CSIRO PUBLISHING

RESEARCH PAPER
https://doi.org/10.1071/AN21499

ANIMAL PRODUCTION SCIENCE

Crossbreeding with a tropically adapted *Bos taurus* breed (Senepol) to improve meat quality and production from Brahman herds in northern Australia. 2. Female performance

T. Schatz[A,*], M. Hearnden[A] and J. Wheeler[B]

For full list of author affiliations and declarations see end of paper

***Correspondence to:**
T. Schatz
NT Department of Industry Tourism and Trade, GPO Box 3000, Darwin, NT 0801, Australia
Email: tim.schatz@nt.gov.au

Handling Editor:
Forbes Brien

Received: 30 September 2021
Accepted: 7 April 2022
Published: 6 June 2022

Cite this:
Schatz T *et al.* (2022)
Animal Production Science, **62**(13), 1219–1228.
doi:10.1071/AN21499

ABSTRACT

Context. Cattle producers with Brahman herds considering crossbreeding with a tropically adapted *Bos taurus* breed would like to know how the females retained for breeding are likely to perform. Currently, there is little relevant information available on their performance in the harsher regions of northern Australia. **Aims.** This study aimed to evaluate the performance of F1 Senepol × Brahman (F1 Senepol) females in a harsh north Australian environment by comparing them with Brahmans. **Methods.** The performance of four year groups of Brahman (total $n = 499$) and F1 Senepol (total $n = 317$) heifers was compared in the Katherine region (NT, Australia) using measures for growth, reproduction and survival. Heifers were first mated as 2-year-olds and the study concluded when the oldest year group was 9.5 years old. Cattle were mustered twice a year for data collection and weaning of calves. **Key results.** F1 Senepol females were heavier ($P < 0.001$) than Brahmans at weaning (+25 kg) and at each subsequent muster. Mature F1 Senepol cows were on average 50 kg heavier ($P < 0.001$), 2 cm taller ($P < 0.001$) and had 2.4 mm lower P8 fat depth ($P < 0.001$). The mean pregnancy rate was higher in F1 Senepol maiden heifers (F1 Senepol 89.4%, Brahman 70.0%, $P < 0.001$), calf loss was higher for Brahman heifers calving for the first time (Brahman 14.4%, F1 Senepol 6.0%, $P < 0.01$), but there were no significant differences in these measures between breeds at any other ages. The average annual weaning rates for the breeds were similar (F1 Senepol 59%, Brahman 57%), as was the mean annual female liveweight production (change in female liveweight plus weight of calf weaned). Average weaner weights were significantly heavier from F1 Senepol for first lactation heifers and 5.5-year-old cows (by 6 and 10 kg, respectively, $P < 0.05$), but only slightly heavier in all other years. There were no significant differences in cumulative mortality rates, for year groups or overall, between breeds. **Conclusions.** This study found that F1 Senepol heifers outperformed Brahman heifers, and that mature cow performance of the breeds was similar. **Implications.** These findings should reassure north Australian cattle producers who are considering crossbreeding Brahmans with a tropically adapted *Bos taurus* breed that the performance of crossbred breeder herds will be similar to that of Brahmans.

Keywords: Brahman, cattle, crossbreeding, fertility, growth, heifer, mortality, northern Australia, Senepol.

Introduction

Bos indicus (usually Brahman) cattle are popular in northern Australia due to their ability to perform better than *Bos taurus* in harsh environments, where high levels of heat, humidity, external parasites, long walking distances and seasonally poor pasture quality can lower cattle performance (Davis 1993). Brahman cattle's high resistance to stress also makes them popular in South East Asian feedlots, and live export has been the main market for steers and cull heifers from north Australian herds in recent decades. However, due to the perception that they have tougher meat (Crouse *et al.* 1989; Johnson *et al.* 1990), Brahman cattle from northern Australia often suffer price discrimination in Australian domestic markets. There are also concerns that being heavily reliant on the live export market makes north Australian cattle producers vulnerable to the impact of fluctuations in that market (e.g. the Indonesian live export ban in 2011). They would have more marketing options and be less vulnerable to live export market fluctuations if they were able to supply cattle that had better meat quality and still had good stress resistance, and hence were in demand in both the live export and Australian domestic markets.

