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# Using ultrasound to derive new reproductive traits in tropical beef breeds: implications for genetic evaluation

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**Abstract.** Key components of female fertility in tropically adapted beef breeds are age at puberty and interval from calving to conception. Presence of an ovarian *corpus luteum* or stage of pregnancy were recorded using trans-rectal ultrasonography in 4649 heifers and 2925 first-lactation cows in seven herds of either Brahman, Droughtmaster or Santa Gertrudis tropical beef cattle breeds in northern Australia. The traits derived from a single ultrasonographic examination were incidence of *corpus luteum* at ~600 days of age in heifers, and weeks pregnant 5 weeks post-mating in heifers at ~2.5 years of age and in first-lactation cows at either 2.5 or 3.5 years of age. At 600 days of age, the bodyweight of heifers averaged 340 kg and 40% had a *corpus luteum*. At 2.5 years of age bodyweight of heifers averaged 452 kg and 80% were pregnant. First-lactation cows averaged 473 kg and 64% were pregnant. Considerable between-herd variation in traits reflected differences in climate and management at each site. However, estimates of heritability of incidence of *corpus luteum* at 600 days (0.18–0.32) and weeks pregnant in lactating cows (0.11–0.20) suggested that a significant proportion of the variation was due to additive gene action. Small to moderate genetic correlations with other economically important traits and the range in estimated breeding values indicate substantial opportunity for genetic improvement of the traits. The study provided evidence to accept the hypothesis that strategically timed ultrasound examinations can be adopted to derive useful traits for genetic evaluation.

**Additional keywords:** cattle, fertility, puberty.

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## Introduction

A major challenge for north Australian beef enterprises is to improve reproduction rate in the tropically adapted beef breeds. While environmental factors influenced by climate and herd-management practices account for a proportion of the variation in reproduction rate (Entwistle 1983), genetic factors also explain individual animal differences (Mackinnon *et al*. 1989; Martin *et al*. 1992). As herd reproduction rate is a major driver of beef enterprise productivity and profitability (McGowan *et al*. 2014), genetic improvement of fertility traits in conjunction with sound breeding-herd management offer a sustainable solution to the challenge.

Ultrasonography has been used in cattle since the early 1980s, providing knowledge of ovarian function (Pierson and Ginther 1984), which has implications for reproduction research (Ginther 2014), genetic evaluation (Carthy *et al*. 2014; Johnston *et al*. 2014*a*), genomic studies (Hawken *et al*. 2012; Fortes *et al*. 2012, 2016) and breeding management (Adams and Singh 2014; Holm *et al*. 2016). Detection of an ovarian *corpus luteum* (CL) using ultrasound allows accurate determination of key component traits of female reproductive performance, such as age at first CL in heifers (Johnston *et al*. 2009) and postpartum anoestrus interval in first-lactation cows (Johnston *et al*. 2014*a*). Heritability of age at first CL in Brahman and Tropical Composite breed females was estimated to be 0.57 and 0.52 respectively (Johnston *et al*. 2009). Heritability of postpartum anoestrus interval in the same breeds was estimated at 0.51 and 0.26 respectively (Johnston *et al*. 2014*a*). Age at first CL and postpartum anoestrus interval were also shown respectively, to be moderately and strongly associated with lifetime reproductive performance (Johnston *et al*. 2014*a*, 2014*b*). However, to accurately derive age at first CL and postpartum anoestrus interval, multiple trans-rectal examinations were required. Such intensity of measurement was necessary for rigorously designed research programs but may not be practical for most commercial beef-producing enterprises.

The extensive beef herds of northern Australia need a robust but simple system of trait recording to identify superior animals for these fertility traits so they can accelerate genetic improvement. The aim of the current research project was to test the practicality of using ultrasound to determine the presence of a CL in peri-pubertal heifers and pregnancy in heifers and lactating cows in Australian seed-stock herds and to evaluate the strength of inheritance of these traits. An additional objective was to estimate the phenotypic and genetic relationships between reproductive and body composition traits. The hypothesis was that a single ultrasound examination of heifers at 600 days of age, and one of heifers and lactating cows 5 weeks post-mating, will provide useful traits for genetic evaluation to aid improvement of herd reproduction.

## Materials and methods

### Ethics

Animal ethics approval was provided by The University of Queensland Production and Companion Animal Ethics Committee as Approval QAAFI\050\13\Smart Futures.

