PIG BREEDING IN HOT CLIMATES

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PREFÁCIO

Esta tese está integrada no plano curricular do 2.º ciclo de Engenharia Zootécnica e é o resultado do estágio realizado no Institute for Pig Genetics localizado em Beuningen, Países Baixos. Tomei conhecimento do IPG e do seu objecto de estudo após uma visita realizada à Topigs a 15 de Janeiro de 2010, que desde logo me suscitou interesse para lá realizar a minha investigação.

Apesar de o estágio ser realizado nos Países Baixos, o interesse por realizar a investigação com dados provenientes de Portugal e Espanha foi sempre uma ambição. Daí surgiu a oportunidade de estudar e quantificar os efeitos do stress térmico na performance produtiva e reprodutiva de porcas, que foi uma opção que veio de encontro às minhas expectativas. Este trabalho está inserido num amplo projecto da Topigs que visa o melhoramento genético de suínos para a robustez.

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ABSTRACT

Pigs are very sensitive to high temperatures, when they are exposed to high temperature, above the thermo-neutral zone, they respond invoking physiological and behavioral mechanisms to facilitate heat losses to the environment or to minimize heat gain from the environment. Feed intake and reproductive performance are affected when sows are exposed to heat stress.

Firstly, it was studied on which day heat stress had the greatest impact on reproductive performance in two different sow lines, a Yorkshire line (D-line) producing mainly in temperate climates and a Large White line (I-line) producing mainly in hot climates. Secondly, the relationship of temperature and humidity collected on-farm and collected on weather stations located at different distances from the farm was studied. Thirdly, new indicator traits, feed intake score and losses in back fat during lactation, to use in Breeding Value Estimation were studied.

From the first analysis, it was possible concluded that total number born (TNB) was negatively affected by Temperature Humidity Index (THI) for D-line and for I-line. Farrowing rate (FR) of D-line was significantly affected by THI and FR of I-line was not significantly affected by the class effect of THI. Temperature Humidity Index had a largest negative effect on TNB of D-line at 14 days after insemination and the largest effect of THI on TNB of I-line was at 5 days before insemination. D-line showed higher losses in reproductive performance than I-line sows when THI increased. These differences may be an indication of genetic differences in heat stress tolerance in sow lines. From the second objective, it was possible concluded that data from on-farm records were more accurate for predict losses in reproduction performance than information from weather station; however, weather station until 117 km far from the farm also provide satisfactory information for quantify losses in reproduction performance under heat stress conditions. From the third objective, feed intake score is a trait affected by high temperature and season. Feed intake score showed a low heritability; however may be introduced at Breeding Value Estimation to improve selection on start up of sows in Spain and Portugal. Losses in back fat during lactation was not a heritable trait.

Key words: feed intake, heat stress, reproductive performance, sow, Temperature Humidity Index.

RESUMO

Os suínos são animais muito sensíveis a elevadas temperaturas. Em presença de elevadas temperaturas, acima da sua zona de termo neutralidade, eles accionam mecanismos fisiológicos e comportamentais que permitem facilitar as perdas de calor para o ambiente ou minimizar ganhos de calor do ambiente. A sua ingestão de alimento, bem como a sua performance reprodutiva são afectadas quando as porcas são expostas ao stress térmico.

Nesta dissertação, em primeiro lugar, foram determinados os dias que têm um maior impacto negativo na performance reprodutiva em duas linhas de porcas distintas, linha Yorkshire (linha D) produzida principalmente em climas temperados, e a linha Large White (linha I) produzida maioritariamente em climas quentes. Em segundo lugar foi estudada a relação dos dados de temperatura e humidade recolhidos na exploração e recolhidos em estações meteorológicas localizadas a diferentes distâncias da exploração. Em terceiro lugar, foi estudada a importância de novos parâmetros para implementar na estimativa de valores genéticos com a finalidade de aperfeiçoar a selecção de porcas reprodutoras baseada na sua capacidade de ingestão de alimento após o parto e na sua mobilização de reservas durante a lactação.

Com esta dissertação pode-se concluir que porcas sujeitas a elevados valores do Índice de Temperatura e Humidade (ITH) diminuem a sua performance reprodutiva traduzindo-se numa diminuição do tamanho da ninhada e da taxa de parto. A taxa de parto da linha D foi afectada significativamente pelo ITH, no entanto a taxa de parto da linha I não foi afectada. O maior impacto negativo do ITH no tamanho da ninhada foi registado 14 dias após a inseminação para a linha D e para a linha I foi registado 5 dias antes da inseminação. A linha D mostrou maiores quebras na performance reprodutiva que a linha I com o aumento do ITH. Dados de temperatura e humidade registados na exploração são mais precisos no estudo das quebras da performance reprodutiva associadas ao stress térmico, no entanto, a estação meteorológica mais próxima da exploração, até uma distância de 117 km, pode também fornecer informação útil para utilizar em estudos relacionados com o stress térmico. No terceiro objectivo, a classificação da ingestão de alimento após o parto mostrou ser um parâmetro interessante para usar no aperfeiçoamento da estimativa de valores genéticos sendo que foi claramente afectado pela temperatura e estação.

Palavras-chave: índice de temperatura e humidade, ingestão de alimento, performance reprodutiva, porca e stress térmico.

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LIST OF ABBREVIATIONS

ACTH	adrenocorticotropic hormone
BGHI	Black Globe Humidity Index
BVE	Breeding Value Estimation
CL	corpus luteum
CRH	corticotrophin releasing hormone
FIS	feed intake score
FR	farrowing rate
FSH	follicle-stimulating hormone
GnRH	gonadotropin-releasing hormone
h^2	heritability
L	linear
LH	luteinizing hormone
LMO	litter mortality
NBA	number born alive
NMP	number mummified piglets
NR28	non return at 28 days
NSB	number stillborn piglets
NW	number weaned
P	Plateau-linear
r^2	repeatability
RH	relative humidity
SD	Standard deviation
T	temperature
THI	Temperature Humidity Index
TNB	total number born
UCTHI	upper critical THI

1. INTRODUCTION

Pigs are homothermous animals; they maintain body temperature within a certain interval, regardless of fluctuations in ambient temperature. Pigs are more sensitive to high ambient temperatures than other farm animals because they can not sweat and pant so well (Huynh, 2005).

Pig production occurs on commercial farms all over the world because of expansion of the human population. This requires that animal protein should be produced not only under favourable but also under the unfavourable meteorological conditions prevailing in tropical, polar and high altitude countries. Here the problem arises of finding animals best suited for producing under such conditions.

Farm animals are selected and bred for productive traits, in contrast to wild animals that have been adapted to their meteorological environment through natural selection. One of the greatest challenges of modern pig farming is to achieve the maximum genetic potential of the animal, improving production and reproductive performance. For many years the research on achieving maximum efficiency in animal production was focused on management, animal health, nutrition and genetics. Nowadays, advances in these areas have been limited by environmental factors, mainly, due to heat stress effects which the animals are subject to. Besides high temperatures decreases animal efficiency, it may as well establish harmful air quality conditions to animals and workers.

TOPIGS is a worldwide breeding company and is active in over 50 countries, as Portugal and Spain. Portugal and Spain have high temperatures during the summer; therefore they are included in countries with tropical climate. Tropical climate in some countries is one important issue that TOPIGS wants to overtake improving the genetic value of its animals. This study is important for improve Breeding Value Estimation on heat stress tolerance and it is part of a larger TOPIGS project on breeding for robustness in pigs.

1.1.Objectives

The objectives of the first part of this study were: 1) to study on which day heat stress has the largest impact on total number born and farrowing rate in two different sow lines, a Yorkshire line (D-line) producing mainly in temperate climates and a Large White line (I-line) producing mainly in hot climates and 2) to identify if on-farm recording of weather parameters is a better predictor of heat stress than off-farm recording when used for application in genetic studies in heat stress tolerance. Study the relation between on-farm and weather station records is important because to our knowledge no study has worked on developed in pigs to understand if the information from on-farm is more accurate in capturing the effect of heat stress as the data collected in the weather station.

The objective of the second part of this study was to analyse new indicator traits which might be implemented in Breeding Value Estimation to improve selection on start up of sows after farrowing during hot periods in Portugal and Spain.

2. LITERATURE REVIEW

2.1. Meteorological elements and sows housing

Meteorological elements constitute a complex system which acts upon the animal body and it can influence the organism singly, or in various combinations of temperature, humidity, solar radiation and air movement (Bianca, 1976). Effective temperature is influenced by five environmental elements: air temperature, humidity, air movement, solar radiation and precipitation. Level of heat stress to which animals are exposed is affected by effective temperature (Fuquay, 1981).

The impact of meteorological elements on pigs, or domestic animals in general, can be detrimental or beneficial. For most meteorological elements there is a range of indifference, i.e. a zone within which compensatory responses by the organism are absent, the thermal neutral zone (Bianca, 1976). If the meteorological elements move outside this range, pigs get stressed and begin to activate its defence mechanisms. Piglets have a thermal neutral zone at a relative high temperature, between 30ºC to 37ºC and lactating sows have a thermal neutral zone at relative low temperature between 12 to 22ºC (Black *et al.*, 1993).

In pigs, cold ambient, with lower temperatures, normally represents a smaller problem than heat. Heat refers to those meteorological elements which either interferes with the dissipation of body heat to the environment or which impose an external heat load on pigs (Bianca, 1976).

Meteorological elements can cause effects with different magnitude on the animal. Different categories can be distinguished: thermal indifference, mild heat when the thermoregulation mechanisms of the body can compensate the extra load, moderate heat when the thermoregulation mechanisms work at higher intensity and body temperature can be stabilized, and severe heat when the thermoregulation mechanisms are overtaxed, body temperature rises continuously and eventually death may occur (Bianca, 1976).

Developments in modern pig housing have occurred in the last decades as a result of researches and improvements in pig industry. The most significant feature in the success operation of any piggery is the achievement of a good standard of environmental conditions required for pig production (Brent, 1986).

The construction of pig pens and houses depend to a certain extent upon the climate and local circumstances. Local conditions are important, in terms, of the construction site (waterlogged, exposed to wind...etc.) or the building materials and the skills available for the construction of the installations (Muys and Westenbrink, 2004). Reduction of the stressful meteorological situation is mostly achieved by reducing the impact of meteorological elements, or by improving the microclimate inside the barn (Bianca, 1976). Thermal properties of materials in the roof have great importance for explanation of temperature oscillations in piggery (Muys and Westenbrink, 2004).

Some equipment can be used for satisfy the best thermal requirements for sows like ventilation systems, evaporative cooling systems and floor cooling systems. Ventilation systems are used to control air temperature and relative humidity, to maintain a satisfactory degree of comfort for stock and operator (including toxic gas levels), to renew stuffy air, and to quantify the speed at which air passes over the sows (Brent, 1986 and Silva, 2005). Evaporative cooling system is an adiabatic humidification process where sensible heat of the air is used to evaporate the water that comes in contact with the air; the reduction of temperature with a complementary increase of relative humidity is a consequence of sensible heat converted to latent heat in the added vapour (Lucas *et al.*, 2000). Floor cooling system increases the differences in temperature between sows' body and floor cooled improving the heat losses between the animal and the floor (Shi *et al.*, 2006).

Brent (1986), concluded that measure house temperature is not easy and measures from mechanical ventilation are often unreliable due to the position of the sensor, accuracy of the controller, precision of design and operation of the house. In practice, precise temperature measurement will be guided by pig behaviour and performance of the pigs in declining the suitability of the temperature control (Brent, 1986).

2.2. Heat stress

Environments of high temperatures and high humidity are detrimental to the productivity of pigs and all farm animals, in general (Fuquay, 1981). Figure 2.1 demonstrates the most important external factors which influence the productivity of the pig. Heat is the major constraint on animal production in hot climates (Habeeb *et al.*, 1992). Animals are considered to be exposed to heat when ambient temperature is above the thermal neutral zone and this zone lies between 12 and 22°C for lactating sows (Black *et al.*, 1993). The thermal neutral zone covers the range of temperatures between the animal's lower critical temperature and its upper critical temperature (Black *et al.*, 1993).

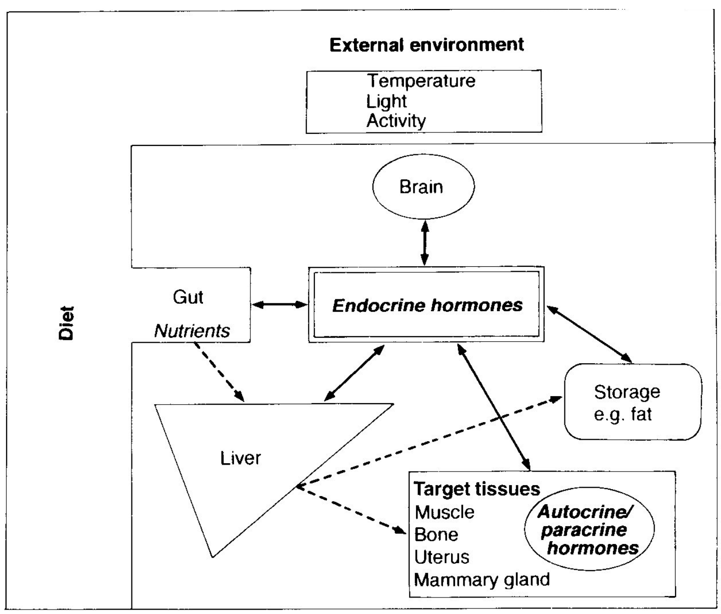

Figure 2.1. Relationship of external and internal factors involved in the maintenance of homoeostasis in pigs (Adapted: Gordon, 1997).

