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# Genetic aspects of heat stress in pigs expressed in fertility traits

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**Abstract.** The number of pig breeding programs has reduced in recent years. This leads to a small number of pig breeding companies producing pigs for many different environments. Therefore, pig breeding programs have to breed pigs capable of facing heat stress challenges during their productive life. Management practices such as cooling offer one option to reduce heat stress and warrant performance during hot seasons. A more sustainable alternative is to breed sows for improved heat tolerance. When evaluating breeding goals for dam lines we were confronted with different appreciation of two dam lines by pig producers in the Netherlands (temperate climate) and in Spain (warmer climate).These two dam lines, differed in the relationship between ambient temperature and reproductive performance. One of the dam lines showed no influence of temperature on performance, the other showed a decrease of 0.1 piglet per 1℃ increase in ambient temperature. In a subsequent study, estimates of heritability reinforced the idea that genetic selection for sow heat stress tolerance is possible. Genetic correlations between reproductive performance in a temperate climate and reproductive performance in a hot climate tend to be unfavourable. In other words, improving reproduction traits without taking heat tolerance into account will lead to animals which have higher performance under temperate conditions, but which are also more sensitive to heat stress.

**Keywords.** Heat stress – Fertility – Pigs – Genetics.

### *Aspects génétiques du stress thermique chez les porcs exprimés par des paramètres de fertilité*

***Résumé.*** *Ces dernières années, le nombre de programmes de sélection porcine a baissé. Ainsi, le nombre de grandes organisations de Sélection Porcine produisant des animaux pour de nombreux environnements a chuté. En conséquence, les programmes de sélection doivent produire des porcs capables de faire face aux problèmes liés au stress thermique au cours de leur carrière de production. Les pratiques de gestion d'élevage telles que le refroidissement sont un moyen de réduire le stress thermique et de garantir des performances de production pendant la saison chaude. L'alternative la plus durable consiste à sélectionner des truies ayant une meilleure tolérance à la chaleur. Lors de l'évaluation des objectifs de sélection pour les lignées femelles, nous étions confrontés à différentes appréciations de deux lignées femelles par des producteurs de porcs aux Pays-Bas (climat tempéré) et en Espagne (climat plus chaud). Ces deux lignées femelles présentaient des différences au niveau de la relation entre la température ambiante et les performances reproductives. Chez l'une des lignées, la température n'avait aucune influence sur les performances alors que l'autre présentait une baisse de 0,1 porcelet par augmentation de 1℃ de la température ambiante. Dans une étude suivante, les estimations d'héritabilité ont renforcé l'idée que la sélection génétique pour la tolérance au stress thermique des truies est possible. Les corrélations génétiques entre les performances reproductives dans un climat tempéré et les performances reproductives dans un climat chaud ont tendance à être défavorables. En d'autres termes, l'amélioration des caractéristiques reproductives sans tenir compte de la tolérance à la chaleur entraînera la production d'animaux ayant de meilleures performances dans des conditions tempérées mais qui seront plus sensibles au stress thermique.*

***Mots-clés.*** *Stress thermique – Fertilité – Porcs – Génétique.*

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# I – Introduction

Genetic potential of pigs has increased during the past 50 years as a result of well-organized pig breeding programs. This improved genetic potential has led to improvement of economically important traits such as daily gain, back fat thickness, feed efficiency, and litter size (Merks, 2000; Brown-Brandl *et al.*, 2004). Implementation of crossbreeding, specialised sire and dam line breeding, BLUP genetic evaluation programs and well-defined selection indices have been responsible for a remarkable reduction of backfat (-75%), improvement in growth rate (+100%), and since the 1990s larger litter sizes (Merks *et al.*, 2012). Since the 21st century, breeding goals within modern pig breeding programs have shifted more and more towards improving product quality as well as to traits related to animal welfare such as piglet survival, sow longevity, and disease resistance (Kanis *et al.*, 2005). During recent years, the number of pig breeding programs has been dramatically reduced and it is expected that in 2020 only a couple of them will be left over. This leads to a small number of pig breeding companies producing pigs for many different environments (Gibbs et al, 2009;Dekkers *et al.*, 2011; Merks *et al.*, 2012).