The Northern Territory Department of Industry Tourism and Trade (NT DITT) began a research program in 2008 to examine whether crossbreeding with Senepols, a tropically adapted *Bos taurus* breed known to have good meat quality (O'Connor *et al*. 1997; Butts 1999), might be an effective way for north Australian cattle producers with herds with a high Brahman content to produce cattle in one generation that perform well under harsh northern conditions, and are better suited to both the domestic and South East Asian live export markets. Results from aspects of this work published previously showed that in comparison with Brahman steers, that F1 Senepol steers were an average of 32 kg heavier at turnoff at approximately 18 months of age (Schatz *et al.* 2020), had more tender meat that graded better in the Meat Standards Australia grading system (Schatz *et al*. 2014) and performed better in an Indonesian feedlot (Schatz 2017). Although these results demonstrate advantages from producing F1 Senepol steers for northern cattle producers, when considering adopting such a crossbreeding program, they will want to know how the female progeny are likely to perform under harsh northern conditions when retained as breeding females. This study compared the performance of four year groups of F1 Senepol × Brahman and Brahman females from 2010 to 2019 near Katherine, NT.

Methodology

Breeding information for animals used in this study is described in Schatz *et al.* (2020). In summary, Brahman and Senepol bulls were mated to Brahman cows over 4 years at two locations in the NT, producing 4-year groups of Brahman and F1 Senepol × Brahman (hereafter referred to as F1 Senepol) calves that were weaned from 2010 to 2013. A total of 14 Senepol and 21 Brahman bulls could potentially have sired the animals used in this study. Calves from these matings were weaned in May each year (when they were approximately 6.5 months old). Heifers were vaccinated against clostridial diseases at weaning, and against botulism annually. They also received a Vibrovax® vaccine against campylobacterosis at approximately 20 months of age, prior to their first mating.

Shortly after weaning, the heifers of both breeds from the two locations were transported to a single location and were managed together as one mob from that point onwards, with the exception of heifers weaned in 2012, which were separated for 1 year after weaning (an explanation follows). The year groups were sent to different locations after weaning as there was insufficient space to keep them all at one location.

The 2010 weaned heifers (No. 10) were located at Victoria River Research Station (VRRS) from shortly after weaning until after they were mated for the first time over a 4-month period at approximately 2 years of age. After pregnancy testing, all pregnant F1 Senepol heifers (n = 30) were retained for this study, and a similar number of pregnant Brahman heifers (n = 35) were also retained. The retained pregnant heifers were transported to a paddock (South Queens) at Manbulloo Station and remained there for the rest of the study.

The 2011 weaned heifers (No. 11) were located at VRRS from shortly after weaning until just prior to their first mating, when they were transported to the same paddock (South Queens) with the No. 10 heifers where they were mated for the first time over a 4 -month period at approximately 2 years of age. After pregnancy testing, all pregnant F1 Senepol heifers (n = 62) and Brahman heifers (n = 104) were retained, and remained in that paddock for the rest of the study.

The 2012 weaned (No. 12) F1 Senepol and Brahman heifers were located at different sites from weaning until approximately 18 months of age. The Brahman heifers were located at Katherine Research Station (KRS) and the F1 Senepol heifers were located at the Douglas Daly Research Farm, where they were mated as yearlings. Of 107 F1 Senepol heifers, 14 became pregnant from mating as yearlings, and although they were included in calculations of maiden pregnancy rates, they were removed from the rest of the study, as they were considered to be different to the other heifers that became pregnant as 2-year-olds. We acknowledge that this is likely to have had a detrimental effect on the subsequent performance of the No. 12 F1 Senepol year group, as the heifers that became pregnant from yearling mating were probably the most fertile animals in the year group. The No. 12 F1 Senepol heifers were transported to KRS after yearling mating and co-located with the No. 12 Brahman heifers. Both breeds were mated together there at 2 years of age for a period of 4 months. The heifers that became pregnant from this 2-year-old mating (F1 Senepol n = 69 and Brahman n = 74) were retained and remained at KRS until after their first calf was weaned. They were then transported to the North Queens paddock at Manbulloo where they remained for the rest of the study.

The 2013 weaned heifers (No. 13) were located at KRS from shortly after weaning until after their first calves were weaned. They were mated at KRS for the first time over a period of 4 months at approximately 2 years of age. Pregnant F1 Senepol heifers ($n = 79$) and Brahman heifers ($n = 59$) were retained, and non-pregnant heifers were sold. They remained at KRS until after their first calf had been weaned, and then they were transported to North Queens paddock at Manbulloo where they remained for the rest of the study (with the No. 12 heifers).