Figure 2.2 illustrates the critical temperatures and zones for pigs. Within C and C', pigs can keep their body temperature constant. Environmental temperatures below C cause body temperature to fall, while above C' the body temperature rises. The zone C-C' can be divided into zones C-B, B-B', A-A' and B'-C'. Within zone C-B, body temperature is kept constant by regulation of heat production. The thermal neutral zone is within zone B-B', where B point is called the lower critical temperature, while B' point is called the upper critical temperature. Zone A-A' is zone of thermal comfort.

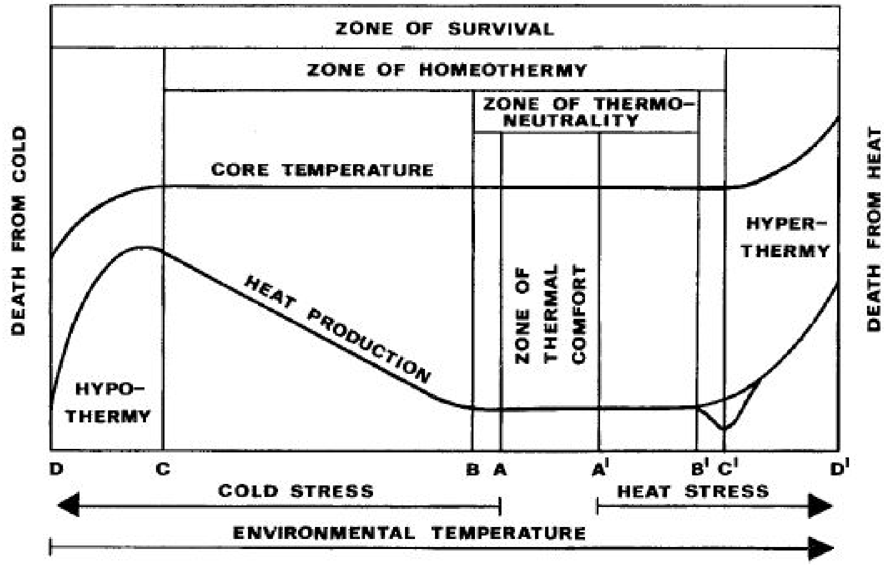

Figure 2.2. Critical temperatures and zones (Source: Bianca, 1976).

Sows are exposed to heat stress when temperature exceeds the upper critical temperature (B'-C', above 22°C). Heat stress results from a negative balance between the net amount of energy flowing from the animal to its surrounding environment and the amount of heat energy produced by the animal. This imbalance is induced by changes in a combination of environmental factors, like radiation, humidity and air temperature, animal properties and thermoregulatory mechanisms (St. Pierre *et al.*, 2003). The more heat an animal produces internally by its metabolism, less is its capacity for tolerating external heat. There is thus a basic incompatibility between a high level of production and a high tolerance to heat (Bianca, 1976).

Heat stress is detrimental not only for economics of the pig industry but also for animal's welfare (St. Pierre *et al.*, 2003 and Huynh, 2005).

A complex of psychological, behavioural and anatomical mechanisms are invoked by the pig in response to heat stress aimed facilitating heat losses or decreasing heat gain from the environment (Huynh, 2005). In the nature, wild pigs can wallow in sludge or water during hot periods. Pigs can lose heat by radiation, conduction, convection and evaporation (Habeeb *et al.*, 1992 and Huynh, 2005). When the pig cannot sustain homeothermy, it reduces the heat production using internal physiological means to help in re-establishment of the thermal balance. Response to heat stress are increased respiration rate or panting, decrease feed intake and increased rectal temperature (Habeeb *et al.*, 1992, Huynh, 2005 and Silva *et al.*, 2009b). Feed consumption and thermogenic hormone secretion decrease to lower the basal mechanism resulting in a quick decline in productivity. If all these physiological mechanisms fail to balance the excessive heat load, the body temperature rises and the pig starts the acute phase of stress. If these systems still fail to stop the increase of body temperature, the animal succumbs with heat stroke and dies (Habeeb *et al.*, 1992).

To characterize and quantify adequate comfort zone for distinct domestic animals species were developed thermal comfort indexes. Several publications are using thermal comfort indexes as Temperature Humidity Index (THI), based on air temperature and relative humidity, and Black Globe Humidity Index (BGHI) associating the use of black globe temperature adding the solar radiation effect (Kelly and Bond, 1971 and Buffington *et al.*, 1981). Temperature Humidity Index values in the Table 2.1 were developed and used for measuring and estimating heat stress conditions in beef cattle, dairy cows and pigs; the normal values were considered lower than 75, alert values were from 75 to 78, danger values are from 79 to 83 and emergency values are higher than 83 (Nããs, 2006).

Table 2.1. Temperature and Humidity Index values related to heat stress safety (Source: Nããs, 2006)

Temperature-Humidity Index Values
Relative Humidity (%)

Temperature (°C)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
20	63	63	63	64	64	64	64	65	65	65	66	66	66	66	67	67	67	67	68	68
22	64	65	65	66	66	66	67	67	67	68	68	69	69	69	70	70	70	71	71	72
24	66	67	67	68	68	69	69	70	70	70	71	71	72	72	73	73	74	74	75	75
26	68	69	69	70	70	71	71	72	73	73	74	74	75	75	76	77	77	78	78	79
28	70	70	71	72	72	73	74	74	75	76	76	77	78	78	79	80	80	81	82	82
30	71	72	73	74	74	75	76	77	78	78	79	80	81	81	82	83	84	84	85	86
32	73	74	75	76	77	77	78	79	80	81	82	83	84	84	85	86	87	88	89	90
34	75	76	77	78	79	80	81	82	83	84	84	85	86	87	88	89	90	91	92	93
36	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	93	94	95	96	97
38	78	79	81	82	83	84	85	86	88	89	90	91	92	93	95	96	97	98	99	100

2.2.1. Physiology of heat stress

An immediate response to stress is activation of the sympathoadrenal system, which consist of the sympathetic nervous system and the adrenal medulla (Turner and Tilbrook, 2006). Another ubiquitous response to stress is activation of the hypothalamo-pituitary adrenal axis which results in the release of corticotrophin releasing hormone (CRH) and vasopressin from the hypothalamus into the hyphotalamo-hypophysial portal circulation (Turner and Tilbrook, 2006). CRH and vasopressin stimulate the anterior pituitary gland to synthesise and release adrenocorticotrophic hormone (ACTH). ACTH induces the increase of plasma cortisol level during acute heat stress and glucocorticoid hormones have hyperglycaemic action to increase gluconeogenesis and provide the expected increase in glucose utilization in heat stressed animals (Habeeb *et al.*, 1992). Although cortisol is the main glucocorticoids produced, ACTH also induces production in the adrenal cortex adrenaline and noradrenaline (Torpy and Chrousos, 1996).

The elevation of circulating concentrations of adrenaline, noradrenaline and cortisol results in the rapid mobilisation of the body's energy stores to allow the necessary responses to cope with the challenge encountered (Turner and Tilbrook, 2006). For example, the increase of adrenaline and noradrenaline results an increase of heart rate, dilatation of bronchial tree, an increase of pupil dilatation and redistribution of blood to skeletal and cardiac muscle and away from organ systems which are not essential (Udelsman and Holbrook, 1994). Turner and Tilbrook (2006) reported that reproduction in female pigs can be impaired by exposure to stress.

In periods with persistent heat stress, the decline of cortisol occur because cortisol is thermogenic in animals and, consequently, the reduction of adrenocortical activity under thermal stress is a thermoregulatory protective mechanism preventing metabolic heat production in a hot environment. This indicates the function of the adrenal cortex gland in adaptation to stress (Habeeb *et al.*, 1992).

In studies on heat stress effects on animal production, weather information are usually obtained from weather stations, which routinely collect daily or even hourly information for temperature, humidity and precipitation. Weather stations are found in many locations all over the world. They can provide reasonable good information for heat stress when they are located in a relative flat area; in other locations, with geographical differences, complicated landscapes, such mountains, the data from weather station may be less useful for prediction of on-farm weather conditions (Freitas *et al.*, 2006).

2.3.Feed intake

To understand the control and regulation of feed intake is important to establish an appropriate feeding strategy and study the main factors which affect feeding behaviour. Voluntary feed intake is affected by several factors; many of them are environmental factors (Gourdine *et al.*, 2006). Lactating sows are particularly sensitive to high temperatures (Silva *et al.*, 2009a). When ambient temperature falls below the lower critical temperature, the animal has to increase its heat production to maintain body temperature; this is done by increasing feed intake (Figure 2.3). Within zone of thermal comfort the animals maintain its body temperature and increase its heat losses by simple mechanisms that require little effort (Williams, 1998). When ambient temperature increase above evaporative critical temperature, the pig increases heat loss by evaporation, mainly through the lungs, and reducing its heat production by reducing its feed intake because of the thermal effect of feed (Silva *et al.*, 2009a).

To support maintenance and milk production, sow physiologically requires nutrients (NRC, 1987). Milk production has a high priority, and if nutrient intake is restricted, the sow will draw on body tissue in an attempt to maintain milk production (NRC, 1987). Consequently, reducing sow's feed intake results in body reserves mobilization, decrease of milk production, and future reproductive and productive performance of the sow is compromised (Dourmad *et al.*, 1998). Reduction in feed intake plays probably a role in the delayed return-to-oestrus after weaning under elevated temperatures (Prunier *et al.*, 1997).

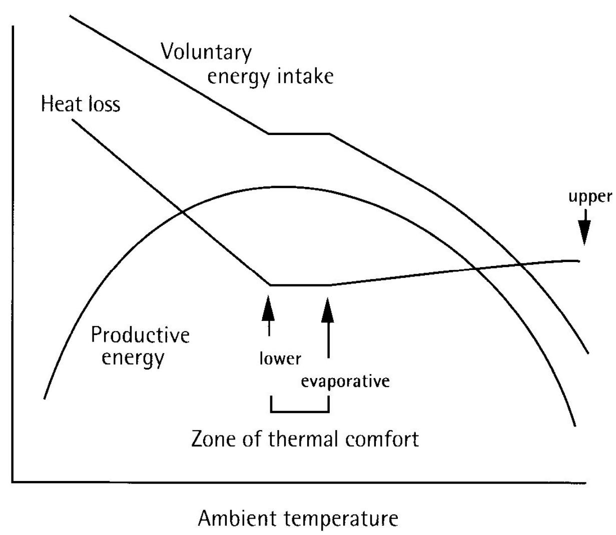

Figure 2.3. Effect of ambient temperature on heat loss, voluntary energy intake and productive energy (Source: Williams, 1998)

2.4. Reproduction

Reproduction has a major impact on the efficiency and productivity of pig production systems. Reproductive performance depends on the genotype of the pig and the environment which it encounters.

Reproductive performance in sows depends on several factors, such as parity number, breed, season, temperature, photoperiod and nutrition (Gourdine *et al.*, 2006; Peltoniemi and Virolainen, 2006; Suriyasomboon *et al.*, 2006 and Silva *et al.*, 2009a). Litter size and number of piglets weaned are the most important measure of sow productivity and has a large effect on overall herd profitability (Gordon, 1997).

Non-pregnant and non-lactating sows and gilts display oestrus or standing heat throughout the year. The oestrus cycle is normally 21 days and is defined as the time between the onsets of one oestrus to the onset of the next. The cycle length can range from 18-24 days (Singleton and Diekman). Several authors reported the influence of high ambient temperature at different moments in the sow's reproductive cycle. Follicular development, oestrus behaviour, oocyte competence, fertility rate, embryo quality and embryonic development may be affected by heat stress (Omtvedt *et al.*, 1971; Wettemann *et al.*, 1988; Tantasuparuk *et al.*, 2000; Hansen *et al.*, 2001 and Suriyasomboon *et al.*, 2006).

2.4.1. Ovarian follicular growth

Ovarian follicular development during lactation and after weaning in sows is a complex process that ultimately determines rebreeding efficiency of sows (Lucy *et al.*, 2001). Sows normally return to oestrus 3-7 days after weaning in order to be inseminated and establish a new pregnancy (Soede and Kemp, 1997).

Multiple patterns of ovarian follicular development before weaning are observed when individual sows are compared (Lucy *et al.*, 2001). In general, sows with normal pattern have follicles of 2-5 mm in diameter when they are weaned and weaning origin a quick development of preovulatory follicles (Lucy *et al.*, 2001). The inhibition of LH secretion by lactation prevents preovulatory follicular development before weaning (Britt *et al.*, 1985; Varley and Foxcroft, 1990) and reducing suckling stimulus as the litter matures results in the increase of LH secretion (Britt *et al.*, 1985; Quesnel and Prunier, 1995). LH pulsatility increases within 4 hours after weaning therefore it is believed that the increase in LH secretion stimulate follicular growth

(Lucy *et al.*, 2001). Growth of ovarian follicles after weaning leads to an increase in oestradiol and decrease in FSH. The decrease in FSH prevents the development of small follicles during the preovulatory period and ensures that only LH-dependent follicles (>5 mm) will continue the development (Lucy *et al.*, 2001). When sows come into oestrus the follicles are maximally steroidogenic at 6-7 mm and they grow slightly larger (7-8 mm) before ovulation. Lucy *et al.* (1999) concluded that sows ovulated on day 5 after weaning have an earlier follicular development than sows ovulated on day 7 or 9 after weaning and their growth curves for the preovulatory follicles are parallel (Figure 2.4). In sows with low body condition or in sows exposed to heat stress a long interval from weaning to oestrus has been observed (Lucy *et al.*, 2001). Nutritional and environmental inputs can modify the secretion of LH. In sows that are under-fed or exposed to high environmental temperatures may occur the decrease of follicular growth associated with reduced LH secretion (Lucy *et al.*, 2001).

