

Heat stress: the effects of temperature on production and reproduction traits

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Introduction

Ambient temperature has long been implicated as a driver for increased phenotypic variation within production traits of all major livestock species (Misztal *et al.* 2010; Nardone *et al.* 2006; Schinckel *et al.* 2010). In pigs, which have a very limited ability to thermo regulate through perspiration, extremes of temperature result in increased production difficulties, reduced performance and increased animal losses (Black *et al.* 1993; Nardone *et al.* 2006). Since Australian pig production is generally located in areas with high summer temperatures, it is pertinent to quantify the effects of temperature on performance, and to investigate whether there is genetic variability in heat tolerance which has implications for performance outcomes.

Recently, Bloemhof *et al.* (2008) reported an association between temperature and litter size, which differed according to genetic line. Line differences suggest there is a significant genetic component to heat tolerance, although the study of Bloemhof *et al.* (2008) did not elaborate on this aspect further. Examination of heat stress in growing pigs and in other species has generally uncovered significant genetic contributions (Pollott and Greeff 2004; Ravagnolo and Misztal 2000; Zumbach *et al.* 2008). It is also plausible that part of the effects of temperature on reproduction occurs as a consequence of the effects of temperature on feed intake as gilts develop, which is illustrated by significant seasonal changes in feed intake and production traits.

For breeding sows, lactation feed intake is also altered by seasonal conditions (Hermesch and Jones 2007; Schinckel *et al.* 2010) and sow longevity is concurrently compromised (Dourmad *et al.* 1994). Adequate lactation feed intake is needed to maintain sow body condition and to provide for suckling offspring. Hermesch and Jones (2007) showed that, on average, primiparous sows eating <3.5kg/day during lactation were significantly less likely to farrow in their second parity.

The objectives of this study were to investigate the effects of temperature on pig performance, using a variety of approaches. Specifically, to 1) quantify the effect of temperature on production and reproductive performance, and 2) to establish whether specific temperature thresholds exist where production traits become compromised.

Data recorded

All reproductive and production data were collected from a single production site in Australia, from two maternal lines of Large White and Landrace origin. Data characteristics are outlined separately for each section of the study.

Climate data used in all analyses

Climate data were collected and validated by the Australian Bureau of Meteorology from a weather station approximately 16km from the piggery. Data provided by the Bureau consisted of the air temperature and relative humidity (RH), recorded hourly. Variables were generated from these data to describe the thermal environment. These included the average and maximum daily temperature, along with three and seven day averages.

Production, reproductive performance and lactation feed intake data

Production data. Routine performance test data retained from 2003 onwards included around 60,000 gilts recorded for lifetime average daily gain (LADG, g/day) and back fat depth (BF, mm). From mid-2006 to the end of 2008, selected females commenced feed intake testing (N~3500) from 20 to 26 weeks of age. These females obtained records for average daily gain while on test (TADG, g/day), average daily feed intake (ADI, kg/day) during the feed test period (*ad-libitum*), and the derived feed conversion ratio (FCR, kg/kg) calculated as ADI/TADG.

Reproduction data. From 2003 onwards, there were 47,780 litters across parities recorded from 16,884 individual sows. All litters were produced using artificial insemination (AI) supplied from a single boar stud. The reproductive traits included total piglets born (TB, pigs/litter), number of piglets born alive (NBA, pigs/litter) and the average piglet birth weight (BWT, kg) for those born alive. Full data described in Table 1.

Table 1. Data demographics for production and reproduction traits

Trait	N	Mean(SD)	Min-Max	Significant Factors
Production Traits				
BF	59,710	10.7(2.37)	6-21.5	TYM,L,TWT
LADG	59,153	596(72.1)	367-936	TYM,L
TADG	3,270	844(163)	298-1,405	TYM,L
ADI	3,269	2.50(0.41)	1.09-4.38	TYM,L
FCR	3,269	3.03(0.54)	1.36-5.16	TYM,L
Reproduction Traits				
TB	47,780	12.2(3.15)	1-32	FYM,L,P,MOD,FAGE
NBA	47,780	10.9(2.92)	0-22	FYM,L,P,MOD,FAGE
BWT	15,667	1.50(0.27)	0.63-2.50	FYM,L,P,TB

TYM: test year-month, L: line, TWT: testweight (kg), FYM: farrowing year-month, P: parity, MOD: unit module, FAGE: farrowing age in days, See the text for trait definitions

Lactation feed intake. Serial data for lactation feed intake was recorded daily on a subset (N=2027) of primiparous sows over their whole lactation. Only records up to day 35 of lactation were used to calculate average daily lactation intake (LADI). Feed delivery during lactation was “to demand” for individual sows to maximise expression for feed intake during lactation, within operational constraints of a three times daily feed delivery. The targeted lactation length was 30 (± 2.5) days with twice weekly weaning.