### Animals

The cattle were located in seven seed-stock herds across Queensland; their numbers and location within breed are shown in Table 1. The collaborating herds were engaged in a research project funded by the Queensland Smart Futures Fund (Burns *et al*. 2016) and represented Brahman, Droughtmaster and Santa Gertrudis beef cattle breeds, each being widely used for beef production in the subtropical and tropical regions of northern Australia. The cattle were born and raised as contemporaries in their cohorts within locations. Females were mated for approximately 3–4 months each year to bulls that had met the standards of bull breeding soundness (Beggs *et al*. 2013). Heifers in some herds were first mated as yearlings so a proportion of females in those herds presented as first-lactation cows at 2 years of age. Heifers in the remaining herds were first mated at 2 years of age.

At all locations, the breeding females were managed on grass-based pasture containing native and introduced species. Diets were supplemented with protein and minerals in the form of a 'dry lick' during periods of poor pasture quality to avoid loss of bodyweight and condition. Animals were vaccinated against endemic diseases (mainly *Clostridium* sp.) and strategically treated to reduce tick (*Rhipicephalus microplus*) and buffalo fly (*Haemotobia irritans exigua*) infestation. In total, 4649 heifers and 2925 first-lactation cows were included in the study from September 2012 through to July 2015. In total, 180 Brahman, 69 Droughtmaster and 116 Santa Gertrudis sires were represented and on average (±s.d.) they sired 9 (±10.0), 15 (±16.6) and 16 (±15.8) daughters respectively, with an overall range of 2–68 daughters per sire.

### Trait measurement

Ovarian activity was assessed in heifers at ~600 days of age by real-time ultrasound scanning. Previous studies reported that average age at puberty in tropically adapted Composite breeds occurred between 580 and 650 days (Burns *et al.* 1992; Johnston *et al.* 2009), at which time sire variation for pubertal rate of their daughters would likely be greatest. The timing of 600 days coincided with the recording of other performance traits submitted for genetic evaluation (e.g. ultrasound-scanned carcass traits) and also with post-joining pregnancy scanning in the older breeding females.

At scanning, the ovaries and uterus of each female were examined trans-rectally by ultrasound imaging with a Honda HS-2000V or HS-2100V (Honda Electronics Co., Ltd, Toyohashi, Japan) using a 10MHz linear array transducer to derive the fertility traits described in Table 2. For each animal, the same transducer was used to provide a cross-sectional image at the P8 rump site (Johnson 1987) and to measure thickness of the subcutaneous fat layer; additional records of liveweight and body condition score (BCS; 1–5 scale) were also kept.

In addition to the traits recorded in the present study, previously calculated estimated breeding values (EBVs) for the ultrasound-scan measures of subcutaneous fat depth, intra-muscular fat percentage (IMF%) and cross-sectional area of the eye-muscle (EMA; *M. longissimus thoracis pars lumborum*) were made available by the Australian Agricultural Business Research Institute, to provide associated body composition data. EBVs for the trait days to calving were also provided. Days to calving was calculated as the period from the start of mating to the date of calving (Johnston and Bunter 1996) and is currently included in BREEDPLAN genetic evaluation for Brahman and Santa Gertrudis, but not for Droughtmaster breeds. Pedigree files spanning several generations were available for each breed and, in total, contained 24 598, 10 339 and 46 815 identities for Brahman, Droughtmaster and Santa Gertrudis respectively.

**Table 1. Numbers of heifers scanned by breed, herd and location**

| Breed | Herd | Location; latitude, longitude | Number of heifers |
|---|---|---|---|
| Brahman | ALC | Valkyrie, central Queensland; –22.32, 148.93 | 576 |
| | ELR | Roundstone, central Queensland; –24.81, 149.74 | 863 |
| | SCC | May Downs, central Queensland; –22.72, 149.16 | 275 |
| Droughtmaster | COM | Canoona, central Queensland; –23.12, 150.17 | 346 |
| | LIS | Gumlu, northern Queensland; –19.82, 147.61 | 741 |
| Santa Gertrudis | GYR | Cracow, central Queensland; –25.26, 150.19 | 1042 |
| | ROS | Diamondy, south-eastern Queensland; –26.71, 151.30 | 806 |
| Total | | | 4649 |