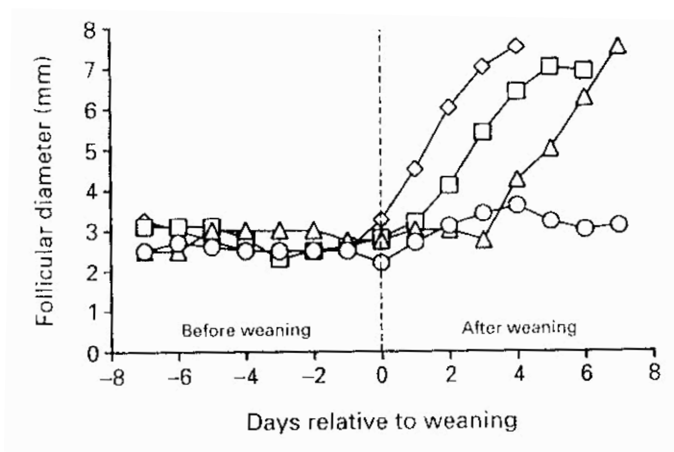

Figure 2.4. Average diameter of the follicular cohort in sows with different weaning to oestrus interval (◇-5 days, □-7 days, △-9 days and ○-anoestrus). (Source: Lucy *et al.*, 2001)

2.4.2. Ovulation

Ovulation usually occurs about 40 hours after the onset of oestrus when the heat period lasts about 2 days and it is a spontaneous process; when the duration of heat is longer than 2 days, ovulation occurs when about 75% of the heat period has elapsed (Gordon, 1997). In normal cyclic sows, the release of the LH being at the onset of oestrus and the interval from release of preovulatory LH to ovulation is about 40 hours (Niswender *et al.*, 1970). The LH surge induces ovulation, the differentiation of follicular cells and the formation of corpus luteum (CL), (Gordon, 1997).

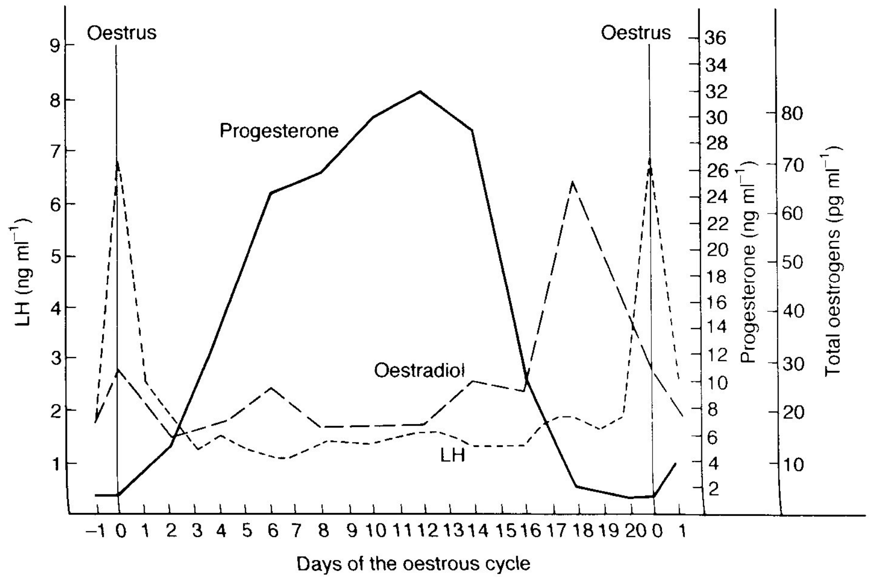

Figure 2.5. Diagrammatic representation of hormone levels during the oestrous cycle of the pig (Source: Gordon, 1997).

Figure 2.5 shows the hormone levels during the oestrous cycle of the sow. Oestrogen level raises during the follicular phase of the cycle, triggering the release of the preovulatory surge of LH at the onset of oestrus. The level of the GnRH remains low during the remainder of the cycle, there is just one sharp LH peak at oestrus (Gordon, 1997).

The oocytes from all of the large follicles from both ovaries ovulate in a relatively short period of time (approximately 3 hours). However, even though there is minimal variation in the time to ovulate all follicles within a female, the time of ovulation after onset of oestrus is highly variable between females (Knox, 2002).

Knox (2002) reported that after ovulation all the large follicles at oestrus, the oocytes, are moved into the oviduct. This movement occurs by the coordinated muscular contractions of a thin piece of tissue called the fimbria. The fimbria wraps around the entire ovary, and under the influence of oestrogen, induces muscular contractions which propel all of the oocytes into the funnel shaped opening of the oviduct (Knox, 2002). Fertilization takes place in the oviduct, at the ampullary-isthmic junction (Gordon, 1997). It is also important to note that the levels of oestrogen and progesterone can affect the movement of the sperm and oocytes in the oviduct. Excessive oestrogen at this time has been reported to cause oocyte retention in the oviduct, while excessive progesterone has the effect of opening the oviduct and speeding entry of the sperm and exit of the oocyte (Knox, 2002).

2.4.3. Maternal recognition and implantation period

The theory of maternal recognition and implantation period in pigs has been reported by several authors (Bazer *et al.*, 1982; Gordon, 1997 and Geisert *et al.*, 2005). Gordon (1997), reported that from day 11-12 of pregnancy, pig blastocysts start elongating and there is a decrease in their diameter, which gives rise to filamentous structures. Migration of embryos from the tip of the uterine horn to the body of the uterus starts after they have hatched and when the blastocyst starts to expand (Gordon, 1997). Ziecik *et al.* (2006) concluded that the period from successful fertilisation to the process of initiation of implantation lasts about 14 days. Also Gordon (1997) concluded that the implantation starts around day 13-14 of pregnancy and embryonic oestrogen play a role in regulating the uterine secretions on which embryos are highly dependent before and after implantation. Oestrogens produced by blastocysts from the day 11 alter the direction of movement of PGF and its secretion remains in an exocrine direction, to the uterine lumen in order to prevent PGF enter in the uterine venous drainage and to exert a luteolytic effect on the CL (Bazer *et al.*, 1982). Prostaglandins are key mediators on reproductive functions as ovulation, fertilisation, implantation and parturition (Ziecik *et al.*, 2006). However, although oestrogen plays a major function in preventing luteolysis and inducing uterine secretions necessary for changes in conceptus morphology for implantation in pigs, the inappropriate timing of uterine exposure to oestrogen has a detrimental effect on conceptus survival (Geisert *et al.*, 2005). According to Ford (1997) pregnancy recognition occurs between day 12 and day 18 after insemination.

2.4.4. Reproduction and heat stress

Summer and hot periods have been characterized by a decline in the pig's reproductive performance in many parts of the world (Wettemann *et al.*, 1988; Tantasuparuk *et al.*, 2000; Suriyasomboon *et al.*, 2006 and Bloemhof *et al.*, 2008). Elevated ambient temperatures have been shown to affect follicular development, increase the incidence of anoestrous which interfere with ovulation, reduce oocyte competence and conception rate and embryo survival (Habeeb *et al.*, 1992; Gordon, 1997 and Hansen *et al.*, 2001). Also male fertility is affected by high temperatures reducing semen quality (Gordon, 1997).

The hormones associated with stress (ACTH) may interfere on preovulatory oocytes and their development after fertilization. ACTH interrupted oocyte maturation by disrupting the integrity of the vitelline membrane and by interfering with the normal action of the cortical granules (Gordon, 1997). Liptrap (1993) suggested that stress in sows may result in a decrease in circulating oestradiol levels. Also Habeeb *et al.* (1992) concluded that insufficient gonadotrophin (FSH and LH) hormone secretion under heat stress may lead to inadequate oestrogen and/or progesterone production and consequently reproductive failure. Decreased LH may lead to ovulation failure with subsequent developmental failure of the corpus luteum (Habeeb *et al.*, 1992). Farghaly (1984) reported that thyroid gland also plays a role in reducing reproductive activity with a decrease in the level of triiodothyronine (T_3) and thyroxine (T_4) hormones.

Reproductive performance is reduced when gilts and sows are exposed to high ambient temperatures during early pregnancy (Wetteman *et al.*, 1988). Heat stress may interfere with early development and implantation of the embryo. Gilts exposed to heat stress have alterations in endocrine functions as decrease of progesterone concentrations and they tended to have smaller embryos at slaughter than gilts confined to the control chamber (Wettemann *et al.*, 1988). Also concentrations of oestrogens in plasma were influenced by exposure of gilts to elevated ambient temperatures. Decreased concentrations of oestradiol of pregnant heat stressed gilts during day 13 to 15 of pregnancy compared with control pregnant gilts may influence maternal recognition of pregnancy (Wettemann *et al.*, 1988).

Some alternatives can minimize the negative effects of high temperatures inside sow's housing. Cooling systems, nutritional solutions and management procedures can be used for to alleviate the negative consequences of heat stress on the sows' performance. However, for production in hot environment, it a more sustainable solution would be to select pigs resistant to heat stress.

2.5.Genetic improvements

Wild animals have been adapted to their environments through natural selection; by contrast farm animals, which are originated from wild animals, have been selected for productive traits (Bianca, 1976 and Owen, 1992).

At the presence of a heat stress situation attempts are made to provide sows capacity for cope with it relatively well. This capacity is increased by breeding and selection. Bianca (1976) reported that in tropical climates, some species of animals are combined breeds from temperate regions, which contributed with a high production capacity, and indigenous breed, which contributed with tolerance to heat and other adverse environmental conditions. The genetic proportion contributed by the indigenous partner is increased with increasing severity of the environmental conditions. Selection can be repeated over many generations and genetic progress made continually (Bianca, 1976).

Genetic differences were found among breeds and animals of the same breed such that there is both genetic and non-genetic variability between pigs of the same breed under the same management system. For reproduction traits, such as litter size, and its components, such as ovulation rate and embryonic survival, genetic variability is due to segregation of many genes which have different effects on each trait and also exist with different frequencies in the population (Hill and Webb, 1982). It is necessary to distinguish between genetic differences in performance observed among and within different breeds, or lines of the same breed in different herds.

For Knap (2005), increasing genetic potential requires advances in animal nutrition and animal management to support its expression; however they are often poorly addressed or overlooked and changes in genetic potential are often not accompanied by changes in the production environment. Selection for increased production and reproduction traits occurs in nucleus level in mainly temperate climates and under improved environmental conditions (Knap, 2005).

In general, environmental sensitivity is increased by selection on production traits under improved environmental conditions (van der Waaij, 2004). Genetic variation in heat stress tolerance between animals has been found for cattle, sheep and sows (Ravagnolo *et al.*, 2000; Finocchiaro *et al.*, 2005 and Bloemhof *et al.*, 2008).

The historical development of the breeds may be important to understand the attributes and problems of today's breeds. The major centres of a breed development were England, China and USA (Jones, 1998).

Peltoniemi and Virolainen (2006) reported a clear difference in reproductive performance between breeds. Yorkshire sows had 1.20 times higher risk of rebreeding and Landrace sows had 1.12 times higher risk of rebreeding than crossbreed sows. However, the Yorkshire breed appeared to be more susceptible to seasonal variation in reproduction than the Landrace breed (Peltoniemi and Virolainen, 2006).

Although there has been confusion about the names Yorkshire and Large White, Large White pig is originated in the United Kingdom, although is known in many countries as the Yorkshire pig (Gordon, 1997). Selection for both breeds has been done in different countries. The Large White breed has been registered since 1884 and the Yorkshire breed had the first herd book published in 1901 (Briggs, 1983). During the past years selection in both lines was based on body weight (BW) gain, back fat, litter size and litter mortality (Bloemhof *et al.*, 2008). Comparing purebred Yorkshire sows with purebred Large White sows, purebred Yorkshire sows showed greater susceptibility to high temperature on litter size and farrowing rate than purebred Large White sows (Bloemhof *et al.*, 2008).

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3. ANALYSIS 1: UTILITY OF WEATHER RECORDS ON PIG BREEDING PROGRAM

3.1. Abstract

The objectives of this study were 1) to study on which day heat stress has the greatest impact on reproductive performance in two different sow lines, a Yorkshire line producing mainly in temperate climates and a Large White line producing mainly in hot climates, and 2) to find whether data from on-farm recording is a better predictor of heat stress than off-farm weather records to evaluate reproductive performance based on Temperature Humidity Index (THI).

