Breeding Focus 2018 - Reducing Heat Stress

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Preface

“Breeding Focus 2018 – Reducing Heat Stress” is the third workshop in the series. The Breeding Focus series was developed to provide an opportunity for exchange between industry and research across a number of agricultural industry sectors. With this goal in mind, workshops have included presentations across the livestock and aquaculture industries to take participants outside their area of expertise and encouraged them to think outside the box. This year we increased the scope even further by also inviting presentations from the cropping and horticulture industries. Since the topic of heat stress has recently gained increased attention, we will discuss a wide range of aspects associated with heat stress, such as the physiology of heat stress and phenotypic indicators, genetic approaches and industry impacts.

Heat stress in animals describes a situation where an animal is exposed to high temperatures and unable to dissipate body heat, which causes an increase in body temperature. In the short term, an animal will react to heat stress with behavioural strategies (e.g. seeking shade, panting) to reduce the heat load. With prolonged excessive heat load, feed intake is reduced and production losses occur. Under extreme circumstances, excessive heat load can lead to death. In plants, heat stress can be defined as irreversible damage to plant function and development as a consequence of hot temperatures. Environmental causes of heat stress in plants and animals include high temperatures and high humidity over a long period of time, which is exacerbated by low cloud cover and high solar radiation.

With raising average temperatures, agricultural industries are faced with the challenge to manage potential impacts of heat stress on their crops, their pasture base and welfare and production of their livestock or aquaculture species. Management strategies such as shade and irrigation are effective but costly and, depending on the severity of climatic conditions, may have limited success. Susceptibility of organisms to heat stress can vary due to factors such as age and general health, but also genetic factors, such as breed or variety. Further, as we will hear during the workshop, genetic variation exists within breeds that enables genetic approaches to address heat stress in plants and animals. Selective breeding provides a long term approach that facilitates improvement of the physiology of plants and animals to cope with excessive heat load. The challenge here is to obtain cost-effective phenotypes to describe heat stress.

The chapters of this book discuss where the current climate is trending, and outlines opportunities for the crop, orchard, livestock and aquaculture industries to describe and measure heat stress, all with the focus on genetic improvement.

We would like to thank everyone who has contributed to this event for their time and effort: the authors for their contributions to the book and presentations, the reviewers who all readily agreed to critique the manuscripts. We would like to express a special thanks to Kathy Dobos for her contributions into the organisation of this workshop and the publication. Thank you!

Susanne Hermesch and Sonja Dominik
Armidale, September 2018

Breeding for reduced seasonal infertility and reduced response to heat stress in sows and boars

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Abstract

This paper describes the impact of heat and seasonal stressors on the reproductive performance of pigs, management strategies to alleviate this impact and the opportunity to breed for pigs with increased ability to cope with seasonal stressors. The climate in Australia has become hotter. Currently, in Corowa NSW, there are about 40 days with a maximum temperature of above 35 °C during the year. This is a challenge for the pig industry due to pigs' limited ability to regulate their body temperature. In sows and boars, heat stress has been identified as a factor contributing to reduction in reproductive performance over the summer/autumn period, known as seasonal infertility. Seasonal infertility is also due to changes in photoperiod and may be alleviated or elevated by multiple stressors such as heat stress, social stress or handling stress. Pig producers implement management strategies to alleviate the impact of heat stress on seasonal infertility. However, these management strategies may not eliminate all heat stress experienced by pigs. Therefore, selection for increased heat tolerance and reduced seasonal infertility of pigs will improve welfare and productivity of pigs. Genetic strategies require traits that describe seasonal infertility in boars and sows, that are of economic importance and that have genetic variation. Evidence for genetic variation in farrowing rate in response to ambient temperature (Bloemhof *et al*., 2008) and in response to ambient temperature and change in daylight (Sevillano *et al*., 2016) have been found. Despite the prominent role of farrowing rate to quantify seasonal infertility, other sow and boar traits to describe heat stress and seasonal infertility also have a genetic basis. A range of traits recorded in sows and boars should be explored to enable the development of selection strategies to reduce heat stress and/or season infertility in pigs.

Is it hotting up?

