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The performance of Brahman–Shorthorn and Sahiwal–Shorthorn beef cattle in the dry tropics of northern Queensland

5. Scrotal circumference, temperament, ectoparasite resistance, and the genetics of growth and other traits in bulls

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Summary. The genetics of growth to 24 months, scrotal circumference (SC) at 24 months and temperaments at 6, 12 and 18 months in 7 year groups of F_2 *et seq.*, 1/2 Brahman, 1/2 Sahiwal, 3/4 Brahman and 3/4 Sahiwal bulls were investigated in the dry tropics of northern Queensland. Cattle tick (*Boophilus microplus*) and buffalo fly (*Haematobia irritans exigua*) resistance were also assessed at 24 months.

Scrotal circumference at 24 months was highest in 1/2 Sahiwal crosses (28 cm *v.* 26–27 cm; $P<0.05$) with pronounced variation between years (24–31 cm; $P<0.05$). Temperaments (TEM score; flight distance) were generally poorest in 3/4 Sahiwal crosses ($P<0.05$). Bulls of 1/2 *Bos indicus* content were twice as susceptible as 3/4 crosses to tick infestations ($P<0.05$). There were no genotype differences in natural buffalo fly infestations.

Temperaments, tick resistance and buffalo fly resistance all had no consistent significant relationships with either each other or with weights or growth rates to 24 months.

Paternal half-sib estimates of heritabilities across all genotypes were generally moderate for weight (0.20–0.36), growth rates (0.08–0.46), and SC (0.32), low for TEM score (0.08–0.14), and high for flight distance (0.32–0.70).

The genetic correlations (r_G) between growth rates in both dry and wet seasons after weaning were high (≥ 0.9); however, the r_G of weaning weight with post-weaning seasonal growth rates to 24 months were consistently negative (−0.09 to −0.71; $P>0.05$). The r_G of SC with post-weaning growth rates were negative (−0.4 to −0.8). The r_G of SC with weights up to 18 months were not significantly different to zero, but tended to be negative with weight at 24 months.

Introduction

Selection of genetically superior breeding stock is an important component of beef production and one technique available to increase overall herd productivity. Selection of bulls for superior growth leads to increases in scrotal circumference (SC) and improved semen characteristics in *Bos taurus* cattle (Abadia *et al.* 1976; Knights *et al.* 1984; Bourdon and Brinks 1986; Smith *et al.* 1989). In Zebu and Zebu-derived cattle in central Queensland, similar responses have been found (Mackinnon *et al.* 1991*b*), along with favourable correlated responses in some adaptive traits (Mackinnon *et al.* 1991*a*). Fordyce *et al.* (1985, 1988) reported that higher growth was phenotypically correlated with good temperaments in northern Queensland. However, since responses to selection for improved production may vary between environments (Frisch and Vercoe 1982), the afore mentioned relationships need to be confirmed for the harsher conditions in the dry tropics of north Australia.

A previous paper in this series (Fordyce *et al.* 1993) described the post-weaning weight and growth performance of male cattle of F_2 *et seq.* generations of 1/2 Brahman, 1/2 Sahiwal, 3/4 Brahman and 3/4 Sahiwal. Animals of 3/4 *Bos indicus* content generally grew faster than those of 1/2 *Bos indicus* content, with Brahman crosses generally performing better than Sahiwal crosses. Their advantages in growth rates may have been partially a function of their adaptation. This paper compares several other commercially important traits, including SC, ectoparasite resistance and temperaments in bulls of these genotypes. Estimates of the heritability of some of these traits and growth rates, as well as genetic and phenotypic correlations between traits are examined.