Data included 2,695 records on reproductive performance from 568 sows on two sow farms, in Portugal and in Spain, collected from July 2007 to February 2010. Sows were from two different purebreds' lines, named D-line (Yorkshire purebred line) and I-line (Large White purebred line). The effect of Temperature Humidity Index was studied on 2 reproduction traits: total number born (TNB) and farrowing rate (FR). Data were corrected for fixed effects of parity, service sire and interaction between farm, year and month. Corrected data were used as observations in two different models to study the effect of Temperature Humidity Index. The models used were a linear regression model and a plateau linear model with the plateau representing the thermo-neutral zone and a linear the decrease above that zone. Each farm was associated with four weather stations to compare weather data.

Total number born of D-line was significantly affected by THI at 14 days after insemination and TNB of I-line was significantly affected by THI at 5 days before insemination. Farrowing rate of D-line was significantly affected by THI at 5 days before insemination and FR of I-line was not significantly affected by THI. The estimate decrease of TNB and FR per unit of THI increased was greater for D-line than for I-line. These differences may be an indication of genetic differences in heat stress tolerance in sow lines. Data from on-farm records were more accurate for predict losses in reproduction performance than information from weather station; however, the closest weather station also provides satisfactory information to quantify losses in reproduction performance under heat stress conditions.

Key words: heat stress, reproductive performance, sow line, Temperature Humidity Index, weather station.

3.2.Introduction

The increase of human population requires that animal protein should be produced in favorable and unfavorable environmental conditions. Portugal and Spain are classified as Mediterranean climate with cold and wet winter and hot and dry summer (Nããs, 2006). Pig production in Portugal is often affected by high temperatures (Lucas *et al.*, 2000). High temperatures combined with higher relative humidity influence productive and reproductive performance of sows (Fuquay, 1981; Prunier *et al.*, 1997; St. Pierre *et al.*, 2003; Peltoniemi and Virolainen, 2006 and Suriyasomboon *et al.*, 2006). Sows are exposed to heat stress when air temperature is above the thermal neutral zone, which lies between 12ºC and 22°C (Black *et al.*, 1993). Heat stress can compromise embryo production by decreasing expression of estrous behavior, altering follicular development, inhibiting embryonic development (Hansen *et al.*, 2001) and also may interfere with early development and embryo implantation (Wettemann *et al.*, 1988). Nevertheless, cattle, sheep and sows showed genetic variation in heat stress tolerance (Ravagnolo *et al.*, 2000; Finocchiaro *et al.*, 2005 and Bloemhof *et al.*, 2008).

In studies in heat stress effects on animal production, weather information are usually obtained from weather stations, which routinely collect daily or even hourly. Weather stations provide useful information, and it may as accurate as data collected on-farm, for studies to quantify the change in milk, protein and fat yield, in response to heat stress in dairy cattle (Ravagnolo *et al.*, 2000 and Freitas *et al.*, 2006). No study was developed to evaluate information from weather station to quantify the production losses in sows.

The objectives of this study were 1) to study on which day heat stress has the greatest impact on total number born (TNB) and farrowing rate (FR) in two different sow lines, a Yorkshire line producing mainly in temperate climates and a Large White line producing mainly in hot climates, and 2) to find whether data from on-farm recording is a better predictor of heat stress than off-farm weather records to evaluate TNB and FR based on Temperature Humidity Index.

3.3. Material and Methods

Animal Care and Use Committee approval was not required for this study because data came from an existing database.

3.3.1. Data

This study was based on data recorded on 2 sow farms, one located in Spain with 318 sows originated from a Dutch (D) purebred Yorkshire sow line and other sow farm in Portugal with 568 sows originated from an International (I) purebred Large White sow line. Data composed of 2,695 records from July 2007 until February 2010. Both sow lines belonged to genetic lines of the TOPIGS breeding company (Vught, The Netherlands). For I-line sows, the nucleus farm operate in Spain, Portugal, Italy, Philippines and Brazil and they provided its own females replacement. For D-line a similar structure existed over these years with solely Dutch nucleus and multiplication farms. Nowadays there are some nucleus farms with D-line in Spain. Data for BVE estimation came from all of these farms.

Data available with individual information for each sow included sow identification number, birth date, parity, farm, sow line, first insemination date, service sire, re-insemination, re-insemination date, non return rate at 28 days (NR28), gestation length, farrowing rate (FR), farrowing date, total number of piglets born (TNB), number of piglets born alive (NBA), number of stillborn piglets (NSB), number of mummified piglets (NMP), litter mortality (LTM), weaning date, number of weaned piglets (NW), interval between weaning to 1st insemination.

Farrowing rate (FR) was recorded as a binomial trait and was defined as 100 if the insemination resulted in a pregnancy and gestation length was longer than 108 days or if litter size was at least 1; otherwise, FR was defined as 0. Non return at 28 days (NR28) was recorded as a binomial trait and defined as 100 if till 28 days after insemination sow did not return in heat (the gestation is confirmed by ultrasound scanning); otherwise NR28 was defined as 0.

Interval weaning to first insemination was defined as the number of days from weaning to first service within 30 days, values longer than 30 days was regarded as missing values.

For the statistical analysis, parity was grouped into 7 classes: 1, 2, 3, 4, 5, 6, 7-10. Intervals between: [μ - 3σ; μ + 3σ] were restricted for TNB, NBA, NSB, NMP and NW, values outside of this range were treated as missing values. Service sire effect was grouped into 22 classes, grouping boars with less than 25 observations by boar line.

In both farms sows, after lactation period, sows stay at service room until pregnancy is confirmed. Then sows are moved to gestation pens until 7 days before farrowing. In gestation pens, groups are composed by 9 pregnant sows grouped by sows with the same body condition and similar weight. In both farms, in Portugal and in Spain ventilation systems are used; and in Portugal there is also water cooling system in the windows at the service, gestation and farrowing unit.

3.3.2. Meteorological data

Meteorological data was available from weather stations and from on-farm recording. Temperature and humidity were recorded on-farm with a data logger at farrowing unit every hour, from July 2007 to February 2010. At farrowing unit, the equipment for record temperature and humidity was placed in the middle of the compartment at a height of about 1.70m. Average, maximum and minimum temperature and humidity were calculated for each day.

For each farm 4 weather stations at different distances from the farm were chosen from the European Climate Assessment Dataset (Klein Tank *et al.*, 2002). Meteorological data from weather station included daily summaries for average, maximum and minimum outside temperature and humidity. For all these weather station, data was available from 2007 and until February 2010. Distance between each farm and each weather station were calculated using their latitude (lat) and longitude (lon) with the following equation of Ravagnolo and Misztal (2002), where the distance (in kilometers) between location 1 and 2 is:

$$distance_{(1,2)}=6371*(acos(sin(lat_1)*sin(lat_2)+cos(lat_1)*cos(lat_2)*cos(lon_{2-1}));$$

The closest weather station for the farm located in Portugal was in Beja, about 40 km far from the farm and the closest weather station for the farm located in Spain was in Valladolid, about 92 km far from the farm. Geographical conditions were studied to understand the influence of distance between farm and weather station on the results.

3.3.3. Calculations and Statistical Analysis

Data were analysed using the MEANS procedure of SAS program (Version 9.2, SAS Institute Inc., Cary, NC).

Weather data used in the analyses consist of humidity data and temperature data during the period of study (from July 2007 to February 2010). The Temperature Humidity Index (THI) is one simpler method to quantify heat stress in animals. THI was calculated for on-farm records by combining values of relative humidity, RH (%) and air temperature, T (°C), using the following equation of Kelly and Bond (1971):

$THI= (1.8\times T) + 32 – (0.55 – 0.0055\ RH) \times ((1.8\times T) – 26)$. [1]

Maximum THI was calculated for each day using maximum temperature (T_{max}) and minimum relative humidity.

For evaluating the effect THI on different reproductive traits was used the GLM Procedure of SAS program (Version 9.2, SAS Institute Inc., Cary, NC). Statistical significance was set on $P<0.05$.

To test whether there was a thermo neutral zone and a UCTHI (upper critical THI), were defined 2 models: a linear regression model and a plateau-linear model.

Model [2], linear regression model, was used to determine at which day (5 days before insemination day, insemination day or 14 days after insemination day) heat stress had a greater influence on TNB and FR. Data from D-line and from I-line were analysed separately. The fixed-effect model (Figure 3.1) was defined as:

$$y_{ijklm} = \mu + ym_i + p_j + v_k + b * THI + e_{ijklm} \quad [2]$$

where y_{ijklm} is the reproductive trait to be tested: TNB and FR; ym_i is the fixed effect of year, month (29 classes); p_j is the fixed effect of parity number (7 classes); v_l is the fixed effect of service sire (22 classes); b is the slope of y when THI increases with 1 unit; and e_{ijklm} is residual.

The effect of THI on TNB and FR was investigated using plateau-linear model (model [3] and model [4]). In model [3], data were corrected for systematic effects using the following model:

$$y_{ijkl} = \mu + ym_i + p_j + v_k + e_{ijkl} \quad [3]$$

where y_{ijkl} is the value of TNB and FR; ym_i is the effect of year, month (29 classes); p_j is the effect of parity number (7 classes); v_k is the effect of service sire (22 classes); b is the slope of y when THI increases with 1 unit; and e_{ijkl} is a random residual term. Corrected observations (y*) for TNB and FR were calculated for each record as:

$$y^*=\mu+\hat{e}_{ijkl} \quad [4]$$

Corrected observations (y*) were used to investigate the effect of THI on TNB and FR. It was tested a plateau-linear model including a thermo-neutral zone (i. e., a plateau) for both sow lines using NLIN procedure (Version 9.2, SAS Institute Inc., Cary, NC). The linear regression model was adapted to thermo-neutral zone theory and a plateau was added to the linear regression model resulting in a plateau-linear model. Relationship between trait and THI is described by this concept:

$$UCTHI = \frac{c - i}{b}, \qquad [5]$$

where UCTHI is the estimate for upper critical THI, c is the constant value of y_i* when TNB and FR of the sow are unaffected by THI, i is the intercept, and b is the slope of the decrease in y_i* when y_i* is affected by THI (Figure 3.2).

$$\begin{cases} y_i^* = c + e_i, \quad \text{if } x_i \leq \text{UCTHI, and} & [6] \\ y_i^* = i + b * x_i + e_i, \quad \text{if } x_i > \text{UCTHI.} & [7] \end{cases}$$

In the first part of equation system [6], TNB and FR are not affected by THI, where y_i* is the corrected observation for TNB and FR, c is the constant value of y_i* when TNB and FR of the sow are unaffected by THI, e_i is a random residual term, and x_i is the THI at the day which had the greater impact on TNB and FR varying from 67 to 77 (Figure 3.2). The second part of equation system [7] estimates the decline of TNB and FR when THI exceeds the UCTHI, where y_i* is the corrected observation for TNB and FR, i is the intercept, b is the slope of the decrease in y_i*, x_i is the THI at the day which had the greater impact on TNB and e_i is a random residual term, and (see also Figure 3.2).

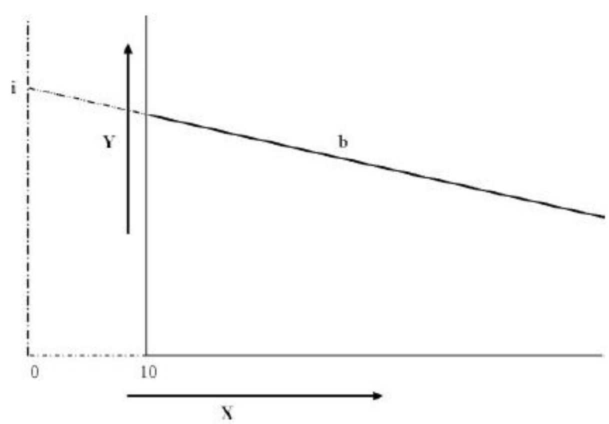


Figure 3.1. Linear regression model: X is the THI, Y is the reproductive traits, TNB and FR, i is the intercept and b is the slope of the decrease in Y per unit of increase of THI (adapted by Bloemhof *et al.*, 2008)

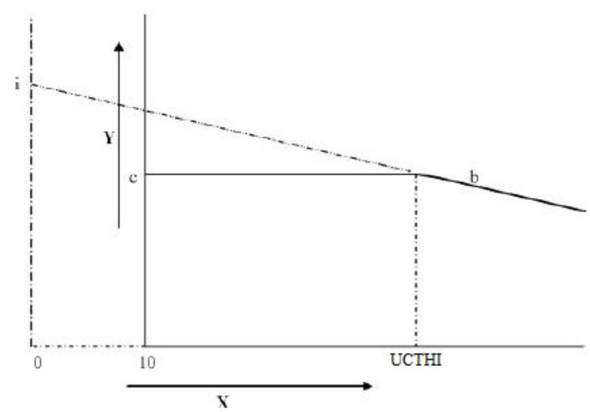


Figure 3.2. Plateau-linear model: X is the THI, Y is the reproductive traits, TNB and FR, UCTHI is the upper critical THI, c is the constant of Y when Y is unaffected by THI, i is the intercept and b is the slope of the decrease in Y per unit of increase of THI (adapted by Bloemhof *et al.*, 2008)

Comparison between plateau-linear model and linear regression model were done for each sow line to investigate the best model that could explain the effect of THI on TNB and FR.

A correlation between THI on-farm and off-farm records from different weather stations was calculated, for Portugal and Spain, using the CORR Procedure of SAS program (Version 9.2, SAS Institute Inc., Cary, NC).

The effect of THI from on-farm and off-farm weather records was studied using the model with higher F-value.