Heifers that failed to conceive during their maiden mating were culled, but from that point on, all females were retained for the duration of the study. All year groups were located in the two paddocks on Manbulloo station (the No. 10 and No. 11 year groups in South Queens paddock and the No. 12 and No. 13 year groups in North Queens paddock) from after their first calf had been weaned (at 3.5 years old) until the study concluded in 2019. The paddocks are adjacent to each other and are located 9 km north-west of the Tindal airport (~17 km south-west of the town of Katherine). The climate is tropical, with almost all rain falling between December and April. The average monthly temperature and rainfall statistics from the Tindal airport weather station are shown in Table 1 (BOM 2021).

The area in which the trial paddocks are located is characterised as monsoon tall-grass savanna. The vegetation is an open eucalypt woodland, and the paddocks are comprised of native pasture consisting of tropical tall grasses, primarily *Heteropogon contortus*, *Themeda triandra*, *Chrysopogon fallax*, *Sorghum plumosum* and *Sehima nervosum*. The cows were stocked at a rate of approximately eight cows per km^2 in the trial paddocks, and were given access to mineral supplements year round; a urea-based mineral supplement in the dry season (mid-April to late November) and a phosphorus-based mineral supplement in the wet season (December to mid-April). Mustering occurred twice a year for data collection and to wean calves. The first muster each year was usually in April, and the second was usually in September up until the first mating and then in August after that. Most calves were weaned at the April muster, but any that weighed <100 kg at the April muster were weaned at the August muster (unless they were considered to be a 'poddy' i.e. not getting milk from a cow). Also, some calves were weaned at August musters due to out-of-season pregnancies caused by stray bulls entering the paddocks. Heifers <3.5 years old were weighed after an overnight curfew (with no access to feed or water for 12 h), but once cows were located in the Manbulloo paddocks, they were not curfewed before weighing. Animals were weighed at each muster and also pregnancy tested at each muster after they were mated for the first time. Hip height and P8 fat depth (Johnson 1987) were usually measured, but this was not performed in all years. Calves were mothered-up at weaning musters to match cow–calf pairs and allow the kilograms of calves weaned from each cow to be calculated. This was performed by keeping the calves separated from the lactating cows overnight, and then the following day, letting a few calves at a time into a yard with the lactating cows and observing which cow they suckled from. After mothering-up, the calves were weighed, removed and weaned. The majority of calves were mothered-up at each muster, but there were usually some that would not suckle. In these cases, the mean weight of calves from other cows of the same breed and year group at that muster was used for their calf weaning weight.

All bulls used for mating had passed a Bull Breeding Soundness Evaluation (Beggs *et al.* 2013) and had been vaccinated with a Vibrovax® vaccine against campylobacterosis. Mating in the Manbulloo paddocks was for a period of approximately 4.5 months starting in late December or early January, and the bulls were removed at the April musters. In 2016, stray bulls entered North Queens paddock, resulting

Table 1. Long-term average climate data from the Tindal Airport Bureau of Meteorology weather station (BOM 2021).

Month	Mean max. temperature (°C)	Mean min. temperature (°C)	Mean rainfall (mm)	Mean 9 am relative humidity (%)
January	34.3	24.4	257.7	80
February	34.0	24.1	235.8	82
March	34.4	23.2	161.5	75
April	34.2	20.6	36.7	66
May	32.3	17.4	2.2	57
June	30.2	14.2	0.6	53
July	30.4	13.6	2.4	53
August	32.4	14.9	1.1	50
September	35.9	19.9	8.3	52
October	37.8	23.9	31.2	55
November	37.5	25.0	94.7	63
December	35.8	24.9	210.0	73
Annual	34.1	20.5	1066.4	63

in a number out-of-season pregnancies in the No. 12 and No. 13 year groups, requiring a third muster in November 2017 to wean late calves. Brahman bulls were used in all years, except in South Queens paddock from late December 2012 to April 2013, when Senepol bulls were mated to the No. 11 maiden heifers and No. 10 first lactation heifers. As a result, in the following year (at 4.5 years old for No.10's and 3.5 years old for No. 11's), F1 Senepol females had 3/4 Senepol × 1/4 Brahman calves, and Brahman females had F1 Senepol calves. In all other years, F1 Senepol females had 1/4 Senepol × 3/4 Brahman calves, and Brahman females had Brahman calves.

When the study finished in 2019, the No. 12 cows were 7.5 years old, and No. 13 cows were 6.5 years old. Therefore, the results for 8.5 year olds used data from only the No. 10 and No. 11 cows, the results for 7.5 year olds used data from all year groups except the No. 13 year group, and the results for 6.5 year olds and younger ages used data from all year groups.