Materials and methods

Location

The study was conducted at Swan's Lagoon Beef Cattle Research Station (20°05'S, 147°14'E) in subcoastal northern Queensland. The climate is dry tropical and is characterised by a distinct hot, wet summer period (wet season) and a warm, dry winter period followed by a hot, dry period (dry season). Mean maximum and minimum temperatures for January are 31 and 23°C, and for July are 26 and 9°C. Distribution and amount of annual rainfall is highly variable. The 29-year average is 880 mm (296–1951 mm). The average start to the wet season (seasonal break) is 17 November. Seasons are poorer when dry seasons are longer, especially if preceded by low wet season rainfall. Details of rainfall in the years of the study are presented in Table 1. Total rainfall in this period was about 80% of the long-term average, and dry seasons were on average 0.2 months longer.

The vegetation is open woodland (primarily *Eucalyptus* spp.) with a native unimproved pasture which is predominantly black spear grass (*Heteropogon contortus*), with tropical tall grasses, and other medium grasses (e.g. *Chrysopogon fallax* and *Bothriochloa petusa*). The experimental area is flat and includes mostly duplex soils (A horizon typically about 20–25 cm). The top soil (10 cm) is slightly acid (pH 6.3) with very low chloride levels (average 18 mg/kg) and electrical conductivity (average 0.025 mS/cm), and generally has low fertility, an average of 5 μg/g phosphorus (bicarbonate-extracted), 2 mg/kg extractable nitrogen, 0.7% organic carbon, and generally low–medium levels of other major minerals.

Table 1. Rainfall during the study period and duration of the dry season (months from 1 June to the seasonal break)

Year	Rainfall (mm) Dry season	Rainfall (mm) Wet season	Dry season duration
1978–79	125	944	5.5
1979–80	71	830	6.9
1980–81	58	915	7.0
1981–82	48	541	5.6
1982–83	58	600	7.6
1983–84	59	409	5.8
1984–85	67	550	4.2
1985–86	108	549	4.7
1986–87	52	423	4.7

Cattle and their management

Male, F_2 *et seq.*, 1/2 Brahman, 1/2 Sahiwal, 3/4 Brahman and 3/4 Sahiwal (x beef Shorthorn) progeny weaned in the years 1979–85 were used in this study. Progeny which were the result of single-sire mating and born in the years 1982–85 were used in genetic studies. Calves were born from November to January inclusive and weaned at 5–7 months of age in early June each year, except in 1983 when calves were weaned in mid-April because of drought.

Year groups were managed as single groups and run predominantly on native pasture stocked at 1 adult equivalent per 4–6 ha. There were no treatments for parasites. Supplements were provided to year groups in years when it was necessary for the prevention of deaths due to poverty. At 18 months of age, 50 and 30% of all genotype groups in the 1979 and 1984 year groups, respectively, were castrated. Castrates had the lowest weights per day of age (WDA). In other year groups, all bulls remained entire to 24 months of age. All data reported are for entire males.

Measurements

Growth traits measured included weights at weaning (5–7 months), 12, 18 and 24 months (WW, W12, W18 and W24 respectively). Weights at weaning and 18 months usually correspond to the ends of wet seasons, while at 12 and 24 months correspond to the ends of dry seasons. Average daily gains were calculated for the first dry season (weaning–12 months), first wet season (12–18 months), and second dry season (18–24 months) after weaning (GRD1, GRW1, and GRD2) plus from weaning to both 18 and 24 months (GR18 and GR24).

Scrotal circumference was measured at 24 months of age (in 50 and 70% of the 1979 and 1984 year groups, respectively). Bulls with the highest WDA at 24 months (40–70%, with the same proportion of each genotype within year) were assessed for resistance to the cattle tick (*Boophilus microplus*); not more than 100 bulls were assessed in each year. Each bull was artificially infested with 20 000 tick larvae. Engorged ticks were counted on the left side of each bull while restrained in a cattle crush, 20 and 21 days after infestation as described by Utech *et al.* (1978).

Resistance to buffalo fly (*Haematobia irritans exigua*) infestation was assessed at 24 months by counting the number of flies (to the nearest 10) on the left side of each bull while it was restrained in a panel of a race (Holroyd *et al.* 1984).