3.4.Results

Descriptive statistics of productive and reproductive traits of D-line and I-line are presented in Table 3.1. Mean parity number after grouping parity 7-10 in D-line (4.2) was slightly greater than in I-line (4.0). Farrowing rate was higher for I-line (83.7%) than for D-line (81.0%). Total number piglets born, number of piglets born alive and number of stillborn piglets was greater for D-line (12.0, 11.3 and 0.6 piglets, respectively) than for I-line (11.8, 11.0 and 0.4 piglets, respectively). Gestation length, number mummified piglets and interval weaning to first insemination were equal in both lines. Means of lactation length, number of piglets weaned and non-return at 28 days were greater for I-line (24.9 days, 10.4 piglets and 91.8%, respectively) than for D-line (23.4 days, 9.9 piglets and 88.7%).

Table 3.1. Number of observations (n), mean, standard deviation (SD) and range of productive and reproductive traits for 2 sow lines, a Dutch purebred Yorkshire line (D) and an International purebred Large White line (I).

Trait	Line	n	Mean	SD	Range
Parity	D	975	4.2	1.9	1-7
	I	1,720	4.0	1.8	1-7
Gestation length, d	D	889	113.2	1.2	108-119
	I	1,589	113.5	1.9	108-119
Farrowing rate (%)	D	975	81.0	39.2	0-100
	I	1,720	83.7	36.9	0-100
Total number born	D	886	12.0	2.5	2-19
	I	1,554	11.8	2.5	2-21
Number born alive	D	884	11.3	2.4	2-19
	I	1,537	11.0	2.5	2-18
Number stillborn	D	902	0.6	0.8	0-3
	I	1,565	0.4	0.8	0-3
Number mummified piglets	D	914	0.1	0.3	0-2
	I	1,575	0.1	0.4	0-2
Lactation length, d	D	884	23.4	3.1	9-41
	I	1,504	24.9	3.7	1-44
Litter mortality (%)	D	884	11.0	12.7	0-100
	I	1,501	6.5	11.4	0-100
Number piglets weaned	D	880	9.9	1.8	3-15
	I	1,490	10.4	1.7	3-15
Interval weaning - 1st insemination, d	D	878	5.5	3.1	2-29
	I	1,515	5.5	4.4	2-30
Non-return at 28 days (%)	D	968	88.7	31.6	0-100
	I	1,704	91.8	27.4	0-100

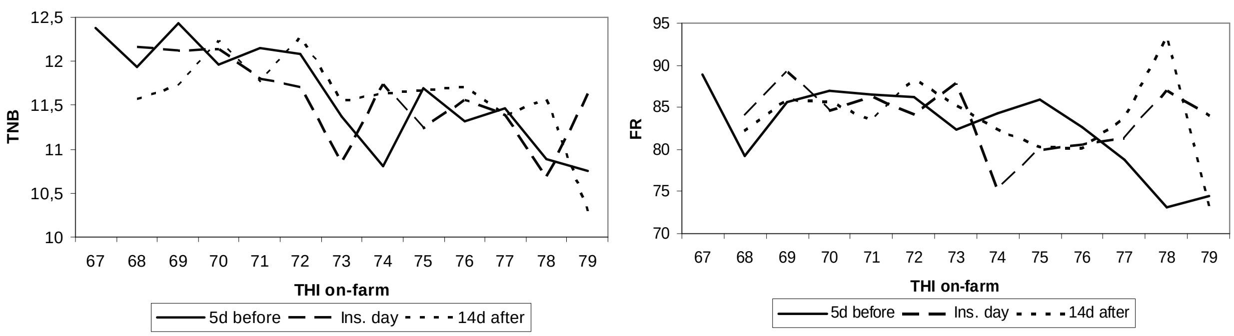
Descriptive data of weather variables are presented in the Table 3.2. During the period of this study sows from I-line had a slightly greater average of maximum temperature and THI on-farm (26.2ºC and 72.3, respectively) than sows from D-line (25.8ºC and 71.9, respectively).

Means of TNB and FR by THI recorded on-farm for two different sow lines at 5 days before insemination, insemination day and 14 days after insemination are presented in Figure 3.3.

Table 3.2. Number of observations (n), mean, standard deviation (SD) and range of maximum temperature and THI measured daily on-farm during the period of study on 2 sow farms, one with a Dutch purebred Yorkshire line (D) and other farm with an International purebred Large White line (I).

Variable	Line	n	Mean	SD	Range
Max. on-farm temperature (ºC)	D	752	26.2	3.0	19-34
	I	631	25.8	3.1	18-35
THI on-farm	D	752	71.9	2.7	64-79
	I	631	72.3	3.5	64-81

a) I-line



b) D-line

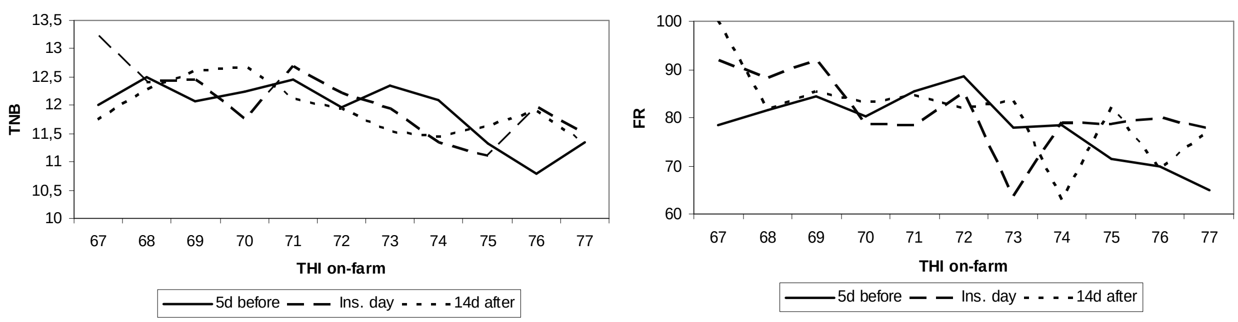


Figure 3.3. Means for total number born (TNB) and farrowing rate (FR) by Temperature Humidity Index (THI) recorded on-farm, at 5 days before insemination (——), insemination day (– – –) and 14 days after insemination (- - - -), for 2 sow lines, an International purebred Large White line (I) and a Dutch purebred Yorkshire line (D).

A preliminary analysis of the effect of maximum temperature and THI on TNB and FR showed a greater coefficient of determination when THI was used in the model instead of maximum temperature (data not shown).

Table 3.3 shows the analysis results of the linear effect of THI on TNB and FR versus a plateau-linear effect of THI on TNB and FR at 5 days before insemination, insemination day and 14 days after insemination for two different sow lines. For D-line, the plateau-linear effect of THI on TNB was more significant than the linear effect of THI at 5 days before insemination (F-value=3.89 and 1.98, respectively), insemination day (F-value=2.74 and 1.97, respectively) and 14 days after insemination (F-value=4.52 and 2.39, respectively). Comparing plateau-linear effect of THI on TNB for D-line, THI at 14 days after insemination showed the highest F-value (4.52) of the model and consequently THI at 14 days after insemination had a largest negative impact on TNB (Table 3.3). For D-line, the estimated decrease in TNB was -0.11 per each unit of THI above 70.0 THI (Table 3.4).

For I-line, analysing the results of the linear effect of THI and the plateau-linear effect of THI on TNB, linear effect of THI on TNB was more significant than the plateau-linear effect of THI at 5 days before insemination (F-value=5.06 and 0.48, respectively), insemination day (F-value=4.75 and 0.73, respectively) and 14 days after insemination (F-value=4.58 and 1.69, respectively). Analysing different moments of sow's cycle, 5 days before insemination had the greatest F-value of the model, 5.06 (Table 3.3). A linear significant negative effect of THI on TNB was found for I-line sows at 5 days before insemination. For I-line sows, the estimated decrease in TNB was -0.09 per each unit of THI (Table 3.4).

Analysing the results of the linear effect and the plateau-linear effect of THI on FR, for D-line sows, F-value from the plateau-linear model was greater than F-value from the linear model effect at 5 days before insemination (3.04 and 2.05, respectively) and at 14 days after insemination (2.70 and 2.12, respectively). For I-line sows, F-value from linear model effect of THI on FR was greater than F-value from the plateau-linear model effect of THI and class effect of THI had no significant influence on FR. Five days before insemination showed the greatest impact on FR for D-line and I-line sows (Table 3.3). For D-line, the estimated decrease in FR was -1.11 per each unit of THI above 66.3 THI and for I-line sows, the estimated decrease in FR at 5 days before insemination was -0.14 per each unit of THI (Table 3.4).

Table 3.3. Significance tests for linear (L) and plateau-linear (P) relations between two reproductive performance traits and Temperature Humidity Index (THI) at different moments, measured on-farm for 2 sow farms, one with a Dutch purebred Yorkshire line (D) and other farm with an International purebred Large White line (I).

Reproduction trait	Day	Line	Model	F_{model}	P_{model}	F_{THI}	P_{THI}
Total number born	5 days before	D	L	1.98	<0.05	0.84	ns
			P	3.89	<0.05		
		I	L	5.06	<0.05	6.63	<0.05
			P	0.48	ns		
	Insemination	D	L	1.97	<0.05	0.53	ns
			P	2.74	0.07		
		I	L	4.75	<0.05	0.37	ns
			P	0.73	ns		
	14 days after	D	L	2.39	<0.05	0.86	ns
			P	4.52	<0.05		
		I	L	4.58	<0.05	2.17	ns
			P	1.69	ns		
Farrowing rate	5 days before	D	L	2.05	<0.05	0.01	ns
			P	3.04	<0.05		
		I	L	2.12	<0.05	0.05	ns
			P	0.92	ns		
	Insemination	D	L	2.02	<0.05	0.06	ns
			P	0.54	ns		
		I	L	2.09	<0.05	0.06	ns
			P	0.50	ns		
	14 days after	D	L	2.12	<0.05	1.13	ns
			P	2.70	0.07		
		I	L	2.12	<0.05	0.00	ns
			P	0.70	ns		

Table 3.4. Estimated values of the total number born (TNB) and farrowing rate (FR) when reproduction is not influenced by THI (constant), upper critical temperature humidity index (UCTHI), and slope of the decrease above the UCTHI (slope), for 2 sow lines, a Dutch purebred Yorkshire line (D) and an International purebred Large White line (I).

Trait	Line	Model	Day	Constant	UCTHI	Slope
TNB	D	P	14 days after	12.2	70.0	-0.11
	I	L	5 days before	—	—	-0.09
FR	D	P	5 days before	86.6	66.3	-1.11
	I	L	5 days before	—	—	-0.14

For I-line sow farm, correlations between THI on- and off-farm records and distance between farm and weather stations are presented in the Table 3.5. On-farm records showed a higher correlation with Beja weather station (+0.92) than with other weather stations far from the farm. All correlations were significant with P<0.001.

Table 3.5. Correlation between THI of Portuguese weather stations and on-farm weather data with distance between farm and weather stations.

Weather stations	Altitude (m)	On-farm	Beja 43 Km	Faro 117 Km	P. Douradas 271 Km	Porto 354 Km
On-farm	75	1.00	0.92	0.89	0.86	0.86
Beja	247		1.00	0.93	0.92	0.91
Faro	4			1.00	0.85	0.86
P. Douradas	1,380				1.00	0.89
Porto	73					1.00

Correlations between THI on- and off-farm records and distance between farm and weather stations, for D-line sow farm, are presented in the Table 3.6. On-farm records showed a higher correlation with Valladolid and Zaragoza weather station (+0.73) than with other weather stations far from the farm. All correlations were significant with P<0.001.In general, correlations between D-line sow farm and weather stations in Spain were lower than correlations between I-line sow farm and weather stations in Portugal.

Table 3.6. Correlation between THI of Spanish weather stations and on-farm weather data with distance between farm and weather stations.

Weather stations	Altitude (m)	On-farm	Valladolid 92 Km	San Sebastian 207 Km	Zaragoza 278 Km	Tortosa 430 Km
On-farm	786	1.00	0.73	0.71	0.73	0.71
Valladolid	854		1.00	0.82	0.92	0.90
San Sebastian	252			1.00	0.86	0.83
Zaragoza	247				1.00	0.95
Tortosa	48					1.00

Results of the evaluation of differences between sources of weather information on TNB of I-line at 5 days before insemination are presented on Table 3.7. Total number born was significantly affected (P=0.01) by on-farm and Beja THI. No differences were found between coefficients of determination from on- and off-farm THI on TNB. When the distance between farm and weather station increased P-value decreased. Evaluation of the effect THI on- and off-farm on FR was not performed because class effect of THI had no significant influence on FR of I-line (Table 3.3).

Table 3.7. Results from the analysis of variance for Temperature Humidity Index on- and off-farm for total number born (TNB) at 5 days before insemination for I-line sow farm.

