse from udder to suckle in the control group was 00:8:34 minutes (min: 00:00:00 min; max: 0:54:00 h), and in the assisted piglets group was 00:10:41 minutes (min: 00:00:00 min; max: 1:56:00 h). One-sample Wilcoxon test results showed a small but significant difference in TUS between treatments (P = 0.05). This time was again shorter for piglets first suckling the anterior and posterior teats (09:48 se 3.52, and 8:38 se 4.93 min) than for mid-section teats (10:30 se 4.72, $F_{7,1} = 2.37$, $P < 0.05$). Figure 5.1 shows TUS variability in relation to the teat position first suckled.

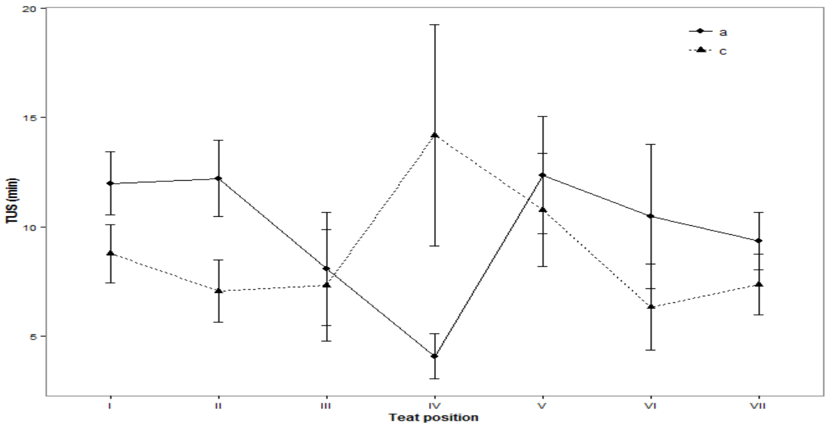


Figure 5. 1 Variability of time elapsed from a piglet's first contact with the udder to suckling (TUS) in minutes, for each teat pair first suckled, according to treatment (a= assisted piglet, c=control).

In the mixed effects model with the latencies as dependent variables, TBS was associated with piglet birth order. The piglets born later found a teat in less time than early born piglets ($F_{7,286} = 5.28$; $P < 0.001$, Figure 5.2). None of the other independent variables affected TBS (piglet birth weight: $F_{1,256} = 1.78$, $P = 0.18$; treatment group: $F_{1,62} = 0.25$, $P = 0.61$; vitality score: $F_{3,256} = 0.66$, $P = 0.57$). The same results were obtained for the dependent variable TUS; piglet birth order affected the latency to suckle once a piglet was already in contact with the udder ($F_{7,286} = 2.21$; $P = 0.03$). However in this case the variability was not between the first piglets born and later ones, but was more randomly distributed; results are shown in Table 5.5. No other piglet characteristic affected TUS (piglet birth weight: $F_{1,286} = 1.36$, $P = 0.24$; treatment group: $F_{1,72} = 1.11$, $P = 0.29$; vitality score: $F_{3,286} = 1.43$, $P = 0.23$).

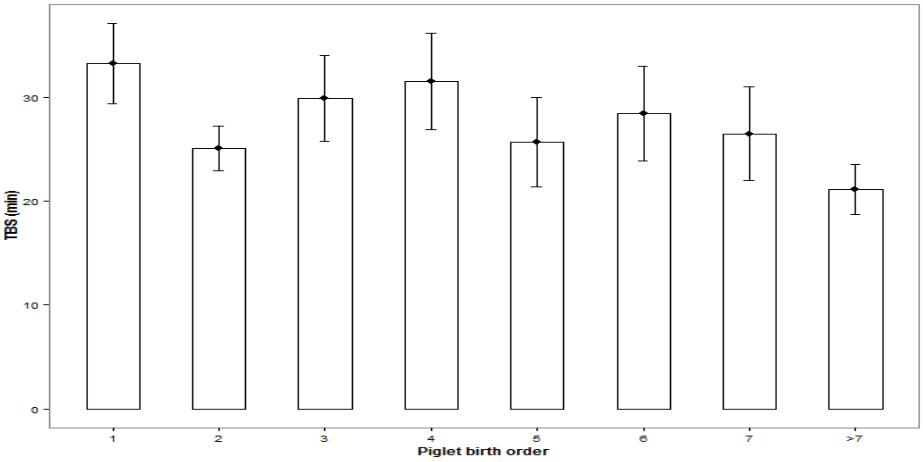


Figure 5. 2 Time elapsed from birth to suckling (TBS) according to piglet birth order categories.

Table 5. 5 Mean and SD of time elapsed from birth to suckling (TBS) and from udder to suckle (TUS) in minutes, according to piglet birth order categories (BO).

| BO | N | TBS | | TUS | |
|---|---|---|---|---|---|
| | | mean | SD | mean | SD |
| 1 | 67 | 36.3$^a$ | 34.68 | 12.8$^a$ | 15.99 |
| 2 | 61 | 27.3$^a$ | 18.43 | 8.2$^b$ | 8.16 |
| 3 | 58 | 31.3$^a$ | 28.47 | 11.6$^a$ | 10.80 |
| 4 | 52 | 31.0$^a$ | 30.65 | 8.0$^b$ | 7.58 |
| 5 | 35 | 26.3$^a$ | 23.69 | 7.7$^b$ | 8.11 |
| 6 | 32 | 28.1$^a$ | 23.59 | 10.2$^a$ | 11.51 |
| 7 | 24 | 27.0$^a$ | 21.31 | 7.4$^b$ | 8.43 |
| >7 | 42 | 21.2$^b$ | 14.72 | 7.7$^b$ | 6.92 |

$^{a,b}$ Within a column, means without a common letter differ ($P < 0.05$).

### *5.4.2.2 Teat preference*

Posterior teats were chosen first by 41% of piglets (teat pair number seven N = 96, teat number six N = 53). Thirty-three percent of piglets first suckled anterior teats (teat number one N = 70, teat number two N = 53). Middle teats (pairs 3 - 5) were chosen only by 27% of piglets. On 64% of occasions different siblings (piglets in the same litter) first suckled the same teat as another piglet. Figure 5.3 shows the frequency of piglets' teat preferences in the same litter according to teat position and row. At least two siblings suckled for the first time on the same teat in 65 litters. Three piglets preferred the same teat in 19 litters; four piglets suckled from the same teat in five litters and only in one litter did more than five siblings suckle the same teat for the first time. In the mixed effects model with TPP as the dependent variable, no association with any of the independent variables was found (birth order: $F_{7,286} = 1.14$, $P = 0.33$; birth weight: $F_{1,286} = 0.46$, $P = 0.49$; treatment group: $F_{1,72} = 0.18$, $P = 0.67$; piglet vitality score: $F_{3,286} = 2.24$, $P = 0.08$).

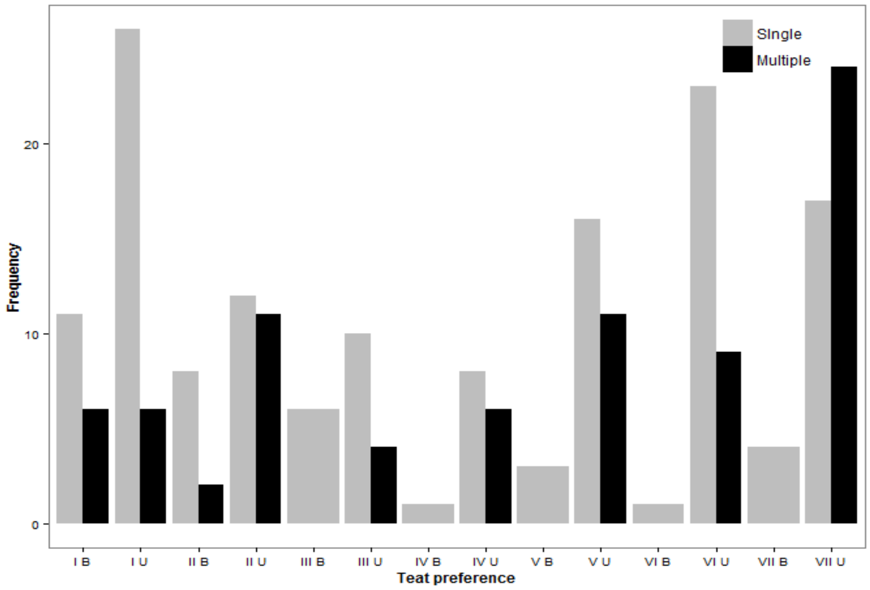


Figure 5. 3. Frequency of teat position (I to VII) and row (U= upper; B= bottom) for first suckling by individual piglets or siblings. Dark bars show the frequency of the teats chosen by more than two piglets in the same litter and grey bars represent the frequency of single piglet preference. The teat pair positions where dark bars are missing indicate that no two piglets suckled for the first time from these teats in all observed litters.

### *5.4.3 Sow characteristics*

Average litter size was 12.5 (range from 2 to 20), giving a total of 914 piglets (of which 35 were stillborn and 22 mummified). Sows that had a litter size category one (from 2 to 11 piglets born in the litter) were 32% (N = 24), 53% of the sows (N = 39) had a litter size category two (12 to 16), and only 14% had a litter size of category three (16 to 20, N = 10). Forty-three sows (60%) stood up after the first piglet was born and 30 (40%) remained for the entire farrowing process lying down on the same flank. Immediately after the first piglet was born only two sows (2%) failed to expose the udder until the second piglet was born; eleven sows (15%) only showed the upper teat rows, six sows (8%) showed the upper teat rows and only the anterior teats of the bottom row, and fifty five sows (73%) showed both teat rows. Mean farrowing duration was 3.10 hours (min = 0.57 h; max = 9.5 h). Sixty sows had farrowing induced by prostaglandin injection according to the farm practice, while 35 sows received an injection of oxytocin during prolonged farrowing (more than two hours between piglets). Descriptive statistics of the morphology traits of the teats first suckled are reported in Table 5.6.

Table 5. 6 Descriptive statistics of 225 sow teat traits recorded in millimeters, first suckled by 371 piglets. (N = number of piglets per group).

| | Udder Traits[1] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Teat | len | | | samer | | | dia | | | aml | | |
| | *N* | *Mean* | *SE* | *N* | *Mean* | *SE* | *N* | *Mean* | *SE* | *N* | *Mean* | *SE* |
| 1 | 69 | 18.03 | 0.41 | 70 | 120.7 | 3.15 | 69 | 9.7 | 0.16 | 69 | 59.7 | 1.42 |
| 2 | 53 | 17.6 | 0.42 | 53 | 112.0 | 2.71 | 53 | 9.3 | 0.16 | 53 | 67.4 | 2.14 |
| 3 | 28 | 18.0 | 0.64 | 28 | 111.9 | 3.71 | 28 | 9.8 | 0.27 | 28 | 88.2 | 2.69 |
| 4 | 23 | 18.1 | 0.66 | 23 | 103.0 | 3.752 | 23 | 11.1 | 0.31 | 23 | 96.7 | 5.33 |
| 5 | 48 | 18.0 | 0.41 | 46 | 96.7 | 3.37 | 48 | 11.1 | 0.24 | 48 | 97.3 | 3.24 |
| 6 | 53 | 17.8 | 0.55 | 45 | 120.0 | 4.15 | 53 | 11.3 | 0.31 | 53 | 77.2 | 3.05 |
| 7 | 95 | 16.9 | 0.29 | 25 | 125.6 | 4.45 | 95 | 10.4 | 0.18 | 95 | 57.0 | 1.95 |

[1] Udder traits definition is reported in table 5.2

Teat orientated perpendicular to the udder were 72% (score 1, N = 265). Suckled teats which were not functional were only 0.2% (score 1, N = 7), 16% of the suckled teats were scored as partially functional (score 2, N = 52), and 82% of teats were scored as perfectly functional (score 3, N = 264). Only in two sows was colostrum available without any intervention (score 0). For 67% of the teats milked, colostrum was very easily available only with the pressure of two finger on the teat (score 1, N = 223), 16% of the sample needed a soft massage of the mammary gland (score 2, N = 52), 7% of the teats only gave colostrum after one or two forceful pressures with all the hand exerted approximately in the centre of the mammary gland system and continuing to the end of the teat (score 3, N = 25). More than three forceful pressures with all the hand exerted approximately in the centre of the mammary gland system and continuously to the end of the teat was required for 5% of the teats (score 4), and only 2% of the mammary glands did not give any colostrum (score 5). Thirty-four percent of the mammary glands (category A, score 0, N = 125) and 71% of the teats observed (category B, score 0, N = 264) were healthy. One or two mammary glands affected and superficial wounds were recorded on 48% of the animals (category A, score 1, N = 177). Only 19% of the sows had more than one mammary gland affected and deeper wounds (category A, score 2, N = 69). Category B score results showed that 24% of the sows had partially damaged posterior teat (score 1, N = 88). Only a few animals had very damaged teats (score 2, N = 12), and even fewer had the milk channel affected (score 3, N = 7).