Two assessments of temperament as described by Fordyce *et al.* (1982) were made at 3 times: 1 month after weaning, and at 12 and 24 months of age. Summing scores for fear responses, including movement (1–7), audible respiration (0–1.5), bellowing (0–1), kicking (0–1), and going down (0–2), during handling of segregated individuals in a panel of a race constituted a TEM score (Fordyce *et al.* 1985). A TEM score was the average of 2 assessments at each age. Flight distance (FD in metres) was the minimum tolerated approach distance of a handler to segregated bulls in a large yard. Approaching closer than the FD elicits a marked increase in fear responses, especially flight. For both temperament assessment methods, high values indicated poor temperaments.

Statistical analyses

All data were analysed by the least squares method for unequal subclass numbers (Harvey 1975) using a model with year weaned (Y), genotype (G), age of dam (3, 4 and 5+ years), date of birth (first, second or third month of the calving season) and the G x Y interaction. Preliminary analyses found other interactions were not significant ($P>0.05$). For analyses, tick counts were transformed to natural log (count + 1) and buffalo fly counts were transformed to natural log.

Heritabilities (h^2), and genetic and phenotypic correlations (r_G and r_P) were estimated by paternal half-sib methods based on least squares procedures as described by Harvey (1975) using only bulls from the single-sire cohorts which were weaned in 1982, 1983, 1984 and 1985. The model fitted included year weaned, genotype, age of dam and date of birth as fixed effects, and sires within genotype as a random effect. Genetic analyses for all traits except FD at 24 months used data from 485 bulls by 49 different sires; analysis of FD at 24 months used 312 bulls by 31 different sires. Sires were used over 2 years where possible to prevent confounding of sires and years. Sires with less than 3 male offspring entire at 24 months were excluded from the genetic analysis. Standard errors of h^2 and r_G were calculated as described by Swiger *et al.* (1964). Insufficient data for tick and buffalo fly counts meant genetic analyses were not possible, and phenotypic correlations could only be estimated for tick counts.

Results

Fixed effects

Scrotal circumference at 24 months was higher in 1/2 Sahiwal crosses than in the other 3 genotypes (Table 2; $P<0.05$). There was large variation between years in SC, ranging from 23.7 cm for the 1981 year group to 31.2 cm for the 1984 year group. Bulls from young dams (<5 years) had a smaller SC than bulls with mature dams (26.6 *v.* 27.3 cm, respectively; $P<0.05$). Those born later in the calving season had a smaller SC than those born early (25.7 *v.* 28.0 cm, respectively; $P<0.05$).

Following artificial infestation, 1/2 *Bos indicus* cross bulls had double the number of engorged ticks that 3/4 *Bos indicus* crosses had (Table 2; $P<0.05$). There was no difference in tick resistance between Brahman and Sahiwal crosses and no differences in buffalo fly resistance between genotypes. Variation across years was large for both tick and buffalo fly counts (Table 2). Three-quarter Sahiwals crosses consistently had higher TEM and FD scores (poorer temperaments) than other genotypes (Table 3; $P<0.05$). There was minor variation between years for temperament scores. Despite a significant genotype x year interaction for FD at

Table 2. Effects of year and genotype on scrotal circumference (SC; cm), tick count, and buffalo fly count of *Bos indicus* cross bulls at 24 months of age

Tick counts were transformed to natural log (count + 1) and buffalo fly counts were transformed to natural log; back-transformed means are in parentheses

Means within factors followed by the same letter are not significantly different at $P = 0.05$

	No. of bulls	SC	No. of bulls	Tick count	No. of bulls	Fly count
Mean ± s.d.	809	27.0 ± 2.9	443	3.89 (48) ± 0.98	255	4.94 (139) ± 0.70
Year of weaning						
1979	67	24.9e	65	4.26a (70)	66	4.88b (131)
1980	142	26.1d	95	4.46a (85)	141	5.34a (209)
1981	52	23.7e	46	3.71b (40)		
1982	114	27.6c	100	4.20a (66)		
1983	216	26.2d	89	4.11a (60)		
1984	48	31.2a	48	2.62c (13)	48	4.59c (98)
1985	170	28.9b				
Crossbred group						
$^{1}/_{2}$ Brahman	229	26.3b	130	4.08a (58)	79	5.00 (149)
$^{3}/_{4}$ Brahman	274	26.9b	153	3.58b (35)	94	4.93 (139)
$^{1}/_{2}$ Sahiwal	175	27.8a	95	4.28a (71)	50	4.97 (144)
$^{3}/_{4}$ Sahiwal	131	26.8b	65	3.63b (37)	32	4.84 (127)