Australia is known for its hot climate and livestock can become heat stressed when exposed to periods of high temperatures. The climate in Australia has become even hotter in the last few decades. Most pigs in Australia are housed in sheds with no or only limited climate control systems (e.g. air ventilation, drip cooling and mister systems) and are therefore exposed to this hotter climate. In order to quantify the potential magnitude of heat stress experienced by sows and boars housed in Corowa NSW, the number of days per year when maximum temperature exceeds the thermal comfort zones of lactating sows (between 8-26°C based on Lorschy, 2005, adapted from Kruger *et al*., 1992) is illustrated in Figure 1. The number of days per year when maximum temperature values exceeded 25, 30 or 35 °C has increased by 28, 24 and 12 days over 30 years, respectively. As a result, maximum temperatures above 35 °C are now observed on close to 40 days during the year, which is nearly twice as many days as were observed in 1986.

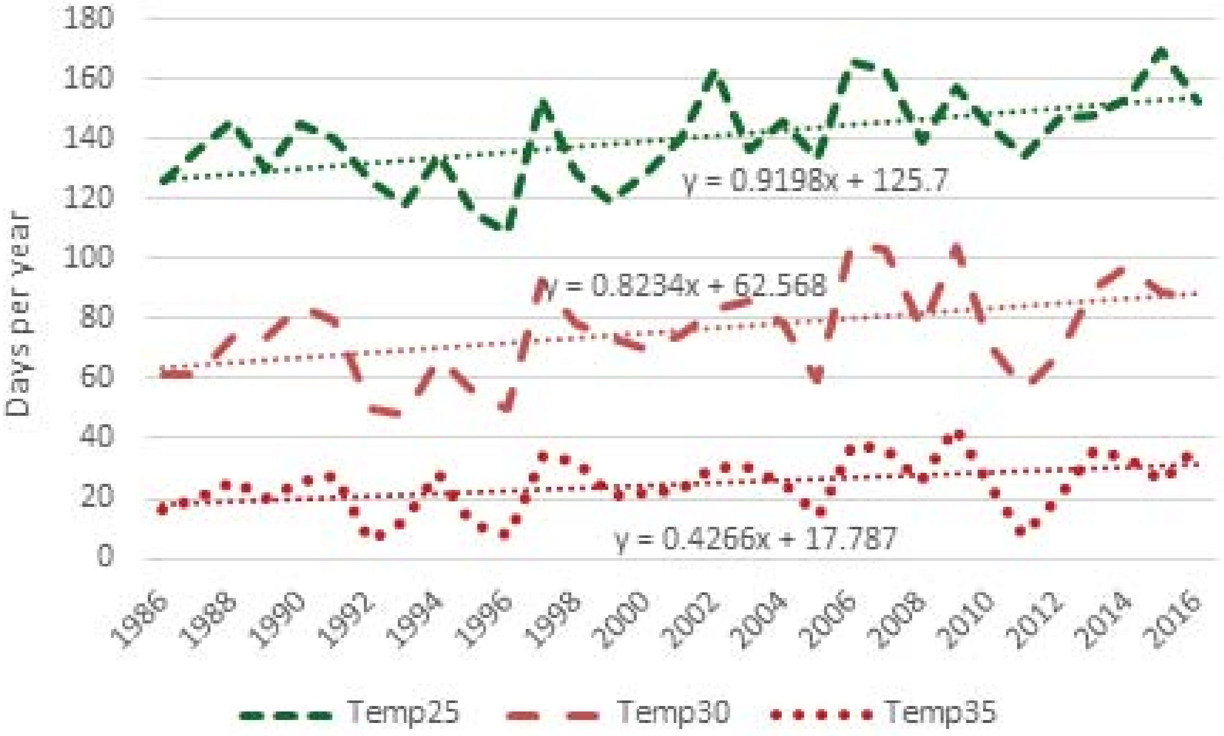

Figure 1. Number of days per year when maximum temperatures exceeded 25 (Temp25), 30 (Temp30) or 35 (Temp35) °C in Corowa NSW Australia.