Analyses performed

Choice of weather variables for further analyses. Preliminary analyses were used to evaluate which variables explained the most observed variation in production and reproductive traits. After inclusion of fixed effects in trait models (see Table 1), the weather variable with the highest contribution to the model coefficient of determination was preferred as an explanatory variable on a trait by trait basis, within the constraints of ease of interpretation. The average of the 24 hourly temperatures (TMP: expressed as an integer) was subsequently used as the primary thermal descriptor for all

production and reproductive traits. However, for ease of interpretation the maximum daily temperature (MT), which is very highly correlated (0.93) with TMP, was used for linear-threshold models (see below). The MT on the day of insemination was compared with the MT ± 3 days around the mating, implantation or farrowing dates, to determine in which time period temperature had the greatest effect on the reproductive traits.

Effects of temperature on commercial traits – plateau-linear and regression analyses. Briefly, the effect of MT on performance traits was assessed using trait residuals (y^*) derived from GLM correcting for other systematic effects (shown in Table 1: TYM=start of test year/month contemporary group effect with 64 levels, L=line with two levels, TWT=final test weight as a linear covariate, FYM=farrowing year/month contemporary group effect with 60 levels, P=parity with nine levels, MOD=module within production site with three levels and FAGE=age in days at farrowing as a linear covariate). However, it is important to note that temperature is partially confounded with contemporary group terms (TYM or FYM), such that some of the variation in temperature, and therefore the effects of temperature, will potentially be removed from these residuals. For example, approximately 62% of the variation in MT itself is explained by the year-month contemporary group.

Residuals for production, reproduction and lactation feed intake data were then analyzed separately by line and parity using simple regression (PROC REG, SAS) and plateau-linear (PROC NLIN, SAS) models, the latter based on the approach of Bloemhof *et al.* (2008). The plateau linear model was defined as: $y_i^* = c + e_i$ when $x_i \leq UCT$, and $y_i^* = i + b * x_i + e_i$ when $x_i > UCT$; where y_i^* = the dependent residual variable, c = is a constant when performance is not effected by temperature, e_i = is the error term, UCT = the upper critical temperature (tipping point) where temperature starts to affect performance ($UCT = (c - int) / b$), int = the intercept, b = the change in y^* when x increases by $1^\circ C$, and x = is the maximum outside temperature on the day used for analysis (for example: the day of insemination). The linear regression and the plateau-linear were then compared using an F-test for goodness of fit (Bloemhof *et al.* 2008). Results from these models were also compared to plots of solutions for MT, obtained from fitting the integer of temperate as another factor in the model.

Results and discussion

Relative information content of prospective temperature variables

Production traits. The correlations between temperature measures at the start and end of test were 0.65 and the change in coefficients of determination for production traits with the alternative dates were generally $< 1\%$. This is unsurprising for intake and feed efficiency due to the relatively short time period that the animals are on feed test. For ease of interpretation, temperature on the final day of test was fitted for production traits, since this also facilitated comparison across traits. The measures of RH were found to be largely uninformative for production traits and no further analyses were performed with RH as an independent variable.

Reproductive traits. In models already accounting for contemporary group and other known systematic effects, the most significant time period for temperature effects on TB or NBA was the 24 hour average temperature around day 10 ± 3 after mating. This interval captures the time period of pregnancy recognition and embryonic implantation, which occurs at around 12 days post-mating (Flowers 2008). For BWT, the 24 hour average temperature on the day of mating was marginally more informative than any other time period. The solution for average temperature on TB in parity one was $-0.0349 (\pm 0.0122)$ per increase of $1^\circ C$. Considering an observed interquartile range of $10.5^\circ C$ this equates to 0.367 piglets born. However, fitting contemporary group reduces the interquartile range to $2.31^\circ C$, equating to 0.081 piglets born, or a loss of approximately a single year of potential genetic gain due to uncontrolled temperature changes within contemporary group.

The correlation between the average temperature on the day of mating and the average temperature at 10 ± 3 days of gestation was 0.83, and the within trait reduction in the coefficient of determination was generally $<1\%$ when fitting TMP instead of MT. This being the case, average daily temperature at mating was subsequently used for all reproductive traits to facilitate direct comparisons between reproductive traits for the same date within sow-parity. Temperature was more informative than RH, which was a statistically insignificant covariate for most reproductive traits, and as informative as indices derived from temperature and RH. Therefore, temperature variables were preferred over thermal indices to aid with interpretation of the results.