Table 3. Effects of year and genotype on temperament scores of *Bos indicus* cross bulls at weaning, and at 12 and 24 months of age

Temperament score (TEM) in a crush on a scale of 1 (good temperament) to 13.5 (poor temperament)
Flight distance (FD) in an open yard in metres—higher scores indicate poorer temperaments
Means within factors followed by the same letter are not significantly different at $P = 0.05$

	No. of bulls[A]	TEM			FD		
		Weaning	12 months	24 months	Weaning	12 months	24 months
Mean ± s.d.	603 (376)	3.0 ± 1.1	2.4 ± 1.1	2.5 ± 1.1	3.4 ± 1.2	3.0 ± 1.1	2.7 ± 1.0
Year of weaning							
1982	117 (115)	2.6c	2.1a	2.4a	5.0a	4.5a	3.2a
1983	214 (213)	3.1b	2.5b	2.9b	3.7b	2.6b	2.5b
1984	97 (48)	2.8c	2.8c	2.3a	2.6c	3.0c	2.4b
1985	175	3.4a	2.4b	2.5a	2.3c	2.4b	—
Genotype							
$^{1}/_{2}$ Brahman	168 (99)	3.0ab	2.4	2.3a	3.1a	2.8a	2.5a
$^{3}/_{4}$ Brahman	190 (115)	2.9a	2.3	2.2a	3.2ab	2.9a	2.6a
$^{1}/_{2}$ Sahiwal	138 (90)	2.8a	2.5	2.5a	3.4b	3.1a	2.5a
$^{3}/_{4}$ Sahiwal	107 (72)	3.3b	2.7	3.0b	3.9c	3.7b	3.2b

[A] Values in parentheses are for FD at 24 months.

24 months, the ranking of genotypes remained generally similar.

Neither dam age nor date of birth had any influence on tick or buffalo fly resistance at 24 months of age or on TEM scores at any age.

Fixed effects on weights and growth rates have been reported previously (Fordyce *et al.* 1993).

Genetic analyses

Heritabilities. Heritabilities of weights and growth rates were generally low to moderate (Table 4). The h^2 estimate was moderate for SC (Table 5). The inclusion of W24 as a covariate in the analysis of SC was significant ($P<0.01$), with the h^2 estimate increasing from 0.32 ± 0.14 to 0.68 ± 0.18. TEM was lowly heritable at all ages (Table 5). However, the h^2 for FD was moderate at weaning and 12 months and very high at 24 months of age (Table 5).

Correlations between growth traits. Genetic correlations between WW and post-weaning seasonal growth rates up to 24 months were consistently negative (Table 4; $P>0.05$). The r_P of WW with subsequent growth rates was generally low and negative.

The r_G of W12 and W18 with post-weaning growth were not significantly different from zero, though generally positive. Phenotypic correlations were low and variable (Table 4).