#### *5.4.3.1 Latency to first suckle*

A mixed effect model showed that TBS was associated with the number of stillborn piglets ($F_{6,54}$ = 4.44, P = 0.001) and induced parturition ($F_{1,54}$ = 5.38, P = 0.007). None of the other sow characteristics affected the variability of TBS (litter size: $F_{2,54}$ = 1.34, P = 0.25 ; parity: $F_{6,54}$ = 0.79, P = 0.57; oxytocin during farrowing: $F_{1,54}$ = 1.55, P = 0.21; number of mummified piglets: $F_{3,54}$ = 0.19, P = 0.90; udder damage category A: $F_{2,56}$ = 0.38, P =0.67; udder damage category B: $F_{3,56}$ = 0.12, P = 0.94; udder damage category C: $F_{1,56}$ = 0.13, P = 0.71; sow udder exposure behaviour: $F_{3,56}$ = 0.92, P = 0.43; sow standing behaviour: $F_{1,56}$ = 2.11, P = 0.13) Time elapsed from first udder contact to suckling showed an association with induced parturition ($F_{1,54}$ = 7.22, P = 0.001), the number of stillborn piglets ($F_{6,54}$ = 6.98, P < 0.001), sow behaviour regarding udder exposure during farrowing ($F_{3,56}$ = 4.19, P = 0.009). Piglets born in a litter with a high number of stillborn, from a non-induced farrowing and from a multiparous sow had a longer latency to find a teat and suckle (Table 5.7). There was a tendency for TUS to be associated with litter size ($F_{2,53}$ = 2.76, P = 0.07); piglets born in bigger litter sizes had a longer latency to find a teat and suckle once they were in contact with the udder. Sow parity number also showed a tendency for an effect on TUS, but not in a consistent pattern ($F_{6,54}$ = 2.11; P = 0.06). Other sow characteristics did not affect TUS (oxytocin during farrowing: $F_{1,54}$ = 1.15, P = 0.28; number of mummified piglets: $F_{3,54}$ = 0.83, P = 0.47; udder damage category A: $F_{2,56}$ = 0.34, P =0.70; udder damage category B: $F_{3,56}$ = 0.75, P = 0.52; udder damage category C: $F_{1,56}$ = 0.64, P = 0.42; sow standing behaviour: $F_{1,56}$ = 0.32, P = 0.72)

Table 5. 7 Mean value of time elapsed in minutes from udder contact to suckling (TUS) and birth to suckling (TBS) in the 74 litters according to the number of stillborn piglets, whether the sow had an induced farrowing or not, and sow parity number. (N = number of piglet per group; SE= standard error).

| *Variation source* | N | TBS | | TUS | |
|---|---|---|---|---|---|
| | | MEAN | SE | MEAN | SE |
| *Stillborn piglet* | | | | | |
| 0 | 193 | $28.4^{a}$ | 1.86 | $8.4^{a}$ | 0.59 |
| 1 | 114 | $25.7^{a}$ | 1.86 | $9.9^{a}$ | 0.86 |
| 2 | 8 | $16.5^{a}$ | 2.71 | $8.1^{a}$ | 2.34 |
| 3 | 7 | $25.4^{a}$ | 7.90 | $17.3^{b}$ | 7.98 |
| 4 | 6 | $20.8^{a}$ | 5.56 | $6.3^{a}$ | 2.20 |
| 5 | 5 | $107.2^{b}$ | 11.14 | $39.0^{b}$ | 16.12 |
| *Induced farrowing* | | | | | |
| Y | 305 | 27.6 | 3.65 | 8.7 | 0.51 |
| N | 66 | 37.5 | 3.47 | 13.3 | 1.92 |
| *Sow Parity number* | | | | | |
| 1 | 62 | 38.3 | 4.93 | $6.8^{a}$ | 1.02 |
| 2 | 50 | 25.2 | 2.95 | $7.9^{a}$ | 1.4 |
| 3 | 67 | 25.5 | 2.20 | $9.7^{a\,b}$ | 1.08 |
| 4 | 58 | 30.5 | 3.58 | $13.3^{b}$ | 1.98 |
| 5 | 60 | 26.1 | 2.24 | $10.1^{b}$ | 1.21 |
| 6 | 40 | 30.8 | 4.51 | $7.4^{ab}$ | 1.25 |
| >6 | 34 | 28.6 | 4.41 | $8.6^{ab}$ | 2.26 |

$^{a,b}$ Values that do not share the same letter are significantly different

#### *5.4.3.2 Teat preference*

Teat pair position suckled was not associated with any of the sow characteristics as independent variable (litter size: $F_{2,54}$ = 0.01, P = 0.98 ; parity: $F_{6,54}$ = 1.83, P = 0.11; oxytocin during farrowing: $F_{1,54}$ = 0.09, P = 0.76; induced parturition: $F_{1,54}$ = 1.93, P = 0.15; stillborn piglets: $F_{6,54}$ = 0.84, P = 0.53; number of mummified piglets: $F_{3,54}$ = 0.30, P = 0.82; udder damage category A: $F_{2,56}$ = 0.71, P =0.49; udder damage category B: $F_{3,56}$ = 0.41, P = 0.75; udder damage category C: $F_{1,56}$ = 2.93, P = 0.09; sow udder exposure behaviour: $F_{3,56}$ = 0.78, P = 0.51; sow standing behaviour: $F_{1,56}$ = 0.65, P = 0.52)

## 5.5 Discussion

The present study was designed to determine the relationship between latency to suckle and udder morphology. The results indicate that newborn piglets immediately after birth most often made the first contact and suckled teats located in the upper row in the posterior or anterior part of the udder. This result seems to be consistent with other research which found that less than half of the sows' functional teats were suckled by neonates on first contact with the udder (Vasdal and Andersen, 2012). Even though more than half of the sows exposed both teat rows during farrowing, piglets suckled from teats located in the bottom row only in the anterior part of the udder. Teat preference results are in accordance with De Passille and Rushen (1989b), who observed newborn piglets from birth to 8 hours of life. In their study each piglet suckled on average seven different teats and there was no preference for anterior teats. In the current study there was a tendency for the teats located in the middle part of the udder to be suckled more often by assisted piglets than control piglets, which may have been because assisted piglets were placed centrally when returned to the udder. Teat preference was not affected by piglet vitality score or birth weight. These results match those observed in earlier studies (De Passille and Rushen, 1989b). However there was a tendency for piglets with low vitality score to suckle teats located in the posterior part of the udder and a tendency for the later piglets born to suckle a teat located in the anterior part of the udder. First- and second-born piglets usually suckled for the first time on a posterior teat; this same tendency was observed in the study of de Passille and Rushen (1989). Posterior and anterior teats have similar teat length and diameter, they are close to the abdominal mid-line and more separated from each other, allowing more space for the siblings to suckle (Balzani *et al.*, 2015c). The comparison between suckled and un-suckled teats showed that piglets first suckled more frequently from teats with larger inter-teat distance within the same row. However the morphological similarity between teats located in the anterior and posterior part of the udder and their higher preference suggests that newborn piglets suckle more easily and quickly from teats with small dimension and close to the abdominal midline.

The results obtained in this study for teat seeking behaviour, considered as the time from birth to suckling and from the first contact with the udder to suckling, were consistent with the data obtained in earlier studies (mean ± se (min); 30.68± 1.96, Baxter et al., 2009; 26.9± 3.5, Tuchscherer *et al.,* 2000), but slightly less than some earlier estimates. Christison *et al.* (1997) reported on average a 40 min interval range 5 to 349 min, whereas

Vasdal *et al.* (2011) observed 62 min latency from birth to suckling ( range from 1 to 496 min). The behaviour of newborn pigs, as described by the time taken to first contact the udder find a teat and suckle, was only slightly affected by treatment. Piglets placed under the lamp and subsequently onto the udder tended to have a longer delay than unassisted piglets to then find a teat and suckle, although the latency to suckle from the time of birth was not affected by treatment. Even though these results differ from some published studies (Andersen *et al.*, 2011), they are consistent with those of Christison *et al.* (1997) who did not find an effect of drying piglets and placing them in the creep area on time to first suckle. Vasdal *et al.* (2010) noticed that dried piglet had a lower mortality, but when comparing unassisted piglets with those dried and placed under the lamp or in front of the udder there was no difference in mortality. However she observed the highest mortality in piglets placed in front of the udder but not dried first. Once the piglets had made udder contact, the time to find a teat and suckle was shorter for offspring of first, second, third and sows with more than 6 parities than for sows of middle parities. It has been previously found that fourth parity sows lose more piglets due to starvation than younger sows, but there was no relationship between sow parity and number of surviving piglets (Andersen *et al.*, 2011). Vasdal and Andersen (2012) stated that piglets born from older sows had less access to a functional teat, but this result was not totally confirmed in our experiment. It could be argued that in our study the majority of the sows had less than six parities, whereas in the Vasdal and Andersen (2012) study the number of sows with high parity number was greater. Piglets born from sows that did not have an induced farrowing, or which had a very large number of stillborn offspring had a longer delay to find a teat after birth. The reason for this is not clear, although litters with many stillborn may have related health or prolonged farrowing problems. More research on this topic needs to be undertaken before the association between sow characteristics and piglet teat-seeking behaviour is more clearly understood.

Piglet birth order affected the time delay from birth to first suckling. The later born piglets found a teat more quickly than the early born ones. This result is in agreement with Tuchscherer *et al.* (2000), although Rohde and Gonyou (1988) did not find a consistent effect of birth order on time to suckle. However Vasdal *et al.* (2011) observed that latency to first suckle was shorter where there were few piglets per teat and generally it is thought that early piglets have an advantage over late born piglets to find a teat and suckle (Fraser and Rushen, 1992). However, in this study results showed the contrary and it is possible that later piglets benefitted by cues left by earlier born piglets, since they often suckled first from a previously used teat. This discrepancy could be also attributed to the small number of litters in which more than seven piglets were observed, due to observer availability, since the later piglets in these litters would have experienced much greater competition at the udder. Birth weight did not affect time to suckle a teat after birth or once piglets had made udder contact; our result is in agreement with Rohde Parfet and Gonyou (1988) and Christison *et al.* (1997), but in contrast with Vasdal I (2011), Baxter *et al.* (2008; 2009) and Tuchscherer *et al.* (2000). These latter authors found that higher weight piglets had a shorter latency to find a teat and suckle. Piglet vitality score also did not affect time to find a teat and suckle. Again, our results are in agreement with Christison *et al.* (1997), who reported that the vigour of piglets did not affect suckling time, but are in disagreement with the results of Baxter *et al.* (2008). There was a tendency for piglets born in bigger size litters to have delayed teat success once they made the first contact with the udder. Tuchscherer *et al.* (2000) observed as well an increased latency in big litter sizes.

Overall the inconsistency of some results of this study with previous findings suggests that, although suckling itself is clearly an instinctive behaviour, acquisition of colostrum depends on many variables, related not only to piglet characteristics but to sow behavioural and morphological characteristics as well. Future studies on the effects of sow characteristics are therefore recommended.

## 5.6 Conclusion

Taken together, the results of this experiment indicate that: (1) piglets most often first suckle teats located in the upper row in the anterior and posterior part of the udder. (2) Piglet born later spend less time finding a teat and suckle than piglet born first. However birth order affect also the latency from the first udder contact to locate a teat and suckle but not in a consistent way. (3) Teat seeking and suckling time was not influenced by piglet vitality at birth, weight, or provision of human assistance such as drying and facilitating the teat seeking process by placing them in front of the udder. Though there was a negative tendency of assistance on TUS but not TBS. (4) Preferred teat location affect the time to find a teat and suckle, posterior and anterior teat were suckled earlier than middle teats. (5) Piglets from multiparous sows and from sows with induced farrowing spend less time seeking for a teat. We tested the main factors that could affect teat-seeking behaviour at farrowing and the results showed that this complex behaviour is not related only to piglets birth characteristics. The delay to find and suckle a teat is shorter when the teats are located in the posterior or anterior part of the udder, where teats have small size, are more distant from each other and are located closer to the abdominal mid-line. This evidence leads to the conclusion that the morphology of the udder influences the success in quickly finding a teat and suckling, thus achieving early colostrum intake. Further study should focus on improving udder morphology in order to increase piglet survival.

# Chapter 6. Evaluation of an on-farm method to assess colostrum IgG content in sows

## 6.1 Summary

The objective of this work was to investigate the evaluation of swine colostrum immunoglobulin G (IgG) concentration using the Brix refractometer. Colostrum samples were collected across all teats, from 124 sows of mixed parities. According to sampling time, three categories were created: samples available from nine hours before the onset of parturition until the first piglet was born were classified as before farrowing; samples collected after the first birth until four hours later were classified as during farrowing; and finally samples collected from this point until 14 hours after parturition, were classified as after farrowing. Samples were drawn and divided into three portions; one was immediately analyzed, a second was refrigerated and the third was frozen at -20 ºC. Fresh and refrigerated colostrum samples were analyzed at the farm with a Brix refractometer. IgG content of frozen samples was analyzed using a Brix refractometer, with a subset of 42 samples also tested with a commercially available Radial Immune Diffusion (RID) kit. The Brix percentage ranged from 18.3% to 33.2%. Brix percentage repeatability, assessed by the intraclass correlation coefficient (ICC), was very strong (fresh ICC = 0.98, refrigerated ICC = 0.88, and frozen ICC = 0.99). One-way repeated-measures ANOVA showed that storage temperature did not affect BRIX percentage of colostrum IgG ($P > 0.05$). ANOVA results show a significant effect of sampling time on colostrum immunoglobulin concentration, measured with both Brix and RID (Brix: $P < 0.003$; RID: $P < 0.05$). Immunoglobulin G concentration measured by RID ranged from 13.27 to 35.08 mg/mL. Pearson correlation coefficient revealed that Brix percentage was positively correlated ($r = 0.56$, $P < 0.001$) with RID results (regression equation: RID = 1.01 (± 0.2) Brix - 1.94 (± 5.66); $R^2 = 0.31$). The results of this study indicate that the Brix refractometer provides a simple, fast, and inexpensive estimation of colostrum IgG in sows.

## 6.2 Introduction

Early and sufficient intake of good quality colostrum is essential for the health and growth of the piglet (Quesnel *et al.*, 2012). Because colostrum yield and composition vary widely among animals, it is of fundamental importance to investigate, on a large scale, the factors affecting composition. This knowledge is needed to ensure an adequate intake of quality colostrum by piglets as quickly as possible after birth, and hence reduce pre-weaning piglet mortality and lifetime risk of disease. Moreover, early postnatal management of piglets is becoming an increasing priority (Boulot, 2009). In this regard, an on-farm method for detecting colostrum IgG concentration is of primary importance to piglet welfare, health, and farm economics. The methods that have been commonly used for the determination of IgG concentration in swine colostrum are the enzyme-linked immunosorbent assay (ELISA) and the gold standard radial immunodiffusion method (RID), both not suitable for on-farm use. In other species, evaluation of colostrum IgG in the farm is a practise used to reduce failed transfer of passive immunity. For this purpose, the most recent method used to evaluate colostrum quality in sheep (Harker, 1978), horses (Chavatte *et al.*, 1998; Cash, 1999) and dairy cattle (Morrill *et al.*, 2012; Quigley *et al.*, 2013; Bartier *et al.*, 2015) is the Brix refractometer. Brix is a rapid, accurate, and inexpensive method, based on the ability of protein to refract light as a measure of total protein in colostrum (Chavatte *et al.*, 1998). To our knowledge, such on-farm tests have not yet been validated for swine colostrum. The aim of this research was therefore to establish if the Brix refractometer could be adopted also for swine. The hypothesis tested was that refraction grade in colostrum allows a meaningful estimation of swine IgG concentration as shown in several other species.