The absence of significant effects in production traits for RH supports previous results of Morrison *et al.* (1966), who found no statistically significant differences in weight gains or feed consumption at RH levels of 45, 70 and 95%, and more recently Huynh *et al.* (2005). However, high humidity (eg RH $>80\%$) provides a mechanism for microbial transmission and increased disease burden, potentially leading to compromised growth and production (McGlone and Pond 2003). For reproductive traits, other studies have also had limited success in identifying trends associated with RH. Suriyasomboon *et al.* (2006) identified some negative trends in litter size with increasing RH in Thailand, but these trends were not consistent across herds.

Effects of heat on production and reproduction traits – plateau-linear and regression analysis

Production traits. When analysed across lines, the linear regressions for performance trait residuals on MT at the end of test were not significant. However, a plateau-linear relationship was identified for LADG: the estimated UCT was 25.8°C and growth rate dropped by -0.24 g/day per $^{\circ}\text{C}$ after this point. When data for each line were analysed separately (Figure 1), different estimates of the UCT and **b** were obtained for each line and the linear model for TADG was also significant. In Figure 1, results are only presented for the model of best fit, which is either linear, or plateau-linear in nature. For LADG, estimates of the UCT and **b** were 25.5°C and -0.38 g/day per $^{\circ}\text{C}$ for line A and 32.5°C and -0.82 g/day per $^{\circ}\text{C}$ for line B. This result suggests that line B can tolerate higher temperatures before growth rates are affected.

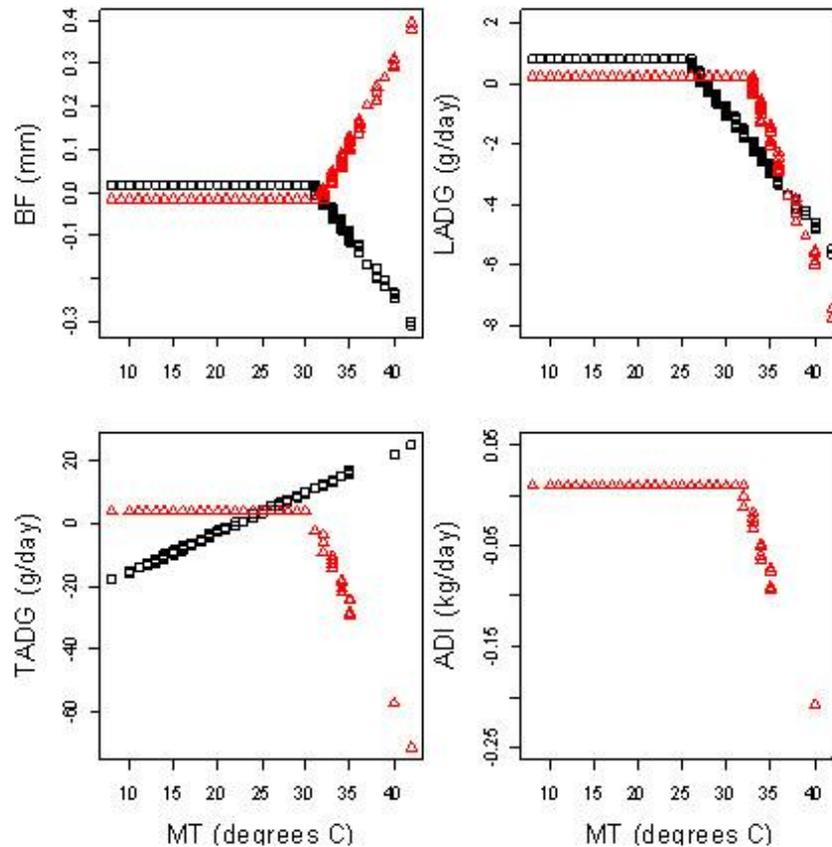


Figure 1. The effect of temperature on production traits, where significant, for the two sow lines in this study, where squares (\square) denote line A and triangles (Δ) denote line B. Temperature (maximum temperature: MT) on the last day of test is on the x axes and the traits are on the y axes (BF: backfat; LADG: lifetime average daily gain; TADG: test average daily gain and ADI: average daily feed intake during test)

Line differences were also observed for BF (Figure 1). Estimates of the UCT and b for BF were 30.6°C and -0.028 for line A, or 31.6°C and $+0.038$ for line B. This suggests that the tipping point at which fat deposition is affected is high and more similar across lines than is the UCT for growth, although the positive b -value was unexpected. Nevertheless, fat levels can increase during times of heat stress as deposition moves from proteins to lipids (Christon 1988; Gentry *et al.* 2002) and in any case the possible magnitude of effect is very low given the small b -value and high UCT.