In major pig breeding organisations, selection takes place in nucleus farms in mainly temperate climates and under high management standards (Knap, 2005). In general, selection on production under improved environmental conditions leads to increased environmental sensitivity (Van der Waaij, 2004). It is anticipated that differences between environmental conditions at nucleus farms and commercial farms will become even larger in the coming years. Meat production is expected to double from 229 million tones in 1999 to 465 million tones in 2050, the growth predicted to be the fastest in regions with hotter climates such as Latin America and South and East Asia (FAO, 2006). Furthermore, the temperature is expected to increase worldwide as a result of climate change (Hofmann, 2010). Therefore, pig breeding programs have to breed pigs capable of facing heat stress challenges during their productive life.

The economic losses from heat stress in the United States in the swine industry in 2003 were estimated to be $299 million and was mainly a result from an increased number of days open for sows and reduced growth for finishers (St-Pierre *et al.*, 2003). Pig management is to some extend a way to deal with high temperatures/ heat stress and can be done via implementation of cooling systems in pig farms and to adapt nutrition (Quiniou *et al.*, 2001). Another way to deal with heat stress would be to breed animals which are tolerant to high temperatures. Breeding for heat tolerance leads to a permanent change in the genetic composition of the swine population. To be able to genetically improve heat tolerance within a population, there is a need to find genetic variation and to choose specialized sire and dam lines and select them for improved production under the given conditions. Genetic variation in heat tolerance has been studied in dairy cattle, sheep, and finishing pigs (Ravagnolo and Misztal, 2000; Finocchiaro *et al.*, 2005; Zumbach *et al.*, 2008). However, there are hardly any studies focusing on genetic variation in sows with respect to heat tolerance.

# II – Heat stress and fertility

## 1. Physiological background of heat stress

Pigs are highly sensitive to elevated ambient temperatures because they cannot sweat and even have problems coping with heat stress through increased respiration or panting. Pigs suffering from cold stress increase their internal heat production by shivering, or by increasing their feed intake. This increased feed intake is mainly used to raise the body temperature rather than to increase production (Quiniou *et al.*, 2001). Pigs also have various physiological processes to cope up with heat stress. Through radiation, conduction, convection, and evaporation pigs can transfer heat from their body to their environment. Wild pigs suffering from heat stress in nature, regulate their body temperature by wallowing in mud or water and changing their activities from day to night. In modern pig industry mud or water is not available and pigs have to cope with the given environment. In fact, the internal heat production of pigs has increased during the past 50 years due to increase in leanness (Brown-Brandl *et al.*, 2004). Higher internal heat production lowers heat tolerance capacity, resulting in increased susceptibility to heat stress (Brown-Brandl *et al.*, 2001).

Heat stress can be measured typically via rectal temperature, respiration rate, skin temperature, and heat production (Omtvedt *et al.*,1971). The rectal temperature increases with initial exposure to heat stress, but gradually decreases with length of exposure to heat stress. However, there is hardly any relationship between rectal temperature and fertility traits in pigs (Omtvedt *et al.*,1971). Next to these physiological measures of heat stress, the detrimental effect of high temperatures can be also measured in reduced performance. In literature, several authors describe that high temperatures reduce feed intake in pigs. This negative effect on feed intake has consequences for reproductive performance of sows as well (Black, 1993). In general, heat stress affects fitness traits, i.e. an animal’s ability to produce and reproduce. In pig production, this relates mainly to reproduction.

## 2. Reproductive performance

Reproductive performance in sow lines is of great importance in current commercial pig breeding programs (Hanenberg *et al.*, 2001). Several factors affect reproductive performance such as breed, parity, lactation length, nutrition, season, day light length and temperature. Litter size has been included in almost all pig breeding programmes and it is one of the most important reproduction traits based on the economic importance (Rhydmer, 2000). Next to litter size, pig breeding programmes should include piglet survival, number of teats, number of stillborn, and longevity of sows as well (Merks *et al.*, 2012). Negative influences of heat stress on reproductive performance, such as litter size and farrowing rate, have been described by several authors (Wetteman *et al.*, 1988; Peltoniemi *et al.*, 1999; Tummaruk *et al.*, 2004). Heat stress during the first two weeks after breeding reduces conception rate and number of viable embryos (Omtvedt *et al.*,1971). The effect during the second week of gestation is more severe. Heat stress during last week of gestation increases the number of still born piglets and reduces the number of live born piglets (Omtvedt *et al.*,1971).