## 6.3 Materials and Methods

### *6.3.1 Animals*

The experiment was conducted at Cockle Park Farm, Newcastle University, Newcastle upon Tyne, UK, and was approved by the Animal Welfare and Ethics Review Body at the University. Colostrum samples were collected from 12 farrowing batches between November 2012 and April 2014. In total samples were collected from 124 sows of different parities (19 sows in each of parities one, three, and four; 24 sows parity two; 18 sows parity five; 13 sows parity six; 3 sows parity seven; 5 sows parity eight; 1 sow each in parity nine, ten, eleven, and twelve. Considering that there were few sows with more than six parities, a group of 12 sows with more than six parities was created). In accordance with normal commercial farm procedures, animals were moved from the group gestation house to the farrowing unit at 110 days post-insemination, where they were kept in individual crates equipped with a feeder and drinker. Ambient temperature averaged 21 ºC. Sows were allowed to farrow normally at term over a 4-day period (Monday to Thursday); sows that had not farrowed within this period were then induced by injection of a prostaglandin analogue on Thursday.

### *6.3.2 Data Collection*

Samples of colostrum were collected when available around parturition, without the use of oxytocin. According to sampling time, three categories were created.   defined a pre-farrowing phase when colostrum could be easily expressed manually from the teats; on average this was from 8 h before the onset of parturition. That study showed that IgG concentration was high before farrowing and decreased rapidly thereafter. Based on this finding, samples available before the onset of parturition until the first piglet was born were classified as before farrowing; samples collected after the first birth until 4 h later were classified as during farrowing; and finally samples collected from this point until manual expression was no longer possible, were classified as after farrowing. The operator quietly approached the sow and obtained a sample by using hand pressure, exerted approximately in the centre of the mammary gland; this system seemed to aid in making the colostrum flow more freely (Edwards, 2002). A 15 mL sample of colostrum was collected by sampling from all the teats located in the upper row and, when possible without disturbing the sow, also from the teats in the lower row of the udder. The sample was collected in a sterile pot (30mL Polystyrene Universal Container, Starlab) labelled with identity of the sow, sampling time, and date.  After the samples were drawn they were immediately divided into three aliquots; one was immediately analyzed (fresh colostrum at room temperature), the second was refrigerated at 4ºC for 24, 48 or 72 h before being analyzed and the third sample was frozen and stored at -20ºC until further analysis.

### *6.3.3 Colostrum Sample Analyses*

The Brix refractometer (MA871 digital, Obione), was calibrated with distilled water before each set of analyses. A drop of well mixed whole colostrum was placed on a Brix refractometer prism and the Brix percentage (%) was recorded. Storage temperature effects were assessed on 65 colostrum subsamples, for which fresh, refrigerated, and frozen samples were analyzed in turn by Brix refractometer. Each sample was analyzed on two consecutive occasions each time to determine repeatability of results. The sampling time effect on IgG concentration was tested on 124 frozen colostrum samples, and analyzed by Brix refractometer. The correlation between RID and Brix percentage was assessed on a subset of 42 frozen colostrum samples. Samples selected were thawed in a warm water bath and thoroughly mixed before RID analysis. Five microliters of mixed colostrum solution was added to each well of a swine IgG RID test plate (Triple J Farms, Bellingham) in duplicate. Radial immunodiffusion plates were incubated for 24 h and the diameter of the precipitin ring was measured and compared with a standard curve created by the internal test standards, to determine IgG concentration.

### *6.3.4 Statistical Analyses*

Prior to statistical analysis, all data were checked for statistical outlier values. No data were excluded for this reason. Descriptive statistics were performed, and data are reported as arithmetic mean and standard deviation (mean ± SD). Normality was assessed by application of the Shapiro-Wilk test. Brix percentage repeatability was assessed with the intra-class correlation coefficient. Data are considered highly reproducible when ICC > 0.8 (Wolak *et al.*, 2012). The storage temperature and length effect on colostrum IgG were analyzed using one-way repeated-measures ANOVA. – Three-way ANOVA was used to investigate the effect on Brix percentage of fresh samples of colostrum sampling time category (three levels), sow parity number (seven levels) and farrowing induction (two levels). Where significant differences were found, a Tukey test was applied as a *post-hoc* tests between multiple means. The Pearson correlation coefficient was calculated to determine the association between Brix and RID results, and a regression equation was produced. The level of significance was taken as $P < 0.05$. The statistical software R version 3.0.2 (2013-09-25) was used for all tests.

## 6.4 Results

### *6.4.1 Descriptive statistics*

Descriptive statistics of colostrum measurements are summarised in Table 1. Colostrum was collected around parturition: 31% of the samples were collected before farrowing (maximum nine h before); 41% during farrowing (from the first piglet born until four h later), and 27% after farrowing (from four h after the first piglet born, until maximum 14 h later). Only three sows did not fully expose at least one row of teats; thereby colostrum was collected from exposed teats. Twenty six percent of the animals showed only one row, 16% showed both rows but only the anterior teats of the lower row; and 54% showed completely all the mammary glands. Only 20% (N = 29) of the sows farrowed over the first four days after entry to the farrowing crates; 79% (N = 95) of the animals were then induced by injection of a prostaglandin analogue.

Brix percentage for fresh colostrum ranged from 18.3 to 33.0%, with a mean of 24.1% and SD 2.65 (Table 6.1). Shapiro-Wilkinson normality test displayed a normal distribution for Brix percentage of the full set of 124 samples (Shapiro- Wilkinson P > 0.05). Radial Immune Diffusion IgG concentration of the subset of 42 samples used for comparison had a normal distribution (Shapiro- Wilkinson P > 0.05), which ranged from 13.3 mg/mL to 35.0 mg/mL. The mean and SEM of RID of the 42 samples were: 22.49 mg/mL ± 0.84.

Table 6. 1 Descriptive statistics of 124 colostrum samples measured at different sampling times in relation to farrowing using a Brix refractometer, and of a subset of 42 samples measured by radial immunodiffusion (RID).

| *Value* | N | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| Brix fresh (%) | 124 | 24.1 | 2.65 | 18.3 | 33.0 |
| Sampling time: | | | | | |
| Before[a] (h) | 38 | -03:17:48 | 02:36:25 | -00:11:00 | -09:00:00 |
| During[b] (h) | 49 | 00:56:20 | 00:59:22 | 00:00:00 | 03:22:00 |
| After[c] (h) | 37 | 09:49:26 | 03:34:07 | 04:02:00 | 14:30:00 |
| RID (mg/mL) | 42 | 22.4 | 5.43 | 13.3 | 35.0 |

[a] Sampling time before farrowing. [b] Sampling time during farrowing. [c] Sampling time after farrowing.

### *6.4.2 Repeatability, storage temperature and storage time effect*

Repeatability of Brix percentage was assessed in a subset of 64 samples for fresh and refrigerated storage temperature and duration; due to shipping loss only 51 frozen samples were used. Brix percentage was highly reproducible for fresh (ICC = 0.98), refrigerated (ICC = 0.88), and frozen (ICC = 0.99) samples. One-way repeated measure ANOVA test results showed no significant differences (P > 0.05) in mean Brix percentage for different refrigeration lengths (24 h, 48 h, and 72 h). Since no significant difference was found between refrigeration lengths, only the Brix percentage values at 24 hours were used to compare the different storage temperatures. A one-way repeated measures ANOVA test was used to assess if there were differences between storage temperatures, There were no differences between fresh samples and those stored at refrigerated temperature or frozen ($P > 0.5$).

### *6.4.3 Sampling time, parity, and farrowing induction effect*

ANOVA results show a significant effect of sampling time on colostrum immunoglobulin concentration, measured with both Brix (N = 124: 38 samples were collected before farrowing; 49 during farrowing; and 37 after farrowing) and RID (N = 42: 13 samples were collected before farrowing; 18 during farrowing; and 11 after farrowing). The Tukey *post hoc* tests revealed that samples collected after farrowing had lower IgG content than before and during farrowing (Brix: $F_{2,103} = 6.04$, $P < 0.003$; RID: $F_{2,32} = 2.86$, $P < 0.05$). Figure 1 presents the result of correlation analysis between fresh and refrigerated colostrum samples for IgG concentration measured with Brix percentage, and also shows the sampling time effect on this measure. There was no effect of sow parity number on IgG concentration (Brix: $F_{6,103} = 1.00$, $P = 0.42$; RID: $F_{6,32} = 0.47$, $P = 0.82$); Furthermore, Brix percentage were not significantly different between sows which were induced and animals that farrowed naturally (Brix: $F_{1,103} = 0.51$, $P = 0.47$; RID: $F_{1,32} = 0.\ 31$, $P = 0.57$).

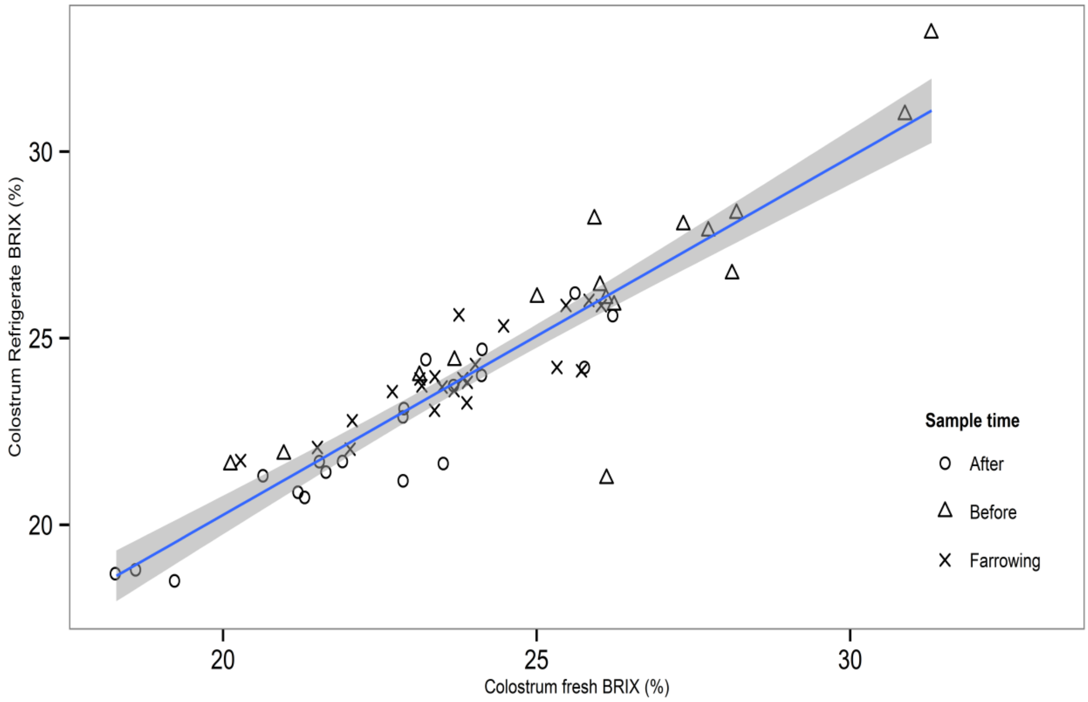


Figure 6. 1. Regression line of Brix refractometer (%) values of fresh and refrigerated samples taken at different sampling times (samptime) (r = 0.86, P < 0.05), also illustrating the effects of different sampling time ($F_{2,110}$ = ; P < 0.001) (After= after farrowing, Before= before farrowing, Farrowing= during farrowing). The grey area represents the confidence interval of the mean.

### *6.4.4 Relationship between Brix and RID values*

Pearson correlation coefficient results showed a significant association between the Brix and RID values (r = 0. 56; P < 0.001, Fig. 2). Further analysis of the data gave the following regression equation: RID = 1.01(±0.2) Brix + 1.94 (±5.66);($R^2$ = 0.31, P < 0.001).

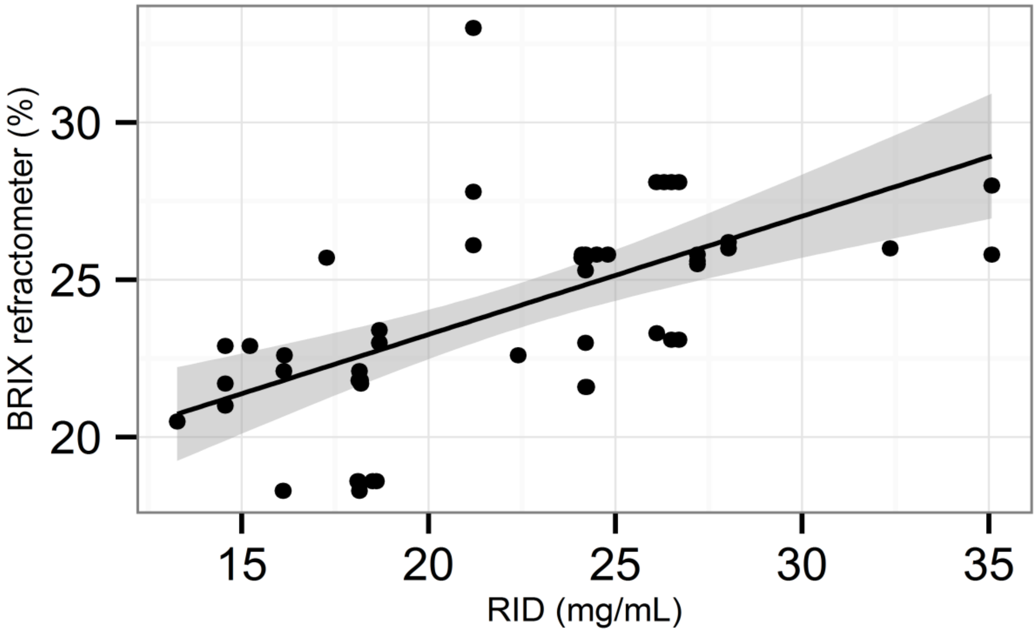


Figure 6. 2. Regression plot between radial immunodiffusion (RID) immunoglobulin G (IgG) concentration and Refractometer Brix (%) of 42 colostrum samples (Regression equation: RID = 1.01(±0.2) Brix + 1.94(±5.6); $R^2 = 0.31$, $P < 0.001$). The grey area represents the confidence interval of the mean.