In Australia, seasonal infertility occurs in sows mated in January and February. During this time of the year, temperatures exceeded the thermal comfort zone of sows on nearly all days (Figure 2) in Corowa. The number of days with maximum temperatures above 35 °C doubled over the last 30 years and is now observed for about 20 days in January and February. Overall, this summary illustrates the increase in temperatures observed in Corowa and the increasing importance of considering the effects of heat stress on reproductive performance of sows and boars in genetic analyses of traits describing seasonal infertility.

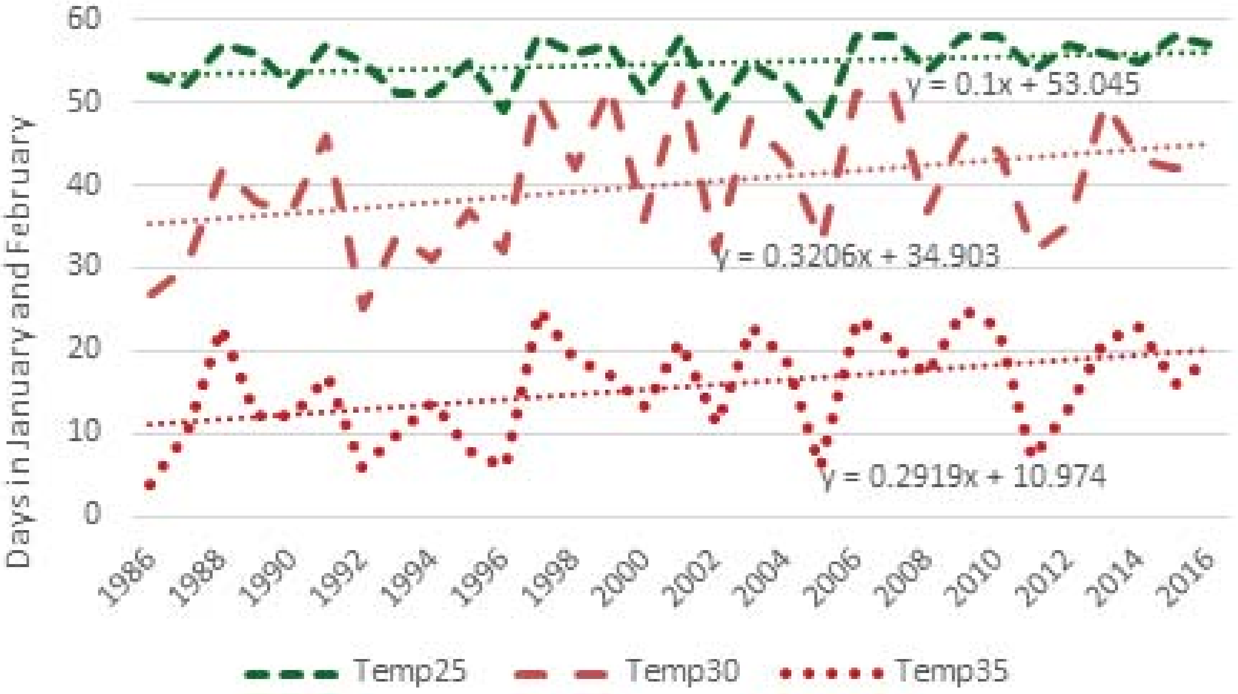

Figure 2. Number of days in January and February when maximum temperatures exceeded 25 (Temp25), 30 (Temp30) or 35 (Temp35) °C in Corowa.

Can sows and boars handle the heat?

Animals feel most comfortable when the temperature is in their thermal comfort zone, which means that the animal is neither feeling cold nor hot (Lorschy, 2005). In pigs, this zone can vary depending on physiological stage (e.g. dry sow versus lactating sow), health status and housing condition of the pig (e.g. cooling system, air flow, *ad libitum* versus restricted feeding regime, grouped versus single housed). For example, the thermal comfort zones in lactating sows is between 8-26°C, and between 12-33 °C in dry sows (Lorschy, 2005, adapted from Kruger *et al.*, 1992). If the temperature increases to the upper limit of the thermal comfort zone, called evaporating critical temperature, animals may start to sweat to maintain their body temperature. However, pigs cannot sweat and they pant instead to increase the evaporative heat loss from their lungs. As temperatures rise further up from the evaporating critical temperature, a point called the upper critical temperature is reached. At this temperature, the pig's evaporative heat loss from lungs and skin is greatest and, if insufficient, the pig is no longer able to control its increasing body temperature (Lorschy, 2005). Information about the range of the thermal comfort zone in boars is rare which may be explained by the limited information available due the circumstance that most breeding boars are housed in environmentally controlled conditions. An early Australian study has reported an upper critical temperature of 29°C in boars (Stone, 1982).