Growth in all post-weaning seasonal periods had very

Table 4. Means and heritabilities of, and phenotypic and genetic correlations between, bull weights and growth rates ($n = 485$)

Heritabilities (± s.e.) on the diagonal; phenotypic correlations above the diagonal; genetic correlations (± s.e.) below the diagonal
Dry 1, wet 1 and dry 2 represent the first dry season, first wet season and second dry season after weaning respectively

	Weight (kg)				Growth rate (g/day)				
	Weaning	12 months	18 months	24 months	Dry 1	Wet 1	Dry 2	Weaning–18 months	Weaning–24 months
Mean ± s.d.	165 ± 22	193 ± 23	277 ± 27	291 ± 27	123 ± 62	535 ± 86	81 ± 78	306 ± 49	233 ± 40
Weight									
Weaning	**0.32 (0.14)**	0.83	0.76	0.62	–0.24	0.11	–0.22	–0.09	–0.23
12 months	0.96 (0.07)	**0.23 (0.13)**	0.86	0.76	0.33	0.03	–0.16	0.28	0.11
18 months	0.75 (0.17)	0.96 (0.07)	**0.20 (0.12)**	0.88	0.21	0.51	–0.17	0.58	0.33
24 months	0.51 (0.23)	0.76 (0.15)	0.96 (0.07)	**0.36 (0.14)**	0.25	0.45	0.31	0.56	0.62
Growth rate									
Dry 1	–0.71 (0.77)	–0.47 (0.54)	0.18 (0.64)	0.49 (0.50)	**0.08 (0.10)**	–0.16	0.08	0.63	0.55
Wet 1	–0.29 (0.41)	0.13 (0.47)	0.42 (0.40)	0.68 (0.28)	1.40 (1.17)	**0.16 (0.12)**	–0.09	0.64	0.44
Dry 2	–0.09 (0.42)	0.18 (0.47)	0.57 (0.54)	0.79 (0.29)	0.95 (0.77)	0.89 (0.60)	**0.18 (0.12)**	–0.00	0.61
Weaning–18 months	–0.50 (0.34)	0.17 (0.36)	0.21 (0.37)	0.47 (0.25)	1.22 (0.45)	1.01 (0.18)	0.79 (0.41)	**0.32 (0.14)**	0.78
Weaning–24 months	–0.32 (0.32)	0.00 (0.34)	0.39 (0.31)	0.65 (0.17)	1.15 (0.48)	1.01 (0.25)	0.95 (0.17)	0.95 (0.07)	**0.46 (0.16)**

Table 5. Means and heritabilities of, and phenotypic and genetic correlations between, SC, temperament scores, and tick burdens in bulls (n = 485, except for estimates including flight distance at 24 months when n = 312)

Heritabilities (± s.e.) on the diagonal; phenotypic correlations above the diagonal, genetic correlations (± s.e.) below the diagonal

Genetic correlations for tick count were not estimated due to negative sire component of variance and insufficient data

TEM, temperament score; FD, flight distance

	SC	TEM			FD			Tick count
		Weaning	12 months	24 months	Weaning	12 months	24 months	
Means ± s.d.	28.6 ± 2.4	3.1 ± 1.1	2.4 ± 1.1	2.7 ± 1.1	3.3 ± 1.2	2.8 ± 1.1	2.6 ± 1.0	4.0 [52^{A}] ± 1.0
SC	**0.32 (0.14)**	0.09	0.06	0.03	0.02	0.03	0.13	–0.05
TEM score								
Weaning	0.72 (0.43)	**0.14 (0.11)**	0.56	0.40	0.23	0.23	0.25	–0.14
12 months	1.04 (0.51)	0.92 (0.32)	**0.12 (0.11)**	0.57	0.25	0.29	0.28	–0.07
24 months	0.54 (0.60)	0.85 (0.55)	0.35 (0.66)	**0.08 (0.10)**	0.21	0.19	0.22	–0.10
FD								
Weaning	–0.13 (0.31)	0.21 (0.40)	0.42 (0.40)	–0.54 (0.50)	**0.40 (0.15)**	0.75	0.55	–0.06
12 months	0.02 (0.34)	0.32 (0.41)	0.54 (0.40)	–0.60 (0.54)	0.98 (0.07)	**0.32 (0.14)**	0.63	–0.09
24 months	0.17 (0.32)	1.06 (0.60)	0.86 (0.28)	0.22 (0.41)	0.93 (0.11)	1.05 (0.08)	**0.70 (0.23)**	–0.06

[A] Back transformation of natural logarithm (tick count + 1).

high positive r_G values with GR18 and GR24, and with W24 (Table 4; P<0.05). Corresponding r_P values were only consistently high with GR24, though they were generally moderate to high with GR18 and W24 (Table 4).