### 6.5 Discussion

The Brix refractometer was evaluated as an on-farm methodology to assess colostrum IgG concentration in swine. Refractometry measures the concentration of any solution of dissolved solids, based on the degree to which the light rays are bent. Brix refractometer estimates colostrum IgG by reporting a Brix percentage (measure of refractive index), which can then be correlated with colostrum IgG concentration. Porter (1969) and Curtis (1970) quantified the immunoglobulin in sow colostrum during farrowing, they noted that 80% of the proteins in sow colostrum were immunoglobulin. Klobasa *et al.* (1987) further investigated the composition of colostrum throughout farrowing and showed that immunoglobulin concentration changed rapidly after the first piglet was born (initially 95.6 mg of IgG/mL, 21.2 mg of IgA/mL and 9.1 mg of IgM/mL) and decreased by half in the first 12 h postpartum (to 32.1 mg of IgG/mL, 10.1 mg of IgA/mL and 4.2 mg of IgM/mL ). This rapid fall has also been reported by others (Klobasa *et al.*, 1987; Bland *et al.*, 2003).

The results of our current study show a significant correlation between the digital Brix instrument and the RID determination, however RID values in this study seem to be lower than previous investigations (Klobasa *et al.*, 1987; Machadoneto *et al.*, 1987; Cabrera *et al.*, 2012). These discrepancies may be due to a different sample preparation; as unfiltered whole colostrum was used in the present study in contrast to previous reports. Furthermore, the RID assay for IgG in the colostrum kit used provides standards that derive from serum IgG, which contains a different ratio of $IgG_1$:$IgG_2$; this difference can cause erroneous quantification (Gapper *et al.*, 2007). Moreover Ig concentration at parturition seems to vary from one study to another, independently of the analytical methods used. Colostrum yield and composition vary among animals depending on many factors including parity, breed, season, udder section, vaccination, number of sows per farm (Inoue, 1981a), number of stillborn piglets (Quesnel, 2011) and farrowing induction (Foisnet *et al.*, 2011). However in this study no difference was detected between Brix percentage of sows that farrowed naturally or were induced. This is likely to be because sows in the current study were only induced if they had not farrowed naturally by day 114, and therefore all farrowing occurred close to the natural gestation length for this farm. Furthermore no difference was detected between Brix percentages of sows with different parities numbers. Although this result differs from some published studies, were it was found that multiparous sows had higher IgG concentration than gilts (Inoue, 1981a; Klobasa *et al.*,1987; Quesnel 2011; Cabrera *et al.*, 2012), it is consistent with the report of Devillers *et al.* (2004).

More important is that the findings of the current study are consistent with those of previous authors who evaluated the relationship of results obtained using the digital refractometer and standard laboratory methods on bovine colostrum ($R^2$ = 0.41, Chigerwe *et al.* (2008); $R^2$ = 0.53, Bielmann *et al.* (2010); $R^2$ = 0.56, Quigley *et al.* (2013); $R^2$ = 0.59, Bartier et al. (2015)) Our results, like the previous ones on bovine colostrum, did not show an extremely strong correlation between RID and Brix values, as has been reported in the literature for equine colostrum ($R^2$ = 0.85; Chavatte *et al.* (1998) ). Bielmann *et al.* (2010) suggested that the composition and the volume of colostrum that is produced in mares and cows could explain these differences in the results. Swine colostrum composition at farrowing contains 24–30% dry matter, 15–19% total proteins, 5–7% fat, 2–3% lactose and 0.63% ash (Klobasa *et al.*, 1987; Csapo *et al.*, 1996). Devillers et al. (2004) reported that an average volume of 3.6 L (range from 1.9 to 5.3 L) of colostrum was produced by sow, and IgG concentration in colostrum has been measured to average around 50 mg/mL (Ariza-Nieto *et al.*, 2011). Production of colostrum by cows on average was 11.2L, with a mean composition of fat 6.7%, total solids 27.6%, and total protein 14.9%, and contains 30 to 96 mg/mL of IgG (Morin *et al.*, 2001). In mares colostrum volume was 5.1L, with a much higher IgG concentration 440 mg/mL, and with 24.3% total solids, and 26.3% fat (Csapo *et al.*, 1995). Comparing these compositions, one possible explanation for the weaker relationship between Brix value and IgG content in swine and cows is that IgG represents a smaller proportion of total solids. Fat and casein concentration may affect the refractometer reader (Bielmann *et al.*, 2010), and therefore the correlation could be influenced by differences in these components of colostrum composition, which have been well demonstrated to vary a lot between sows (Inoue, 1981b) as well as in cows (Morin *et al.*, 2001)

The effect of storage temperature on colostrum IgG assessment using the Brix refractometer was evaluated and Brix percentages were the same for samples which were fresh, refrigerated or frozen. Similar results were obtained in previous studies to validate the digital refractometer to estimate bovine and equine colostrum IgG (Chavatte *et al.*, 1998; Bielmann *et al.*, 2010). Morrill *et al.* (2015) showed that there was no effect of storage temperature of cow colostrum on Brix percentages. Furthermore, they demonstrated that one freeze- thaw cycle (after 7 days) did not affect IgG content, measured by RID, and that a difference in colostrum IgG between stored samples was detected only after two freeze- thaw cycles. We also assessed the effect of length of refrigeration period to determine the consistency of measurement of IgG in colostrum refrigerated for more than 24 hours. The results suggest that the methodology is robust to procedural variations on farm.

The mean value for IgG after four hours from the onset of farrowing was significantly lower than in colostrum samples taken before and at farrowing. These results match those reported by Bourne (1969) and Klobasa et al. (1987), who reported that colostrum Ig concentration at birth (in mg/mL) decreased from 95.6 at the beginning of lactation to 64.8 after 6 h, and to 32.1 after 12 h.

Based on the literature, at present ELISA is the analytical method most commonly used to measure swine colostrum IgG concentration. However this analysis requires specific laboratory equipment, the kit cost is very high, it needs expertise to run the test and the results are not immediate. The RID test, in comparison with ELISA, requires less experience but it remains a laboratory analysis, which is expensive and time consuming. These results indicate that the Brix refractometer can be a useful on-farm tool and can cheaply generate large scale data, with important implications for improved selection of sows with better maternal characteristics.

Future research will investigate whether it could be also possible to assess failed transfer of passive immunity by measuring the piglet serum IgG with the refractometer, as has been done in calves (Chigerwe and Hagey, 2014) and cows (Morrill *et al.*, 2013).

## 6.6 Conclusion

In accordance with the hypothesis for the work, the results indicate that the Brix refractometer can be used as an on-farm method to assess IgG concentration in swine colostrum, with a positive correlation between Brix percentage and the gold standard RID values. The Brix refractometer results in this investigation demonstrate that the method is highly repeatable and that storage temperature and duration do not affect the IgG assessment. Colostrum concentration changed by four hours after the birth of the first piglet, and so sampling time needs to be taken into account as IgG concentration decreased significantly. The Brix refractometer is durable and affordable, expertise is not necessary and the calibration process is simple, making it a very practical farm tool. Because sow colostrum IgG is not yet well estimated, the refractometer can be used to investigate the variation in colostrum produced under field conditions, reducing cost and time, and facilitating research requiring a large sample size. Moreover, incorporating the use of a refractometer into colostrum management on farm, will allow farmers to feed weak piglets with good quality colostrum, improving welfare and economy by reducing piglet mortality.

# Chapter 7. Heritability of udder morphology and colostrum quality traits in swine

## 7.1 Summary

The heritability of udder quality traits, defined as morphological traits and colostrum Immunoglobulin G concentration, was estimated together with the genetic and phenotypic correlation of these traits with other production and reproduction criteria. Udder morphology traits were record in 988 sows and colostrum samples were collected from 528sows. Teat length (len), diameter (dia), inter-teat distance within the same row (samer), and teat distance from the abdominal mid line (aml) were recorded to the nearest millimetre with a ruler and a calliper (dia). For each sow, a record was also made of udder development score (dev), the proportion of teats not oriented perpendicular to the udder (OR) and the proportion of non-functional teats (NoFun). Immunoglobulin G concentration (COL) in colostrum was estimated with the Brix refractometer. Reproductive traits investigated were gestation length (GLEN), total number of piglets born (TB), number of live-born (NBA), and number of stillborn (STB), birth weight (LW0), litter size and weight at ten days (LS10 – LW10), number of liveborn piglets which were dead before ten days (LiveD). Production traits investigated were average daily gain (ADG) during a rearing test period and back fat thickness (BFAT) at the end of test period. Heritability of udder morphology traits varied from high (len: $h^2 = 0.46$; dia $h^2 = 0.56$) to moderate (samer $h^2 = 0.37$; COL $h^2 = 0.35$; aml $h^2 = 0.22$; dev $h^2 = 0.25$; NoFun $h^2 = 0.3$ and OR $h^2 = 0.1$). Genotypic ($r_g$) and phenotypic ($r_p$) correlations between udder quality traits were high between teat dimensions (len and dia, $r_g = 0.55$, $r_p = 0.62$), dia was high correlated also with udder size (samer $r_g = 052$, $r_p = 0.34$; aml $r_g = 0.25$, $r_p = 0.23$ and dev $r_g = 0.31$, $r_p = 0.29$). Udder dimensions aml and samer were also correlated ($r_g = 0.54$, $r_p = 0.22$). Colostrum IgG was genetically correlated with samer ($r_g = 0.54$). A negative phenotypic correlation was found only between total number of teats (TT) and samer ($r_p = - 0.48$); and a low but significant correlation with teat dimensions (len $r_p = - 0.07$ and dia $r_p = - 0.11$). The inter teat distance within the same row was negatively genetically correlated with the number of stillborn piglets ($r_g = -0.48$), and positively with the NBA ($r_g = 0.69$). The distance from the abdominal midline was negatively genetically correlated with NBA ($r_g = - 0.40$) and positively with stillborn ($r_g = 0.40$). Phenotypic correlation was also positive between the latter udder trait and LW0 ($r_p = 0.11$, $r_p = 0.17$).

Colostrum and dev were positively phenotypically correlated with LW0 ($r_p = 0.08$, $r_p = 0.09$). Phenotypic correlation between udder size and NBA was positive for both traits (samer $r_p = 0.14$; aml $r_p = 0.12$). The highest genetic correlation with productive traits was estimated between aml and ADG ($r_g$: 0.42), although this had a negative phenotypic correlation ($r_p = - 0.13$). Teat length was also moderately correlated with ADG ($r_g = 0.28$). Back fat thickness was positively correlated with dia and TT ($r_g = 0.2$; $r_g = 0.36$), and negatively only with dev ($r_g = - 0.22$). The same result were found for the phenotypic correlation between BFAT and dev and TT ($r_p = - 0.09$; $r_p = 0.10$). Udder quality traits should be included in the breeding goal and weighted appropriately with other important traits in the breeding objectives to enhance optimal genetic progress.

## 7.2 Introduction

Mammalian neonates' survival and growth is highly dependent on maternal care during the first day of life. Domestic pigs produce large litters and small young (Fraser and Thompson, 1991) with limited energy resources available at birth (Herpin *et al.*, 1996). Piglet survival is strongly influenced by sow behaviour (Canario *et al.*, 2014). Furthermore, the sow's udder plays a very important role, as colostrum and milk are the main source of energy and passive immune protection for piglets and access to an early and plentiful supply of these are therefore essential for their growth and health. The sow's udder usually has from 13 to 17 mammary glands with, on average, 15 functional teats (Vasdal *et al.*, 2011). In the young gilts, it is possible find teats which are less functional than others as they can be inverted, small or supernumery and these types of teat are not suitable for suckling (Chalkias *et al.*, 2013). However she found that most inverted teats became normal during farrowing. The past thirty years have seen increasingly rapid advances in the field of swine genetic selection for efficient feed conversion, high growth rate, carcass leanness and sow prolificacy. Unfortunately, these traits often have unfavourable genetic correlations with piglet mortality around farrowing (Canario *et al.*, 2007; Tribout *et al.*, 2010) and sow behaviour modification, with negative repercussions for their own and their offspring welfare (Rauw *et al.*, 1998; Rauw, 2007; Canario *et al.*, 2012; Canario *et al.*, 2014). Rydhmer (2000) reviewed sow selection criteria and stated that the present genetic increase in number of piglets born must be accompanied by improvements in sow maternal ability traits in order to increase overall production and satisfy welfare requirements. Traits considered beneficial for production and welfare are often similar across livestock sectors, although the most valuable traits vary depending on the intended use of the animal and the species in question. It has been established that some udder characteristics in dairy cattle are controlled by both genetic and environmental factors (Hickman, 1964). Moreover, interest has increased in udder traits in sheep (Marie-Etancelin *et al.*, 2005; Casu *et al.*, 2006) to consider functional traits such as milk-ability. In pig production, udder morphology has not received the same attention, despite its fundamental role in nursing piglets. To date, only teat number (Pumfrey *et al.*, 1980; Toro *et al.*, 1986; McKay and Rahnefeld, 1990; Ligonesche *et al.*, 1995; Hirooka *et al.*, 2001; Ding *et al.*, 2009) and teat functionality (Chalkias *et al.*, 2013) are traits included in swine breeding programs. Although some research has been carried out on sow maternal ability traits (Grandinson *et al.*, 2003; Vangen *et al.*, 2005; Gaede *et al.*, 2008), no study exists which investigates the heritability of udder morphology. Moreover, the way that these traits relate to important traits for production (e.g. growth rate, backfat thickness etc.) and reproduction (e.g. gestation length, litter size etc.) have never been included in genetic evaluations. The objective of this work was therefore to estimate the heritability of udder morphology traits, colostrum quality and their correlation with other production and reproduction traits.