## 3. Concept of upper critical temperature

Pigs suffer from heat stress when temperature exceeds the upper critical temperature of the thermo-neutral zone. The thermo-neutral zone is the range of ambient temperatures between the lower critical temperature and the upper critical temperature (Bianca, 1976). Below the lower critical temperature the animal needs to increase heat production via shivering and other processes to maintain body temperature. Above the upper critical temperature, the animal starts to be stressed by heat and energy is used to maintain body temperature particularly through the lungs by increased respiration (Black, 1993). The thermo-neutral zone is based on the body temperature of the pig. One could argue that there is as well a lower critical temperature and an upper critical temperature for pig production (e.g. finisher growth, litter size, farrowing rate). Below the lower critical temperature the pig has to reduce performance to use the energy for maintaining body temperature and above the upper critical temperature the pig has to reduce performance to avoid extra heat production (Bloemhof *et al.,* 2008). This concept is visualized in Fig. 1.

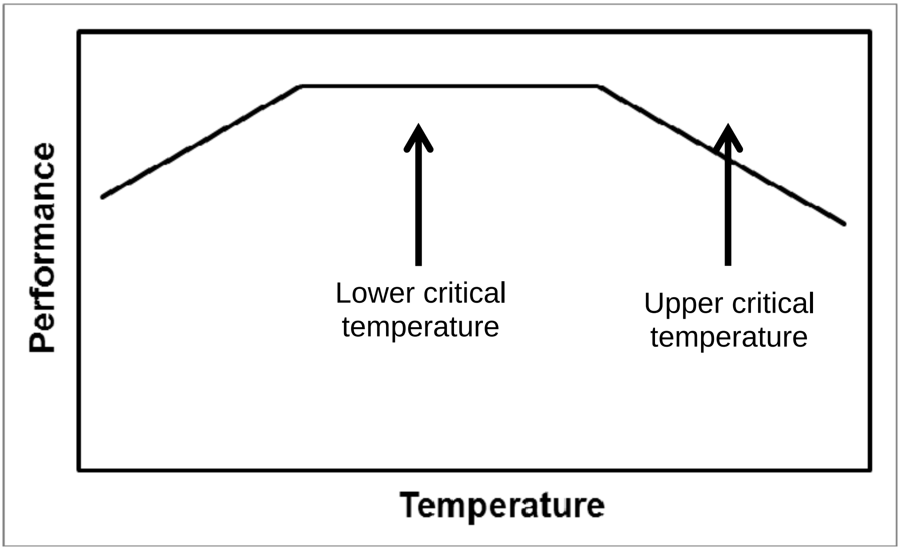


**Fig. 1. Concept of thermo-neutral zone for pig performance.**

## III – Genetic differences

### 1. Genetic differences between lines

When evaluating breeding goals for dam lines we were confronted with different appreciation of 2 dam lines by pig producers in the Netherlands (temperate climate) and in Spain (warmer climate). The dam line preferred by the Spanish producers was not preferred by the Dutch and vice versa. Reproduction differences between Spanish and Dutch farms supported this opinion. Therefore an analysis was performed. Data included 32,361 records on reproductive performance from 11,935 sows on 20 farms in Spain, collected from 2003 to 2005. Sows belonged to two purebred dam lines named Dutch (a Yorkshire dam line, originally selected in the Netherlands) and International (a Large White dam line, selected based on data from all around the world). For each parity first insemination records were used and combined with maximum outside temperature at day of insemination (from a weather station close to the farm). First of all a descriptive analysis was performed and means for farrowing rate, litter size and the combination of farrowing rate and litter size (total number piglets born per first insemination) were calculated for each maximum outside temperature class (range from 10ºC to 36ºC). The results from this descriptive analysis are shown in Fig. 3. For temperatures below 23ºC farrowing rate, litter size, and total number piglets born per first insemination were higher for sows from the Dutch line than for sows from the International line. Above 24ºC litter size was almost the same in both dam lines, but farrowing rate and total number piglets born per first insemination were higher for the International line sows when temperature exceeded 25ºC (Bloemhof *et al.*, 2008). In a study by Bergsma and Hermesch (2012) the interaction between temperature and lactation feed intake of 4 dam line crosses was studied, the results of this study are shown in Fig. 2. For three of the four dam line crosses highest feed intake was recorded during the medium temperature range from 14ºC to 24ºC. The reaction norms for lactation feed intake on temperature were similar for cross A and cross B, even though cross A had a higher lactation feed intake. Cross D had a lower lactation feed intake than cross A and B and had in the extreme temperatures a larger decline in feed intake than cross A and B. Cross C showed a different reaction norm curve than the other 3 crosses. At temperatures below 5ºC these sows responded by increasing lactation feed intake. Cross C could be called the least temperature sensitive dam line and intriguingly this dam line cross descends from the International dam line which was investigated in the study by Bloemhof *et al.* (2008).