## Statistical analyses

### Fixed-effect modelling

Significant fixed effects were identified separately for each breed using linear mixed model procedures in GENSTAT (16th Edition, VSN International, Hemel Hempstead, UK). Models included the fixed effects of year (2012–2015), herd (2 or 3 herds per breed), birth month, dam age (2–12 years), management group, their interactions and sire as a random effect. The effect of animal age was included as a covariate for all traits. BCS and P8 fat depth were tested as discrete variables in initial models to ascertain co-variability with CL score. Birth month of the individual was included in heifer trait models to account for differences in environmental conditions experienced across the calving period. Calving periods generally started in August and ended in late January, but there were differences in the start and end calving month across herds and years. Within herd–cohort subclasses, adjacent birth months with fewer than five animals were combined. Calving birth month was included in lactating-cow trait models to account for any effects that the age of their suckling calf might have on their ability to reconceive before bull removal. Non-significant ($P > 0.05$) terms were sequentially removed from the models to yield the final model for each trait. Final models for heifer traits generally consisted of a concatenated term for Herd + Year + Birth month and the age covariate. For cow traits, final models generally included terms for herd, year, management group (or paddock mated) and calving birth month.

### Variance component estimation

Additive genetic variance and heritability for each trait were estimated in univariate analyses separately for each breed, using restricted maximum-likelihood procedures in ASRemL (Gilmour *et al*. 2009). The binary traits (CL rate and pregnancy rate) were analysed using sire models with a logit-link function. Trait heritability on the observed binomial scale was approximated by multiplying the underlying logit-scale heritability by $p\,(1-p)$, where $p$ is the mean trait incidence (Gilmour *et al*. 2009). Heritability for binary traits was also derived with a linear model for comparison. The linear traits (CL score and weeks pregnant) were analysed by fitting an additive genetic effect for the animal, assuming a linear model. Both sire and animal models included the final fixed effects identified for each trait. Genetic correlations among pairwise combinations of 600d CL score with body condition score and P8 fat depth were estimated in a series of bivariate analyses for each breed separately.

Estimated breeding values were generated for the linear traits as solutions for the random effect of animal. Genetic associations between 600d CL score, weeks pregnant, body composition traits and days to calving were estimated by simple correlations between the EBVs of each trait for all individuals in the pedigree with EBV accuracy greater than 40% for all traits (including days to calving for the Brahman and Santa Gertrudis herds). From the available data, 4207 Brahman, 1516 Droughtmaster and 2339 Santa Gertrudis females had EBV accuracy greater than 40% for all traits and were included in the simple correlation matrices.

## Results

### Trait means

The numbers of females, their mean liveweight, body condition, fatness and scanned reproductive-trait measures within breed are presented in Table 3. The scanning of heifers at 600 days of age over 3 years and across seven herds captured an overall mean incidence of CL of 0.39 (±0.48). The differences in CL rate among breeds was confounded by herd and, therefore, prevailing seasonal conditions at the various locations. As females from each of the breeds were not kept together and raised as contemporaries, a valid breed comparison cannot be made.

### Trait heritability and EBVs

Heritability of the scanned reproductive traits measured at different ages within breed are presented in Table 4. Heritability estimates for binary traits on the logit scale were higher than those on the observed scale and the latter were generally similar to the linear-model estimates. The heritability of 600-day CL rate (0.22–0.33) was higher than that of pregnancy rate measured in heifers (0.04–0.18) and lactating cows (0.01–0.08), particularly in the Droughtmaster herds. Converting CL rate to CL score resulted in no appreciable change to the magnitude of heritability estimates, but generally reduced the standard error of the estimates. Conversion of heifer pregnancy rate to weeks pregnant did not affect either magnitude or standard error of the heritability estimates. However, converting pregnancy rate to weeks pregnant in first-lactation cows improved heritability estimates. The heritability of 2.5-year-old heifer pregnancy traits in Droughtmaster and Santa Gertrudis breeds was low or zero, reflecting high incidence (0.84 and 0.85 respectively) and little or no additive variance for the traits. However, in Brahman

**Table 2. Description of derived fertility traits**
CA, *corpus albicans*; CL, *corpus luteum*

| Trait | Description |
|---|---|
| CL rate | Presence (= 1) or absence (= 0) of CL or CA on either ovary observed by ultrasound imagery of all heifers in the cohort at ~600 days of age |
| CL score | Scored using ultrasound imagery of the reproductive tract at 600 days of age as: 0 = infantile tract, inactive or undetectable ovaries; 1 = ovarian follicles ≤ 10 mm; 2 = ovarian follicles >10 mm; 3 = presence of CL or CA |
| Pregnancy rate | Presence (= 1) or absence (= 0) of conceptus observed by ultrasound imagery of the reproductive tract ~5 weeks after completion of mating in heifers and first-lactation cows |
| Weeks pregnant | Weeks pregnant as determined by fetal size using ultrasound imagery 5 weeks after completion of mating in heifers and first-lactation cows; animals with no visible pregnancy but with detectable CL were given a value of 1 week, otherwise a zero; values ranged from 0 to 20 weeks |

