The performance of Brahman–Shorthorn and Sahiwal–Shorthorn cattle in the dry tropics of northern Queensland 4. Postweaning growth and carcass traits

G. Fordyce[A], *I. D. Loxton*[AB], *R. G. Holroyd*[AC] *and R. J. Mayer*[D]

[A] Queensland Department of Primary Industries, Swan's Lagoon, Millaroo, via Ayr, Qld 4807, Australia.
[B] Current address: Queensland Department of Primary Industries, PO Box 6014, Rockhampton Mail Centre, Qld 4702, Australia.
[C] Current address: Queensland Department of Primary Industries, PO Box 46, Brisbane, Qld 4001, Australia.
[D] Queensland Department of Primary Industries, PO Box 1085, Townsville, Qld 4810, Australia.

Summary. Postweaning growth to slaughter at 42 months of age in males and to initial mating at 27 months of age in females was studied in 4 *inter se* mated *Bos indicus* crosses in a dry tropical environment. Six-monthly growth periods from weaning (at about 6 months of age) generally coincided with wet and dry seasons. The cattle represented were second and subsequent generations of 1/2 Brahman and 1/2 Sahiwal crosses and first backcross and later generations of 3/4 Brahman and 3/4 Sahiwal crosses. The *Bos taurus* component of the crosses was primarily Beef Shorthorn.

Annual growth averaged 300 g/day, with annual gain ranging from 60 to 180 kg. Average growth rates were about 50 g/day in the dry season (–352 to +374 g/day) and 500 g/day in the wet season (221–830 g/day).

Postweaning growth of Brahman crosses was about 4% higher than Sahiwal crosses, with most of this advantage expressed in wet seasons. Sahiwal crosses were earlier maturing than Brahman crosses. Wet season growth was higher in 3/4 crosses than in 1/2 crosses, which probably reflected significant environmental stress in this period. Higher growth of 3/4 crosses tended to be maintained during dry seasons.

Calves born late in a wet season grew more rapidly in dry seasons than early-born calves, so that liveweight differences which were apparent at weaning were reduced by one-third at 24 months of age. The difference between liveweights of weaners with young dams and those with mature dams was also reduced from 12–18 kg to 5–6 kg by 24 months.

Dressing percentages of 3/4 cross steers at slaughter were 0.6 units higher than in half crosses, with no difference between Brahman and Sahiwal crosses. Sarcomere lengths, Warner–Bratzler shear force values, and Instron compression values together showed that M. longissimus dorsi muscle samples from 1/2 Brahman steers were the most tender of the breed crosses studied. Samples from Sahiwal cross and 3/4 Brahman steers appeared most affected by connective tissue toughness. Those from 3/4 Sahiwals appeared most affected by meat processing factors, causing them to be the least tender.

Introduction

Growth rates of cattle grazing native pastures in the dry tropics are not high and are extremely variable (6–183 kg/year), creating a major limitation to beef productivity in this region (Winks 1984). Combining *Bos indicus* traits for adaptation to tropical stresses with *Bos taurus* traits for high productivity may increase beef production (Frisch and Vercoe 1984). Of 3 primary zebu beef breeds available in Australia until recently, there has been significant research of Brahmans and Africanders and their half crosses with British breeds (Durand *et al.* 1985), but few objective productivity data are available for the Sahiwal or 3/4 *Bos indicus* crosses.

This study compares postweaning growth and carcass traits of 1/2 and 3/4 Brahman and Sahiwal cattle, whose *Bos taurus* component was primarily Beef Shorthorn, to determine the productivity of these breed crosses and, so, to provide an indication of the most appropriate breed crosses for use in the dry tropics of northern Australia.

Materials and methods

Location

The experiment was conducted at Swan's Lagoon Beef Cattle Research Station (20°05'S., 147°14'E.) in the subcoastal black spear grass region of North Queensland (Weston *et al.* 1981). 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 are 31°C and 23°C for January, and 26°C and 9°C for July.

Distribution and amount of annual rainfall is highly variable. The 25-year averages (and ranges) for rainfall in the dry season (June–October) and wet season (November–May) were 137 mm (0–379 mm) and 782 mm (226–1572 mm). Total rainfall averaged 919 mm (296–1951 mm). The average start to the wet season (seasonal break) is 14 November (30 August–16 January), with a seasonal break occurring when there is sufficient rainfall to initiate grass growth and a significant increase in cattle growth. This generally occurs after at least 25–50 mm of rainfall (depending on severity of the dry season) with a minimum of 25 mm of further rainfall within 40 days. Detailed rainfall data are presented by Holroyd *et al.* (1990*a*).

The vegetation, as described by Weston *et al.* (1981), is open woodland (primarily *Eucalyptus* spp.) with a native unimproved pasture of predominantly black spear grass (*Heteropogon contortus*), with tropical tall grasses and other medium grasses (e.g. *Eulalia fulva*, *Themeda triandra*, *Bothriochloa petusa*). Soils are generally of low fertility with acid-extractable phosphorus levels of 2–8 µg/g and organic carbon <1% (oven-dry weight). A more detailed description of the site is provided by Holroyd *et al.* (1990*a*).

Cattle and their management

The development of the crosses was described by Holroyd *et al.* (1990*a*). A program was commenced in 1967 to develop 1/2 and 3/4 Brahman cross herds. This was expanded to include 1/2 and 3/4 Sahiwal cross herds. The *Bos taurus* component of the crosses was predominantly Beef Shorthorn.