		On-farm	Beja	Faro	Penhas Douradas	Porto
TNB	Total	9,376	9,373	9,376	9,376	9,376
	Model	1,025	1,030	1,005	997	992
	Error	8,352	8,343	8,372	8,379	8,385
	THI SS III	38.4	45.6	18.3	10.6	5.2
	R^2	0.11	0.11	0.11	0.11	0.11
	β	-0.09	-0.05	-0.04	-0.02	-0.02
	F value	5.06	7.88	3.15	1.83	0.90
	P-value	0.01	0.01	0.08	0.18	0.34

Table 3.8 shows the results of the evaluation of differences between on- and off-farm records on TNB at 14 days after insemination and on FR at 5 days before insemination for D-line using plateau-linear analysis. No large differences were found between constant values from plateau-analysis for on- and off-farm records on TNB. Valladolid and San Sebastian weather station showed the lowest upper critical THI. Plateau-linear analysis from Valladolid and Tortosa weather station tended to be significant. Total number born was significantly affected ($P<0.05$) by THI from on-farm, San Sebastian and Zaragoza weather station. Farrowing rate was significantly affected by THI from on- and off-farm records. Differences were found between constant values from the plateau analysis for on- and off-farm weather records. Valladolid and San Sebastian weather station showed the lowest UCTHI from plateau linear analysis. On- and off-farm THI had always a negative effect on TNB and FR for D-line sows.

Table 3.8. Results from the plateau-linear analysis for average Temperature Humidity Index on- and off-farm on total number born (TNB) at 14 days after insemination and on farrowing rate (FR) at 5 days before insemination for D-line sow farm.

		On-farm	Valladolid	San Sebastian	Zaragoza	Tortosa
TNB	Constant	12.2	12.1	12.2	12.1	12.1
	UCTHI	70.0	63.2	61.0	71.3	72.0
	β	-0.11	-0.05	-0.04	-0.04	-0.03
	F value	4.52	2.85	3.80	3.68	2.91
	P-value	0.01	0.06	0.02	0.03	0.06
FR	Constant	86.8	84.9	86.7	86.6	88.0
	UCTHI	66.3	53.0	45.9	71.3	72.0
	β	-1.11	-0.50	-0.42	-0.30	-0.26
	F value	3.04	4.80	4.38	4.04	3.91
	P-value	0.05	0.01	0.01	0.02	0.02

3.5.Discussion

General

The present study investigated the influence of temperature and humidity on reproductive performance of purebred Yorkshire and purebred Large White sows in hot climates. The relation between temperature and humidity recorded on-farm and recorded in the weather station was also studied.

The overall results of the present study reveal that temperature humidity index influences reproductive performance of the sows and differences between sow lines in reproductive performance were found. Data from weather station may be useful to study heat stress effects when weather data of on-farm is not available.

Different reproductive performance results for purebred Yorkshire sow line and Large White sow line had been found in Spain on average of total number born (11.3 and 10.9 piglets, respectively), parity number (3.4 and 3.2 cycles, respectively), number born alive (10.3 and 10.0 piglets, respectively) and number of stillborn piglets (2.5 and 2.1 piglets, respectively) (Bloemhof *et al.*, 2008). Comparing our results with results from Bloemhof *et al.* (2008), sows from our analysis had a better performance and this may due to genetic improvements in the past years.

Temperature-Humidity effects on Reproductive Performance

Negative influence of high temperature and humidity on reproductive performance of sows has been described by several authors (Omtvedt *et al.*, 1971; Wettemann *et al.*, 1988; Tantasuparuk *et al.*, 2000; Hansen *et al.*, 2001; Suriyasomboon *et al.*, 2006 and Bloemhof *et al.*, 2008).

The day which heat stress had the greatest negative impact on total number born was different for both sow lines. Total number born of D-line was more affected by THI at 14 days after insemination and TNB of I-line was more affected by THI at 5 days before insemination. Although sows are from different lines, was not expected result different days with the largest negative impact on TNB; the lowest number of observations may be one reason for this difference For farrowing rate both lines were more negatively affected by THI at 5 days before insemination. Hansen *et al.* (2001) reported that heat stress decrease follicular growth and follicular fluid concentration of oestradiol. Also oocyte competence can be affected by heat stress; the disruption of patterns of folliculogenesis could lead to ovulation of an aged oocyte with lowered potential for fertilization (Hansen *et al.*, 2001). Although the exposure of spermatozoa to elevated temperatures while in the uterus or oviduct of a hyperthermic female could compromise sperm survival or fertilizing capability, THI at insemination day had not the greatest impact on TNB and FR. Suriyasomboon *et al.* (2006) found a significant negative effect of temperature and humidity after mating on total number born. Omtvedt *et al.* (1971) concluded that gilts exposed to heat stress from 8 to 16 days post breeding had fewer viable embryos at slaughter than gilts exposed to heat stress from 0 to 8 days after mating. Wettemann *et al.* (1988) also concluded that the decrease of oestradiol concentrations during days 13 to 15 in heat-stressed gilts compared with not heat-stressed gilts suggests that heat stress may influence maternal recognition of pregnancy. This indicates that the implantation period and maternal recognition of pregnancy may be the most critical period which influences TNB.

A clear upper critical THI for reproductive performance of D-line sows was estimated. For I-line sows, it was not possible estimate upper critical THI for reproductive performance. No literature was found to compare with our calculation of upper critical THI. Ravagnolo *et al* (2000) reported that heat stress in dairy cattle starts at a THI of 72. The upper critical THI recorded on-farm for TNB of D-line was 70 which correspond to 21ºC at 100% humidity, 22ºC at 80% humidity or 23ºC at 60% of humidity. The upper critical THI recorded on-farm for FR of D-line was 66.3 which correspond to 19ºC at 100% humidity, 20ºC at 70% humidity or 21ºC at 50% of humidity. Bloemhof *et al*. (2008) found an upper critical temperature at day of insemination of 21.7ºC for litter size for D-line. The same study also found an upper critical temperature at day of insemination of 19.2ºC for farrowing rate of D-line sows. In our study and Bloemhof *et al*. (2008) upper critical THI and upper critical temperature, respectively, were lower for farrowing rate than for TNB or litter size.

The estimate decrease of TNB per unit of THI increased was larger for D-line than for I-line sows. Different results were found by Bloemhof *et al*. (2008) on litter size where D-line had an estimated decrease of -0.05 per 1ºC increased above upper critical temperature and I-line had an estimated decrease of -0.01 in a linear model. For farrowing rate, I-line proved to be more resistant to high THI showing a lower slope than D-line. Although I-line had a significant F-value of the model for FR, the class effect of THI on FR was not significant. No effect of maximum temperature at day of insemination on FR was found for I-line (Bloemhof *et al.*, 2008). For D-line sows, Bloemhof *et al*. (2008) estimated a decrease of -0.01 of FR measured as a binomial trait (0 and 1) with maximum temperature at day of insemination above 19.2ºC. Tantasuparuk *et al*, (2000) reported for TNB a regression coefficient of -0.06 per each unit of heat index increased and for FR a regression coefficient of -0.07 per each unit of heat index increased during the first four weeks after mating for Landrace and Yorkshire sows.

Meteorological data

Correlation between Temperature Humidity Index recorded on-farm of I-line and at different weather stations, during the period of the analysis, showed a greater correlation between on-farm and the closest weather station (+0.92) as expected. For I-line farm, when the distance between farm and weather station increased, the correlation between THI on-farm and THI from weather station decreased.

I-line farm is situated in the south of Portugal, in Alentejo. Alentejo is characterized by great uniformity peneplains, where stands out, dispersed and remote, mountainous masses of low altitude. Altitudes between farm and the closest weather station range from 75 to 247 m. Alentejo is particularly hot during the summer and temperatures can reach 40°C. The uncomplicated landscape and the short distance (40 km) between farm and the closest weather station may explain the high correlation between THI on-farm and THI at Beja weather station (+0.92). Correlations between farm and weather station may be affected by distance between farm and weather station and geographical conditions between them. Distance between farm and Porto weather station is greater than distance between farm and Penhas Douradas weather station; however correlation is the same. Penhas Douradas weather station is located in a mountain, while Porto weather station is located in the coast. Different altitude of Penhas Douradas and Porto weather station may be the reason which explains the same correlation for different weather stations with different distances and different geographical conditions.

Temperature humidity index recorded on-farm of D-line and Spanish weather stations had lower correlations comparing to correlations between THI recorded on-farm of I-line and Portuguese weather stations. The highest correlation between THI of D-line farm and its weather stations was recorded in the closest weather station and Zaragoza weather station. D-line farm is situated close to Burgos, in the north of Spain, in the autonomous community of Castile and León. The closest weather station is located in Valladolid which is 92 km far and a higher altitude than D-line farm. Between D-line farm and Valladolid weather station, landscapes and geographical conditions are different which can influence weather conditions. The large distance (92 km), differences in altitude and complicated landscapes between D-line farm and it closest weather station may be the reason for lower correlation (+0.73) between THI measured at the D-line farm and Valladolid weather station when compared with I-line farm and Beja weather station.

Analysing results of the effect of THI on TNB and FR, in spite of larger distances between farm and weather stations, all weather stations were able to record the negative effect of THI on TNB and FR for D-line and TNB for I-line. When distance between farm and weather station increased, the significant effect of THI on TNB of D-line and I-line, in general decreased.

For I-line farm, the effect of THI on TNB tended to be significant for distances between farm and weather station lower than 117 Km. Distant weather stations until 117 Km may provide reasonably good information to account heat stress losses when they are located in relatively flat area. In other areas, with complicated landscape, mountains, rivers or close to the forest, data from a distant weather station may be less useful or not accurate in capturing the effect of heat stress as the data collected on-farm. Freitas *et al.* (2006) found a correlation of 0.9 between on-farm weather data and weather station data was estimated even for weather stations more than 300 km away from the farm but it was in geographically uncomplicated terrain.

Solar radiation and wind speed are parameters susceptible to huge differences among diverse locations; however they were not included in any model in this study. On this study was used THI, which is one of many approaches used to quantify heat stress in animals. Other approaches to quantify heat stress could be used, one example is black globe humidity index (BGHI) which characterize the thermal ambient in one value based on dry bulb temperature, relative humidity, radiation and air movement (Sampaio *et al.*, 2004).

3.6.Conclusion

The aim of this study was to investigate the effect of temperature and humidity on reproductive performance of sows and to estimate if on-farm records are a better predictor of heat stress than off-farm recording when used for application in genetic studies on heat stress tolerance.

A clear negative effect of temperature and humidity on reproductive performance was found. When Temperature Humidity Index increased total number born and farrowing rate decreased. The decrease in reproductive performance was different between sow lines; sows from D-line showed a higher decrease in reproductive performance than I-line with increasing THI. This difference may conclude that there is variation in heat stress tolerance between sow lines as measured by the differences between reproductive performances.

The results from the analysis of on- and off-farm records showed that weather data from on-farm records are more accurate for predict losses in reproductive performance than information from weather station. However, weather data from the closest weather station may be as accurate as the data recorded on farm when distance is not higher than 117 Km. Also, study the geographical conditions between the farm and the weather station is important; however, individual study for all farms is not realistic. For that, it would be advisable to use weather information from on-farm records in BVE.

3.7.References

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4. ANALYSIS 2: EVALUATION OF NEW TRAITS TO USE IN BREEDING VALUE ESTIMATION

4.1. Abstract

The objectives of this study were to analyse new indicator traits: feed intake score and losses in back fat during lactation, estimate their genetic parameters and to study genetic correlation between these new indicators and reproductive traits. Data were collected on two sows' farms, in Portugal and in Spain, from July 2007 to March 2010 and included 5,098 observations on reproductive performance from 1,894 sows. Temperature was recorded on-farm at farrowing unit. Feed intake score was evaluated as a school-report and it is an indicator to estimate the capacity of a quick start feed intake after farrowing. Feed intake score after farrowing and losses in back fat during lactation were analysed per farm and per line. The effect of temperature and season on feed intake score and change in back fat during lactation were studied. Heritability, repeatability and genetic correlation between new traits and reproductive traits were estimated.

Feed intake score is a trait affected by high temperature and season; however differences in accuracy of feed intake score classification between farms were found. Feed intake score is a trait with low heritability and may be introduced at Breeding Value Estimation to improve selection on start up of sows in Spain and Portugal; however it classification must be as accurate as possible. No clear effect was found between temperature at farrowing day and change in back fat during lactation and losses in back fat during lactation was not a heritable trait.

Key words: feed intake, back fat, sow, genetic parameters, Breeding Value Estimation.

4.2. Introduction

Last decades, intensive genetic selection and management changes have been done to increase litter size and number of weaned piglets (Hanenberg *et al.*, 2001 and Bergsma *et al.*, 2008). To support large litters it is important to keep sows in proper body condition. During lactation, sow's requirements are high; milk production has a high priority (NRC, 1987). A common problem on commercial swine farms is an inadequate voluntary feed intake by lactating sows to satisfy their nutritional requirements (Koketsu *et al.*, 1996).

When ambient temperatures increase above the thermal neutral zone, which lies between 12ºC and 22°C, voluntary feed intake is reduced in order to reduce heat production because of the thermal effect of feed (Black *et al.*, 1993 and Silva *et al.*, 2009). Reduced feed intake sows have body reserves mobilization as a result, in an attempt to maintain milk production; however this can compromise future reproductive and productive performance of the sow (NRC, 1987 and Dourmad *et al.*, 1998).

Differences in technical farm results have been found between different breeding lines in Spain and Portugal especially during hot periods. Some lines showed a more constantly production during those long hot periods. Other lines, although they show better technical results in colder areas like Western Europe, really dropped in terms of fertility rate which was indicated by more returns and more lost days at culling. Those performance indicators were not yet implemented at Breeding Value Estimation. Important differences on heat stress tolerance between sow lines as measured in reproductive performance have been found and this suggests that genetic selection on sow heat stress tolerance may be possible (Bloemhof *et al.*, 2008).