Weaning rates were calculated by dividing the number of calves weaned by the number of cows mated each year, and the lactation rate for first lactation heifers was calculated by dividing the number of calves weaned by the number of pregnant heifers retained. This is because not all pregnant heifers were retained each year due to the breeds having uneven numbers of maiden heifers. Therefore, the lactation rate from first lactation heifers was really just the result of subtracting the calf loss rate from 100%.

Weaner production was calculated by multiplying the weaning rate (and lactation rate in first lactation heifers) by the average weight of the calves weaned from each breed of cows in each year. Lifetime mean annual female liveweight production was calculated individually for each female that was retained after the maiden mating, by adding the total weight of calves that were weaned from a cow to her final liveweight recorded less her weaning weight, and then dividing this by her age at the end of the study less her age at weaning. If a cow died, then the number used for her final liveweight was zero and the denominator used was the age at which she died less her age at weaning.

Statistical analyses

Liveweights were corrected for stage of pregnancy using the method described by O'Rourke *et al.* (1991). All statistical tests were performed using R 4.1.0 (R Core Team 2021). Models for assessing the effect of breed on the pre-calving cow liveweights (post-weaning to Year 3), post-calving cow liveweights (from 3.5 to 8.5 years of age), calf weaning liveweights, annual female liveweight production, hip–height (mean of measurements at 5.5 and 6.5 years of age) and P8 fat-depth (No. 10 group at 6.5 years of age, and the No. 11, 12 and 13 groups at 5.5 years of age) were fitted with linear mixed effects models by REML for the fixed effect of breed (*lmerTest*; package Kuznetsova *et al.* 2017; Bates *et al.* 2015). Random intercept effects were fitted for the weaner's property of origin, year born and the year group's location. For pre-calving liveweights, the cow's weaning weight was used as a continuous covariate. For post-calving liveweight models, the fixed effect of lactation status (lactating or non-lactating) was nested within breed. Comparisons of estimated marginal means for breed were performed with the *emmeans* and *multcomp* packages (Lenth 2021 and Hothorn *et al.* 2008 respectively).

Models for assessing the effect of breed and lactation status on pregnancy rate, and the calf loss rate, calf weaning rate, lactation rate in first lactation heifers and calving rate of pregnant individuals were fitted using generalised linear mixed-effects models by maximum likelihood for the binomial response (*lme4* package; Bates *et al.* 2015). Random intercept effects were fitted for the weaner's property of origin. For assessing the effect of breed on cow mortality rates, generalised linear models for the binomial response were fitted to each year group separately, using year as a fixed factor. All means were tested on the log odds ratio scale.

Models for assessing the effect of breed on the number of calves produced during the trial (year groups nested within breed) were fitted using generalised linear mixed-effects models by maximum likelihood for the poisson response (*lme4* package; Bates *et al.* 2015). Means were tested on a log scale.

In cases for tests with binomial response data where complete or quasi-complete separation occurred (typically where categories exist with 100% successes for the outcome; Kosmidis *et al.* 2020), bias reduction was applied to model fit estimators using the *brglm2* package (Kosmidis 2021).

For all tests, final models of effects were chosen by assessing the significance of the reduction in model deviance for the number of parameters fitted (Chambers and Hastie 1992). All significance tests used 0.05 as the type I error rate.

Results and discussion

Key results of this study indicate that overall, F1 Senepols had heavier weaning and mature cow weights, and higher pregnancy rates in maiden heifers, but there were no significant differences in pregnancy or calf loss rates, average annual weaning rates, mean annual liveweight production, or cumulative mortality rates for mature cows.

Growth

The corrected mean liveweights of heifers of each breed from all four year groups, from weaning (at age 6 months) to 8.5 years old, are shown in Table 2. F1 Senepol heifers were

Table 2. Corrected mean liveweights (kg) and 95% CI (in brackets) for Brahman and F1 Senepol × Brahman (F1 Senepol) females (total means of 4 year groups) at April weaning musters from weaning (at ~6 months old) until 8.5 years old.

Age (years)	Non-lactating		Lactating	
	Brahman mean LW (kg)	F1 Senepol mean LW (kg)	Brahman mean LW (kg)	F1 Senepol mean LW (kg)
0.5	172A (156, 187)	197B (181, 212)		
1	190A (167, 213)	198B (175, 222)		
1.5	276A (234, 318)	290B (248, 332)		
2	279A (232, 325)	296B (250, 342)		
2.5	382A (351, 413)	398B (367, 430)		
3	382A (336, 428)	401B (356, 447)		
3.5	403A (367, 438)	455B (420, 491)	339C (301, 377)	376D (338, 414)
4.5	446A (380, 513)	493B (427, 559)	383C (318, 447)	437A (373, 501)
5.5	488A (445, 531)	527B (484, 570)	413C (369, 458)	446D (403, 490)
6.5	488A (442, 533)	538B (493, 583)	431C (385, 477)	479A (433, 526)
7.5	509A (472, 547)	564B (527, 601)	448C (411, 486)	489A (455, 522)
8.5	502A (435, 568)	561B (514, 609)	439C (380, 498)	488A (440, 536)