## 7.3 Material and methods

### *7.3.1 Animals*

The study was approved by the Newcastle University Animal Welfare and Ethical Review Body and was carried out at the ACMC breeding company (Beeford, UK) from July 2014 to February 2015. The study population consisted of 988 Meidam (MDM; cross breed Large White X Meishan) sows. Animals were moved from the group gestation house to the farrowing unit at 110 days post-insemination, where they were kept in individual crates equipped with a feeder and drinker. Ambient temperature in farrowing rooms averaged 21$^{o}$C. No specific interventions were applied in the study; feed, environment and management were maintained as standard commercial practice.

### *7.3.2 Udder Traits*

The total number of teat present in both rows (TT), teat length (len), diameter (dia), inter-teat distance within the same row (samer), and teat distance from the abdominal mid line (aml) were recorded with a ruler and a calliper (dia) and were taken to the nearest millimetre (Table 1). The methodology used for measuring morphological parameters was that described by Balzani *et al.* (2015 a,c). For each sow, a record was also made of udder development score (dev score from 1 to 3, where 1 was defined as udder is not developed and mammary glands are not defined, 2 as udder is well developed but the mammary glands are not clearly distinct, and 3 as udder is well developed and mammary glands are clearly distinct), of the proportion of teats not oriented perpendicular to the udder (OR score 0 or 1, where 0 was defined as teat not orientated perpendicular to the mammary gland and 1 was defined as teat orientated perpendicular to the mammary gland), and of the proportion of non-functional teats (NoFun score 0 as a non-functional teat with the milk channel not working, including teats which were blind: teats that were injured early in the life of the pig, and remain as a small protuberance; inverted: the top of the teat, or even the entire teat, is inverted to form a crater; very damaged: teat injured were milk ejection is not possible; or supernumerary: small teats in between two normal teats. Score 1 indicated a functional teat). All these traits were recorded on one occasion per sow, at one to three days prior to farrowing, from the upper row of teats whilst the sow was in a lying down posture.

### *7.3.3 Litter Traits*

A descriptive list of recorded phenotypic traits is reported in Table 1. After the last piglets were born, litter weight was recorded (LW0) excluding the stillborn. Litter size at birth was recorded for the total number of piglets born (TB), the number which were born alive (NBA) and stillborn (STB). Cross-fostering was permitted during the whole suckling period in order to ensure animal welfare. This practice was applied very often in all the units. During the first ten days after farrowing, the number (total number of dead piglets per nursing sow LiveD) of dead piglets in each litter was recorded. Also were recorded litter size and weight again at ten days (LS10 – LW10), corrected for fostering (plus number/weight of fostered piglet out, minus number/weight of fostered piglet in).

### *7.3.4 Sow Traits*

The observation day, sow age at current farrowing (SAF), sow parity number, and gestation length (GLEN) were recorded. Records taken from gilt test data gathered during the rearing period included average daily gain (ADG) and back fat at end of test at 100 kg (BFAT). A full list of trait descriptions is reported in Table 7.1.

### *7.3.5 Colostrum Sample Collection*

Samples of colostrum were collected when available around parturition, without the use of oxytocin. The operator quietly approached the sow and obtained a sample by using hand pressure, exerted approximately in the centre of the mammary gland; this system seemed to aid in making the colostrum flow more freely (Fraser *et al.*, 1984). A 15 ml sample of colostrum was collected by sampling from all the teats located in the upper row and, when possible without disturbing the sow, also from the teats in the lower row of the udder. The sample was collected and stored in a sterile pot (30ml Polystyrene Universal Container, Starlab, Milton Keynes, UK) labelled with identity of the sow, sampling time, and date.  After the samples were drawn they were frozen and stored at -20ºC until further analysis.

### *7.3.6 Colostrum Sample Analyses*

The Brix refractometer (MA871 digital, Obione, La Valette, France), was used to estimate colostrum IgG content (COL) as described in Balzani *et al.* (2015b). Briefly, at the start of each set of analyses it was calibrated with distilled water before proceeding with the sample analysis. A drop of well mixed whole colostrum was then placed on a refractometer prism and the Brix score (%) was recorded.

Table 7. 1 Description of reproduction, production, udder morphology and colostrum quality traits recorded.

| Trait | Description |
|---|---|
| *Reproduction* | |
| SAF | Sow age at current farrowing (days) |
| GLEN | sow gestation length (days) |
| NBA | number of piglets born alive |
| LW0 | litter weight at birth excluding stillborn (Kg) |
| TB | total number of piglets born |
| LS10 | litter size at ten days after farrowing |
| LW10 | litter weight at 10 d after farrowing corrected for fostering weight (Kg) + weight of fostered piglet out - weight of fostered piglet in. |
| LiveD | total number of piglets born alive which died during the first 10 d of age |
| STB | number of stillborn piglets |
| *Udder morphology* | |
| COL | Estimated colostrum IgG concentration (Brix percentage) |
| samer (SD) | average inter-teat distance within the same row (mm) (Standard deviation) |
| len (SD) | average teat length (mm) (Standard deviation value of teat length) |
| dia (SD) | average teat diameter (mm) (Standard deviation value of teat diameter) |
| aml (SD) | average teat distance from the abdominal-midline (mm) (Standard deviation value of teat distance from the abdominal-midline) |
| OR | proportion of teats orientated perpendicular to the udder |
| NoFun | proportion of non-functional teats |
| TT | total number of teats |
| dev | udder development score (1: not developed; to 3: fully developed) |
| *Production* | |
| ADG | avarage daily gain (g) |
| BFAT | back fat thickness at end of test (mm $P_2$) |

### *7.3.7 Statistical Analyses*

Phenotypic correlations between udder morphology traits were calculated. The Pearson correlation coefficient was used and traits were calculated as the arithmetic mean of the entire udder for each animal. Phenotypic correlations was also estimated between udder quality traits and sow productive (ADG, BFAT) and reproductive traits (GLEN, NBA, TB, LW0, LS10, LW10, LIVED, STB). The statistical software R version 3.0.2 (2013-09-25) was used. Genetic analysis of heritability of udder traits and genetic correlations with productive and reproductive traits were estimated for the same traits as the phenotypic analyses, but in this case LW0 was not included.

For genetic analysis, udder morphology measurements and reproductive traits were adjusted for parity number and batch, year, month effect of the day of the observation (BYM-OD). Productive traits were adjusted for batch, year, month effect of the day of the performance test (BYM-TEST). Sow was included as a random effect in the analyses. The genetic parameters were estimated using single-trait animal models in VCE and PEST. Variance and covariance estimates obtained from these analyses were used to estimate heritability estimates and genetic correlations between traits. The mixed model equation used, was as follows:

$$Y = \mu + \text{BSM-OD} + \text{BSMP-TEST} + a + e$$

where, Y is the vector of observations for sow udder morphology traits, $\mu$ is the overall mean, BSM-OD is the fixed effect of batch, year, month of the day of the observation, BSM_TEST is the fixed effect of batch, year, month of the day of the performance test, and the vectors of random effects consisted of random animal additive genetic (a) and residual (e) effects.

## 7.4 Results

### *7.4.1 Descriptive statistics*

Descriptive statistics of udder morphology, reproductive and productive traits of the sows are shown in Table 7.2. Data were collected from 10 farrowing batches; in total 988 sows of different parities (230 sows in parity one, 196 sows parity two, 141 sows parity three, 170 sows parity four, 68 sows parity five, 70 sows parity six, 113 sows with more than six parities: parity seven, eight, nine and ten) were observed in three units (321 sows at unit B, 339 sows at unit F and 327 sows at unit U). For female reproduction traits, the heritability estimates were quite low (0.03 - 0.1), whereas heritability estimates for productive traits were moderate. Heritability estimates for udder morphological traits were moderate to high (Table 7.2). Stillborn distribution is discrete (566 had not stillborn piglets; 198 sows had only one stillborn; 128 sows had two; 56 sows had three; 24 sows had four; 12 sows had five and only three sows had more than six stillborn piglets). Sixty four percent of the sows had all teat oriented perpendicular to the mammary gland and 57%of the sows had all functional teats.

Table 7. 2. Descriptive statistics of sow morphological, reproduction and production traits together with corresponding heritability estimates.

| Traits | N | Mean | SD | Min | Max | $h^2$ ± SE |
|---|---|---|---|---|---|---|
| *Reproduction*[1] | | | | | | |
| SAF | 988 | 738.6 | 338.87 | 315.0 | 1794.0 | - |
| GLEN | 988 | 115.5 | 1.55 | 110 | 125 | 0.01 ± 0.01 |
| NBA | 988 | 11.7 | 3.11 | 1.0 | 21.0 | 0.06 ± 0.04 |
| TB0 | 988 | 12.5 | 3.16 | 1.0 | 21.0 | 0.06 ± 0.04 |
| LW0 | 988 | 16.7 | 4.42 | 0.87 | 28.96 | 0.11 ± 0.03 |
| LS10 | 715 | 10.9 | 1.68 | 4.0 | 16.0 | 0.05 ± 0.03 |
| LW10 | 607 | 21.49 | 8.84 | 0.0 | 48.0 | 0.11 ± 0.04 |
| LiveD | 691 | 0.88 | 1.54 | 0.0 | 14.0 | 0.04 ± 0.02 |
| Stillborn | 987 | 0.8 | 1.21 | 0.0 | 8.0 | 0.03 ± 0.04 |
| *Udder morphology*[1] | | | | | | |
| col | 528 | 25.5 | 3.50 | 15.1 | 35.0 | 0.35 ± 0.07 |
| samer | 987 | 104.5 | 14.45 | 62.2 | 154.0 | 0.37 ± 0.06 |
| samer SD | 987 | 21.62 | 7.94 | 4.8 | 74.8 | 0.18 ± 0.03 |
| len | 986 | 16.1 | 3.00 | 7.0 | 31.3 | 0.46 ± 0.04 |
| len SD | 986 | 2.81 | 2.21 | 0.0 | 11.34 | 0.42 ± 0.1 |
| dia | 987 | 10.5 | 1.70 | 4.6 | 16.2 | 0.53 ± 0.02 |
| dia SD | 987 | 1.77 | 1.38 | 0.1 | 9.4 | 0.11 ± 0.03 |
| aml | 987 | 61.2 | 10.88 | 30.0 | 105.0 | 0.22 ± 0.04 |
| aml SD | 987 | 17 | 4.95 | 5.0 | 47.8 | 0.19 ± 0.03 |
| OR | 987 | 0.9 | 0.21 | 0.0 | 1.0 | 0.14 ± 0.03 |
| NoFun | 987 | 0.04 | 0.05 | 0.0 | 0.4 | 0.22 ± 0.05 |
| TT | 987 | 15.6 | 1.12 | 12.0 | 19.0 | 0.42 ± 0.02 |
| dev | 987 | 2.24 | 0.51 | 1.0 | 3.0 | 0.25 ± 0.04 |
| *Production*[1] | | | | | | |
| ADG | 863 | 448.5 | 169.39 | 45.9 | 755.1 | 0.53 ± 0.04 |
| BFAT | 732 | 12.1 | 3.79 | 2.3 | 32.7 | 0.51 ± 0.05 |

N = number of observations; SD = standard deviation; Min = minimum; Max = maximum; $h^2$ = heritability; SE = standard error. [1]Traits descriptions are reported in table 7.1.

### *7.4.2 Estimates of genetic and phenotypic correlations*

The estimates of genetic and phenotypic correlations between udder morphological traits are presented in Table 7.3. Almost all udder morphological traits showed medium to high genotic correlations with each other. The strongest genotic ($r_g$) and phenotypic ($r_p$) correlation was found between teat dimensions (len and dia, $r_g = 0.55$, $r_p = 0.62$), dia was highly correlated also with udder size (samer $r_g = 052$, $r_p = 0.34$; aml $r_g$: 0.25, $r_p = 0.23$ and dev $r_g = 0.31$, $r_p = 0.29$). Udder dimensions aml and samer were also highly correlated ($r_g = 0.54$, $r_p = 0.22$). Colostrum IgG was genetically correlated with samer ($r_g = 0.54$). Negative phenotypic correlation was found only between total number of teats (TT) and samer ($r_p = -0.48$); and a very low significant negative correlation also with teat dimension (len $r_p = - 0.07$ and dia $r_p = - 0.11$).

Table 7. 3 Estimated genetic (above the diagonal line) and phenotypic (below the diagonal line) correlations between udder morphology traits (standard error as subscripts). Estimates significantly different from zero are in bold.

| Morphology Traits[1] | len | dia | aml | samer | NoFun | dev | OR | TT | COL |
|---|---|---|---|---|---|---|---|---|---|
| len | | **$0.55_{0.06}$** | $-0.06_{0.06}$ | **$0.21_{0.05}$** | $-0.04_{0.11}$ | $0.04_{0.09}$ | **$-0.47_{0.09}$** | $-0.01_{0.05}$ | **$-0.16_{0.06}$** |
| dia | **0.62** | | **$0.25_{0.12}$** | **$0.52_{0.06}$** | **$-0.21_{0.09}$** | **$0.31_{0.07}$** | **$-0.21_{0.05}$** | $0.13_{0.08}$ | $0.07_{0.06}$ |
| aml | **0.13** | **0.23** | | **$0.54_{0.11}$** | **$0.68_{0.09}$** | $0.29_{0.16}$ | $0.13_{0.11}$ | $-0.08_{0.18}$ | $0.15_{0.11}$ |
| samer | **0.24** | **0.34** | **0.22** | | $-0.04_{0.1}$ | $0.12_{0.12}$ | $-0.09_{0.10}$ | **$-0.74_{0.05}$** | **$0.41_{0.06}$** |
| NoFun | **-0.06** | **-0.12** | 0.08 | 0.06 | | **$0.25_{0.1}$** | **$0.17_{0.02}$** | **$0.4_{0.06}$** | $-0.12_{0.10}$ |
| dev | **0.21** | **0.29** | **0.17** | **0.21** | -0.01 | | **$0.48_{0.1}$** | $0.07_{0.06}$ | $0.1_{0.07}$ |
| OR | **-0.22** | **-0.10** | 0.12 | -0.06 | -0.18 | 0.06 | | **$-0.42_{0.14}$** | **$-0.43_{0.11}$** |
| TT | **-0.07** | **-0.11** | 0.01 | **-0.48** | 0.01 | **-0.07** | $0.02_{0.12}$ | | $-0.17_{0.12}$ |
| COL | 0.06 | **0.09** | -0.04 | 0.04 | -0.02 | 0.07 | **-0.14** | 0.02 | |

[1] Udder morphology traits descriptions are reported in table 7.1.