**Table 3. Descriptive statistics of age, weight, body condition, fatness and reproductive scan data recorded on females at 600 days, 2.5 years and 3.5 years within breed**

Table values are given as a variable mean ± s.d.; *n*, number of animals scanned. 600d, heifers scanned at 600 days of age; 2yH, heifers scanned at 2.5 years of age; 2yL and 3yL, lactating cows scanned at 2.5 and 3.5 years of age; Santa Gertrudis herds mated a proportion of heifers at yearling so that some 2.5-year-olds are first-lactation cows (2yL) and 3yL will include first- and second-lactation cows in that breed. For CL or preg (incidence), tract scan variable at 600 days is shown as incidence of *corpus luteum* (CL); at other ages it is incidence of pregnancy.BCS, body condition score

| Cohort | *n* | Age (days) | Weight (kg) | BCS (1–5) | P8 fat (mm) | CL or preg (incidence) | Weeks pregnant |
|---|---|---|---|---|---|---|---|
| | | | | *Brahman* | | | |
| 600d | 1714 | 627 ± 74.6 | 336 ± 35.0 | 3.1 ± 0.52 | 5 ± 3.0 | 0.39 ± 0.49 | |
| 2yH | 1605 | 930 ± 96.0 | 436 ± 42.3 | 3.6 ± 0.48 | 8 ± 4.2 | 0.76 ± 0.43 | 11 ± 7.1 |
| 3yL | 875 | 1285 ± 44.9 | 461 ± 50.6 | 2.9 ± 0.69 | 5 ± 4.6 | 0.63 ± 0.48 | 9 ± 7.5 |
| | | | | *Droughtmaster* | | | |
| 600d | 1087 | 591 ± 47.2 | 342 ± 38.4 | 3.0 ± 0.48 | 4 ± 1.9 | 0.17 ± 0.38 | |
| 2yH | 754 | 894 ± 50.0 | 466 ± 37.6 | 3.8 ± 0.44 | 11 ± 4.0 | 0.84 ± 0.36 | 11 ± 5.5 |
| 3yL | 595 | 1283 ± 38.1 | 476 ± 47.3 | 2.9 ± 0.53 | 5 ± 3.9 | 0.66 ± 0.48 | 8 ± 6.7 |
| | | | | *Santa Gertrudis* | | | |
| 600d | 1848 | 521 ± 62.3 | 361 ± 39.7 | 3.1 ± 0.46 | 4 ± 2.6 | 0.53 ± 0.50 | |
| 2yH | 535 | 862 ± 48.0 | 482 ± 39.5 | 3.9 ± 0.40 | 10 ± 4.1 | 0.85 ± 0.35 | 11 ± 5.7 |
| 2yL | 581 | 923 ± 34.5 | 488 ± 52.2 | 2.9 ± 0.57 | 4 ± 4.0 | 0.64 ± 0.48 | 8 ± 6.7 |
| 3yL | 874 | 1291 ± 41.9 | 551 ± 69.1 | 2.9 ± 0.61 | 6 ± 4.8 | 0.82 ± 0.39 | 11 ± 7.1 |

**Table 4. Heritability of reproductive traits at 600 days, 2.5 years and 3.5 years in Brahman, Droughtmaster and Santa Gertrudis females**

600d, heifers scanned at 600 days of age; 2yH, heifers scanned at 2.5 years of age; 2yL and 3yL, lactating cows scanned at 2.5 and 3.5 years of age; Santa Gertrudis herds mated a proportion of heifers at yearling so that some 2.5-year-olds are first-lactation cows (2yL) and 3yL will include first- and second-lactation cows in that breed. Logit model shows estimates for binary traits using a sire model with a logit-link function; *p*, trait incidence; $\sigma^2_A = 4 \times \sigma^2_S$; $h^2_L$, heritability on the logit scale; $h^2$, heritability on the observed binomial scale approximated by $h^2_L \times p(1-p)$. Linear model, estimates for binary traits from linear sire models, estimates for linear traits from animal models. Standard errors are shown in parentheses. ne, inestimable. See Table 2 for trait definition