Data reported in this study were collected for year groups from 1973 (born in 1972–73) to 1985 (born in 1984–85). The progeny represented were second and subsequent filial generations of 1/2 Brahman and Sahiwal crosses and first backcross and later generations of 3/4 Brahman and Sahiwal crosses. First backcrosses were called F_1 3/4 crosses; the progeny from the *inter se* mating of these were called F_2 3/4 crosses. Calves of the third and later generations were pooled and called the F_3 *et seq.* generation. Filial generation of the progeny was taken to be the filial generation of the dam plus 1.

All cows in the experimental herds were seasonally mated with bulls of the same breed cross except for some F_1 1/2 crosses, which were mated to purebred *Bos indicus* bulls to produce F_1 3/4 crosses. The calving period generally commenced in late October, with the latest calves born in early February; however, it continued until late April in 1973 and mid–late March in 1974 and 1975 because of extended mating periods in preceding years. Mating was timed so that the calving period would start close to the beginning of the wet season. This coincided with the peak calving period for typical North Queensland herds (Holroyd *et al.* 1979).

Calves were tagged within 3 days of birth and records were made of date, dam, and sex and were branded at least 6 weeks before weaning and were generally weighed and weaned at 5–7 months of age in late May or early June, which is the end of the wet season. The exceptions were the 1973 year group, in which most calves were weaned on 3 July 1973, with calves born in March and April weaned on 21 August 1973; the 1974 year group, in which all calves were weaned on 24 June 1974; the 1982 year group, in which half of the females were weaned on 20 April 1982 as part of an observation of weaning age effects on the incidence of coccidiosis (Parker *et al.* 1986); and the 1983 year group, in which all calves were weaned on 18 April 1983 just before the end of a severe drought.

Following weaning, year groups of female progeny were managed as 1 group until 27 months of age at initial mating. Male progeny were similarly managed through to slaughter. The 1982 males and half of the 1983 males [1983(E)] were transferred to other properties at 30 months of age; they continued to be managed as 1 group at these sites until slaughter. Allocation to 1983(E) and 1983(S) (the remaining 1983 males) groups was random within sire group after blocking on liveweight.

All cattle were weighed at 6-monthly intervals that generally coincided with the transitions between dry and wet seasons. Growth at weaning–12 months, 18–24 months, and 30–36 months is defined as dry season growth; growth at 12–18 months, 24–27 months (females) or castration–30 months (steers), and 36–42 months is defined as wet season growth. Management problems in some years resulted in inability to weigh all or part of a group at the scheduled time; this did not skew growth data, as ability to recover cattle was not related to growth.

Replacement bulls for the herd were selected from males produced from the breeding program. Initial selection and castration was carried out at 18 months of age in some year groups (1973–79 and 1984 groups) and at 24 months of age in the other year groups. Only a few castrations were left until final selection at 27 months of age. The same selection procedures, based primarily on growth, were applied to each experimental herd.

Measurements

Slaughter data were collected from males not selected as replacement sires. Data were not collected from the 1974, 1984, and 1985 year groups. All other groups except the 1983 year group were slaughtered at about 42 months of age. The 1983(E) group was slaughtered at 48 months of age. The 1983(S) group was slaughtered at the same abattoir at 53 months of age when they reached the same target carcass weight (290 kg) as their contemporaries. The 1983(E) and 1983(S) groups were each allocated to 2 consecutive slaughter days, using the same method as for their initial allocation.

Carcass measurements included hot trimmed carcass weight and subcutaneous fat thickness at the 12–13th rib in steers (up to, and including, the 1979 year group) and the P8 rump site (Anon. 1985) in subsequent year groups. Dressing percentage was defined as the ratio of hot trimmed carcass weight to full liveweight measured 1–2 days before slaughter.

Meat quality traits were measured in the 1983 year group steers. At slaughter, all carcasses were electrically stimulated within 10 min of stunning with a Koch Britton unit utilising 36 V for a 40-s continuous cycle. Following chilling (minimum temperature 2°C, 24 h post-mortem), 1-kg samples were taken of the M. longissimus dorsi (LD) between the 8th and 12th thoracic vertebrae. After plastic wrapping, samples were blast-frozen and stored at –18°C. Before thawing, 100-g subsamples were finely minced, freeze-dried, then soxhlet-extracted with petroleum ether (b.p. 40–60°C) for 16 h to determine fat content. The balance of each sample was thawed at 5–6°C for 48 h. The LD ultimate pH values and sarcomere lengths were determined (Bouton *et al.* 1973) before weighed samples (about 200 g) were cooked in a water bath at 80°C for 1 h. Cooked samples were stored overnight at 1°C, then at least 6 replications of Warner–Bratzler (WB) shear and Instron compression measures were taken (Bouton and Harris 1972): (i) peak force, representing total toughness; (ii) initial yield, indicating the myofibrillar contribution to toughness; (iii) peak force minus initial yield, indicating the contribution of connective tissue to toughness; (iv) Instron compression, considered a more sensitive indicator of connective tissue's contribution to differences in muscle toughness than peak force minus initial yield (Harris and Shorthose 1988).

Statistical analyses

Analyses were performed on liveweights at weaning and at 12, 18, 24, 27 (heifers), 30 (steers), and 42 (steers) months of age, and on average daily gain (ADG) between consecutive weighings. Due to the minor confounding effect of castration time in males, ADG to 30 months of age was estimated from castration rather than from 24 months of age. Data for males up to 24 months were excluded from analyses if they had been castrated. Beyond this age, all data for males was from castrates. Carcass and meat quality traits were also analysed.