Means with a different letter in each row are significantly different ($P < 0.05$).

on average 25 kg heavier at weaning and remained heavier at each subsequent measurement date. The differences between breed means were significant in all years ($P < 0.001$). The weight advantage of F1 Senepol heifers was reduced to 8 kg after the post-weaning dry season, when they appeared to not perform as well as Brahmans in the harsh conditions after weaning (on average, F1 Senepol heifers only gained 2 kg over the post-weaning dry season, whereas Brahman heifers gained 18 kg). However, F1 Senepols gained more weight over the next year to have a weight advantage of 18 kg prior to the first mating (at 2 years old), and were on average 19 kg heavier prior to calving for the first time at 3 years old (Table 2). Other studies have also shown that *Bos taurus* × *Bos indicus* crossbred animals are heavier at weaning than pure *Bos indicus* animals due to hybrid vigour, and show higher post-weaning growth provided that they have enough stress resistance to cope with the environment that they are in (Frisch and Vercoe 1984; Frisch 1987; Chase *et al.* 1998; Prayaga 2003; Burrow 2006).

The liveweight data have been separated for lactating and non-lactating cows at each muster after 3.5 years old, when the first calves were weaned. F1 Senepol cows were heavier at April weaning musters in each year of the study both in lactating and non-lactating cows (Table 2). At the oldest age that data from all year groups were available (6.5 years old), F1 Senepol non-lactating cows were 50 kg heavier, and lactating cows were 48 kg heavier than Brahmans.

The mean P8 fat depth of mature cows was significantly greater in Brahman cows in all year groups, except for No. 13, and over all year groups Brahman cows were on average 2.4 mm fatter than F1 Senepols (Brahman 7.1 mm, 95% CI 4.9–9.3; F1 Senepol 4.7 mm, 95% CI 2.6–6.9; $P < 0.001$). The mean hip height of mature F1 Senepol cows from all year groups was 2 cm higher than Brahmans (F1 Senepol 138 cm, 95% CI 132–144; Brahman 136 cm, 95% CI 130–142; $P < 0.001$).

The liveweight, P8 fat depth and hip height data indicate that F1 Senepol cows have a larger mature size than Brahmans, and were able to maintain weight in the harsh northern conditions. It is likely that the larger mature size of F1 Senepol cows is at least partly due to hybrid vigor. Wildeus (1999) states that the Senepol is characterised as a medium sized breed, with a mature cow weight of between 420 and 500 kg, although the Australian Senepol Cattle Breeders Association website (2021) states that the average mature weight of Senepol cows can range from 550 to 650 kg. The heavier mature weights of F1 Senepol cows mean that they would have higher value when culled for age, but also that stocking rates should be adjusted to allow for the higher grazing pressure from larger animals.

Reproduction and production

Over all year groups, the mean maiden heifer pregnancy rate was 19.4% higher in F1 Senepols (Table 3). This is likely to be due to both their hybrid vigor (Rudder *et al.* 1975; Frisch 1987; Burrow 2006) and their lower Brahman content, as Brahman heifers have been shown to reach puberty at older ages and heavier weights than most *Bos taurus* breeds (Hearnshaw *et al.* 1994; Johnston *et al.* 2009). There were no significant differences in pregnancy rate between breeds in any of the subsequent years after the first mating, indicating that the breeds have similar fertility after the first mating in this environment. Burrow (2006) states that although tropically adapted taurine breeds are relatively

Table 3. Mean pregnancy rates and fetal and calf loss rates of Brahman and F1 Senepol × Brahman (F1 Senepol) females (total means of 4 year groups) at April weaning musters from after mating for the first time at 2.5 years old until 8.5 years old.