In sows and boars, heat stress has been identified as a factor contributing to seasonal infertility which is characterised by a reduction in reproductive performance in late summer and early autumn. Early studies concluded that seasonal infertility is mainly caused by heat stress of sows shortly after mating (e.g. Love 1978, Paterson *et al.,* 1978). For example, Paterson *et al.* (1978) found that the number of sows failing to maintain pregnancy increased when mean daily maximum temperatures exceeded 32 °C during the week of mating. The authors concluded that heat stress around the time of mating may affect ovarian function, resulting in temporary infertility and an endocrine imbalance, which caused delayed, irregular returns to oestrus. Seasonal infertility observed in the domestic pig is a remnant of the wild pig ancestry (Mauget, 1985). In European wild boars and sows, seasonal patterns of reproductive function occur to avoid farrowing in mid-winter when offspring have a lower chance of survival (Tast 2002). The effects of photoperiod on seasonal infertility were reviewed by Love *et al.* (1995) who outlined that seasonal infertility in domestic pigs is regulated primarily by photoperiod and heat stress. In addition, other environmental factors may interact with photoperiod to intensify the problem of summer infertility. This highlights the need to consider multiple environmental stressors and their potential interactions to define seasonal infertility in sows and boars.

Seasonal infertility and heat stress- how to measure it?

Seasonal infertility over the summer and autumn period is reflected by differences in multiple fertility measures. Most studies have focussed on pregnancy failures. An example is shown in Table 1, based on the study conducted in Spain by Lopes *et al.* (2014). In summary, farrowing rate and number of piglets born alive were reduced, while aborted pregnancies were increased in summer/autumn showing a seasonal effect on reproductive performance of sows.

Further, studies have shown that semen characteristics are affected by season (Smital 2009, Petrocelli *et al.,* 2015). For example, in a study by Petrocelli *et al.* (2015) the lowest semen quality was observed in autumn, whereas the highest semen quality was observed in winter.

Table 1. Typical patterns of pregnancy losses or failure during the seasonal infertility period observed in study conducted in Spain based on 94 sows, which were selected at weaning during winter-spring and summer-autumn (adapted from Lopes et al., 2014)

Sows	Winter/Spring	Summer/Autumn
Inseminated	51	43
Return to oestrus, n (%)	4 (7.8)	6 (13.9)
Pregnant, n (%)	47 (92.2)	37 (86.1)
Pregnancy disrupted, n (%)	1 (2)^{a}	5 (11.6)^{b}
Farrowed, n (%)	46 (90.2)^{a}	32 (74.4)^{b}
Number of piglet born, mean ± standard error of the mean (Range)	12.9±0.3 (9-18)^{a}	11.3±0.5 (5-15)^{b}

Different superscripts indicate significant differences between periods of the year

Management strategies to reduce the impact of heat stress and their effect on farm profitability

Pig producers affected by seasonal infertility try to reduce production losses by increasing the number of sows mated during this period (Lewis and Bunter, 2011). However, this strategy requires increased resources in labour, facilities and space and this management practice is not a solution to seasonal infertility. Therefore, other strategies to reduce the incidence of seasonal infertility are required.