In terms of TADG line A had a positive linear relationship with temperature (slope= 1.27). This was potentially a surprising result considering that feed intake tends to decrease with increasing temperature. However, it could also suggest that gain was improved in line A when less energy is required to maintain body temperature in the fast growing animal. Lower thermal insulation in Line A (due to lower fat cover) potentially contributes to this result. In line B, however, much more intuitive results were observed. Estimates from the plateau-linear model were a UCT of 30.3°C and a slope of -6.49 grams/day per $^{\circ}\text{C}$. A plateau-linear model was also significant in line B for ADI; intake decreased (slope= -0.03 kg/day per $^{\circ}\text{C}$) once a UCT of 31.5°C was achieved. This result is of low magnitude but consistent in direction with the observed reduction in TADG. Huynh *et al.* (2005) demonstrated, using a ‘broken line’ methodology, that intake decreased after 25.5°C by 95.5 grams per $^{\circ}\text{C}$. The difference between these studies for the UCT might indicate a higher thermal tolerance of selection lines in this study, or alternatively reflect the difference between short term climate control studies versus field data, where continuous adaptation to the thermal environment occurs. Further, as previously noted,

some of the thermal effect on performance will be removed as part of the contemporary group effects.

There were no significant temperature effects on ADI in line A or for FCR in both of the lines from either linear or non-linear models, whereas contemporary group (also containing thermal effects) were significant. Overall these results highlight that there is variation between the lines studied in their response to temperature for these production traits even within contemporary groups.

Reproductive traits. Across lines, MT at mating was a significant linear covariate for TB1 and TB3, whereas MT at farrowing was significant for NBA2 and BWT3. However, while statistically significant, the small magnitude of the regression coefficient is biologically redundant considering the overall temperature interquartile range is ~10.5 degrees and thus generally a difference of only 0.1 piglet would be seen. However, reproductive records are censored in that only animals holding to service during periods of high temperature (i.e. due to seasonal infertility) have data, so the estimate might be biased downwards. For NBA2 the result was similar to that attained for the TB traits in that a positive linear trend was identified (also ~0.01 piglets per increase of 1°C). Finally, for BWT3 a linear regression of -0.002 kg per increase of 1°C was identified. Again the biological significance of this result is small.

Results by line were of similar magnitude and direction. There were no significant plateau-linear relationships identified for the reproductive traits analysed here, which is overall in line with the results of by Bloemhof *et al.* (2008) within their international line partially selected in hotter environments. Solutions for MT, centred around zero and rescaled to phenotypic standard deviation units, are shown for TB in Figure 2, along with regression curves (linear and quadratic) fitted to the solutions. Only the linear trend line for TB3, the quadratic trend for NBA1 and the linear trends for BWT2 and BWT3 described variation in solutions for MT. The curves fitted to these temperature solutions illustrate why linear and plateau-linear models may not be significant or adequate for these traits. For example, for TB2 the curve could suggest that extremes of temperature negatively affect this trait, although there are limited data at the temperature extremes.

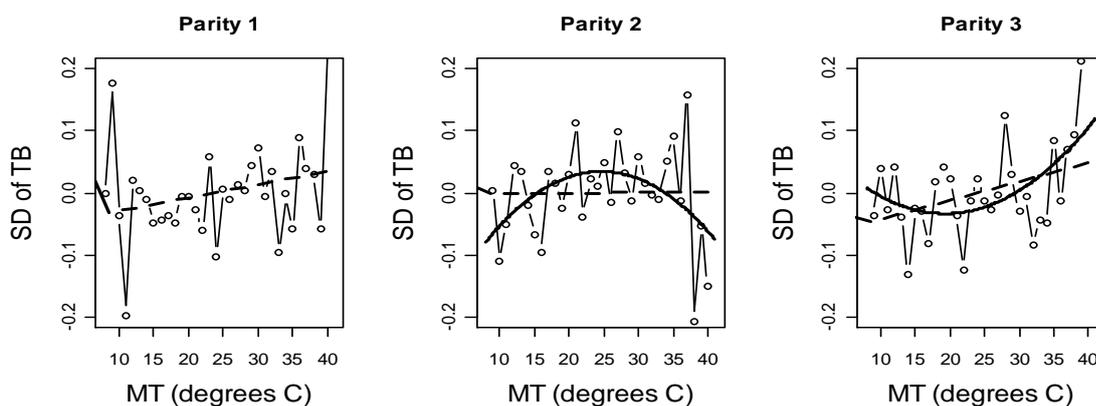


Figure 2. Ordinary least square solutions by parity for maximum temperature (MT) at mating on total born (TB). Total born is centred and rescaled to phenotypic standard deviations on the y axis. Linear (slashed) and/or quadratic (solid) lines of best fit are plotted through solutions for illustration; the quadratic is only plotted when fit is improved