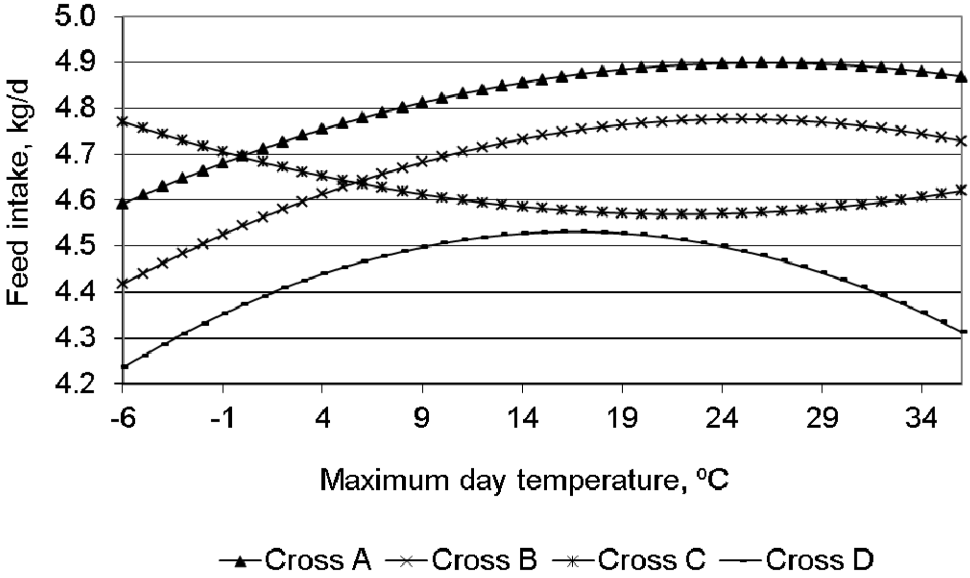


**Fig. 2.** **Reaction norms for 4 dam line crosses of daily lactation feed intake records on maximum outside temperature measured at the nearest weather station (Adapted from Bergsma and Hermesch, 2012).**

## 2. Genotype-environment interactions

Pig breeding programmes are more and more operating on a worldwide basis. This results in pigs that have to perform in a variety of environments. Therefore, genotype-environment interactions are expected to occur. However, their magnitude may vary depending upon the degree of differences between the genotypes or lines and the level of differences between the environments (Mathur and Horst, 1994). Due to genotype-environment interaction, pigs selected for best performance in one environment might not be the best in a different environment (Falconer, 1960).