Other management strategies used by the Australian pig industry (Table 2 adapted from King and Mitchell, 2013) are aimed to improve welfare of pigs and to alleviate the impact of heat stress on seasonal infertility. These management strategies include maximising lactation feed intake, providing cooling systems during gestation and farrowing, reducing stocking density in group gestation housing systems, handling semen adequately, increasing intensity of boar exposure and training of staff in accurate oestrus detection and identifying animals that are not pregnant. A major strategy is to build climate controlled sheds or retrofit existing sheds to provide better climate for specific animal classes. However, the different thermal requirements of lactating sows (thermal comfort zone of 8 to 26 °C) and their suckling piglets (thermal comfort zone of 26 to 35 °C) is a challenge for the pig producer (Lorschy, 2005, adapted from Kruger *et al.,* 1992). A possible solution are local cooling mats and systems for sows which enable the sow to control their body temperature without negatively impacting their suckling piglets (Renaudeau *et al*., 2012). All previously mentioned management strategies are targeting the heat stress component of seasonal infertility. Photoperiod seems to play also an important role in seasonal infertility (Love *et al.,* 1995). However, it seems there are currently no effective management strategies available to alleviate the photoperiod component of seasonal infertility (Hälli *et al.*, 2008).

These management strategies increase costs and secondly may not eliminate all heat stress experienced by pigs. Therefore, selection for increased heat tolerance and reduced seasonal infertility of pigs will improve welfare and productivity of pigs. Development of genetic strategies to improve sows and boars' ability to better handle high temperature and change in photoperiod requires knowledge of economic importance of traits with genetic variation that describe seasonal infertility in boars and sows.

Table 2. Management strategies to alleviate heat stress in sows and boars (adapted from King and Mitchell, (2013)).

Section	Observation	Action
Oestrus detection and insemination procedure	Hormone signal for inducing age at puberty and regular return to oestrus after weaning are supressed during seasonal infertility period	✓ Increase physical boar contact for young sows and gilts for at least 10 minutes twice daily with a matured, similar size boar ✓ Training of staff in accurate oestrus detection ✓ Mate gilts and sows after the first standing rather than delay insemination until PM or next morning
Maximise nutrition intake of lactating and weaned sows	Higher lactation weight loss over summer due to lower lactation feed intake has been observed which is causing a poor onset on hormone activity after weaning	✓ Increase feed frequency especially in the cooler time of the day ✓ increase energy, protein and nutrient density in summer sow lactation diet
Housing and feeding in early pregnancy	Stress in early pregnancy increase the risk for reproductive failure Sows in group-housing are more affected by seasonal infertility which may is explained by social stress between sows (Love et al., 1995)	✓ Avoid stress in the first 2-3 weeks of gestation due to regrouping, high stocking density, suboptimal climate, rough handling and low feed intake (Spoolder et al., 2009) ✓ Individually feed mated gilts and sows for at least the first month of gestation
Ensure adequate water intake of sows during summer	Sows have an average water intake of ~27 litres per day (Kruse et al., 2011) and any restriction of water intake such as reduced water flow through drinkers may impacts voluntary feed intake during lactation negatively.	✓ Ensure a water flow rate of 2 litres per minute ✓ Check drinkers and water quality regularly
Provide cooling for sows and boars	High temperature reduces signs of oestrus in female pigs and libido in boars. Further, heat stress compromises boar semen quality and sow reproduction performance	✓ Provide cooling system ✓ Provide chilled water

Opportunities to reduce heat and seasonal stress in sows and boars genetically

Seasonal stress in sows and boars seems to be mainly explained by changes in photoperiod and can be alleviated or elevated by multiple stressors such as heat stress, social stress or handling stress (Auvigne *et al*., 2010). Traits are required that define individual animal's ability to cope with seasonal and heat stressors. These traits can potentially be based on performance records, which already have been recorded on farm as part of genetic or management evaluations. However, observed changes in those traits can be due to management, season or a genetic component and their interactions. Therefore, careful implementation is required to derive phenotypes indicative of the response to heat stress from routine performance traits.