| Trait | Logit model | | | | Linear model | |
|---|---|---|---|---|---|---|
| | *p* | $\sigma^2_A$ | $h^2_L$ | $h^2$ | $\sigma^2_A$ | $h^2$ |
| | | | *Brahman* | | | |
| 600d CL rate | 0.39 | 1.581 | 1.13 (0.29) | 0.27 | 0.033 | 0.23 (0.07) |
| 600d CL score | – | – | – | – | 0.201 | 0.21 (0.06) |
| 2yH pregnancy rate | 0.76 | 1.310 | 0.99 (0.29) | 0.18 | 0.027 | 0.18 (0.06) |
| 2yH weeks pregnant | – | – | – | – | 5.907 | 0.15 (0.05) |
| 3yL pregnancy rate | 0.65 | 0.906 | 0.74 (0.50) | 0.17 | 0.011 | 0.08 (0.09) |
| 3yL weeks pregnant | – | – | – | – | 5.722 | 0.17 (0.10) |
| | | | *Droughtmaster* | | | |
| 600d CL rate | 0.17 | 2.836 | 1.66 (0.37) | 0.23 | 0.043 | 0.35 (0.11) |
| 600d CL score | – | – | – | – | 0.169 | 0.33 (0.09) |
| 2yH pregnancy rate | 0.84 | 0.274 | 0.26 (0.42) | 0.03 | 0.005 | 0.04 (0.06) |
| 2yH weeks pregnant | – | – | – | – | 0.052 | 0.00 (0.04) |
| 3yL pregnancy rate | 0.66 | 0.404 | 0.37 (0.52) | 0.08 | 0.008 | 0.05 (0.09) |
| 3yL weeks pregnant | – | – | – | – | 2.529 | 0.10 (0.09) |
| | | | *Santa Gertrudis* | | | |
| 600d CL rate | 0.53 | 1.115 | 0.87 (0.24) | 0.22 | 0.042 | 0.22 (0.07) |
| 600d CL score | – | – | – | – | 0.269 | 0.21 (0.05) |
| 2yH pregnancy rate | 0.85 | 0.000 | ne | ne | 0.000 | ne |
| 2yH weeks pregnant | – | – | – | – | 0.000 | ne |
| 2yL pregnancy rate | 0.64 | 0.301 | 0.28 (0.48) | 0.06 | 0.009 | 0.05 (0.10) |
| 2yL weeks pregnant | – | – | – | – | 3.630 | 0.13 (0.10) |
| 3yL pregnancy rate | 0.82 | 0.254 | 0.24 (0.46) | 0.04 | 0.002 | 0.01 (0.06) |
| 3yL weeks pregnant | – | – | – | – | 1.107 | 0.03 (0.06) |

females, the incidence of heifer pregnancy was lower at 0.76 and the heritability of 0.18 was significantly greater than zero.

Estimated breeding values for 600-day CL score (0–3) ranged from +0.91 to –0.88 in Brahman, from +0.73 to –0.64 in Droughtmaster and from +1.3 to –0.9 in Santa Gertrudis cattle. The range of EBVs for first-lactation weeks pregnant was highest in Brahman at +4.1 to –4.4 weeks, intermediate in Santa Gertrudis at +3.0 to –2.3 and lowest in Droughtmaster cattle at +1.8 to –2.2 weeks. Further work is required to collate Droughtmaster animal records so that days to calving can be genetically evaluated and EBVs assigned.

### *Correlation among traits*

Correlations between EBVs for the female scanned traits and EBVs for days to calving, a trait currently recorded for BREEDPLAN analyses in Brahman and Santa Gertrudis cattle, are presented in Table 5. Accuracy of EBVs for Santa Gertrudis and Droughtmaster heifer pregnancy rate could not be estimated as additive variance was close to zero and, hence, not shown in the correlation matrix in Table 5. In Brahman females, 600-day CL score was moderately correlated with heifer pregnancy, but had low correlation with weeks pregnant in first-lactation cows and days to calving. Weeks pregnant in Brahman heifers and first-lactation cows had small to moderate favourable correlations with each other and with days to calving. In Santa Gertrudis females, there was moderate favourable correlation among all reproductive measures assessed.

Genetic and phenotypic correlations among 600d CL score, BCS and P8 fat depth in heifers measured at the time of 600-day ultrasonic examination of reproductive tracts are shown in Table 6. Genetic correlations were moderate between CL score and BCS and low between CL score and P8 fat depth. Genetic correlations between BCS and P8 fat depth were moderate to high. Genetic correlations were generally associated with a high standard error.