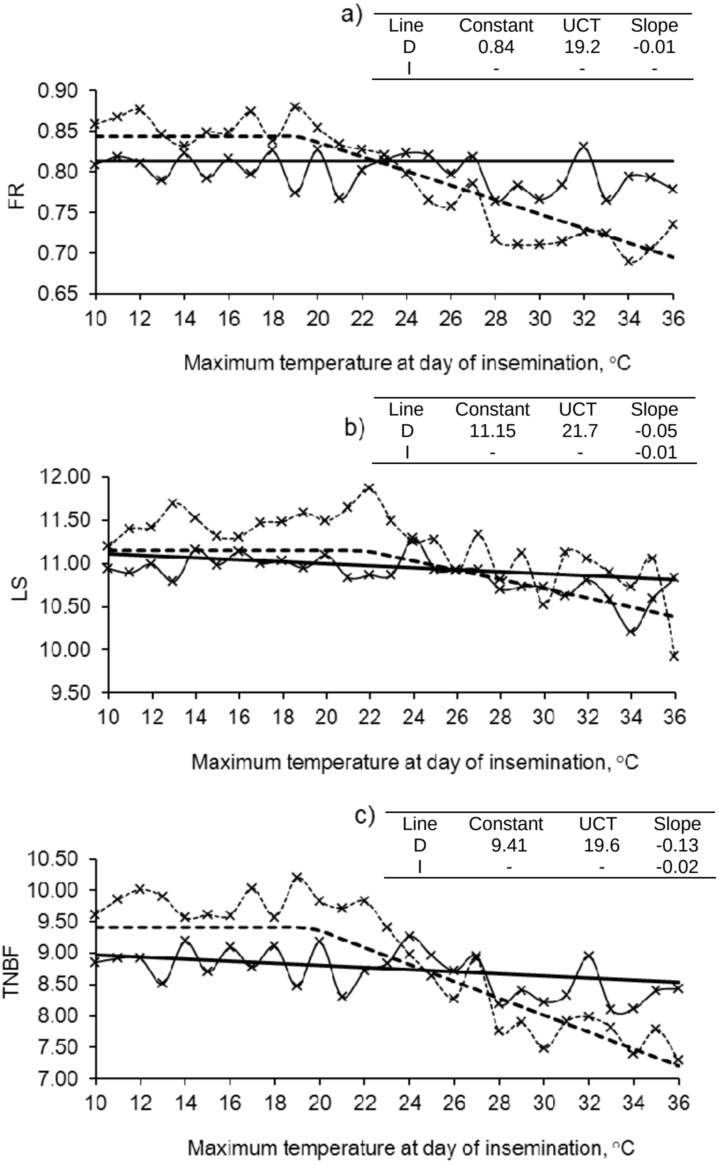
In the study by Bloemhof *et al.* (2008), the thermo-neutral zone concept was adapted for the two dam lines to the relation between temperature and reproductive performance (Fig. 1). Subsequently, upper critical temperatures were estimated for reproductive performance of these two dam lines. Two models were compared for goodness of fit: a linear model, in which it was assumed that temperature above 10℃ affects reproductive performance with a linear decrease, and a plateau-linear model with the plateau representing the thermo-neutral zone and a linear decrease above the upper critical temperature of this zone. Results of this analysis are shown in Figure 3. The goodness-of-fit tests showed that for the Dutch dam-line sows the plateau-linear model fitted best for all 3 reproductive performance traits (farrowing rate, litter size and total number piglets born per first insemination). This means that there is an upper critical temperature for the reproductive performance of the Dutch line sows. The upper critical temperature of this zone varied from 19.2℃ for farrowing rate, to 21.7℃ for litter size, to 19.6℃ for total number piglets born per first insemination. Above these temperatures the decrease in farrowing rate was 1% per ℃, 0.05 piglet in litter size per ℃ and 0.13 piglet per ℃ per first insemination (Fig. 3). For the sows from the International dam line no upper critical temperature could be estimated for reproductive performance. However, a linear significant adverse effect of temperature on litter size and total number piglets born per first insemination was found. The decrease in performance of International line sows with increasing temperature was much less than in the Dutch line sows (Bloemhof *et al.*, 2008). These results suggest a significant genotype-environment interaction. This is a typical example of a genotype-environment interaction in livestock breeding programs (Mathur and Horst, 1994) where there is a larger reduction in performance of one genotype (Dutch line) compared to the other (International line) due to heat stress.

Dutch line sows were selected on reproductive performance based on data collected in the Netherlands, which is a temperate climate, and these sows showed quite a large reduction in farrowing rate and litter size with increasing temperatures in Spain. The International line sows showed less problems with high temperatures and were originally selected based on international data from mainly tropical countries (Brazil, Spain, Italy, Philippines). So even though Dutch line sows had higher levels of farrowing rate and litter size under relatively stress-free (e.g. lower temperature) conditions, sows of the International line were superior than sows of the Dutch line when temperatures where higher than 25℃. This is a clear indication for a genotype- environment interaction. We think that for the International line families were selected which did well for farrowing rate and litter size in these tropical conditions, adapting therefore to the local environments. These differences suggest that genetic selection on sow heat stress tolerance might be possible (Bloemhof *et al.*, 2008).