Data were analysed within sex groups by the least squares method for unequal subclass numbers (Harvey 1960). Factors included in the models for bulls and heifers were year group, breed cross, birth date, and dam age (at calving). Birth date was included as a 3-level factor. Calves born at <309 days, 310–339 days, and >339 days from the start of mating were called early, midseason, and late calves. Dam age was categorised as 3 years, 4 years, or >4 years. Birth date and dam age were not included in final analyses of male post-castration parameters. Weaning date was not included in analyses due to confounding with year and the very small number of animals weaned outside the principle time of weaning in each year.

Initial analyses showed no differences between F_2 and F_3 *et seq.* 1/2 cross progeny, which were then bulked to form an F_2 *et seq.* 1/2 cross class. F_2 and F_3 *et seq.* 3/4 cross progeny were bulked into an F_2 *et seq.* 3/4 cross class for the same reason. The confounding of year group with filial generation prevented any statistical comparison of all crosses in a single analysis. The F_1 3/4 Brahman and Sahiwal crosses (n = 341) from the 1973–77 year groups were compared. Data from F_2 *et seq.* 1/2 and 3/4 Brahman and Sahiwal crosses from the 1979–85 year groups were analysed together. Data from the 1982 and 1983(E) steers were excluded from analyses of parameters beyond 30 months of age.

Initial analyses included all main effects and all first-order interactions that could be fitted. Interactions were tested individually and a stepwise procedure was used to eliminate all those which were not significant. The only significant interactions were between breed cross and year group. Pairwise comparisons between levels within significant main effects and interactions were tested using the protected least significant difference procedure (Snedecor and Cochran 1974).

For analyses of meat quality attributes, the main effects of location (prior to slaughter), slaughter day, and breed cross, and the location × breed cross interaction were fitted using the method of least squares. The covariate 'cooking day' (days 1–4 within locations) was included in all meat quality attributes except for fat content (measured in fresh samples and not after cooking).

Results

Brahman v. *Sahiwal cross*

Within the F_1 3/4 crosses, Brahman crosses were heavier than Sahiwal crosses at weaning (males, +10 kg, P<0.05; females, +5 kg, P = 0.06; Table 1). Brahman crosses remained heavier until slaughter in males, although the difference was not significant beyond 2 years of age (Table 1), and increased their weight advantage to 15 kg by 27 months of age in females (Table 1). Brahman crosses had higher (P<0.05) wet season growth rates (+19–154 g/day), and Sahiwal crosses generally had higher dry season growth rates (+30–49 g/day), except for postweaning dry season growth rate in females when the advantage was 17 g/day (P<0.05) to Brahman crosses.

In F_2 *et seq.* crosses of both sexes, 3/4 Brahmans were heavier (P<0.05) at weaning than 3/4 Sahiwals

Table 1. Least squares means (± s.d.) for genotype, birth date and dam age effects on weights, growth and carcass traits of first backcross (3/4) *Bos indicus* males from weaning to slaughter and females from weaning to 27 months of age

B, Brahman; S, Sahiwal. Means followed by the same letter within factor do not differ significantly at $P = 0.05$

	Males				Females			
	n	Mean	B	S	*n*	Mean	B	S
n			197	144			222	121
Liveweight (kg)								
Weaning	341	184 ± 21	189a	179b	343	159 ± 24	162	157
18 months	306	281 ± 23	286a	276b	232	242 ± 34	250a	233b
27 months	—	—	—	—	335	297 ± 35	305a	290b
30 months	170	394 ± 41	399	389				
42 months	134	501 ± 46	505	496				
Average daily gain (g/day)								
Weaning–12 months	329	97 ± 69	82b	112a	331	89 ± 62	98a	81b
12–18 months	305	489 ± 81	506a	473b	227	373 ± 97	407a	340b
18–24 months	117	81 ± 66	56b	105a	229	84 ± 73	69b	100a
24–27 months	—	—	—	—	330	467 ± 181	544a	390b
Castration–30 months	169	372 ± 61	382	363				
30–42 months	126	277 ± 44	286	267				
Carcass traits								
Hot trimmed weight (kg)	134	253 ± 26	253	253				
Dressing percentage	133	50.2 ± 1.8	50.0	50.4				
Fat at 12–13th rib (mm)	63	5.3 ± 2.6	4.6	5.9				

(+7 kg; Table 2). This advantage increased due to the higher (P<0.05) growth rate of Brahmans in the wet season (+28–55 g/day), with no differences in dry season growth rates. Ultimately, 3/4 Brahman steer carcasses averaged 10 kg heavier (P<0.05) than 3/4 Sahiwals (Table 2). At 27 months, 3/4 Brahman heifers were 15 kg heavier (P<0.05) than 3/4 Sahiwal heifers (Table 2).

No differences between Brahman and Sahiwal crosses were evident at weaning within F_2 *et seq.* 1/2 crosses. Male and female 1/2 Brahman crosses were

Table 2. Least squares means (± s.d.) for main effects of genotype, birth date and dam age on weights, growth and carcass traits of F_2 *et seq. Bos indicus* cross males between weaning and slaughter and females between weaning and 27 months of age

B, Brahman; S, Sahiwal. Means followed by the same letter within factor do not differ significantly at $P = 0.05$