The correlations between reproductive trait EBVs and carcass trait EBVs are presented in Table 7. The correlations were generally low for most pair-wise combinations; the few exceptions were low to moderate correlation between 600-day CL and rump fat (–0.28) and the moderate correlations of weeks pregnant with EMA (–0.30) and IMF% (0.41) in Santa Gertrudis females.

## Discussion

This study used ultrasound imagery of reproductive tracts in tropically adapted heifers and cows in Australian seed-stock herds to demonstrate genetic variation in and derive estimates of genetic merit for presence of an ovarian CL or stage of pregnancy. These unique measures have previously been reported only by Johnston

**Table 5. Simple correlations among estimated breeding values (EBVs) for reproductive traits in Brahman and Santa Gertrudis breeds**

600d, heifers scanned at 600 days of age; 2yH, heifers scanned at 2.5 years of age; 2yL and 3yL, lactating cows scanned at 2.5 and 3.5 years of age; Santa Gertrudis herds mated a proportion of heifers at yearling so that some 2.5-year-olds are first-lactation cows (2yL) and 3yL will include first- and second-lactation cows in that breed. *n* = number of individuals with EBVs >40% accuracy included in the correlation matrix. EBVs for Santa Gertrudis 2yH not included due to low additive variance and zero accuracy; Droughtmaster had few EBVs with >40% accuracy for 2yH weeks pregnant and no days to calving EBVs so not included

| Trait | 2yH weeks pregnant | 3yL weeks pregnant | Days to calving |
|---|---|---|---|
| | *Brahman* (*n = 4207*) | | |
| 600d CL score | 0.39 | 0.06 | –0.08 |
| 2yH weeks pregnant | – | 0.25 | –0.23 |
| 3yL weeks pregnant | | – | –0.25 |
| | *Santa Gertrudis* (*n = 2339*) | | |
| 600d CL score | – | 0.31 | –0.38 |
| 2yL weeks pregnant | – | 0.34 | –0.41 |
| 3yL weeks pregnant | | – | –0.58 |

**Table 6. Genetic and phenotypic correlations among heifer *corpus luteum* (CL) score, body condition score (BCS) and rump fat (P8 fat) at 600 days**

Genetic correlations above diagonal, phenotypic below, estimates from bivariate analyses; standard errors are shown in parentheses; 600d, heifers scanned at 600 days

| Trait | 600d CL score | BCS | P8 fat |
|---|---|---|---|
| | *Brahman* | | |
| 600d CL score | | 0.36 (0.18) | 0.29 (0.18) |
| BCS | 0.19 (0.03) | | 0.85 (0.07) |
| P8 fat | 0.19 (0.02) | 0.58 (0.02) | |
| | *Droughtmaster* | | |
| 600d CL score | | 0.31 (0.20) | 0.25 (0.18) |
| BCS | 0.17 (0.03) | | 0.43 (0.16) |
| P8 Fat | 0.20 (0.03) | 0.44 (0.02) | |
| | *Santa Gertrudis* | | |
| 600d CL score | | 0.49 (0.19) | 0.10 (0.18) |
| BCS | 0.30 (0.02) | | 0.74 (0.11) |
| P8 fat | 0.31 (0.02) | 0.55 (0.02) | |

**Table 7. Simple correlations of female reproduction-trait estimated breeding values (EBVs) with carcass-trait EBVs for Brahman, Droughtmaster and Santa Gertrudis breeds**

600d, heifers scanned at 600 days; 2yL and 3yL, first-lactation cows scanned at 2.5 and 3.5 years respectively. *n* = number of individuals with EBVs >40% accuracy included in the correlation matrix; EBVs for intramuscular fat (IMF%) were not available for Brahman

| Trait | Rump fat | Rib fat | EMA | IMF% |
|---|---|---|---|---|
| | *Brahman* (*n = 4207*) | | | |
| 600d CL score | 0.12 | 0.09 | –0.11 | – |
| 3yL weeks pregnant | 0.15 | 0.08 | 0.10 | – |
| | *Droughtmaster* (*n = 1516*) | | | |
| 600d CL score | 0.10 | 0.10 | 0.21 | 0.10 |
| 3yL weeks pregnant | 0.01 | 0.00 | –0.11 | –0.09 |
| | *Santa Gertrudis* (*n = 2339*) | | | |
| 600d CL score | –0.28 | –0.21 | –0.11 | 0.11 |
| 2yL weeks pregnant | 0.00 | 0.04 | –0.30 | 0.41 |