Correlations between growth and other measured traits. Genetic correlations between post-weaning growth rates and SC were consistently negative (Table 6). The r_G values of SC with WW, W12 and W18 were not significantly different to zero. The r_G of SC with W24 was moderate and negative. Phenotypic correlations between SC and weights were all moderate and positive, but were low with post-weaning growth rates (Table 6).

Genetic correlations of TEM scores at weaning with weights were consistently positive, but with post-weaning growth were not significantly different from zero (Table 6). Temperament scores at 18 and 24 months had no consistent relationships with either weights or post-weaning growth. The r_P of weights and growth rates with TEM scores, tick counts, and buffalo fly counts have not been presented in this paper as they were all close to zero.

Correlations between scrotal circumference, temperament scores, and tick resistance. The r_G of SC with TEM scores were generally not significantly different to zero (Table 5). Phenotypic correlations were close to zero (Table 5).

Table 6. Phenotypic and genetic (± s.e.) correlations of bull weights and growth rates with scrotal circumference (SC) at 24 months and temperaments between weaning and 24 months of age (n = 485, except for estimates including flight distance at 24 months when n = 312)

TEM, temperament score; FD, flight distance

	Weight (kg)				Growth rate (g/day)				
	Weaning	12 months	18 months	24 months	Dry 1	Wet 1	Dry 2	Weaning–18 months	Weaning–24 months
Phenotypic correlations SC	0.34	0.37	0.40	0.45	0.08	0.18	0.11	0.20	0.22
Genetic correlations SC	0.29 (0.31)	–0.05 (0.38)	–0.23 (0.37)	–0.41 (0.27)	–1.13 (0.73)	–0.39 (0.40)	–0.80 (0.37)	–0.66 (0.27)	–0.71 (0.23)
TEM									
Weaning	0.89 (0.46)	1.10 (0.53)	1.06 (0.56)	0.94 (0.45)	0.10 (0.76)	0.27 (0.57)	0.43 (0.56)	0.10 (0.45)	0.27 (0.41)
12 months	–0.06 (0.48)	–0.03 (0.53)	–0.11 (0.56)	–0.04 (0.46)	–0.03 (0.80)	0.17 (0.61)	–0.09 (0.58)	–0.06 (0.48)	–0.02 (0.43)
24 months	0.36 (0.59)	0.34 (0.63)	–0.02 (0.66)	–0.20 (0.54)	–0.42 (0.95)	–0.61 (0.78)	–0.57 (0.73)	–0.57 (0.60)	–0.56 (0.55)
FD									
Weaning	0.33 (0.31)	0.31 (0.34)	0.47 (0.36)	0.42 (0.29)	–0.20 (0.54)	0.51 (0.40)	0.14 (0.39)	0.14 (0.32)	0.18 (0.28)
12 months	–0.03 (0.34)	–0.02 (0.37)	0.08 (0.39)	–0.03 (0.33)	–0.04 (0.56)	0.44 (0.42)	–0.38 (0.42)	0.20 (0.33)	–0.01 (0.30)
24 months	n.a.	1.12 (1.51)	0.44 (0.43)	0.08 (0.34)	0.68 (1.29)	0.51 (0.32)	–0.54 (0.37)	n.a.	–0.19 (0.36)

n.a., not available.

Genetic and phenotypic correlations between TEM scores at all ages were moderate to very high, while those between FD at all ages were all very high (Table 5). Genetic correlations between TEM scores and FD were highly variable ($P>0.05$). The r_P between TEM scores and FD were generally low.

Phenotypic correlations between tick counts and TEM scores were close to zero (Table 5).