	Males						Females					
	n	Mean	1/2 B	3/4 B	1/2 S	3/4 S	*n*	Mean	1/2 B	3/4 B	1/2 S	3/4 S
n			308	363	227	163			266	366	253	155
Liveweight (kg)												
Weaning	1061	149 ± 22	149a	152a	150a	145b	1040	138 ± 26	139a	140a	139a	133b
18 months	1007	253 ± 27	254b	262a	247c	248c	1008	228 ± 36	232a	236a	223b	222b
27 months	—	—	—	—	—	—	925	273 ± 39	277a	281a	268b	266b
30 months	650	369 ± 35	374b	382a	360c	361c						
42 months	362	480 ± 42	481b	494a	470c	474bc						
Average daily gain (g/day)												
Weaning–12 months	1022	38 ± 62	47a	44a	20b	40a	1009	25 ± 75	33a	34a	5b	28a
12–18 months	1002	477 ± 86	469bc	505a	456c	477b	989	465 ± 100	470b	488a	450c	452c
18–24 months	869	86 ± 82	77b	92ab	76b	100a	964	116 ± 102	117	117	112	119
24–27 months	—	—	—	—	—	—	895	350 ± 181	374a	357a	349ab	323b
Castration–30 months	605	575 ± 112	600a	598a	560b	543b						
30–42 months	349	341 ± 68	345	350	338	330						
Carcass traits												
Hot trimmed weight	301	253 ± 25	246b	254a	235c	244bc						
Dressing percentage	301	50.3 ± 2.1	50.2b	50.8a	49.7b	50.4ab						
P8 fat	292	9.9 ± 4.2	8.6b	9.8a	10.1a	11.0a						

Table 3. Least squares means (± s.d.) for genotype effects on carcass traits and meat quality traits measured in M. longissimus dorsi (LD) muscle samples taken between the 8th and 12th ribs of F_2 *et seq.* steers of the 1983 year group

B, Brahman; S, Sahiwal. Means followed by the same letter within factor do not differ significantly at $P = 0.05$

	Mean	1/2 B	3/4 B	1/2 S	3/4 S
n		38	59	38	39
		Carcass traits			
Hot trimmed carcass weight (kg)	289 ± 25	297b	307a	287bc	285c
Dressing percentage	51.5 ± 1.6	51.1	51.7	51.7	51.7
Rump (P8) fat thickness (mm)	15.6 ± 4.6	13.4b	16.4a	15.0ab	15.9a
		LD muscle traits			
Fat content (%)	2.7 ± 1.3	2.7	2.6	2.6	3.3
Ultimate pH	5.62 ± 0.07	5.62	5.61	5.63	5.63
Sarcomere length (μm)	1.80 ± 0.12	1.84a	1.82a	1.79ab	1.75b
WB initial yield (IY; kg)	5.72 ± 1.67	4.97c	5.41bc	5.88ab	6.39a
WB peak force (PF; kg)	6.64 ± 1.68	5.89c	6.41bc	6.81ab	7.28a
PF – IY (kg)	0.92 ± 0.39	0.92	1.00	0.93	0.89
Instron compression (kg)	2.32 ± 0.26	2.20b	2.32a	2.37a	2.28ab

both heavier (P<0.05) than their Sahiwal counterparts by 18 months because of higher (P<0.05) growth rates in wet and dry seasons (+1–40 g/day; Table 2). An advantage (P<0.05) to 1/2 Brahman steers also occurred in the wet season after castration. The weight advantage of 1/2 Brahman steers was maintained to slaughter (42 months), when their carcasses were 11 kg heavier (P<0.05) than 1/2 Sahiwals. Half Brahman heifers were 9 kg heavier (P<0.05) at 27 months than 1/2 Sahiwals (Table 2).

No differences between Brahmans and Sahiwals within 1/2 and 3/4 crosses occurred for dressing percentage (Table 2). Within 3/4 cross steers, Brahman and Sahiwal crosses had similar subcutaneous fat thickness, but within 1/2 crosses, Brahmans had less (P<0.05) fat by 1.5 mm (Table 2).

In the 1983 year group, LD sarcomere length tended to be greater in Brahman crosses (+55–60 nm), but the difference between Brahmans and Sahiwals was only significant (P<0.05) within 3/4 crosses (Table 3). Within both 1/2 and 3/4 crosses, WB initial yield and peak shear force values were, on average, 17% (0.9 kg) higher (P<0.05) in Sahiwals. Instron compression values were lower (P<0.05) for Brahmans within 1/2, but not 3/4, crosses. No differences between Brahman and Sahiwal crosses occurred for other meat quality traits measured.

Percentage Bos indicus

Within F_2 *et seq.* Brahman cross males, there was no difference in weaning weight due to *Bos indicus* content, though by 18 months of age, 3/4 crosses were 8 kg heavier (P<0.05; Table 2). This was a result of higher (P<0.05) growth rate in the first wet season after weaning (+36 g/day). This weight advantage was maintained to slaughter. The same growth advantage tended to occur in females, but was not significant (4 kg at 27 months of age; Table 2).

For F_2 *et seq.* Sahiwals, 1/2 crosses were heavier (P<0.05) at weaning than 3/4 crosses. The 3/4 crosses had a higher (P<0.05) growth rate after weaning (Table 2), which persisted to 24 months of age in males and 12 months in females.

Within Sahiwal crosses, 3/4 crosses had consistently higher (P<0.05) growth rates than 1/2 crosses in dry seasons (Table 2). Within Brahman crosses, this trend was only evident in males at 18–24 months of age. The effect was independent of severity of the season.

Greater liveweight and a higher (P<0.05) dressing percentage (+ 0.6% units) in 3/4 Brahman cross steers produced carcasses 8 kg heavier (P<0.05) than 1/2 Brahmans (Table 2). The subcutaneous fat of their carcasses was also 1.2 mm thicker (P<0.05; Table 2). Dressing percentage tended (P<0.05) to be higher (+0.7% units) in 3/4 Sahiwals than in 1/2 Sahiwals (Table 2). This, plus the slight weight advantage at 42 months of age, tended to result in heavier 3/4 Sahiwal cross carcasses, although this advantage was not significant.