Measure	Age (years)	Brahman		F1 Senepol	
		Mean (%)	(95% CI)	Mean (%)	(95% CI)
Pregnancy rate	2.5	70.0A	(54.9, 81.7)	89.4B	(80.2, 94.6)
	3.5	12.4	(4.3, 30.9)	17.0	(6.0, 39.6)
	4.5	64.1	(38.5, 83.6)	61.7	(35.9, 82.2)
	5.5	68.4	(51.0, 81.8)	78.4	(62.2, 88.9)
	6.5	78.9	(54.1, 92.2)	72.2	(44.8, 89.3)
	7.5	72.5	(42.6, 90.4)	65.9	(35.2, 87.3)
	8.5	73.3	(57.1, 85.0)	66.3	(47.4, 81.1)
Calf loss rate	3.5	14.4A	(10.5, 19.5)	6.0B	(3.2, 10.8)
	4.5	10.6	(5.1, 20.8)	14.9	(7.4, 27.7)
	5.5	10.2	(6.4, 15.8)	5.5	(2.3, 12.4)
	6.5	9.9	(5.7, 16.7)	5.4	(2.3, 12.0)
	7.5	14.8	(9.2 22.9)	7.1	(2.3, 19.7)
	8.5	13.2	(4.9, 30.9)	8.1	(2.4, 23.5)

Means in each row with a different letter are significantly different ($P < 0.001$ for pregnancy rate and $P < 0.01$ for calf loss rate). The pregnancy rates presented are for all females (lactating and non-lactating) in each year, except for in first lactation heifers (3.5 years old), when the pregnancy rates are only for lactating heifers, as there were few non-lactating heifers in that year.

well adapted to the (sub) tropics, their resistance to environmental stressors is generally below that of pure *Bos indicus*. In less stressful environments, it is likely that F1 Brahman × *Bos taurus* cows would have higher pregnancy rates than pure *Bos indicus*, but in the harsh environment of this study, the higher reproductive potential from the *Bos taurus* content was countered by lower stress resistance, resulting in the breeds having similar pregnancy rates.

The calf loss rate in heifers calving for the first time was 8.4% higher in Brahman than F1 Senepol (Table 3). There were no significant differences between breeds at any of the other ages, although calf loss rates in mature cows tended to be higher in Brahmans at all ages, except at 4.5 years of age. The calf loss rates recorded in this study are generally low compared with those previously reported for mature cows on commercial properties in this environment. Calf loss rates in F1 Senepols ranged from 6.0 to 14.9% (average of all ages 7.8%), and from 9.9 to 14.8% (average of all ages 12.2%) in Brahmans (Table 3), whereas the median calf loss rate reported for mature cows on commercial properties in the Northern Forest zone of northern Australia was 13% (McGowan *et al.* 2013).

When data from all year groups was combined, the mean weight of calves weaned from F1 Senepols was heavier in all years, but the only ages at which the differences were significant were from 3.5-year-old first lactation heifers and 5.5-year-old cows (Table 4). In most years, F1 Senepol females produced 1/4 Senepol × 3/4 Brahman calves. and Brahman females produced Brahman calves so it is not surprising that weaner weights tended to be higher from F1

Table 4. The average weaner weight, weaning rate (lactation rate in first lactation heifers), and weaner production of four year groups of Brahman and F1 Senepol × Brahman (F1 Senepol) cows each year from weaning of their first calf (at 3.5 years old) until 7.5 years of age (calves were not mothered-up in the final year of the study, so data are not presented for 8.5-year-old cows).

Age (years)	Brahman			F1 Senepol		
	Avg. weaner weight (kg)	Weaning rate (%)	Weaner production (kg)	Avg. weaner weight (kg)	Weaning rate (%)	Weaner production (kg)
3.5[A]	152A	85.6	130.1	158B	94.0	148.5
4.5	143	30.1	43.0	149	32.0	47.7
5.5	166A	68.6	113.9	176B	68.5	120.6
6.5	154	58.9A	90.7	156	70.5B	110.0
7.5	154	59.0	90.9	164	45.3	74.3

Breed means with a different letter for the same measure in each row are significantly different ($P < 0.05$).
[A]Lactation rate was calculated for 3.5 year olds instead of weaning rate, as not all pregnant maiden heifers were retained.

Senepol females due to hybrid vigour (Frisch and Vercoe 1984; Frisch 1987; Chase *et al.* 1998; Prayaga 2003). Hybrid vigour is greatest in the F1 generation, and declines in subsequent generations (Frisch 1987; Burrow 2006), which in addition to the lower Senepol content of the calves explains why the differences between the breeds were not as great as seen between the weaning weights of the F1 Senepol and Brahman females (Table 2).

The lactation rate from F1 Senepol first lactation heifers was 8.4% higher than from Brahmans (Table 4), although it should be noted that this is just a function of the higher calf loss among Brahmans. There were no differences in weaning rate between breeds in mature cows except for in 6.5 year-old cows when the weaning rate was 11.6% higher from F1 Senepol cows (Table 4). This occurred because there was a higher pregnancy rate in F1 Senepol in 6-year-old cows, and then they had a lower calf loss rate at 6.5 years old, and although neither of these differences were significant, their combined effect resulted in a significantly higher weaning rate. When averaged over all the years of the study, the average annual weaning rate from the breeds was similar (F1 Senepol 59.2%, Brahman 57.2%).