*et al*. (2009, 2014*a*, 2014*b*). Measuring the ability of heifers to mature sexually earlier in life and for first-lactation cows to reconceive earlier in the breeding season are principal components to determining lifetime reproductive performance of beef-producing cows (Johnston *et al*. 2014*a*, 2014*b*). Obtaining measurements or indicators of reproductive capability at these two critical periods in the breeding time-line of bovine females should enable selection of genetically superior individuals as parents to pass on these attributes to the next generation.

Johnston *et al*. (2009) reported the mean age of heifers at the time of detection of their first CL to be ~750 days in Brahman and 650 days in Tropical Composite breeds. In the current study, 40% of the Brahman heifers had, on average, a CL at 630 days, showing a tendency to earlier age at first CL than that reported in Brahman research herds by Johnston *et al*. (2009), where 50% had a CL by ~750 days. However, the Droughtmaster heifers in the current study, despite having weight and body fatness similar to the Brahmans, had only 17% with a CL at an average 590 days. Approximately 50% of Santa Gertrudis heifers had CL by 520 days and weighed ~20–25 kg more than did heifers from the Brahman and Droughtmaster herds at approximately the same ages, which is likely reflecting better nutritional conditions at the locations of Santa Gertrudis herds. The results provided evidence to suggest substantial breed and environmental influences on the incidence of CL at 600 days of age.

Despite environmental effects, ultrasound scanning of ovaries to ascertain presence of an ovarian CL in heifers at 600 days provided a trait with heritability of between 0.21 and 0.33. In a review, Martin *et al*. (1992) reported a pooled heritability estimate of 0.40 for age at puberty. These estimates were moderate, compared with the higher heritability of the trait age at first CL (0.51–0.57) estimated by Johnston *et al*. (2009). However, 600-day CL in the current study was derived from a single scan and poses a viable alternative to monthly scanning of heifers to ascertain age at first CL. No other literature estimates of heritability were found for pubertal traits in beef cattle, determined using ultrasound scans for presence of CL.

Fetal ageing of first-lactation cows 5 weeks after the completion of the joining period provided a continuous measure of reconception with a normal distribution and a higher heritability estimate than the binary trait of pregnancy rate (0.17 versus 0.08 in Brahman cows, 0.10 versus 0.05 in Droughtmaster cows and 0.13 versus 0.05 in Santa Gertrudis cows). Johnston *et al*. (2014*a*) estimated the heritability of pregnancy rate, anoestrus interval and days to calving in the first-lactation Tropical Composite cows to be 0.05, 0.26 and 0.35 respectively; and in the first-lactation Brahman cows to be 0.25, 0.51 and 0.49 respectively. The heritability estimates for first-lactation pregnancy from the current study were generally similar (Cavani *et al*. 2015; Terakado *et al*. 2015) or greater (Cammack *et al*. 2009; Berry *et al*. 2014) than were those reported from studies of other breeds internationally.

The heritability estimates for first-lactation anoestrus from the study of Johnston *et al*. (2014*a*) were moderate to large and a key finding of that study. The strong estimated heritability may be resultant of the robust experimental design in the research herds and the ability of regular ultrasound scans to more precisely determine when the cows returned to oestrus post-calving. The heritability estimates of Johnston *et al*. (2014*a*) in Brahman cows were associated with a considerably higher standard error (0.19) than that for the Tropical Composite cows (0.09) and those estimated for weeks pregnant in the current study (0.06–0.10). Nonetheless, the results signify marked differences among heritability estimates for related traits measured across breeds and herds. The differences emphasise the need for breed-specific genetic variances and for strong genetic linkage among herds contributing performance data to within-breed genetic evaluation programs.