There were no significant differences between 1/2 and 3/4 Sahiwals in meat quality and carcass traits in the 1983 steer year group (Table 3). Within the Brahmans, 3/4 crosses had higher (P<0.05) Instron compression values. There were non-significant trends in both Brahman and Sahiwal crosses for 3/4 crosses to have higher WB shear force values than 1/2 crosses. There was a consistent trend for sarcomere length to be longer (25–30 nm) in 1/2 than 3/4 *Bos indicus* crosses.

Table 4. General means across *Bos indicus* cross genotypes for seasonal growth (g/day) of male and female cattle

Dry, dry season; wet, wet season

Year	Males									Females				
	Dry 1	Wet 1	Dry 2	Wet 2	Dry 3	Wet 3	Year 1	Year 2	Year 3	Dry 1	Wet 1	Dry 2	Wet 2	Year 1
Age[A]:	W–12	12–18	18–24	24–30	30–36	36–42	W–18	18–30	30–42	W–12	12–18	18–24	24–27	W–18
1973–74	187	348					303			163	221			191
1974–75	184	550	315				366			146		274	389	
1975–76	60	452	–33	403			225	412		60	351		319	206
1976–77	15	533	72	402			263	402	348	–6	423	–131	904	221
1977–78	37	565	8	332	11	682	294	240	278	23	495	77	64	278
1978–79			43	325	–40	629	185	234	230	–94	481	74	905	205
1979–80	–46	379		372	–352	632	196	289	252	–87	376	–151	513	162
1980–81	–41	416	–1	258			183	254	403	3	472	–67	99	173
1981–82	38	472	131	778			298	422	214	51	567	374	253	295
1982–83	–33	354	–213	830			231	324	487	–41	358	–127	351	220
1983–84	189	520	270	481	325	684		351	313	110	485	370	389	304
1984–85	25	623	–74	744	271	352	375	378	305	–5	444	170	758	267
1985–86	133	575	283	354	132	474		357	258	131	589	81	328	306
1986–87			208	575	–106	618		355				–6	186	

[A] Approximate age intervals (months); W, weaning (about 6 months of age).

Year

Seasonal growth, particularly in dry seasons, varied markedly between years (Table 4). Dry season growth averaged about 50 g/day (–352 to +374) and wet season growth 500 g/day (221–830), with an annual average of about 300 g/day (162–487). Year differences in growth rates and liveweights cannot be attributed purely to seasonal conditions because of confounding with paddocks, stocking rates, and management. Because 6-monthly age increments often did not coincide directly with seasonal changes, and because a transitional period of weight maintenance generally occurs between the wet and dry seasons, the reported wet season growth rates are generally underestimates and those of the dry season overestimates.

Year x *breed cross interactions*

Interactions between breed cross and year group occurred in most analyses ($P<0.05$). The frequently higher postweaning growth of 3/4 *Bos indicus* crosses, which occurred during both wet and dry seasons, did not consistently occur in years of either relatively low or high growth.

The ranking of breed crosses was generally consistent across years. Significant changes in ranking of growth rates of breed crosses between subsequent seasons (about one-third of the time) appeared mostly due to 1/2 Brahmans having relatively lower growth rates in some dry seasons and relatively higher growth rates in some wet seasons, with the converse occurring in 3/4 Sahiwals. This shows that in many years, there is a clear growth advantage to 3/4 *Bos indicus* crosses over 1/2 crosses during dry seasons, and a growth advantage to Brahman crosses over Sahiwal crosses during wet seasons. Almost invariably, changes in ranking were reversed in consecutive seasons. This occurred independently of whether seasons were good or poor.

Birth date

In F_1 3/4 crosses, early calves were 35% heavier ($P<0.05$) than late calves at weaning (males, +53 kg; females, +48 kg). Within F_2 *et seq.* calves, those born early were 42 kg heavier ($P<0.05$) at weaning. The liveweight advantage of early calves was reduced to about 33 kg by 24 months of age in both F_1 3/4 crosses and F_2 *et seq.* crossbred calves. This was due to higher ($P<0.05$) dry season growth of late calves, both after weaning and at 18–24 months of age (+13–45 g/day), with no differences in wet season growth.

Age of dam

Although there was no age-of-dam effect on weaning weights within F_1 3/4 crosses, calves from young dams had higher ($P<0.05$) postweaning growth rates up to 12 and 18 months of age for males and females, respectively, than progeny of mature dams. However, the differences were small and only produced significant effects on liveweights of female progeny (+12 kg at 27 months for calves with young dams).

Within F_2 *et seq.* calves at weaning, those from mature dams had a liveweight advantage ($P<0.05$) at weaning of about 11% over calves from first-calf dams (males, +18 kg; females, +12 kg). Calves reared by second-calf cows were intermediate. Calves with mature dams had the lowest ($P<0.05$) growth rates in the postweaning dry season. This trend continued after 12 months of age but was only significant at 18–24 months of age in males. The overall advantage to calves from mature dams was reduced to 5–6 kg by 24 months of age ($P<0.05$).

Other effects on meat quality

There was no significant preslaughter location x breed cross interaction, nor any significant effect of slaughter day for any of the meat quality variates measured.

The cooking day covariate was significant ($P<0.01$) for ultimate pH, WB peak force, and WB peak force minus initial yield. The effects of preslaughter location on meat quality were reported by Loxton *et al.* (1990).