The estimated genetic correlations between reproduction traits and udder morphology traits are presented in Table 7.4. Most of the estimates were not significantly different from zero. However, some significant correlation estimates were observed. The inter-teat distance within the same row showed a genetic association with almost all the considered reproductive traits. The highest correlations estimated were positive between samer and litter size at birth (0.89) and negative also between samer and STB (- 0.48)

Table 7. 4 Estimated genetic correlations between reproduction and udder morphology traits (standard error as subscripts). Estimates significantly different from zero are in bold

| | Morphology Traits[1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | len | dia | aml | samer | OR | NoFun | dev | TT | COL |
| Reproduction Traits[1] | | | | | | | | | |
| GLEN | $0.08_{0.10}$ | $0.17_{0.11}$ | $0.36_{0.28}$ | $-0.14_{0.23}$ | $-0.01_{0.11}$ | $-0.03_{0.11}$ | **$-0.36_{0.1}$** | **$0.42_{0.16}$** | **$-0.41_{0.18}$** |
| NBA | $-0.1_{0.15}$ | $0.04_{0.04}$ | **$-0.4_{0.19}$** | **$0.69_{0.08}$** | $-0.03_{0.24}$ | $0.17_{0.15}$ | $0.42_{0.34}$ | **$-0.47_{0.08}$** | **$0.54_{0.13}$** |
| TB0 | $-0.33_{0.20}$ | $-0.24_{0.21}$ | $-0.26_{0.23}$ | **$0.89_{0.13}$** | $-0.37_{0.3}$ | $-0.3_{0.22}$ | $0.13_{0.17}$ | **$-0.46_{0.08}$** | $0.55_{0.29}$ |
| LW0 | $-0.02_{0.09}$ | $0.14_{0.16}$ | **$0.69_{0.12}$** | **$0.78_{0.15}$** | $0.10_{0.08}$ | $0.09_{0.15}$ | $0.04_{0.11}$ | **$-0.7_{0.13}$** | **$0.45_{0.11}$** |
| LS10 | $-0.15_{0.1}$ | **$-0.5_{0.09}$** | **$0.22_{0.11}$** | **$0.38_{0.11}$** | $-0.15_{0.15}$ | $-0.16_{0.17}$ | **$-0.52_{0.1}$** | $-0.03_{0.11}$ | $-0.2_{0.11}$ |
| LW10 | **$0.58_{0.17}$** | **$-0.13_{0.11}$** | **$-0.56_{0.15}$** | **$-0.37_{0.13}$** | **$-0.17_{0.08}$** | **$-0.51_{0.13}$** | $0.16_{0.18}$ | $0.5_{0.24}$ | $-0.11_{0.11}$ |
| LiveD | $-0.13_{0.07}$ | **$0.45_{0.14}$** | $-0.21_{0.22}$ | **$0.87_{0.09}$** | $-0.41_{0.13}$ | $-0.07_{0.11}$ | **$0.46_{0.17}$** | **$-0.57_{0.18}$** | **$0.55_{0.17}$** |
| STB | $-0.2_{0.2}$ | $-0.27_{0.18}$ | **$0.4_{0.2}$** | **$-0.48_{0.12}$** | $-0.01_{0.27}$ | $-0.12_{0.22}$ | $0.16_{0.25}$ | **$0.52_{0.25}$** | $-0.44_{0.24}$ |

[1]Trait descriptions are reported in table 7.1.

Table 7.5 presents the estimated phenotypic correlation between udder morphology traits, colostrum quality and reproductive traits. The phenotypic correlations between udder quality traits and sow reproductive traits followed the same pattern as the genetic correlations.

Table 7. 5 Estimated phenotypic correlations between reproduction traits and udder morphology traits. Estimates significantly different from zero are in bold

| | Morphology Traits[1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | len | dia | aml | samer | OR | NoFun | dev | TT | COL |
| Reproduction Traits[1] | | | | | | | | | |
| SAF | **0.45** | **0.41** | **0.17** | **0.37** | **0.22** | 0.09 | **-0.22** | **-0.07** | 0.05 |
| NBA | 0.01 | 0.04 | **0.12** | **0.14** | 0.07 | 0.03 | 0.03 | 0.00 | **0.08** |
| TB0 | 0.03 | 0.05 | **0.11** | **0.16** | -0.03 | 0.04 | 0.03 | 0.01 | 0.05 |
| LW0 | 0.04 | **0.07** | **0.11** | **0.17** | -0.00 | 0.02 | **0.09** | -0.03 | **0.09** |
| LS10 | **-0.09** | **-0.12** | 0.05 | -0.01 | 0.03 | -0.01 | -0.04 | 0.06 | -0.01 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| LW10 | -0.04 | **-0.14** | 0.02 | -0.03 | 0.03 | -0.03 | -0.01 | 0.07 | 0.01 |
| LiveD | 0.03 | **0.13** | 0.02 | **0.09** | -0.00 | 0.04 | 0.02 | -0.05 | 0.05 |
| STB | 0.04 | 0.02 | -0.01 | 0.05 | **0.08** | -0.01 | -0.16 | 0.02 | -0.08 |

[1] Trait descriptions are reported in table 1.

The estimated genetic correlations between production traits and udder morphology traits are presented in Table 7.6. Only a few traits were significantly correlated. Table 7.7 presents the estimated phenotypic correlations between udder morphology traits, colostrum quality and productive traits.

Table 7. 6 Estimated genetic correlations between production traits and udder morphology traits (standard error as subscripts). Estimates significantly different from zero are in bold

| | Morphology Traits [1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | len | dia | aml | samer | OR | NoFun | dev | TT | COL |
| Production Traits[1] | | | | | | | | | |
| ADG | **$0.27_{0.11}$** | $0.14_{0.11}$ | **$0.42_{0.14}$** | $-0.06_{0.18}$ | $0.00_{0.01}$ | $0.01_{0.02}$ | $0.03_{0.11}$ | $-0.03_{0.06}$ | $0.26_{0.16}$ |
| BFAT | $-0.02_{0.07}$ | **$0.28_{0.08}$** | $0.15_{0.13}$ | $-0.13_{0.1}$ | $0.00_{0.02}$ | $0.01_{0.07}$ | **$-0.22_{0.06}$** | **$0.36_{0.07}$** | $0.01_{0.02}$ |

[1] Trait descriptions are reported in table 7.1.

Table 7. 7 Estimated phenotypic correlations between production traits and udder morphology traits. Estimates significantly different from zero are in bold

| | Morphology Traits [1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | len | dia | aml | samer | OR | NoFun | dev | TT | COL |
| Production Traits[1] | | | | | | | | | |
| ADG | -0.23 | **-0.24** | **-0.13** | **-0.23** | **-0.13** | **-0.08** | -0.03 | 0.02 | -0.03 |
| BFAT | **0.08** | -0.02 | -0.03 | 0.00 | **0.09** | -0.16 | **-0.09** | **0.10** | 0.07 |

[1] Trait descriptions are reported in table 7.1.

## 7.5 Discussion

This is the first study to estimate the heritability of sow udder morphology traits, colostrum quality and their correlation with important reproductive and productive traits. A combination of measurements and linear scores was applied to assess udder morphology. Similar methods have been used to evaluate udder morphology in dairy ewes (Labussiere *et al.*, 1981; Fernandez *et al.*, 1995; delaFuente *et al.*, 1996; Casu *et al.*, 2006; Huntley *et al.*, 2012), cows (Seykora and McDaniel, 1985; Kuczaj, 2003; Zwertvaegher *et al.*, 2011), and goats (Horak and Gerza, 1969; Wang, 1989). A recently developed methodology was adopted in this study for large scale evaluation of sow udder morphology (Balzani *et al.*, 2015c) and colostrum quality (Balzani *et al.*, 2015b). Heritability estimates of udder morphology traits found in this study were moderate to high (0.1 to 0.53).

When considering the estimates obtained for reproductive and productive traits, which have been reported in many previous studies, stillborn number heritability was on average similar to the literature (around 0.05) (Knol *et al.*, 2002). The heritability of total number of piglet born and litter size at ten days in this study, for the Meidam breed, was similar to the estimated values for Landrace (respectively: 0.10 and 0.09) and Yorkshire (respectively: 0.12 and 0.10) found in the study of Nielsen *et al.* (2013), but estimated genetic parameters for number of piglets born alive, total number of piglets born and stillborn were slightly lower compared with the values found by Canario *et al.* (2007). In this study the results show both positive and negative genotypic and phenotypic correlations between udder quality traits and productive and reproductive traits.

Teat length and teat diameter were highly heritable. Similar results, regarding the inheritance of teat size (length and diameter considered as two distinct traits), have been reported by Mavrogenis *et al.* (1988) for Chios sheep and Seykora and McDaniel (1981) for first lactation Holstein cows. The estimates of Gootwine *et al.* (1980) for the Assaf sheep, and Horak and Gerza (1969) for Cigaja and Valaska sheep were much lower (0.04 to 0.21). Data in the analyses by Gootwine and Horak were recorded using linear scores, whereas the data used in the current analysis and by Mavrogenis *et al.* (1988) and Seykora and McDaniel (1981) used measurement in millimeters, which could contribute to the heritability differences. These two teat dimensions were also correlated genetically and phenotypically with each other. Furthermore all measured traits as expected were all positively genetically correlated. Likewise, teat length had a positive genetic correlation with teat form, placement, and position also in cattle ($r_g = 0.54$ to 0.82; Vukasinovic *et al.* (1997)). This suggests that the same genes might control both teat length and diameter; indeed in cattle those traits are evaluated together as teat size, defined as a combination of teat length and circumference (Kirschten, 2001; Sapp *et al.*, 2004; Bunter and Johnston, 2014; Bradford *et al.*, 2015).

There was a high positive genetic correlation between teat length and the sow milking ability expressed as litter weight at ten days. However all the other traits were negatively genetically correlated with the sow milking ability, a part from teat functionality, in fact an increased litter weight at ten days was correlated with high non-functional teat. A positive genetic correlation between teat length and sow average daily gain during gilt testing; this suggests that teat length could be selected for or against without much effect on these traits. Teat length phenotypic correlation was positive with sow age at farrowing and negative with litter size at ten days.

A negative genotypic and phenotypic correlation was recorded between the teat diameter and the number and weight of piglets alive at ten days of age and showed a positive genetic correlation with the number of piglets born alive but dead before ten days. This result might suggest that teat size is linked with piglet mortality. Large teats may be more difficult to suckle and impair early colostrum intake. There was a low genetic correlation between teat diameter and sow back fat thickness, suggesting that teat diameter could be selected for or against without much effect on this trait. A positive phenotypic correlation between teat diameter and sow age at farrowing is to be expected as udder size generally increases with age. As for teat length a negative phenotypic correlation between teat diameter and litter size at ten days, and for this trait also with litter weight at ten days, was recorded. Altogether these outcomes agree with the previous size-related finding on the association between parity and teat size (Balzani *et al.*, 2015c) and confirm the hypothesis of Vasdal and Andersen (2012) that older sow with bigger udder size impair teat access and therefore negatively influence piglets survival.

Genetic correlation estimates of the teat distance from the abdominal mid-line was high with inter-teat distance within the same row and with the proportion of non-functional teats. This result might suggest that these traits are all associated with larger udder size. To support this statement, more evidence was provided by the positive phenotypic correlation between teat distance from the abdominal mid line and sow parity number, sow age at farrowing, litter size and weight at birth.

As expected, the inter-teat distance within the same row was negatively genetically correlated with the total number of teats and between these two traits there was also a negative phenotypic correlation. These results are supported by the positive genetic correlation between inter-teat distances and sow reproductive traits (total born and born alive ) and the negative genetic correlation between those traits and the total teat number. Inter-teat distance within the same row was also a trait which was positively highly genetically correlated with, litter size and weight at ten days, number of piglets born alive but dead before ten days and negatively with the number of stillborn piglets. At the contrary the trait total teat number was negatively genetically correlated with the number of piglet born alive but dead before ten days and positively correlated with the number of stillborn. The heritability of total teat number was similar to the average values reported in the literature, which range from 0.10 to 0.42 (Pumfrey *et al.*, 1980; Rydhmer, 2000; Chalkias *et al.*, 2013). The genetic correlations between teat number and sow reproductive traits are consistent with data obtained by Pumfrey *et al.* (1980). Korkman (1947) found a significant genotypic correlation between teat number and litter size at weaning. Allen *et al.* (1959) found that total teat number was correlated with litter size at birth. However Pumfrey *et al.* (1980) found a significant but negative genotypic correlation between functional teat number and litter size at weaning. One interesting finding is that the number of stillborn piglets was negatively correlated with the inter-teat distance within the same row trait and highly positively correlated with the total teat number. Canario *et al.* (2007) stated that number of stillborn piglets is positively correlated with number of total piglet born (0.58). It can thus be suggested that selection for an increment in inter-teat distance within the same row will reduce the number of stilborn but a negative one on total teat number. Another interesting result was the genetic correlation between inter-teat distance within the same row and colostrum quality estimate. However, colostrum quality was not correlated with total teat number. This result, accompanied by the genetic correlation between inter-teat distance within the same row and litter size, suggests that colostrum quality could be related to increased litter size. Colostrum quality was also strongly genetically correlated with the number and weight of piglets born alive. Positive phenotypic correlation was also confirmed between colostrum IgG and number of born alive piglet and their litter weight. These results are in accord with recent studies indicating a positive correlation between colostrum yield and litter size (Vadmand *et al.*, 2015). However Farmer and Quesnel (2009) reviewed the factors that influence colostrum and stated that litter size does not affect the total production of colostrum. Quesnel (2011) confirmed the previous finding of no evidence of a relationship between litter size and colostrum yield and quality, but she found a negative correlation between stillborn and colostrum yield (r = - 0.33). Colostrum quality and stillborn were slightly negatively correlated in the current study, but this correlation was not significant. Considering the relationship between inter-teat distance and teat number, and the genetic correlation between these two traits and stillborn, careful decisions need to be made in order to select for number of teats to reduce piglet mortality.