Discussion

Genetics of growth

The moderate h^2 estimates found for weights and growth rates are lower than those reported for *Bos taurus* cattle (Neely *et al.* 1982; Knights *et al.* 1984; Bourdon and Brinks 1986). However, they agree well with estimates obtained by Mackinnon *et al.* (1991*a*) measuring weight and growth from weaning to 18 months (0.16–0.33), and Robinson and O'Rourke (1992) measuring weights from weaning to 30 months (0.15–0.64). Both studies used *Bos indicus* cross cattle in the tropics.

The negative relationships between weaning weight and post-weaning growth rates differ from previous studies using *Bos taurus* cattle in temperate environments (Neely *et al.* 1982; Knights *et al.* 1984; Bourdon and Brinks 1986; Smith *et al.* 1989) and Zebu-derived cattle in tropical environments (Seifert 1975) where growth rates pre- and post-weaning are reported as being positively correlated. Mackinnon *et al.* (1991*a*) also reported a positive r_G value (0.34) between weaning weight and post-weaning wet season gain (12–18 months). However, they also reported a negative r_G value (−0.26) between weaning weight and post-weaning dry season gain, and no relationships between wet season and both dry season (weaning–12 months) and overall (weaning–18 months) gains post-weaning.

The hypothesised negative correlation between growth potential (growth under good nutrition in an environment relatively free of stressors) and adaptation to environmental stresses, particularly poor nutrition, heat, and resistance to parasites (Frisch and Vercoe 1984) could explain the negative correlations of weaning weight with post-weaning growth rates in our study and with dry season growth rates in that of Mackinnon *et al.* (1991*a*) in an environment which imposes less wet season stress. Holroyd *et al.* (1979) and Hunter and Magner (1988), using *Bos indicus* cross cattle in this environment, have shown moderate to high correlations of preweaning growth with milk production of the dam. Therefore, growth to weaning may be more a function of growth potential than environmental adaptation.

The correlations between weaning weight and subsequent weights were positive, though reduced with increasing age as weaning weight remained a major component of overall weight despite the negative correlation between weaning weight and post-weaning growth rate. Mackinnon *et al.* (1991*a*) reported similarly high genetic correlations (0.79–0.90) between weights at weaning, yearling and 18 months, while Robinson and O'Rourke (1992) obtained values of 0.63–0.92 between weights at weaning, 12, 18 and 24 months.

Coupled with previously discussed relationships, the low correlations of 12-month weight with any growth traits, and the low h^2 of 12-month weight indicate that selection for growth at less than 18 months of age will be inefficient. As post-weaning growth rates did not have a significant r_G value with weight until 24 months of age, it appears that selection for overall growth to 24 months or beyond is more efficient if delayed from 18 to 24 months, despite the strong relationship between weights at 18 and 24 months.

Scrotal circumference

The larger SC in 1/2 Sahiwal crosses than in other genotypes occurred over a period when this cross had the lowest growth rates (Fordyce *et al.* 1993). A parallel relationship in cows was reported in a previous paper in this series, where 1/2 Sahiwal crosses tended to have higher pregnancy rates ($P>0.05$) and Sahiwal crosses were lighter than Brahman crosses (Holroyd *et al.* 1990). However, any potential reproductive advantage of the Sahiwal crosses is offset by their greater calf losses from birth to weaning as a consequence of bottle teats (Holroyd 1987) and other causes including the lethal congenital disease, epitheliogenesis imperfecta (Fordyce *et al.* 1987).

Scrotal size at 24 months of age was correlated with seasonal conditions, with smallest (24 cm) and largest SC (31 cm) following the worst and best seasons, respectively (30% range). Nolan *et al.* (1990) previously reported that the rate of SC increase was more than 20% slower in slow-growing (0.10–0.25 kg/day) than in high-gain (0.75–1.00 kg/day) Brahman bulls. Minimum acceptable SC at 2 years of age must be varied according to seasons in dry tropical areas for bulls grazing unsupplemented native pasture.