Indicator traits for sows

Variation in susceptibility to seasonal infertility exists in sows, which may be linked to a genetic component influencing seasonal infertility (Lemoine, 2013). Evidence for this genetic component has been found. For example, Bloemhof *et al*. (2008) found differences in farrowing rate in response to high ambient temperature in two genetically different maternal lines. In the same study, an upper critical temperature for farrowing rate was around 20°C for the D-line (producing mostly in temperate climate), whereas no upper critical temperature could be found for the I-line (producing mostly in hot climate). Under ambient temperature in that study, the D-line had a better farrowing rate. However, as soon as the temperate rose above 22°C, the I-line had superior farrowing rate compared to the D-line which is a typical example of genotype by heat stress interaction. A reduction in farrowing rate was still apparent even after correcting for ambient temperature. To be able to capture more of the seasonal variation in farrowing rate, Sevillano *et al*. (2016) analysed the response of first mating farrowing rate in response to change in ambient temperature and change in photoperiod. Their study used data from environmentally controlled pig farms, and even in these well-controlled environments the negative effects of decreasing daylight and high ambient temperature on farrowing rate occurred. Further, genetic variation in the ability to tolerate change in photoperiod and heat stress was identified in their study.

Despite the prominent role of farrowing rate as a seasonal infertility trait, other sow traits may also have a genotype by season or heat stress interaction. For example, first mating age, which has been observed to be 10 days higher in summer/autumn, can be considered as seasonal infertility trait (Peltoniemi *et al*., 1999). Management strategies can impact age at first mating. For example, Iida and Koketsu (2013) found, that regardless of the number of hot days (maximum temperature above 25 ◦C) or the length of photoperiod, high-performing farms had lower age at first mating than lower performing farms. This result implies that high performing farms are conducting better management strategies to archive lower age at first mating. However, this study also shows that the observed difference in first mating age between high and low performing farms decreases as the severity of the environmental stress increases (e.g. shorter photoperiod, higher number of hot days). Further, weaning to conception interval after the first parity, which is already incorporated as a trait in Australian pig breeding programs, is prolonged over the summer-autumn period and requires investigation as a potential seasonal infertility trait (Prunier *et al.,* 1996, Tholen *et al.*, 1996). Further, the proportion of gilts and sows which was never mated, because oestrus was not detected, may increase over summer and requires further exploration. There is evidence in the literature, that gilts that were selected in winter had a lower risk of being culled compared to gilts selected in spring or summer (Lewis and Bunter, 2006). Sows and gilts that fail to produce a litter after weaning or after entering the breeding herd, will leave the breeding herd. This trait is called stayability of the sow or the gilt and should be further investigated as a seasonal infertility trait. Gourdine *et al.* (2017) were able to show, that in response to high ambient temperature first parity lactating sows had a higher body temperature and respiration rate than older parity lactating sows. Martins et al. (2008) had similar results under comparable hot climate conditions. In their study, the rectal body temperature was 3 days after birth significant higher in first parity sows (40.16°C) than in older parity sows (39.12°C in parity-five sows). These results could be due to the higher metabolic heat production for growth of parity-one sows. These results indicate a heat stress by genotype by parity interaction and seasonal infertility traits recorded in gilts and multiparous sows may need to be treated as separate traits in pig breeding programs.

Semen quality traits

A seasonal effect on semen quality measurements of boars has been observed, such as sperm concentration and total number of abnormalities, which may negatively impact on farrowing rates of sows (Kennedy and Wilkins 1984, Smital 2009, Petrocelli *et al.* 2015). For example, in the study by Petrocelli *et al.* (2015) the mean sperm concentration was significantly higher in winter 309.9 ($\times 10^6.\text{mL}^{-1}$) than in autumn 213.6 ($\times 10^6.\text{mL}^{-1}$). Decreasing daily photoperiod and high ambient temperature seemed to play a role in the seasonal variation in semen quality traits (Claus *et al.*, 1985, Petrocelli *et al.*, 2015). The effect of high ambient temperature on semen quality was mostly visible three to four weeks later (Cameron and Blackshaw, 1980). Genetic variation for semen quality traits exists and moderate heritabilities have been found for those traits (Smital *et al.*, 2005). Several studies have shown lower semen quality traits, such as sperm viability and sperm concentration, in the summer-autumn period (Claus *et al.*, 1985, Smital, 2009, Petrocelli, *et al.* 2015). However, it is unknown if a genetic variation in semen quality traits interacts with high ambient temperature and/or photoperiod. Most stud boars are housed under environmental controlled conditions and their semen ejaculate has to meet certain standards before leaving the stud. This would lead to the assumption that service sires would not impact the mating success of a sow during the autumn/summer period. However, Sevillano *et al.* (2016) investigated sow farrowing rate as a trait for seasonal infertility. In this study service sire was as a random effect in the genetic model and a large variance of the sire effect for farrowing rate as a seasonal infertility trait of the sow was observed. A recent review by Peña *et al.* (2017) suggests that, beside the classical parameters of sperm quality, damage of the DNA could reduce male fertility and subsequent embryo survival. This means, that sperms may swim and fertilised eggs normally but embryos that have got a damaged paternal genome may not survive. It is unknown if genetic variation for farrowing rate as a boar trait interacts with seasonal environmental changes. Further, other seasonal infertility sow traits, such as weaning to first successful mating interval, can be explored as a trait of the boar.