Weaner production was similar for both breeds (Table 4) and was slightly higher for F1 Senepols in each year (except for the 7.5-year-old cows), due to generally higher weaning rates and heavier calf weaning weights. This is consistent with the findings of Fordyce *et al.* (2021), who reported that tropical composites had consistently higher lactation rates and higher calf weaning weights, and as a result, higher annual liveweight production than Brahmans.

The mean number of calves weaned per cow and the mean annual female liveweight production for each year group of Brahman and F1 Senepol cows over the duration of the study is shown in Table 5. There was large variation between individual cows. For example, some No. 10 cows produced six calves over the study, whereas others produced only one (cows were not culled for poor fertility). There were no significant differences between breeds in any of the year groups, nor overall, for the mean number of calves produced per cow. Similarly, there were no significant differences between breeds in annual female liveweight production, either overall or in any of the year groups. Total annual female liveweight production in this study was 6% higher for the F1 Senepols (Table 5). This was largely due to the greater increase in weight of F1 Senepol females over the duration of the trial and their larger mature size. However, when comparing the breeds for efficiency of liveweight production, the effect of heavier mature weights of F1 Senepol females on stocking rates requires consideration. Relative to Brahmans, fewer F1 Senepol cows should be carried per unit area due to their higher pasture consumption. Using liveweight data from Table 2, Brahman cows were significantly smaller at every age. On average, they were 9.65% smaller for non-lactating cows, 9.67% smaller for lactating cows and 9.66% smaller overall. If annual female liveweight production is adjusted to account for the fact that a property could carry more Brahman cows at the same utilisation rate, then the annual female liveweight production per ha for the breeds would be comparable.

When the reproductive measures of pregnancy rate, calf loss rate, weaning rate, weaner production, number of calves weaned and annual female liveweight production are considered, the only significant differences between breeds were that pregnancy rates in maiden heifers were on average 19% higher for F1 Senepols, calf loss rates were 8% higher for Brahman heifers calving for the first time, the average weight of calves weaned was 6 kg heavier from F1 Senepol first lactation heifers and 10 kg heavier from 5.5-year-old F1 Senepol cows. All the other measures were similar for the breeds, and these results indicate that overall the reproductive performance of the breeds was similar in this environment. This is likely to be because the higher reproductive potential of the F1 Senepol was offset

Table 5. Mean number of calves weaned and annual female liveweight production (kg) from four year groups of Brahman and F1 Senepol × Brahman (F1 Senepol) females over the duration of the study.

Measure	Year group	Brahman		F1 Senepol	
		Mean	(95% CI)	Mean	(95% CI)
No. of calves weaned	No. 10	3.09	(2.56, 3.73)	3.40	(2.83, 4.13)
	No. 11	3.26	(2.93, 3.63)	3.15	(2.73, 3.62)
	No. 12	2.84	(2.48, 3.25)	2.86	(2.48, 3.28)
	No. 13	2.66	(2.28, 3.11)	2.84	(2.49, 3.23)
Annual female liveweight prod. (kg)	No. 10	96.8	(85.9, 108)	108.1	(96.5, 120)
	No. 11	93.0	(84.2, 102)	96.1	(84.7, 107)
	No. 12	95.1	(87.4, 103)	99.9	(90.2, 110)
	No. 13	107.7	(98.0, 117)	112.5	(99.9, 125)

No. 10 and No. 11 cows had the opportunity to wean six calves, and No. 12 and No. 13 cows had the opportunity to wean five and four calves, respectively. None of the differences between breeds were significant.

Table 6. Summary of cumulative mortality rates of four year groups of Brahman and F1 Senepol × Brahman (F1 Senepol) cows from after they were first mated at 2 years of age until the study finished (the ages of the year groups at the end of the study were (No. 10 9.5 years old, No. 11 8.5 years old, No. 12 7.5 years old, No. 13 6.5 years old).

Year group	Brahman				F1 Senepol			
	Number at risk	Number of cases	Cumulative incidence (%)	(95% CI)	Number at risk	Number of cases	Cumulative incidence (%)	(95% CI)
No. 10	35	2	6.1	(2.0, 21.6)	30	2	7.1	(2.3, 24.6)
No. 11	104	8	8.2	(4.2, 15.1)	62	7	12.3	(5.9, 22.6)
No. 12	74	3	4.2	(1.6, 12.6)	69	6	9.2	(4.3, 18.8)
No. 13	59	1	1.7	(0.5, 11.6)	79	3	3.9	(1.5, 11.9)

None of the differences between means were statistically different.

by their slightly lower resistance to environmental stresses (Frisch and Vercoe 1984, Fordyce and Holroyd 2003; Burrow 2006).