Discussion

Year differences, which were primarily a reflection of nutrition, with some effects of paddocks and management, were the dominant influences on liveweight gains throughout the experimental period. Because of the variability in amount and timing of rainfall, variation between years in growth rates within both dry and wet seasons was very high. Some of the consequences of this to commercial beef production in the region include variability in preparation of steers for markets at specific times or ages at low cost, variable maiden heifer fertility (Holroyd *et al.* 1990*b*; Doogan *et al.* 1991), and the frequent requirement for dry season feeding to ensure survival. The large between-year variation in cow growth in this environment results in major variation between years in lactating cow fertility (Holroyd *et al.* 1990*b*).

Our results show that growth rates of Brahman crosses are about 4% higher than those of Sahiwal crosses. Holroyd *et al.* (1990*a*) reported that within mature crossbred cows, Brahman crosses are 12% heavier than Sahiwal crosses. This is in contrast to the report of Winks *et al.* (1978) that there were no differences in postweaning growth between F_1 1/2 Brahman and Sahiwal crosses. Our study showed that most differences occurred in wet seasons when growth was highest. During dry seasons, when growth was low, no overall significant differences in growth between Brahman and Sahiwal crosses occurred.

Winks *et al.* (1978) suggested that Sahiwal crosses were earlier maturing than Brahman crosses. As earlier maturing cattle are fatter at lower liveweights (Berg and Butterfield 1976), our data are in agreement because Sahiwal crosses had greater subcutaneous fat thickness than Brahman crosses at lower slaughter weights at the same age. This explains the much larger relative difference in mature liveweight than in growth rate between the 2 breeds.

Growth potential under low-stress conditions is expected to be lower in cattle with higher levels of *Bos indicus* (Frisch and Vercoe 1984). These authors also reported that under stressful conditions, cattle with higher levels of *Bos indicus* have higher growth due to environmental adaptation. Lapworth *et al.* (1976) and Fordyce *et al.* (1988*b*) also reported that, under stressful tropical conditions, increasing levels of *Bos indicus* result in higher growth rates. Wythes and Ramsay (1981) concluded that in tropical environments, better adapted cattle (e.g. Brahmans) will grow and fatten faster, despite the Brahman being a slower maturing breed than British breeds. Therefore, our results indicate that growth in most seasons in this dry tropical environment is under stress, but that this stress is not always sufficient to enable 3/4 *Bos indicus* crosses to have higher growth rates than 1/2 crosses. Poorer environmental adaptation of 1/2 crosses, which reduced overall growth, may have also been partially responsible for their lesser subcutaneous fat thickness at slaughter (significant only in Brahman crosses).

In their review of comparative breed performance in the tropics, Durand *et al.* (1985) concluded that dressing percentage was higher in *Bos indicus* cross cattle than in *Bos taurus* cattle. This is consistent with our finding that, at the same age and similar carcass fatness, 3/4 crosses had higher dressing percentages by 0.6–0.7 percentage units than 1/2 crosses.

In a previous study, calves with older dams grew faster to weaning (Fordyce *et al.* 1993). Results reported here show that calves from younger dams compensate by 60–70% postweaning, with the bulk of this compensation occurring in the postweaning dry season. Seifert *et al.* (1980) reported similar effects in *Bos indicus* cross steers in a marginally better tropical environment, with most of the age-of-dam effect absorbed by 17 months of age when average liveweight was 320–330 kg. Lapworth *et al.* (1976) reported a small but persistent age-of-dam effect to 29 months of age. However, these results contrast with those of Burrow *et al.* (1991), who found no postweaning compensation in calves with younger dams; however, their study involved tropically adapted cattle in a tropical environment with higher growth than in our study.

Consistent growth rate advantages from weaning to 24 months of age of late-born calves over early calves in both dry seasons reduced advantages in weaning weight of early-born calves by one-third. This effect is not compensation for preweaning growth rate differences due to birth date, as there were none (Fordyce *et al.* 1993). Lapworth *et al.* (1976), using 4 year groups, also observed that weight advantages of early calves were diminished in the dry season at 18–23 months of age.

Parameter values for LD muscle samples taken from 1 year group of 4.0–4.5-year-old steers in this study were in the normal range reported for northern Australian *Bos indicus* cross cattle, which are often older than 4.5 years and of both sexes (Wythes *et al.* 1989; Wythes and Shorthose 1991). Values were often higher than recorded in experiments where *Bos indicus* cross steers of a similar age were of average tenderness (I. D. Loxton unpublished data).

Ultimate pH values were generally <5.7, suggesting preslaughter stress was minimal in each breed cross. Values ≥5.7 indicate preslaughter stress, and values ≥5.8 may result in dark cutting (Loxton *et al.* 1992).

Muscle shortening reduces tenderness and is indicated by sarcomere lengths <1.8 μm (Harris 1976) and WB initial yield values >5 kg (Shorthose and Harris 1990). This occurred in our study, and with Instron compression values >2.0 kg considered high, LD muscle was less tender than average. This was probably because electrical stimulation was not completely effective, and because cattle were >4 years of age at slaughter (Shorthose and Harris 1990).

Heavier and fatter carcasses are expected to chill more slowly and to result in longer sarcomeres (Shorthose and Harris 1991), but this does not explain the observed breed differences in tenderness. The heavier carcasses of the Brahman crosses may partially explain their long sarcomeres compared with Sahiwal crosses but not the differences between 1/2 and 3/4 crosses. As well, 1/2 Brahmans had the least fat cover but the longest sarcomere lengths.

The WB initial yield and peak force values reflect differences recorded in sarcomere lengths. Instron compression values paralleled sarcomere length and WB shear force values across both Brahman cross groups and the 1/2 Sahiwals. However, Instron compression values of 3/4 Sahiwals were lower than for 1/2 Sahiwals and intermediate between 1/2 and 3/4 Brahmans, despite the strong evidence of cold shortening (shorter sarcomeres) in the 3/4 Sahiwal group and the consequent high WB shear force values.