The estimated heritability value for the proportion of non-functional teats matches that observed in earlier studies (0.32, Long *et al.* (2010); 0.29, Chalkias *et al.* (2013)). The positive correlation between number of teats and non-functional teats suggests that single trait selection for increased teat number could increase the number of non-functional teats. These results are in line with those of Long *et al.* (2010) and Chalkias *et al.* (2013). The proportion of non-functional teats was highly  but negatively genetically correlated with litter weight at ten days. This might suggest that sows that have a high proportion of non-functional teats cannot provide enough good quality teats to allow the offspring to survive until ten days of age. As suggested by Long *et al.* (2010) and Chalkias *et al.* (2013) and the results of the current study, it is possible to state that adding to the genetic selection scheme a negative weighting on the number of non-functional teats will reduce piglet mortality. Chalkias *et al.* (2013)showed that non-functional teat number recorded in males at 3 weeks of age was negatively genetically correlated with sidefat thickness recorded at the age of 100 kg live weight. This differs from the findings presented here; backfat thickness was recorded at performance testing but a significant genetic correlation was found with the total teat number and not with the proportion of non-functional teats. Also, Smith *et al.* (1986) did not find any genetic correlation between teat number and production traits in male pigs.

In this study, the number of piglet born alive but dead before ten days of age was positively genetically correlated with teat diameter, inter-teat distance within the same row and udder development score, and negatively correlated with the total number of teats. These results are in line with those of previous studies in cattle (Bunter and Johnston, 2014).  Moreover litter weight at ten days was positively genetically correlated with length, but negatively with all the other traits. The high number of missing datat can explain the inconsistency of these results at ten days due to the intense cross-fostering applied to the litters. The observed correlation between some udder morphology traits and piglet survival traits might be due to the fact that increasing teat length, diameter and distance between teat and abdominal mid line impairs teat access, with an impact on piglet mortality.

## 7.6 Conclusion

These findings, as the first of their type, will doubtless be much scrutinized, but there are some immediately dependable conclusions for the hereditability of udder morphology traits and their importance for piglet survival and performance. All udder morphology traits measured in this study were moderate to highly hereditable and with some important correlations with reproductive and productive traits. These traits should be included in the breeding goal and weighed appropriately with other important traits in the breeding objectives to enhance optimal genetic progress. In further research, the use of these data to create scores to evaluate udder morphology in sows, as in cows and sheep, by grouping together some morphology traits will facilitate simpler data collection and allow larger databases for further interpretation of results.

# Chapter 8. General discussion and Conclusion

The urgent need to improve animal welfare and reduce economic losses is a major driver of research in animal science. Reducing pre-weaning mortality is therefore essential to meet these needs. The aim of this research project was to develop and extend the knowledge on sow udder morphology and colostrum quality to aid survival and performance of piglets.

The hypothesis that has been formulated to account for pre-weaning mortality is based on the role of udder morphology to facilitate colostrum intake of piglets from hyperprolific sows. It was expected that sows with large udder size, non-functional teats or teats which are located too high from the pen floor or poorly exposed, could prevent teat access and therefore give litters with higher pre-weaning mortality rate (Vasdal *et al.,* 2010; Chalkias *et al.,* 2014). This assumption was based on the evidence that neonatal piglets, like other mammals, are completely dependent on maternal care and the acquisition of adequate colostrum is vital for their survival and development (Devillers *et al.,* 2011). Therefore, all factors that prevent teat access are a disadvantage for their subsistence. Poor udder quality leading to delayed colostrum intake has been reported in cattle (Wythe *et al.,*1970; Edwards *et al.,* 1982; Ventorp and Michanek, 1992) and sheep (Huntley *et al.,* 2012). The literature review in Chapter 2, indicated that sow udder conformation has received very little attention. With the exception of teat number (Pumfrey *et al.,* 1980), and more recently teat functionality (Chalkias *et al.,* 2014), there is only one other study on udder firmness focused on preventing sow culling (Aziz *et al.,* 1995), whilst no other traits related to sow nursing ability have been investigated.

In order to define sow udder morphology traits, a review of the literature available on the evaluation of udder morphology in other species was carried out (Chapter 2). The review outcomes gave rise to the first pilot experiment that investigated how to measure sow udder morphology (Chapter 3). Preliminary study outcomes were used to design a methodology to classify udder conformation and investigate the causes of variation in udder morphology traits as well as how these traits change during the lifetime of the sow (Chapter 4). The outcomes were then included in a study of the relationship between udder morphology traits, ease of colostrum extraction and piglet suckling behaviour (Chapter 5). During this experiment, colostrum samples were also collected and used to evaluate a practical on-farm methodology to assess immunoglobulin G concentration

(Chapter 6). Using the methodologies validated in the former experiments, a study to investigate the genetic component of different udder traits and colostrum quality, and their genetic and phenotypic correlations with important reproductive and productive traits, was carried out in order to generate new knowledge to improve piglet survival and performance (Chapter 7). As each experimental chapter contains a comprehensive discussion of the results, the purpose of this general discussion will be: (1) to draw together the results and discussions on the role and definition of udder morphology traits; (2) to speculate on how these traits could be improved genetically and actually bring benefit to the pig industry in terms of welfare and profit; and finally (3) suggest future work in the field of udder quality traits.

## 8.1 What is the definition of good udder quality in sows?

When discussing the linkage between udder morphology and teat access, how udder morphology traits vary between animals and how they change during the sow life cycle, it is relevant to consider the effects of the past decade of genetic selection for increased litter size, fast growth rates and lean meat percentage (Vasdal *et al.*, 2012). Since their domestication, sows have been selected for their ability to produce and rear large litters and strong piglets. It is common knowledge that teat position and conformation are equally important as the number of teats for piglet suckling. Almost a century ago Spencer, (1919), in his textbook entitled “Breeding, rearing, and marketing” dedicated a chapter to the sow udder. In this section he stated that, apart from a sufficient number of teats, the distance between the teats, a small and fine teat size, compactness of the udder and teat functionality had to be checked before selecting a female pig for breeding purposes. The evidence provided in this thesis extends this statement, providing detailed scientific information about udder morphology traits and their relationship with piglet behaviour.

### *8.1.1 Trait definition*

The outcomes of the preliminary study pointed out which were the more feasible traits to record, the more convenient days to record the traits in order to reduce the variability of the measurements, the ideal posture to evaluate the sow in the farrowing crate to limit measurements errors, and the most appropriate devices to optimize data collection time and repeatability. The evaluation methodology for udder morphology traits developed in this research (Chapter 3) offered a repeatable and feasible measurement tool.

Another important observation that emerged was the extent of anatomical differences in udder morphology traits between sows. The investigation presented in Chapter 4 highlighted some causes of variation in udder morphology traits such as breed type, parity number and teat pair position. Meidam sows had shorter and more uniform teats compared to Large White x Landrace. Meidam sows are a cross-breed of Large White and the Chinese Meishan. The latter tends to have higher teat numbers (Meishan average: 17 teats; Meidam average: 16.2 teats) and it is well known for its high prolificacy, but also for its poor growth and body composition (high backfat thickness percentage) (Bazer and First, 1983; Haley *et al.*, 1995). Meishan sows have also received great interest for their good temperament, which has been associated with a higher offspring survival rate (Van der Steen and De Groot, 1992), and heavier piglets at weaning (Edwards, 2002). The outcomes originating from this thesis add knowledge on the nursing ability of the Meidam, with better udder traits in respect to the distance between the teat and the abdominal midline and the teat length. However, the inter-teat distance within the same row and the teat diameter were not different between the two breeds which were studied and other factors have been pointed out to affect udder size. In accordance with Vasdal *et al.* (2012), who noted that teat access was reduced in old sows compared with younger ones, sow udder morphology traits of both breeds were affected by parity number. At the population level, increased sow parity number was associated with increased teat dimensions, but surprisingly not with a larger teat distance from the abdominal mid line. However, comparing udder morphology of the same sow at consecutives parities showed that the distance between teat and abdominal mid line does increase with increasing parity number. Hyperprolific sows have become larger and their body size grows greatly with each lactation compared to sows of almost 30 years ago (O'Connell *et al.*, 2007; Moustsen *et al.*, 2011). The comparison of phenotypic traits of the same animal at consecutives parities showed that around a quarter of the variation in the measurements was explained by sow identity, much more than by parity group. This outcome adds information on the udder evaluation methodology suggesting that one standardised measurement in the life cycle of the sow might be adequate to describe the phenotypic trait.

Moreover anatomical differences have been shown within sow. Mammary glands are not uniform; the glands located in the most cranial part of the body are more compact than the glands located in the caudal part (Kim *et al.*, 2000). The measurements of both studied breeds revealed that the udder could be separated in three sectors: anterior (the two most cranial mammary gland pairs) and posterior (the two most caudal pairs) with teats of small length and diameter, shorter distance from the abdominal midline and longer inter-teat distance within the same row; and a middle section with larger length and diameter of teats, closer to each other and more distant from the abdominal mid line. However, the majority of variance in udder morphology traits could not be accounted for and it was not clear which were the causes of variation of the distance from the abdominal mid-line. Kim *et al.* (2000) suggested that a bigger size of the middle portion of the udder after farrowing indicates that, during gestation, growth rate of mammary gland tissue differs between anatomical locations.

Phenotypic correlations between udder morphology traits and production and reproduction performance of the sow extended the knowledge about this variation (Chapter 7). Heavier litters at birth were correlated with a larger udder dimension, measured as inter-teat distance within the same row, teat distance from the abdominal mid line and udder development score. Moreover, litter size at birth was positively correlated with larger udder dimensions. This could be explained by the evidence that litter size at birth is associated with milk production (Auldist *et al.*, 1998; Kim *et al.*, 2001; Nielsen *et al.*, 2001; Vadmand *et al.*, 2015). In their review, Quesnel *et al.* (2012) suggested that, as milk yield depends on the number of milk-producing cells present in the gland at the onset of lactation, colostrum production should follow the same process. In our study also, colostrum IgG concentration was positively correlated with the total born number and litter weight at birth. Ogawa *et al.* (2014) noted that higher colostrum yield tends to contain more IgG. Another recent study confirms the positive relationship between litter size and weight at birth and colostrum production (Vadmand *et al.*, 2015). In contrast, in the study of Quesnel (2011), colostrum yield did not increase as a result of a higher litter size whereas it did increase with piglet birth weight (Devillers *et al.*, 2007; Quesnel, 2011). Altogether, the results from the literature and the evidence arising from this work suggest that colostrum IgG concentration is positively associated with colostrum yield.

Ogawa *et al.* (2014) found that IgG concentration was associated with the teat location on the udder. This result supports previous findings on the relationship between daily body weight gain of piglets and teat order (Kim *et al.* 2000; Skok *et al.* 2007). Kim *et al.* (2000) did not find any difference in body weight of piglets that suckled either anterior or middle teats. In our study, colostrum was collected from all teats and no relationship was found of mean Ig concentration with litter performance (size and weight) at ten days. A possible explanation for this might be that during our experiment a great number of cross fostering took place and many data were missing during this process. The literature also indicates ambiguous results about the relationship between teat position and immunoglobulin content: anterior (Rooke *et al.*, 1998; Wu *et al.*, 2010), posterior (Klobasa *et al.,* 1987) and middle regions (Tuchscherer *et al.,* 2006) have all been reported to be richer in IgG concentration. In contrast, there is a strong consensus that neonatal teat preference seems to be driven by colostrum outflow (Fraser, 1976; Fraser, 1977; Jeppesen, 1981; Fraser, 1984; King *et al.*, 1997; Skok *et al.,* 2007). However, another important driver that needs to be considered is that anterior mammary glands are more appealing, since they offer more protection, are closer to the mother's head and piglets are attracted by maternal odour and grunting (Jeppesen, 1981; Castren *et al.*, 1989; Kasanen and Algers, 2002; Skok and Škorjanc, 2013). In the light of these considerations it could be hypothesised that this favourable position is attained by the more vital and strong piglets that then deliver a greater stimulation of their gland, in turn making it more productive. However, Kim *et al.*(2000) and Skok *et al.* (2013) did not find a correlation between birth weight and teat position. This was also the case for the outcomes of our research. To support the hypothesis that piglet teat preference for anterior teats results from their attractiveness, Nielsen *et al.* (2001) found that mammary glands of primiparous sows did not differ in milk yield, as measured by piglet growth rate. This assumption could also hold true for colostrum yield, as suggested by Quesnel *et al.* (2012) from the relationship between milk-producing cells and milk yield. However, in the multiparous sows, growth rate was higher in the piglets suckling the front teats than in the piglets suckling the rear teats. Kornblum *et al.* (1993) found similar results for milk yield in first and later parity sows. Farmer *et al.* (2012) discovered that mammary glands that have not been used in a previous lactation have decreased productivity in a subsequent lactation. Altogether, these evidence suggest that mammary gland productivity and size are correlated to the stimulation of piglets influencing the production in the subsequent lactation (King *et al.,* 1997). This assumption gives an explanation about the differences in udder morphology traits and body weight of piglets that suckled from anterior teat in multiparous sows.