In view of the genotype-environment interactions one could consider using specific genotypes for specific environments, e.g. the International line for hot environments and the Dutch line for temperate environments. Maximum selection response can then be obtained by recording data under the production environment and using them for genetic selection (Mulder and Bijma, 2005).

## 3. Environmental sensitivity

The presence of genotype-environment interactions for pig breeding in hot climates could be considered as an opportunity rather than a problem. This provides opportunity for breeding of more robust pigs for the desired environments. To our opinion a robust pig is a pig tolerant against environmental perturbations without compromising production. These environmental perturbations could be high temperatures, disease pressure, low-quality feed or other challenges in pig management. In pig breeding it is generally accepted that selection for increased performance in one environment will lead to increased production in that particular environment. However, it does not necessarily mean that these pigs with increased performance will perform as well in a second environment (van der Waaij, 2004). It might even occur that selection on production under improved environmental conditions leads to increased environmental sensitivity (van der Waaij, 2004). In breeding programs where a specific line is used for a variety of temperature conditions, sensitivity to temperature stress should be considered as part of the genetic evaluation and selection. Another option for genetic evaluation procedures for environmental sensitivity is to use genetic reaction-norm models. Reaction-norm of a genotype is the phenotype expressed over a range of environments and is a measure of environmental sensitivity or robustness (Kolmodin and Bijma, 2004). The advantage of using reaction-norm models is that they will produce BLUP breeding values for general performance potential and for the environmental sensitivity of animals. This allows implementing environmental sensitivity as a trait into the selection index (Kolmodin *et al.*, 2003; Knap, 2005; Knap and Su, 2008). Reaction-norm models provide measures especially for improving robustness across environments.



a)

| Line | Constant | UCT | Slope |
|---|---|---|---|
| D | 0.84 | 19.2 | -0.01 |
| I | - | - | - |

b)

| Line | Constant | UCT | Slope |
|---|---|---|---|
| D | 11.15 | 21.7 | -0.05 |
| I | - | - | -0.01 |

c)

| Line | Constant | UCT | Slope |
|---|---|---|---|
| D | 9.41 | 19.6 | -0.13 |
| I | - | - | -0.02 |

**Fig. 3. Observed means per ºC maximum outside temperature at day of insemination for three reproductive performance traits (a= farrowing rate (FR), b= litter size (LS), c= total number piglets born per first insemination (TNBF)) calculated for two sow lines, a Dutch purebred Yorkshire line (- x - - - x - - -) and an International purebred Large White line (—x— ) and the estimated effect of maximum outside temperature at day of insemination for these three reproductive performance traits for both sow lines, a Dutch purebred Yorkshire line (- - -) and an International purebred Large White line ( — ). For the Dutch line and the International line the estimates are given of the constant level of the reproductive performance trait where reproduction is not influenced by temperature (constant), of the upper critical temperature in ºC (UCT), and of the slope of the decrease above the UCT (slope), all estimates were significant different from 0 (adapted from Bloemhof *et al.,* 2008).**

# IV – Opportunities for genetic selection

## 1. Genetic parameters

An additional way to improve environmental robustness (e.g. breeding less sensitive animals) is to explicitly define robustness traits that can be included into profit equations and that can be used in breeding goals. An example of this might be breeding for improved heat tolerance.

To be able to genetically improve heat tolerance within a population, there is a need to find genetic variation. Therefore, heritability for the random regression slope of farrowing rate against increasing temperature at day of insemination (=heat tolerance) and the genetic correlation between farrowing rate and heat tolerance were estimated (Bloemhof *et al.*, 2012). The estimates were based on 93,969 first insemination records per cycle, from 24,456 sows inseminated between January 2003 and July 2008. Sows originated, again, from a Dutch purebred Yorkshire dam line and an International purebred Large White dam line and were raised in Spain and Portugal. Heritability estimates for farrowing rate were 0.05 for Dutch line sows and 0.08 for International line sows. Heritability estimates for heat tolerance at 29.3℃ were 0.04 for Dutch line sows and 0.02 for International line sows. Genetic correlations between farrowing rate and heat tolerance were around 0 (Table 1).