The simple correlation between EBVs for 600-day CL score in heifers and weeks pregnant in first-lactation cows was low in Brahman herds (0.06) and moderate in Santa Gertrudis herds (0.31). Johnston *et al*. (2014*b*) estimated genetic correlations between age at first CL and pregnancy rate in first-lactation cows to be considerably stronger for Brahman (–0.14) and for Tropical Composite (–0.68) females in the rigidly controlled research herds. The genetic relationship between 600-day CL score and days to calving, estimated in the current study by simple correlation of the trait EBVs, was low in Brahman herds (–0.08) and moderate in Santa Gertrudis herds (–0.38), but favourable. The genetic correlation between age at first CL and days to calving in first-lactation cows estimated by Johnston *et al*. (2014*a*) was 0.08 in Brahman and 0.43 in Tropical Composite females, similar in magnitude to the seed-stock herd estimates, and also favourable. The results indicated that selection for earlier age at first CL, or for increased incidence of CL in heifers at 600 days will have correlated responses in pregnancy rate and days to calving in first-lactation cows, particularly in Santa Gertrudis and Tropical Composite breeds.

Correlation between EBVs for weeks pregnant in first-lactation cows and days to calving EBVs in the seed-stock herds was moderate for both Brahman (–0.25) and Santa Gertrudis (–0.41) breeds. In the research herds, Johnston *et al*. (2014*a*) estimated genetic correlations among the reconception traits measured in first-lactation cows (pregnancy rate, anoestrus interval and days to calving) to be close to unity in both Brahman and Tropical Composite herds, suggesting that the traits may be controlled by the same genes. Johnston *et al*. (2014*a*, 2014*b*) also reported that age at first CL and reconception traits were genetically associated with lifetime reproductive performance (genetic correlations ranged from 0.30 to 0.55).

Genetic correlation estimates of 600-day CL score were stronger with BCS than with P8 fat depth, particularly in Santa Gertrudis heifers. Johnston *et al*. (2009) and Wolcott *et al*. (2014*a*) reported genetic correlations of age at first CL with BCS and P8 fat depth at 600 days to have similar trends in Brahman heifers, but not in Tropical Composite heifers. The Santa Gertrudis heifers at 600 days in the current study were heavier, leaner and less variable in P8 fat than were the Brahman heifers. The results suggested that body mass and overall body condition could be more important than subcutaneous fat reserves for the attainment of puberty in some breeds.

Correlations of EBVs for 600-day CL score and weeks pregnant in first-lactation cows with body composition trait EBVs within Brahman and Droughtmaster breeds were generally low and showed no consistent trends or antagonisms. These results suggest that selection for increased fertility would have no adverse effects on fatness or muscling in those breeds.

However, the correlations between reproduction and body-composition traits in Santa Gertrudis cattle indicated that selection for increased early pregnancy in first-lactation cows may be associated with a higher IMF% and a lower EMA. Wolcott *et al*. (2014*b*) also reported contrasting genetic associations between EMA and first-lactation pregnancy rate in Brahman (–0.03) and Tropical Composite (0.50) breeds. In Brahman cattle, Johnston *et al*. (2009) found moderate genetic correlation between age at first CL and fatness in heifers (–0.35) but not in their steer siblings (0.04). The genetic correlations reported by Johnston *et al*. (2009) indicated that selection for increased heifer fatness at 600 days would reduce age at CL in both Brahman and Tropical Composite breeds. By contrast, the correlation between rump fat and 600-day CL score EBVs (–0.28) in Santa Gertrudis in the current study suggested that selection for increased fatness in heifers would be associated with reduced incidence of CL at 600 days, or, at best, that presence of CL in Santa Gertrudis heifers is not dependent on fat cover at the rump. As discussed previously, bodyweight and condition may be more important for attainment of a CL at 600 days than is fatness recorded at the rump P8 site in Santa Gertrudis heifers.

Developments in genomic technologies aim to improve the accuracy of selection, particularly for the difficult-to-measure reproductive traits (Hawken *et al*. 2012; Zhang *et al*. 2014; Fortes *et al*. 2016; Reverter *et al*. 2016). However, collection of phenotypes will still be needed, in resource populations at least, to refine genomic predictions. Further work is required to determine the genetic relationship of these single-scan reproductive traits with measures of whole-herd productivity and how they might be implemented into the genetic evaluation process of BREEDPLAN. However, heritability, relationships with days to calving and the range of EBVs provided evidence to suggest that 600-day CL score and weeks pregnant traits might add value to the current genetic evaluation, possibly by contributing to an index for reproductive capability.

## Conclusions

The use of ultrasound provides a practical means of detection of early sexual maturity and pregnancy in heifers and lactating cows. These attributes of fertility provide information to derive heritable traits that should prove useful in genetic evaluation programs. For this form of reproductive-trait recording to become widely implemented in Australian seed-stock herds, the cost of scanning replacement heifers at 600 days of age has to be perceptibly outweighed by the proven benefits of selecting superior individuals.

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