### *8.1.2 Udder traits related to teat access*

Evidence arising from the present study highlighted that neonatal teat access is linked with udder location. In Chapter 5, neonatal suckling behaviour was recorded and variation in suckling latency was not entirely explained by the birth condition of piglets or by maternal behaviour. The results of this study emphasized the role of teat location on the udder. Posterior and anterior teats located in the upper row were the most suckled; this behaviour seems to be a frequently recorded pattern (De Passille *et al.*, 1988; Vasdal and Andersen, 2012). The time delay from birth to suckling and from the first contact with the mammary gland to suckling was also shorter when neonates suckled for the first time from a teat located in the posterior or anterior section. In Chapter 4, udder morphology trait measurements pointed out a similarity in the conformation of the teats located in the posterior and anterior part of the udder. In these two portions of the udder, teat length and diameter are smaller on average and, by observing the teat seeking behaviour, it seems that neonatal piglets suckle more easily from teats with small dimensions. In addition, teats located in the posterior and anterior part of the udder are also closer to the abdominal mid-line; this might suggest that the height above the pen floor or poor exposure of the lower row might prevent teat access. A comparison between suckled and un-suckled teats showed that piglets suckled for the first time more frequently from teats with larger inter-teat distance within the same row, allowing more space for the siblings to suckle. That trait is of vital importance in hyperprolific sows, where the fights over a teat increase with increased litter size (Milligan *et al.*, 2001; Andersen *et al.*, 2011). From our results, it seems that posterior teats also play an important role in colostrum intake but this assertion is not supported by previous study outcomes. However, a recent study showed that mammary gland productivity per se cannot be considered a factor affecting piglet distribution along the udder (Skok *et al.*, 2013). From the literature it seems that in intensive farms piglets mainly suckle from the anterior-middle teats, whereas in wild boar it has been reported that piglets prefer posterior teats, where the leg provides a protection from competition (Fernández-Llario and Mateos-Quesada, 2005). Skok *et al.* (2013) suggested that selection for increased hindquarter muscularity could have altered piglet territoriality on the udder. In this thesis, piglet teat seeking behaviour was observed only until the first teat was suckled. It might be that piglets instinctively suckled first from a teat located in the rear part of the mammary gland as did their ancestors, but then found the anterior part safer or more productive. Another assumption is that anterior teats are easy to keep at the beginning of the farrowing because there is less competition, and later on piglets that started to suckle undisturbed from the front sections should have more energy to fight to keep the position. The results from our study showed that 65% of the time siblings suckled for the first time from the same teat as suckled by a previous littermate, and that 41% of the teats first suckled were located in the posterior part versus 33% in the anterior part of the udder. Teat order position is quickly settled; it has been reported that it becomes established around four hours after birth (McBride *et al.*, 1965; Hemsworth *et al.*, 1976). Another possible explanation for the lower weight gain of the piglets that suckle from the posterior teats could be explained by the different physiological conformation of the mammary glands. Kim *et al.* (2000) and Nielsen *et al.* (2001) reported that posterior glands have lower weight than other glands and they found a correlation between wet weight and piglet weight gain. Moreover, posterior glands are prone to loose attachment and become firm, which is likely to occur with increasing parity number (Aziz *et al.,* 1995). Phenotypic correlations of udder traits with sow reproductive and productive traits showed that litter size and litter weight gain at ten days was negatively correlated with teat diameter and length and tended to be negatively correlated with larger udder dimensions. These results indicate that large udder size, impairs teat access, affecting piglet performance. This statement is valid without considering the inter-teat distance from the same row, since the results presented in the suckling behaviour study showed an associated with the teat suckled during the first contact with the udder and this traits, but later on the genetic investigation the outcomes showed negative correlation between this traits and the performance at ten days. The evidence presented in th suckling behaviour might be biased by other factors, such as the distance of the teats from the abdominal mid line, the safety of the position, the odour of the udder, the grounding of the mother as has been previously proved. Nevertheless considering also the negative relationship between this traits and the number of stillborn it is advisable to include this traits maybe with a single measurement from the first teat to the last ones in the same row.

However, estimated colostrum IgG concentration was not related with piglet performance at ten days in this study, possibly because infectious disease challenge was not high in this early stage.

Overall, the outcomes of this research have produced a detailed description of the traits and a scientific base that accounts for modern hyperprolific sows and highlights the main causes of variation. In summary, a sow with a good quality udder must have a sufficient number of teats positioned in two parallel rows, equidistant within the same row and close to the abdominal mid-line. Furthermore, it is now possible to state that the better maternal qualities of the Meidam breed include also the udder morphology traits. Altogether, these results can be summarised to distinguish between two main shapes: the parallel rows and the arch rows. This simplification allows a quick interpretation of the data and highlights the main characteristics that determine a good quality udder (Figure 8.1).

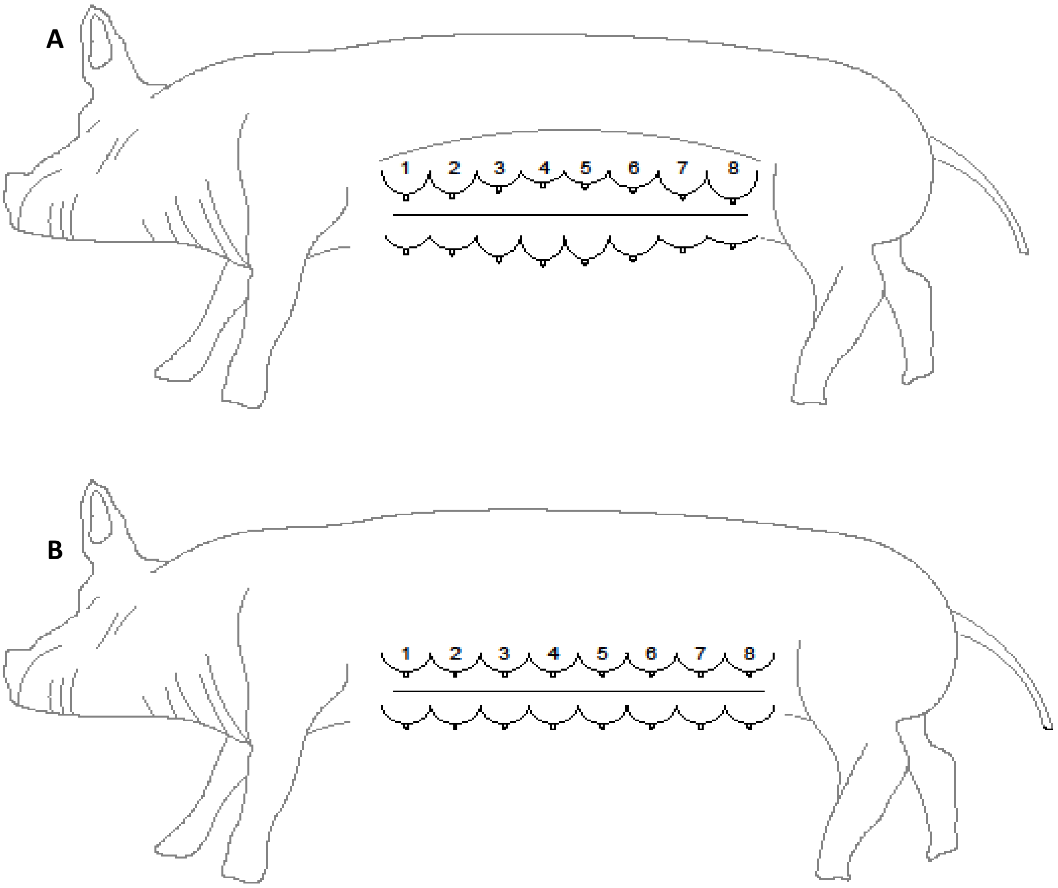


Figure 8. 1 Udder morphology shape A: average udder morphology, “arch shape”. B: good udder morphology: “parallel shape”

## 8.2 Udder morphology improvement

The development of strategies that can improve breeding values is of increasing interest and importance to the livestock industry. Genetic selection is mainly focused on production and reproduction traits (the most obvious economically valuable traits) such as growth rate, feed efficiency, lean meat percentage and litter size. Selected traits are recorded in nucleus herds, multiplier herds and test-stations, and the breeding organisation stores the registrations from all pigs in the nucleus herds. Despite the evidence that sow udder morphology traits play an important role in rearing offspring, increasing milk production and promoting mammary gland health, they have not been included in any selection programme so far except from total teat number. Udder quality represents one of the most important traits in beef production, and in other species udder traits are largely exploited for their relationship with milking ability. This gap in swine may be explained by the lack of interest in the milking ability of the sow, since sow milk is not directly a production outcome but only indirectly seen in piglet growth. Moreover, sow behaviour and udder conformation make the evaluation process more complicated than udder evaluation of cows or sheep. On the other hand, pig genetic selection has focused on cumulative short-term genetic change driven only by market economy. There is much evidence to show that specialised dam line selection has led to undesirable side effects that contribute to increased piglet mortality. In her review, Rydhmer (2000) emphasised the issue that increasing sow prolificacy is no longer a sustainable selection strategy per se and, in order to allow the sow to rear extra piglets by herself, other traits must be included in the genetic criteria. This issue becomes even more urgent when considering the need to improve animal welfare, pig health and reduce environmental impact of the swine production system (Kanis *et al.*, 2005). In light of these considerations, appropriate animal breeding programs and breeding goals should be considered as an integrative strategy to implement a sustainable production system.

This study is one of the first investigations to assess udder quality in sows. The evaluation methodology developed in this project proved to be a functional tool to carry out data collection on a large sample size in order to assess the heritability of these traits. All the evaluated traits had moderate to high heritability, indicating that genetic progress could be made rather quickly. However, such selection would be complicated in commercial practice; this measurement process is physically demanding for the operators and requires time. In the light of this limitation, only some traits should be recorded according with their impact on teat accessibility and considering favourable and unfavourable correlations within the udder traits, and with economically important reproductive and productive traits.

The results of this study show a positive genetic correlation between the inter-teat distance and the other traits; this should mean that selection for smaller udder dimension and increased teat number would lead to a diminution of inter-teat distance. Teat length and diameter were negatively correlated with teat functionality, which is easily explained since in the definition of teat functionality given in this thesis there were also teats that remain as a small protuberance. Interestingly, teat non-functionality was positively genetically correlated with the distance from the abdominal mid line. This result suggests that by selecting for a shorter teat distance from the abdominal mid-line the number of non-functional teats will also be reduced.

The ultimate goal of the udder quality selection is to increase nursing activity in all the functional mammary glands. What makes these traits very interesting is their impact on animal welfare, as well as on the farm profit. It has been estimated (BPEX, 2009) that a 5% reduction in total piglet mortality will reduce cost of production by ~3p/kg carcass. Moreover it is estimated that 40 to 50% of sows are culled before their third or fourth parity, a time by which initial replacement costs have not been met, and 20 to 30% of this is due to poor litter performance, related with udder problems. It is therefore reasonable to assume that by improving udder morphology sow culling will also be prevented.

In the light of this consideration, including udder quality traits in the selection program can be considered as worthy of promotion (Olesen *et al.*, 2000). A trait of an animal has an economic value if a level change of that trait results in economic benefit. Kanis *et al.*, (2005) suggested that there are also non-economic reasons to change the level of a trait. By improving teat accessibility, piglet immediate and long term performance will improve, milk production will increase, sow culling will be reduced and the environmental footprint of pig meat production will decrease. Overall these changes not only produce financial benefit for the enterprise, but will also improve the welfare of both mother and offspring. Considering the impact of udder quality traits on pig production, these traits can be considered both non-economic and economic, accomplishing the needs of modern pig production.

## 8.3 Study limitations and future investigations

The present thesis provides novel tools to measure sow udder quality, which can be applied to improve and expand the knowledge in this field. Future directions to be taken are briefly suggested below.

- This thesis emphasised the importance of udder morphology traits but used a very detailed and labour demanding assessment method; it might be of great interest to develop a simpler teat and udder score system and establish standard guidelines for the scoring process to encourage and facilitate use as selection criteria on pig farms and at breeding company level. The results of this thesis provide a solid base to develop a simple and visual scoring system. To improve the measurements in the future, other tools such as, for example, digital technology and image analysis software might be used, as has been done in sheep (Marie-Etancelin *et al.*, 2005), and cow (Zwertvaegher *et al.*, 2011)
- To develop a full picture of udder morphology traits and the linkage between udder morphology and teat access, additional studies will be needed that monitor the entire lactation period to determine the trait variation and the relationship between milk production, udder morphology and piglet performance.
- This thesis did not document the detailed relationship between udder morphology, teat preference and colostrum intake in the first 24 hours due to limited availability and experience of the operator. To extend the definition of good udder quality, piglet performance and colostrum intake at 24 hours should be linked to teat preference. For this purpose the evaluation of the ability of the Brix refractometer to quantify neonatal serum immunoglobulin on-farm should be made, as has already been done in dairy cow.
- Another aspect requiring more detailed study is colostrum evaluation. The results of the first evaluation showed good promise for use of the Brix refractometer as a quick on-farm method. However the comparison was done only with the golden standard RID due to limited funding for further laboratory tests. Further research should be undertaken to evaluate colostrum IgG comparing more analytical techniques such as ELISA. The addition of caprylic acid to remove the other protein effects and quantify only IgG, as has been done in dairy cow, could be evaluated for application also in sow (Morrill *et al.*, 2013).

- The Brix refractometer should be evaluated as tool to improve farrowing assistance by identifying colostrum with high IgG concentration to feed weak piglets in order to improve their survival.
- Investigation of the effect of sow nutrition on udder morphology traits will be of great interest to explain the variation that remains unknown.
- Future research projects that apply the udder evaluation methodology in other farrowing management systems, e.g. loose pen and outdoor could also explain more about the relationship between udder morphology and teat accessibility.
- It would be interesting to investigate udder morphology differences across a wider range of pure and cross breeds.
- An important question remaining to be answered is whether showing both teat rows is a behavioural characteristic of the sow or is a consequence of her increased size and available space where she is confined. Studying the association between behaviour and udder size in a range of farrowing management systems, e.g. crates, loose pens and outdoor huts, may answer this question.
- The genetic correlation of udder morphology traits with disease traits should also be considered.
- In future investigations, it might be possible to use the evaluation methodology and the Brix refractometer to carry out genomic study of colostrum quality and udder morphology traits.

## 8.4 Summary and conclusions

Returning to the hypotheses posed at the beginning of this study, it is now possible to state that sow udder morphology and colostrum IgG can be evaluated in an easy and relatively rapid way, making these traits feasible for genetic improvement with implications for piglet performance and survival. This research has shown that udder and colostrum characteristics are heritable, and thus change can be made through selection.

In light of the present study, increased udder size causes limitations in teat utilisation because of restricted space between the mammary glands, inaccessible teats due to an excessive height above the ground for the upper row or poor exposure of the lower row. Teat access is fundamental for the survival and growth of the neonatal piglets, as well as for milk production and mammary gland health. It is therefore recommended to measure the teat distance from the abdominal mid line, at least of the middle mammary glands, and the distance from the first to the last teat in accordance with the total number of functional teats. The outcomes of this work will lead to formulation of pig herds where health and welfare are improved, in turn resulting in better pig performance, reduced environmental impact and increased sustainability.

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