The objective of this study was to analyse new indicators: feed intake score and losses in back fat during lactation to implement at Breeding Value Estimation and estimate their genetic parameters. Second goal was to study genetic correlation between these new indicators and reproductive traits.

4.3.Material and Methods

Animal Care and Use Committee approval was not required for this study because data came from an existing database.

4.3.1. Data

Data was available from two sow farms, one in Portugal (PRT) and one in Spain (SP) from 1st of July 2007 until March 2010. Data comprised 5,098 cycles and it was available from the TOPIGS breeding program (Vught, The Netherlands) which included sow identification number, birth date, parity, farm, sow line, insemination date, service sire, gestation length, farrowing date, litter size, number live born piglets, number of stillborn piglets, number of mummified piglets, weaning date, number of weaned piglets and interval between weaning to 1st insemination. Also new traits for use at Breeding Value Estimation were included: feed intake score, back fat at farrowing and back fat at weaning.

Feed intake score is an indicator to estimate the capacity of a quick start feed intake after farrowing. The sow is judged how easy it starts producing after farrowing, looking at behaviour and activity (eating and drinking) of the sow at day 1 and 2 after farrowing under normal housing conditions. Its feed should be eaten within an acceptable time after feeding, approximately 1.5 to 2 hours after feeding. It is implemented as a given score at a school-report: 4 (minimum score = not passed), 6 (medium score = passed but with remarks) and 8 (good score = passed without problems).

Moreover, back fat measurements at start of the farrowing period and at the end of farrowing period were performed to measure body condition of each sow on P2, at position of the last rib, 6.5 cm out of spinal cord.

Sow line was divided in 5 groups (Table 4.1).

Table 4.1. Number of records per line per farm

	Line					
Farm:	I-Line	D-Line	25%I75%D	50%I50%D	75%I25%D	Total
PRT	2,612	—	—	60	92	2,764
SP	—	1,117	458	677	82	2,334
Total	2,612	1,117	458	737	174	5,098

4.3.2. Statistical analysis

Descriptive analysis was performed using the MEANS procedure (SAS 9.2, SAS Institute Inc., Cary, NC). Means were also calculated per line and per farm. Data were corrected for parity number of sows using GLM procedure (SAS Inst. Inc.).

Feed intake score and change in back fat during lactation were merged with temperature data recorded on-farm at day of farrowing and the effect of temperature on feed intake and body condition of lactating sows was studied.

For feed intake data and reproductive traits phenotypic variance, heritability and repeatability were estimated by univariate analysis using ASReml 2.0 (VSN International Ltd.). Several models were used for estimating genetic parameters for each trait (random effects are underlined). Model 1 was used to estimate genetic parameters for feed intake score, back fat at farrowing, back fat at weaning and change in back fat during lactation:

Y = μ + parity number + herd year month of farrowing + sow line + litter cross or purebred + animal + permanent environment + e;

Model 2 was used to estimate genetic parameters for litter mortality:

Y = μ + parity number + sow line + litter cross or purebred + herd year month of farrowing + animal + permanent environment + e;

Model 3 was used to estimate genetic parameters for total number born and number of weaned piglets:

Y = μ + re-insemination + sow line_ parity number + litter cross or purebred + herd year month of farrowing + animal + service sire + permanent environment + e;

Model 4 was used to estimate genetic parameters for number of stillborn piglets, where Y is number of stillborn piglets log transformed.

Y = μ + re-insemination + sow line* parity number + litter cross or purebred + interval weaning pregnancy + herd year month of farrowing + animal + service sire + permanent environment + e;

Herd, year, month of farrowing was included as a random effect because number of observations per class was quite low (ranged from 14 to 129).

Genetic correlations between traits were estimated using bivariate analysis and estimated using the same model used to estimate the heritability.

4.4.Results

Averages of total number born, litter mortality, number weaned and parity number were calculated per line (Table 4.2). I-line had lowest total number born (11.5 piglets) and litter mortality (6.7%) and highest number of weaned piglets (9.7). D-line had highest litter mortality (11.2%) and parity number (4.2). Line with 50% of I-Line genes and 50% of D-line genes had highest total number born (12.0). Sow line with lowest number of weaned piglets (8.9) and parity number (1.4) was 75% I-line genes and 25% D-line genes.

Table 4.2. Number of observations (n), mean and standard deviation (SD) of total number born, litter mortality, number weaned and parity number per line; I-line is an International purebred Large White line, D-line is a Dutch purebred Yorkshire line and %I:%D is the percentage of genes from sow lines.

Trait:	Total number born			Litter mortality			Number weaned			Parity number		
Line:	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
I-line	2,612	11.5	3.2	2,478	6.7	11.0	2,586	9.7	2.7	2,612	3.6	2.0
75%I : 25%D	174	11.7	4.2	146	8.3	12.5	161	8.9	3.5	174	1.4	0.6
50%I : 50%D	737	12.0	3.3	685	10.7	10.8	708	9.5	2.5	737	2.4	1.5
25%I : 75%D	458	11.9	3.6	424	11.0	11.7	443	9.3	2.7	458	2.5	1.5
D-line	1,117	11.9	3.2	1,079	11.2	13.1	1,115	9.4	2.6	1,117	4.2	1.9

Means of feed intake score by line show differences between animals from different lines (Table 4.3). Average feed intake score of I-line sows was 5.6 and it was higher than average feed intake score of D-line sows (4.7). For crosses between two lines, it seemed that when sows had higher percentage of D-line genes average of feed intake score decrease.

Table 4.3. Descriptive statistics and frequency of feed intake score per line; I-line is an International purebred Large White line, D-line is a Dutch purebred Yorkshire line and %I:%D is the percentage of genes from sow lines.

Line		n	Mean	SD	Class		
					4	6	8
I-line	n	1885	5.6	1.0	454	1341	90
	%				24	71	4
75%I : 25%D	n	144	4.8	1.0	93	49	2
	%				65	34	1
50%I : 50%D	n	639	4.4	0.7	536	102	1
	%				84	16	0
25%I : 75%D	n	397	4.3	0.7	348	49	0
	%				88	12	0
D-line	n	1007	4.7	1.0	654	347	6
	%				65	34	1

Differences between farms in feed intake score were found: PRT farm classified 70% of sows with feed intake score 6 and SP farm classified 74 % of sows with feed intake score 4 (Table 4.4). In Figure 4.1, average feed intake score per month is given for both farms. For PRT farm a clear seasonal pattern is shown, with highest feed intake scores during the winter and the lowest during summer period. For SP farm no seasonal pattern is shown but remarkable is that after January 2009 the feed intake score was always 4.

Table 4.4. Descriptive statistics and frequency of feed intake score per farm.

Farm		n	Mean	SD	Class		
					4	6	8
PRT	N	2,059	5.5	1.0	517	1448	94
	%				25	70	5
SP	N	2,013	4.5	0.9	1494	511	8
	%				74.2	25.4	0.4

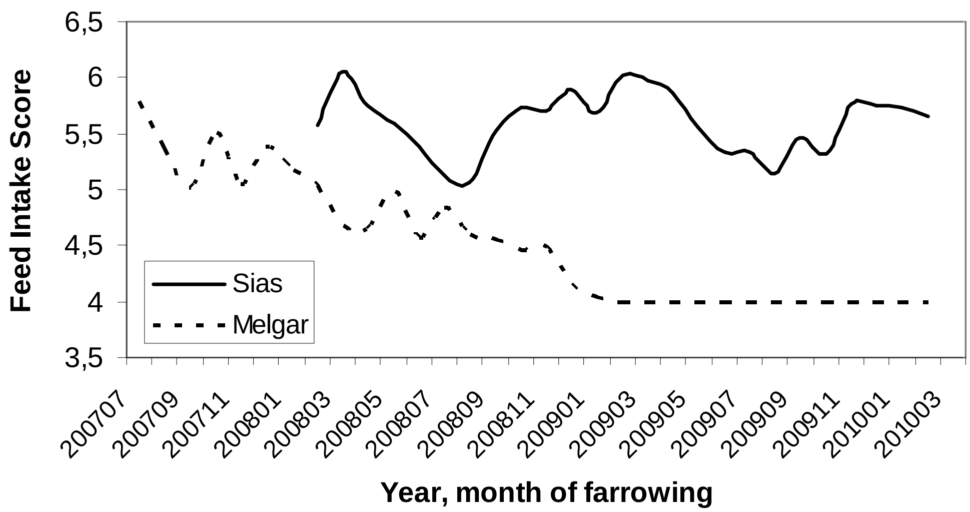

Figure 4.1. Average feed intake score (FIS) per month of farrowing for two farms (PRT — and SP - - -).

Figure 4.2 shows the result of the analysis of feed intake score per maximum temperature at day of farrowing recorded on-farm. For PRT farm, sows are classified with higher feed intake scores when the values of daily maximum temperature decreased and with lower feed intake scores when the daily maximum temperatures increased. No relation was found between feed intake score and maximum temperatures at farrowing on SP farm.

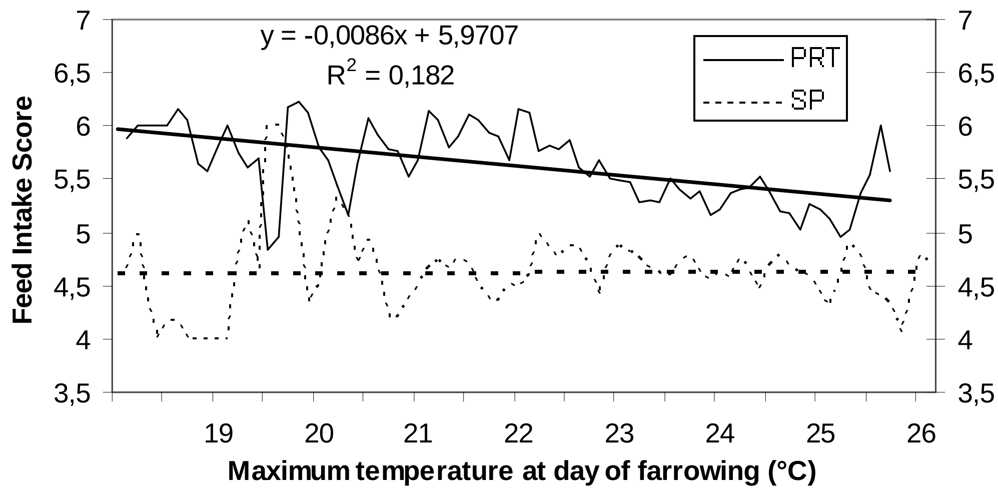

Figure 4.2. Average feed intake score per maximum temperature at day of farrowing for two farms (PRT —— and SP - - -) with trend lines.

Average of back fat at farrowing and at weaning for period July 2007 to March 2010 was calculated per sow line and per farm (Table 4.5 and Table 4.6). D-line sows had an average of back fat at farrowing and at weaning of 22.8 and 19.0 mm, respectively. I-line sows showed less back fat at farrowing and at weaning (17.1 and 13.7 mm, respectively) than the other lines. For crosses between I-line and D-line, when percentage D-line genes increased in sow line, average back fat increased, ranged from 20.6 to 23.8 at farrowing and from 17.1 to 19.8 at weaning.

Sows from PRT farm showed, around 6.1 and 5.6 mm, less back fat at farrowing and at weaning, respectively, than sows from SP farm (Table 4.6).

Analysing losses in back fat per maximum temperature recorded on-farm at farrowing day, for SP farm when maximum temperature at farrowing increased losses in back fat during lactation were higher; for PRT farm when maximum temperature at farrowing increased losses in back fat during lactation were lower (Figure 4.3).

Table 4.5. Number of observations, mean and standard deviation (SD) of farrowing and weaning back fat per line; I-line is an International purebred Large White line, D-line is a Dutch purebred Yorkshire line and %I:%D is the percentage of genes from sow lines.