Lactation intake. Across all data, there was no statistical evidence for linear or plateau-linear associations between average lactation intake and temperature. Separate analyses by line yielded much the same result. Therefore, the bulk of the thermal effect on average lactation intake is removed by contemporary group. However, solutions for MT showed that lactation intake reduced

with increasing temperature in an approximately linear fashion until an MT of around 25 degrees C, when average daily intake levelled out (not shown). Heat suppression of intake has been previously demonstrated by many authors (Hawton 1990; Nienaber *et al.* 1996; Schinckel *et al.* 2010) in experimental scenarios or when analysing lactation feed intake by season. However, our data suggests that in practice this effect is not truly linear nor well described by the models fitted in this study. Since we describe intake as an average value, it is possible that during lactation sows compensate for short term reductions in intake due to temperature if feed delivery is at demand, as occurred here, thereby reducing the overall effect on the average value within contemporary group. In addition, high MT at the end of lactation might not adequately reflect average temperature during the entire lactation, making it a relatively poor thermal descriptor for the entire lactation period. Previous work using daily records for intake and temperature shows that lactation intake reduced by 0.04 kg per day per 1°C increase in average temperature during lactation (Lewis *et al.* 2010).

Overall, plotting solutions for MT (as done in Figure 2) illustrates why there was no statistical evidence supporting a plateau-linear model for reproductive traits. In order for the plateau linear model to describe significant variation in the data, trait expression must be constant below the UCT, followed by a linear trend above the UCT. Our data suggest that the relationships between reproductive performance measures and temperature generally did not take this form. Curvilinear relationships between performance and temperature seem to be evident for some traits, consistent with the expectation that detrimental effects might be seen outside the pigs thermal neutral zone (Black *et al.* 1993) or at temperature extremes, but unfortunately data at the extremes are limited.

To examine short term effects of temperature, heat stress events were identified in these data to mirror the experimental studies using controlled temperatures. Two heat wave events were identified in the data where the MT on a specific day was considerably higher than that of the previous day. Across two separate heat wave events (for N ~140), with a temperature change of ~7°C, the average daily lactation intake was significantly reduced by ~0.5 kg the day after the temperature increase. However, sows returned relatively quickly to pre-heat wave intake levels even at higher temperatures (Figure 3). This observation is in line with the study of Patience *et al.*, (2005), who demonstrated recovery starting after about two days. However, it could also be observed that the two lines differed in their ability to recover from the heat stress events. The line with slower recovery also had a significantly lower average lactation feed intake. This small sample helps illustrate that there is certainly an effect of temperature on production that is perhaps better identified using experimental models or large but short term changes in temperature.

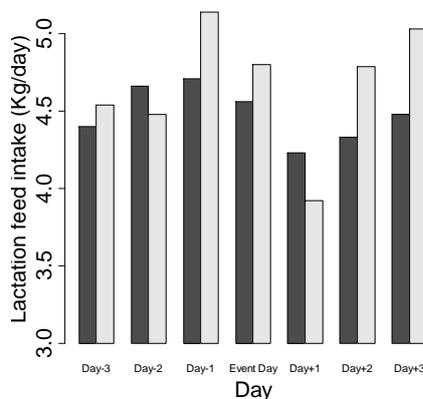


Figure 3. The effect of a short term heat event on lactation feed intake. The darkest (left) columns represent line A while the lighter columns represent line B

The data provides evidence that lines can differ in how they respond to increasing temperature even though these lines were selected within the same environment. These differences were illustrated using both the plateau-linear methodology, mainly for production traits, and also by examining the effects of significant short term changes in temperature on lactation feed intake.

Conclusions

While previous experimental work using climate controlled facilities have shown the effects of temperature on production traits and the underlying physiology of the pig, acclimatization, adaptation of feeding patterns to the diurnal range, and the partial confounding of temperature with contemporary group limit the ability to observe these effects as clearly in commercial data. Nevertheless, the expected short term consequences of heat stress, along with differences between lines in thermal tolerance, were observed. Since differences in performance data with season are used as proxies for thermal tolerance, and much of the thermal effect is removed in contemporary group solutions, the overall impact of improving thermal tolerance for production outcomes may be larger than is suggested by the results in this study. Therefore, identification of thermal tolerance traits which can be routinely recorded on individual animals within lines could offer opportunities to improve performance in frequently hot production environments.

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