Deriving a heat stress phenotype from performance traits

Heat stress response of individuals can potentially be evaluated by modelling changes in phenotypic performance with changes in the environment. The effects of temperature on farrowing rate has been modelled with a plateau-linear model (Bloemhof *et al*. 2008). This model has a plateau representing the thermal neutral zone where farrowing rate is unaffected by the ambient temperature. After reaching the upper critical temperature a linear relationship is fitted, where the slope represents the decline in farrowing rate for each 1°C increase in ambient temperature recorded on the day of mating. The study by Lewis and Bunter (2011) used a bivariate model to estimate the genetic correlation between the same reproductive traits (e.g. number born alive) defined as different traits when recorded in different seasons (e.g. number born alive observed in summer versus winter). All genetic correlations in this study between the same reproduction traits (total born, number born alive and piglet birthweight) recorded in summer versus in winter were highly positive. There was only one exception, the genetic correlation for total born in autumn versus spring matings was only 0.65(±0.09), reflecting the seasonal infertility impact on litter size. Sevillano *et al.* (2016) used a reaction norm model with two climatic factors to estimate genetic variation between pigs in their response to changes in photoperiod and ambient temperature. Variation for a trait in response to photoperiod or ambient temperature reflects a genotype by heat stress or genotype by season interaction and is shown by nonparallel reaction norms. In the same study the heritability of farrowing rate increased at more stressful environment (temperature > 23°C and daylight length from mid-summer until mid-autumn) from 0.02 to 0.08 using a reaction norm model which allowed heterogeneity of residual variance based on ambient temperature. The genetic correlation between farrowing rate observed in non-stressful and stressful environments reached 0.46 (±0.13) indicating that farrowing rate in a stressful and no-stressful environment should be treated as a separate trait. Sevillano *et al.* (2016) were able to distinguish between genetic variation in the response to changes in photoperiod and genetic variation in response to ambient temperature. These results indicate that sows with a high farrowing rate in a thermal neutral environment tended to be less tolerant to change in photoperiod or change in ambient temperature. In addition, the study found a positive genetic correlation between heat stress tolerance and tolerance to decreasing daylight. Therefore, it is speculated that selection for improved heat tolerance will also improve tolerance to decrease daylight or vice versa. The study by Sevillano *et al.* (2016) was conducted on farms with controlled environment sheds and it is expected that the magnitude of the differences of this study is larger in Australia where most pigs are housed in sheds with no or only limited climate control systems compared to e.g. Europe.

The effect of temperature on production and reproduction traits may not be linear and using a model which allows more flexibility, such as a curvilinear relationship, may be a better approach (Lewis and Bunter, 2011). Guy *et al.* (2017) fitted monthly weather records as splines which define segments along the climate trajectory and then fitted polynomial functions within individual segments. This approach allowed greater flexibility in modelling the sources of associations between climate and performance records, and could also be useful to evaluate seasonal infertility or heat stress traits.

In conclusion, there are opportunities to genetically improve seasonal infertility. Research is underway to estimate genetic variation for boar and sow seasonal infertility traits and to evaluate their economic value. As always, genetic improvement of seasonal infertility should be complemented by management strategies targeted to improve environmental conditions.

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