**Table 1. Estimated heritabilities and genetic correlations, with corresponding standard errors, for farrowing rate and heat tolerance for two damlines ($h^2$ = heritability, $r_g$ genetic correlation)**

| Trait | | Line sow | |
|---|---|---|---|
| | | Dutch | International |
| Farrowing rate | $h^2$ production | $0.05_{0.02}$ | $0.08_{0.01}$ |
| | $h^2$ response to heat stress† | $0.04_{0.01}$ | $0.02_{0.01}$ |
| | $r_g$production, response | $0.16_{0.37}$ | $-0.36_{0.17}$ |

†at heat load index 10 (=equal to temperature of 29.3℃).

## 2. Possibilities for selection

In the study by Bloemhof *et al.* (2012) it could be concluded that there were possibilities for genetic improvement of heat tolerance as expressed in farrowing rate. These results are in line with other studies in which additive variances for heat tolerance have been found to be important for non-return rate, milk production in dairy cattle, milk yield in sheep, and growth in finisher pigs. When heat stress was present the additive variances for heat tolerance were as large as the additive variances for non-return rate, milk yield and growth under non-stressed conditions (Ravagnolo and Misztal, 2000; Ravagnolo and Misztal, 2002; Finocchiaro *et al.*, 2005; Zumbach *et al.*, 2008). Selection for production traits often increases environmental sensitivity (van der Waaij, 2004). This was not fully supported by the results in Table 1. However, in finishing pigs a genetic correlation of -0.5 between carcass weight and heat tolerance has been reported (Zumbach *et al.*, 2008). In dairy cattle as well, genetic correlations between milk production and heat tolerance were negative, ranging from -0.30 to -0.95 (Aguilar *et al.*, 2009; Ravagnolo and Misztal, 2000). These correlations imply that selection strategies which focus on improving reproduction and production traits using data from only moderate climates will reduce heat tolerance and might lead to animals which are even more sensitive to environmental stress from high temperatures.

## V – Pig breeding for hot environments

It is expected that heat tolerance may become more and more a limiting factor for worldwide pig production. First of all, as genetic progress in pigs has mainly focused in the past 50 years in reducing back fat thickness, animals have become more lean which results in an increased susceptibility to heat stress (Brown-Brandl *et al.*, 2001). Second, as a result of climate change temperature is expected to increase worldwide (Hofmann, 2010). A third reason for the increasing importance of heat tolerance is that meat production is expected to double in the next 50 years, with increase is predicted to be the fastest in warm climates (FAO, 2006). These 3 reasons show that breeding animals for improved heat tolerance is relevant. The differences described previously between the Dutch dam line and the International dam line can be used to select as a specific dam line for environments with high temperatures. However, one needs to realize that a line specifically bred for high temperatures will have a lower performance level under temperate climate (non-heat stressed conditions) than a line specifically bred for temperate climate. To ensure firm breeding value estimation for heat tolerance or robustness for all breeding candidates in a practical breeding programme, it should be ensured that selection candidates have relatives tested under both temperate and hot conditions in the field. Testing animals in an experimental heat chamber might also be a powerful alternative, however for testing large numbers of pigs this might be unpractical.

## VI – Future perspectives

Due to globalization of pig breeding programs and concentration of genetic selection in fewer breeding organisations, pigs should be expected to perform in a different environment than the selection environment.These environmental differences could include differences in housing, feeding, climate and pig management. Selection is typically performed in nucleus populations under most optimal conditions while commercial pigs often have to perform under sub-optimal conditions and face therefore a variety of stressors. Heat stress is one of these stressors and could have significant adverse effects on sow reproduction. The results of our investigations show that there are differences between offspring from different lines in their responses to heat stress and in the relationship between heat stress and fertility traits. This provides an opportunity to select specific lines for specific environmental conditions e.g. one line for Dutch environment and another one for international use. Further, there are opportunities to select lines destined for international use to be genetically more robust to heat stress. Pig breeding programs especially for hot environments need to consider sensitivity of sows to heat stress in their selection decisions.

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