Overall interpretation of each meat tenderness factor indicates that the 1/2 Brahmans produced the most tender meat. The meat of 3/4 Sahiwals was most affected by processing factors (a combination of less-than-effective electrical stimulation and rapid chilling rates resulting in shortened sarcomeres), and meat of 1/2 Sahiwals and 3/4 Brahmans was most affected by connective tissue toughness (high Instron compression values).

Differences in tenderness due to breed or level of *Bos indicus* may be partially related to temperament. Concurrent research showed that Sahiwals have poorer temperaments than Brahmans and that 3/4 crosses have poorer temperaments than 1/2 crosses (G. Fordyce unpublished data). Cattle with poorer temperaments have previously been shown to have less tender meat (Fordyce *et al.* 1988*a*), although the effect in that study was not related to either sarcomere length or pH.

Inconsistent effects on meat quality due to level of *Bos indicus* was also reported by Carpenter *et al.* (1961) in a study using steers of similar weights. In a comprehensive study, Crouse *et al.* (1989) reported that, as either Brahman or Sahiwal content increased, there was an almost linear decrease in tenderness. Johnson *et al.* (1990) drew a similar conclusion, using Brahman cross steers whose carcass weights were not stated. In the study by Crouse *et al.* (1989), there were large differences in carcass weight between breed crosses, and this may have been primarily responsible for the differences in tenderness. It is apparent from our current knowledge that meat tenderness may not be a function of *Bos indicus* content *per se*; rather, it could be related to a combination of other factors such as carcass weight, fatness, temperament, slaughter age, and processing procedures.

Conclusion

The highest growth rates of beef cattle in the dry tropics are achieved, on average, with crosses that include >1/2 *Bos indicus* content. This must be balanced against a slight reduction in meat quality. Brahman rather than Sahiwal is the preferred *Bos indicus* component to achieve high growth and, possibly, slightly better meat quality.

Acknowledgments

We thank the many people who assisted in the conduct of this research, particularly R. Barnett, K. Beaman (nee Heater), N. Beaman, G. Blight, V. Doogan (nee Anderson), C. Howitt, T. James, J. Laetsch, Dr A. Neill, P. O'Rourke, H. Stephenson, and R. Tyler from the Queensland Department of Primary Industries; Dr P. Harris and Dr R. Shorthose from CSIRO Meat Research Laboratory, Cannon Hill; and the staff of the Central Queensland Meat Export Company in Rockhampton. We also thank the Australian Meat Research Committee for partial funding of the project (DAQ44).

References

Anon. (1985). 'Aus-Meat National Language.' October 1985. (AMLC: Sydney.)

Berg, R. T., and Butterfield, R. M. (1976). 'New Concepts in Cattle Growth.' (Sydney University Press: Sydney.)

Bouton, P. E., Carroll, F. D., Harris, P. V., and Shorthose, W. R. (1973). Influence of pH and fibre contraction state upon factors affecting the tenderness of bovine muscle. *Journal of Food Science* **38**, 404–7.

Bouton, P. E., and Harris, P. V. (1972). A comparison of some objective methods used to assess meat tenderness. *Journal of Food Science* **37**, 218–21.

Burrow, H., Seifert, G. W., and Hetzel, D. J. S. (1991). Consequences of selection for weaning weight in zebu, *Bos taurus* and zebu x *Bos taurus* cattle in the tropics. *Australian Journal of Agricultural Research* **42**, 295–307.

Carpenter, J. W., Palmer, A. Z., Kirk, W. G., Peacock, F. M., and Koger, M. (1961). Slaughter and carcase characteristics of Brahman and Brahman–Shorthorn crossbred steers. *Journal of Animal Science* **20**, 336–40.

Crouse, J. D., Cundiff, L. V., Koch, R. M., Koohmaraie, M., and Seideman, S. C. (1989). Comparisons of *Bos indicus* and *Bos taurus* inheritance for carcass beef characteristics and meat palatability. *Journal of Animal Science* **67**, 2661–8.

Doogan, V. J., Fordyce, G., Shepherd, R. K., James, T. J., and Holroyd, R. G. (1991). The relationships between liveweight, growth between weaning and mating and conception rate of *Bos indicus* cross heifers in the dry tropics of north Queensland. *Australian Journal of Experimental Agriculture* **31**, 139–44.

Durand, M. R. E., Rudder, T. H., and Holroyd, R. G. (1985). Evaluation of beef genotypes by the Queensland Department of Primary Industries. *In* 'Evaluation of Large Ruminants for the Tropics.' (Ed. J. W. Copland.) pp. 145–55. (Australian Centre for International Agricultural Research: Canberra.)

Fordyce, G., James, T. A., Holroyd, R. G., Beaman, N. J., Mayer, R. J., and O'Rourke, P. K. (1993). The performance of Brahman–Shorthorn and Sahiwal-Shorthorn cattle in the dry tropics of northern Queensland. 3. Birth weights and growth to weaning. *Australian Journal of Experimental Agriculture* **33**, 119–27.

Fordyce, G., Saithanoo, S., and Goddard, M. E. (1988*b*). Factors affecting mature size and dry-seasons weight loss in *Bos indicus* cross cows in north Queensland. *Australian Journal of Agricultural Research* **39**, 1169–80.