Small effects (<1 cm) of dam age on SC which persist up to 24 months of age are of minor practical significance. But a persistent difference of over 2 cm at 24 months of age due to a difference in birth date of only 2 months indicates that SC should be adjusted for age when selecting bulls up to 2 years of age. Our h^2 estimate for SC is within the lower end of the ranges reported in the literature for *Bos taurus* cattle (Neely *et al.* 1982; Bourdon and Brinks 1986; Nelson *et al.* 1986). However, it agrees well with that obtained by Mackinnon *et al.* (1991*b*) for Zebu-derived bulls in central Queensland at 18 months (0.28 ± 0.10).

Genetic and phenotypic correlations of SC with weaning weight agree with previous reports, but the high negative genetic correlations with post-weaning growth rates are opposite to reports for both *Bos taurus* bulls (Bourdon and Brinks 1986; Smith *et al.* 1989), and *Bos indicus* bulls (Mackinnon *et al.* 1991*b*). This difference may be related to a positive r_G value between SC and growth potential, and a negative r_G value of growth potential with adaptation (Frisch and Vercoe 1984), and therefore with post-weaning growth as previously discussed.

Bulls with larger scrota are often assumed to have better fertility than bulls with smaller scrota (Elmore *et al.* 1976; Blockey 1980; Smith *et al.* 1981). As well, in tropically-adapted cattle, cow fertility has been favourably genetically correlated with bull fertility (Mackinnon *et al.* 1990). Our data indicate that selection for scrotal size, with the objective of increasing fertility, will be less efficient in *Bos indicus* cross genotypes in the dry tropics than in better environments, when there is concurrent selection for high post-weaning growth.

The low but positive phenotypic correlations between growth and SC are in contrast to the corresponding genetic correlations. This probably occurs because young bulls achieve higher growth by improving nutrients available to body tissues including the testes, the development of which are sensitive to nutrition (Wildeus *et al.* 1984; Nolan *et al.* 1990).

Temperament

A previous report that Sahiwal crosses have poorer temperaments than Brahman crosses (Fordyce 1984) was supported by the present results, though it was only at the higher level (3/4) of Sahiwal content that this breed effect was expressed.

Flight distance had moderate to high h^2, while that of TEM score was low. Previous literature reports of h^2 of temperament of *Bos indicus* cross cattle measured during restraint (e.g. TEM score) or when released from restraint (e.g. flight speed) have on average been moderate with some low and high estimates (Fordyce *et al.* 1982; Fordyce and Goddard 1984; Hearnshaw and Morris 1984; Burrow *et al.* 1988).

Fordyce (1984) reported that assessing temperaments of unrestrained cattle (e.g. FD) is a superior method to assessing them in a restrained situation (e.g. TEM score). The correlations between temperament scores at various ages were high to very high for FD and moderate to high for TEM scores, indicating that FD is more repeatable as previously reported by Fordyce (1984). The moderately positive phenotypic correlations between the 2 scores further confirm the conclusion of Fordyce (1984) that the 2 scores measure different expressions of temperament.

Our data suggest that temperament is a relatively independent trait, though there was an indication that selection for higher weaning weights will result in poorer temperaments.

Ectoparasite resistance

Bulls of 1/2 *Bos indicus* content were twice as susceptible to cattle ticks as 3/4 *Bos indicus* crosses. This agrees with previous reports by Utech *et al.* (1978) and Nicol *et al.* (1982). Though this result was derived from bulls with the highest WDA to 24 months of age, the proportion of each genotype represented within each year group was constant; therefore, it is most probably valid. Similar levels of buffalo fly infestation were found in the 4 crosses, suggesting similar levels of adaptation to this parasite.

As genetic parameters could not be estimated for ectoparasite resistance, the direct or indirect effects of selection cannot be predicted from our data.

The poor phenotypic correlations between tick burdens and growth confirm several other studies that used growing cattle in which cattle tick was not controlled (Seifert 1971; Sutherst *et al.* 1979; O'Rourke 1982). This is despite evidence that tick control improves production in this environment (e.g. Holroyd *et al.* 1988).

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