Line	Back fat farrowing (mm)			Back fat weaning (mm)		
	n	Mean	SD	n	Mean	SD
I-line	1,928	17.1	2.4	1,827	13.7	2.2
75% I : 25% D	145	20.6	4.0	131	17.1	3.6
50% I : 50% D	641	23.4	2.8	523	19.5	2.6
25% I : 75% D	397	23.8	2.0	326	19.8	1.9
D-line	1,007	22.8	2.2	551	19.0	2.4

Table 4.6. Number of observations (n), mean and standard deviation (SD) of farrowing and weaning back fat per farm

Farm	Back fat farrowing (mm)			Back fat weaning (mm)		
	n	Mean	SD	n	Mean	SD
PRT	2,053	17.3	2.3	1,991	14.0	2.2
SP	2,061	23.4	2.1	1,709	19.6	2.2

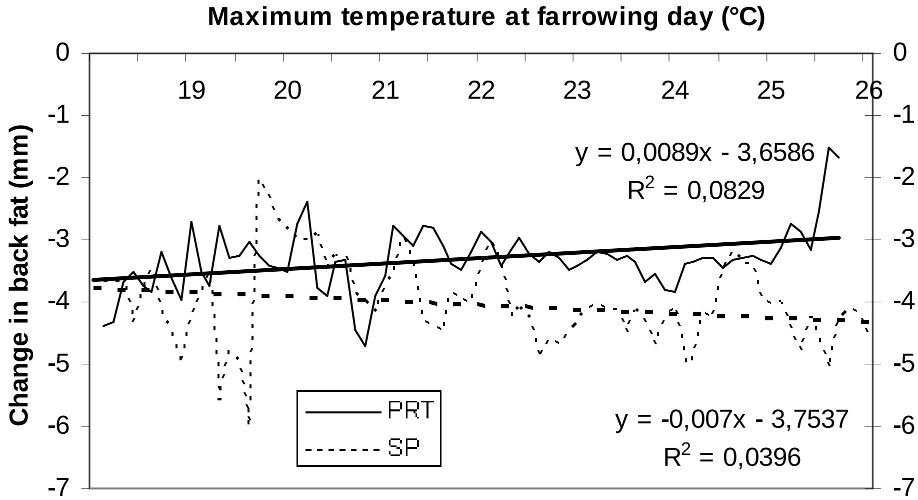

Figure 4.3. Change in back fat between weaning and farrowing per maximum temperature at farrowing day with trend lines for two farms (PRT —— and SP - - -)

Evaluation of genetic parameters

Variance components, heritabilities and repeatabilities of FIS, back fat at farrowing, back fat at weaning, total number born, litter mortality and number of piglets weaned are summarized in Table 4.7. For female reproduction traits, the heritability estimates were quite low, ranging from 0.02 to 0.15. Total number born, back fat at farrowing and back fat at weaning showed highest heritabilities (0.08, 0.15 and 0.09 respectively). Heritability for litter mortality was 0.06 and heritability for number of stillborn was 0.05. Number of piglets weaned and feed intake score had the lowest heritabilities, 0.03 and 0.02, respectively.

For total number born, number of stillborn, feed intake score and back fat at weaning, a substantial proportion of the total variation could be explained by non genetic effect, the permanent environment. No permanent environment effect was found for litter mortality because heritability and repeatability were both 0.06. Repeatability of number of weaned piglets and back fat at farrowing was 0.04 and 0.18.

Table 4.7. Phenotypic variance, heritability and repeatability for different traits (in parenthesis: standard error).

Trait:	N	$\sigma^2_{fenotype}$	h^2	r^2
Total number born	5,828	6.70	0.08 (0.02)	0.12 (0.01)
Litter mortality	5,502	138.4	0.06 (0.02)	0.06 (0.01)
Stillborn piglets	5,828	0.25	0.05 (0.01)	0.09 (0.01)
Number weaned	5,730	7.20	0.02 (0.01)	0.04 (0.01)
Feed intake score	4,696	0.69	0.03 (0.01)	0.08 (0.02)
Backfat farrowing	4,747	3.66	0.15 (0.03)	0.18 (0.02)
Backfat weaning	3,700	3.93	0.09 (0.03)	0.17 (0.02)
Loss in backfat	3,700	2.23	—	—

Table 4.8 shows the genetic correlations between different traits. A positive correlation between TNB and NSB/NW was found (+0.37 and +0.54), however it was not significant. TNB showed a significant negative correlation with back fat at farrowing (-0.34).

Sows with higher LTM showed (genetically) less NW (-0.96) and greater NSB (+0.15). A positive genetic correlation was found between NSB and NW (+0.97), FIS (+0.62) and back fat at farrowing (+0.42). A stronger correlation was found between back fat at farrowing and back fat at weaning.

Table 4.8. Genetic correlations (r_g) between 7 reproductive traits. Standard Errors in parenthesis. The estimates that differ more than 1.96 x SE from zero are presented in bold.

Trait:	Litter mortality	Number stillborn	Weaned piglets	Feed intake score	Back fat farrowing	Back fat weaning
Total number born	-0.01 (0.15)	+ 0.37 (0.20)	+ 0.54 (0.29)	- 0.04 (0.28)	**- 0.34 (0.16)**	- 0.34 (0.20)
Litter mortality		**+ 0.15 (0.03)**	**- 0.96 (0.00)**	- 0.10 (0.30)	+ 0.21 (0.12)	+ 0.30 (0.22)
Number stillborn			**+ 0.97 (0.00)**	**+ 0.62 (0.26)**	**+ 0.42 (0.17)**	+ 0.31 (0.21)
Weaned piglets				+ 0.36 (0.37)	- 0.13 (0.31)	-0.43 (0.38)
Feed intake score					+ 0.30 (0.21)	+ 0.08 (0.32)
Back fat farrowing						**+ 0.997 (0.00)**

4.5.Discussion

Evaluation of feed intake and back fat measurements

Great differences were found between sow lines in productive traits. D-line had average of 11.9 piglets born per litter and 4.2 parity number. Different results from purebred Yorkshire sow line had been found in Spain for total number born (11.3) and parity number (3.4) (Bloemhof *et al.*, 2008). For purebred Large White sow line, same experiment found average total number born 10.9 piglets and average parity number of 3.2. Comparing our results with results from Bloemhof *et al.* (2008), sows from our analysis had a better performance and this may due to genetic improvements in the past years.

Average feed intake score showed one score point difference between farms. In Figure 4.1, average of feed intake score for PRT farm during two years followed a clear seasonal pattern. Highest feed intake scores were recorded during winter and lowest feed intake scores were recorded during summer. For SP farm, no seasonal effect was found but it was notable that after January 2009 average feed intake score was always 4; lack of accuracy pointing the score may be one of the reasons for that.

Analysing feed intake score per maximum temperature at farrowing day, a clear effect of temperature on feed intake score was found for PRT farm; when maximum temperature increased at day of farrowing, feed intake score decreased. For each 1°C increase in temperature, feed intake score decrease 0.01. As feed intake score is used as an indicator for feed intake this agrees with several studies that have been done on the effect of high ambient temperature in voluntary feed intake. For each 1°C increase in ambient temperature above 16°C, daily voluntary feed intake decline 0.17 kg (Black *et al.*, 1993). SP farm didn't show any trend for the variation of feed intake score by maximum temperature.

I-line showed to have a better capacity to start to eat after farrowing than D-line sows. For crosses between I-line and D-line, when percentage D-line genes increased in sow line, average feed intake score decreased ranged from 4.8 to 4.3.

Back fat at farrowing is related with gestation feed consumption and lower feed intake during lactation has been correlated to greater body condition scores at farrowing (Baker *et al.*, 1969; O'Grady *et al.*, 1985). During lactation period, back fat measurements decreased in both herds around 3 mm. No clear influence of temperatures on back fat changes between farrowing and weaning was found. A negative influence of temperatures at farrowing day on back fat losses during lactation was found for SP farm; when maximum temperature at farrowing day increased, sows from SP farm increased their losses in back fat. Data from PRT farm showed the opposite tend. Black *et al.* (1993) failed to show a significant effect of temperature on body mobilization.

<u>Evaluation of genetic parameters</u>

Heritability for total number born was 0.08, which was lower compared to earlier research in which heritability ranged from 0.10-0.13 (Hanenberg *et al.*, 2001; Canario *et al.*, 2006 and Bergsma *et al.*, 2008). Repeatability estimated for total number born in our study was lower than repeatability estimated by Bergsma *et al.* (2008): 0.12 compared with 0.22.

Heritability estimated for number of weaned piglets was 0.02 and it is in agreement with heritability estimated for mother ability of 0.02/0.03 (Hanenberg *et al.*, 2001). Litter size traits have a tendency for their heritability to decrease when the trait is more dependent on piglet survival; which is in agreement with literature (Serenius *et al.*, 2004).

Litter mortality during lactation showed heritability and repeatability of 0.06; hence there was no permanent environment effect on litter mortality. Bergsma *et al.* (2008) estimated also heritability of 0.04 and repeatability of 0.09 for litter mortality.

For stillborn piglets, heritability estimated was 0.05. Hanenberg *et al.* (2001) and Siewerdt and Cardellino (1996) estimated heritability for number of stillborn piglets ranged from 0.02–0.08 and concluded that stillbirth rates are higher in purebred than in crossbred litters.

No literature was found to compare with our estimate of heritability for feed intake score. This study was the first study estimating heritabilities for feed intake score, therefore no comparison could be made with literature.

Back fat at farrowing and at weaning got the highest heritabilities, comparing with other traits, 0.15 and 0.09, respectively. Grandinson *et al.* (2005) estimated 0.47 for heritability of back fat at farrowing and 0.10 for back fat loss during lactation. In our study back fat loss during lactation was not heritable. In both studies, models used included permanent environment, genetic (a) and residual effects as random effects, the difference was in fixed effects where Grandinson *et al.* (2005) model included litter size as fixed effect.

No genetic correlation between total number born and litter mortality was found in our study. Genetic correlations between total number born and litter mortality have been reported ranging from 0.22-0.39 (Serenius *et al.*, 2004 and Bergsma *et al.*, 2008). An explanation for unfavorable correlation is that larger litter size has been shown to be associated with low birth weight of piglets which might result in lower survival rates of piglets.

Total number born and number of stillborn piglets showed a positive genetic correlation (+0.37) and this was in agreement with Canario *et al.* (2006) where a positive genetic correlation of +0.46 was found between these two traits. It indicates that selection for total number born is likely to result in a noticeable increase in number of stillborn piglets, as recently observed in several pig populations (Canario *et al.*, 2006).

A positive genetic correlation, but not significant, between total number born and number of weaned piglets was found in our study. Roehe and Kennedy (1995) found also a positive correlation ranging from +0.51 to +0.85 for two different sow lines and for different parity numbers. However, selection for total number born has always the risk of increasing the number of pigs born dead. Selection for number of weaned piglets is very difficult under conditions of cross-fostering (Roehe and Kennedy, 1995). Litter size at weaning is of greater commercial importance than litter size at birth (Haley *et al.*, 1988).

Negative genetic correlation was found between number total born and back fat at farrowing. This could mean that when sows have high merit for to increase number of total piglets born they would show lower levels of back fat.

Genetic correlation between litter mortality and number of stillborn piglets in our study was positive. Litter mortality and number of weaned piglets are negatively genetic correlated as expected. Sows with greater genetic merit for high number of weaned piglets show less mortality of piglets during lactation period.

Litter mortality and back fat at farrowing showed a positive but not significant genetic correlation; Grandinson *et al.* (2005) found also a positive and not significant genetic correlation between them. Sow lines selected for leanness tend to have higher mortalities rates due factors related to the sow and the piglet (Grandinson *et al.*, 2005). Sows selected for leanness are more restless and stood up and lay down frequently and this can increase the risk of piglets crushing. Piglets from genetically leaner sows seem more psychologically immature. However, milk from genetically obese sows had higher dry matter content and a higher fat content in their milk, which may have a positive relation on piglet survival (Mersmann *et al.*, 1984 and Herpin *et al.*, 1993).

A strong positive genetic correlation was found between number of stillborn piglets and number of weaned piglets. Our result differed with Serenius *et al.* (2004) that estimated genetic correlation between number of stillborn piglets and number of weaned piglets as -0.24 for Landrace and -0.00 for Large White pigs.

Genetic correlation between number of stillborn and feed intake score / back fat at farrowing estimated was positive +0.62 and +0.42, respectively. This is not in agreement with Grandinson *et al.* (2005) that estimated negative genetic correlation of -0.23 between maternal effect of number of stillborn piglets and back fat at farrowing. Sows with low fat reserves at farrowing seem to have a higher incidence of stillbirth (Grandinson *et al.*, 2005).

4.6.Conclusion

The aims of this study were to analyse new indicators: feed intake score and losses in back fat during lactation, estimate their genetic parameters and to study genetic correlation between these new indicators and reproductive traits.

The present results confirm, for one farm, the effect of season and high temperature on feed intake score of lactating sows in hot climates. Feed intake score may be a good trait for estimate the capacity of a quick start feed intake after farrowing, however it classification must be as accurate as possible. Feed intake score may be introduced at Breeding Value Estimation to improve selection on start up of sows in Spain and Portugal; however it is a trait with very low heritability. It would be advisable use traits with a high heritability because they have a large part of phenotypic variation due to additive genetic differences. At high heritabilities, phenotype provides more information about animals breeding value than at low heritabilities.

No clear effect was found between temperature at farrowing day and change in back fat during lactation; more studies must be done about that.

4.7.References

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"It is not the strongest of the species that survives, nor the most intelligent, but rather the one most adaptable to change."

(Charles Darwin)

5. Final Considerations

As previously mentioned, several factors affect reproductive performance of sows. Ambient air temperature and humidity influence reproductive performance of sows, such as farrowing rate and total number born. Follicular development, embryo quality, maternal recognition and implantation period may be affected by heat stress in sows. Differences in heat stress tolerance between sow lines were found, measured by differences in reproductive performance, and may be an indication of genetic differences in heat stress tolerance in sow lines.

Usually, in Breeding Value Estimation is used weather information from the closest weather station from the farm. The closest weather station may provide satisfactory information in capturing the effect of heat stress in sows as the data collected on-farm when they are located on a relatively flat area.

It was also concluded that, high ambient temperature influences the start up of sows after farrowing by the negative effect of heat stress on feed intake. Create a feed intake score to evaluate the capacity of a quick start producing after farrowing may be useful improve the selection of sows the start up after farrowing.

For the future, most studies most be done to study the effect of temperature, humidity and other environmental factors in the reproductive performance of the sows. Study which day has the largest effect on reproductive performance of sows must be done with a larger database in order to estimate accurately the effects of heat stress for different sow lines.