Fordyce, G., Wythes, J. R., Shorthose, W. R., Underwood, D. W., and Shepherd, R. K. (1988*a*). Cattle temperaments in extensive beef herds in north Queensland. II. Effect of temperament on carcass and meat quality. *Australian Journal of Experimental Agriculture* **28**, 689–93.

Frisch, J. E., and Vercoe, J. E. (1984). An analysis of growth of different cattle genotypes reared in different environments. *Journal of Agricultural Science, Cambridge* **103**, 137–53.

Harris, P. V. (1976). Structural and other aspects of meat tenderness. *Journal of Textural Studies* **7**, 49–63.

Harris, P. V., and Shorthose, W. R. (1988). Meat texture. *In* 'Developments in Meat Science.' (Ed. R. A. Lawrie.) pp. 245–96. (Elsevier Applied Science: London.)

Harvey, W. R. (1960). Least squares analysis of data with unequal subclass numbers. United States Department of Agriculture, Agricultural Research Service, No. ARS-20-8.

Holroyd, R. G., Arthur, B. A., and Mayer, B. G. (1979). Reproductive performance of beef cattle in north-western Queensland. *Australian Veterinary Journal* **55**, 257–62.

Holroyd, R. G., James, T. A., Doogan, V. J., Fordyce, G., and O'Rourke, P. K. (1990*a*). The performance of Brahman–Shorthorn and Sahiwal–Shorthorn cattle in the dry tropics of northern Queensland. 1. Reproductive rates and liveweights of F_1 and backcross females. *Australian Journal of Experimental Agriculture* **30**, 717–25.

Holroyd, R. G., James, T. A., Doogan, V. J., Fordyce, G., Tyler, R., and O'Rourke, P. K. (1990*b*). The performance of Brahman–Shorthorn and Sahiwal–Shorthorn cattle in the dry tropics of northern Queensland. 2. Reproductive rates and liveweights of F_2 *et seq.* females. *Australian Journal of Experimental Agriculture* **30**, 727–33.

Johnson, D. D., Huffman, R. D., Williams, S. E., and Hargrove, D. D. (1990). Effects of percentage Brahman and Angus on breeding, age, season of feeding and slaughter end point on meat palatability and muscle characteristics. *Journal of Animal Science* **68**, 1980–6.

Lapworth, J. W., Bean, K. G., Seifert, G. W., and Rudder, T. H. (1976). Factors affecting the performance of steers grown under commercial conditions in a subtropical environment. *Australian Journal of Experimental Agriculture and Animal Husbandry* **16**, 636–9.

Loxton, I. D., Shorthose, W. R., Harris, P. V., Fordyce, G., Blight, G. W., Neill, A. R., and Barnett, R. A. (1990). Meat quality of *Bos indicus* cross steers grown at two different locations from thirty months of age to slaughter. *Proceedings of the Australian Society of Animal Production* **18**, 280–3.

Loxton, I. D., Shorthose, W. R., Neill, A. R., Rogers, S. A., Blight, G. W., and Holroyd, R. G. (1992). Effect of post-weaning nutrition on carcass yield and meat quality. DAQ.052 Final Report, Meat Research Corporation, Sydney, Australia, May 1992.

Parker, R. J., Jones, G. W., Ellis, K. J., Heater, K. M., Schroter, K. L., Tyler, R., and Holroyd, R. G. (1986). Post-weaning coccidiosis in beef calves in the dry tropics: experimental control with continuous monensin supplementation via intra-ruminal devices and concurrent epidemiological observations. *Tropical Animal Health and Production* **18**, 198–208.

Seifert, G. W., Corlis, P. L., and Rudder, T. H. (1980). The influence on dam age on weight for age of steers at weaning and after weaning. *Proceedings of the Australian Society of Animal Production* **13**, 373–6.

Shorthose, W. R., and Harris, P. V. (1990). Effect of animal age on the tenderness of selected beef muscles. *Journal of Food Science* **55**, 1–8, 14.

Shorthose, W. R., and Harris, P. V. (1991). Effect of growth and composition on meat quality. *In* 'Advances in Meat Research.' (Eds A. M. Pearson and T. R. Dutson.) Volume 7. pp. 515–49. (Elsevier: Barking, U.K.)

Snedecor, G. W., and Cochran, W. G. (1974). 'Statistical Methods.' 6th Edn. (Iowa State University Press: Ames, IA, U.S.A.)

Weston, E. J., Harbison, J., Leslie, J. K., Rosenthal, K. M., and Mayer, R. J. (1981). Assessment of the agricultural and pastoral potential of Queensland. Queensland Department of Primary Industries, Brisbane. Agriculture Branch Technical Report No. 27.

Winks, L. (1984). Cattle growth in the dry tropics of Australia. Australian Meat Research Committee Review, No. 45.

Winks, L., O'Rourke, P. K., and Smith, P. C. (1978). Performance of F_1 Brahman x Shorthorn cattle from weaning to slaughter in north Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **18**, 500–4.

Wythes, J. R., and Ramsay, W. R. (1981). Beef carcass composition and meat quality. Beef Cattle Husbandry Branch, Queensland Department of Primary Industries, Brisbane. Technical Bulletin No. 18.

Wythes, J. R., and Shorthose, W. R. (1991). Chronological age and dentition effects on carcass and meat quality of cattle in northern Australia. *Australian Journal of Experimental Agriculture* **31**, 145–52.

Wythes, J. R., Shorthose, W. R., Dodt, R. M., and Dickinson, R. M. (1989). Carcass and meat quality of *Bos indicus* x *Bos taurus* and *Bos taurus* cattle in northern Australia. *Australian Journal of Experimental Agriculture* **29**, 575–63.

Received 5 March 1992, accepted 21 January 1993