Mortality/missing rate

The annual cow mortality rate averaged 1%, with no effect of cohort, breed or age. The cumulative mortality rate for the year groups of cows over the duration of the trial are shown in Table 6. The cumulative mortality rates tended to be higher in F1 Senepol cows (between 1 and 5% higher in different year groups), although none of the differences were statistically significant. If the F1 Senepol cows did not have sufficient ability to cope with the environmental stresses at the trial location, then it would be expected that they would have had significantly higher mortality rates, and lower growth and reproductive performance. As these measures were similar for the breeds, these results suggest that F1 Senepol females have sufficient resilience to cope with a stressful environment when managed with correct stocking rates (based on utilisation rate), good supplementation and weaning management.

Hair loss

Each year, it was noticeable that some of the lactating F1 Senepol cows suffered significant hair loss on their rump and back, and the skin appeared red and sunburnt in these areas. The hair loss was only seen in F1 Senepol cows when they were lactating, and the condition healed rapidly after calves were weaned, so that by the September musters it was difficult to tell which cows had previously been affected. The incidence of the condition was recorded in the South Queens herd in the final year of the study. It was noted that 3% of lactating F1 Senepol cows had quite severe hair loss and sunburnt skin, 15% had a reasonable amount of hair loss, and a total of 35% of lactating F1 Senepol cows had some hair loss. The total number of calves weaned per cow over the duration of the study was slightly higher in cows that were recorded as having had some hair loss (3.3) than cows that did not (3.0), but this difference was not considered to be important. The cause of the hair loss was not investigated, but it is hypothesised that it was due to alopecia areata, which is an autoimmune disease. Cattle with the *SLICK* hair gene, such as Senepols (Olson *et al*. 2003), normally have upregulated immune cell regulation to keep hair follicles in stasis, which results in a short and sleek hair coat, and it is possible that an extreme reaction occurred in some F1 Senepol cows with the hormonal flux postpartum to the prolactin axis (T Sonstegard, pers. comm.).

Conclusion

When the performance of F1 Senepol and Brahman females was compared in this environment, we found that heifer performance was better in F1 Senepols, but there were few differences in mature cow performance between the breeds. Weaning rates, calf production, weaner weights, weaner production, annual female liveweight production and mortality rates were similar in both breeds. The weight of F1 Senepol mature cows was approximately 50 kg heavier. North Australian cattle producers with Brahman herds considering adopting a crossbreeding program using a tropically adapted *Bos taurus* breed, such as Senepol, to improve the meat tenderness of the progeny they sell can be confident that the performance of the crossbred females they retain for breeding will not underperform that of their existing Brahman herds if they are well managed.

References

Australian Senepol Cattle Breeders Association website (2021) Available at https://www.senepol.com.au/breed#history. (sourced 5 August 2021)

Bates D, Mäechler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* **67**(1), 1–48. doi:10.18637/jss.v067.i01

Beggs D, Bertram J, Chenoweth P, Entwistle KW, Fordyce G, Johnston H, Johnston P, McGowan MR, Niethe G, Norman S, Perry V (2013) Veterinary bull breeding soundness evaluation. Australian Cattle Veterinarians, Brisbane.

BOM (2021) Bureau of Meteorology website. Available at http://www.bom.gov.au/climate/averages/tables/cw_014932.shtml (Sourced 22 July 2021)

Burrow HM (2006) Utilization of diverse breed resources for tropical beef production. In 'Proceedings of the 8th World congress on genetics applied to livestock production, 13–18 August 2006, Belo Horizonte, MG, Brazil'. pp. 31–39. ISBN No. 85-60088-01-6. Available at www.wcgalp8.org.br/wcgalp8/articles

Butts WT (1999) Feedlot performance and carcass traits of purebred and crossbred Senepol cattle. In 'Senepol Cattle. Proceedings, International Senepol Research Symposium'. (Ed. S Wildeus) pp. 105–107. (University of the Virgin Islands: St. Croix)

Chambers JM, Hastie TJ (1992) 'Statistical Models in S.' (Wadsworth & Brooks/Cole: Pacific Grove, CA)

Chase CC Jr, Olson TA, Hammond AC, Menchaca MA, West RL, Johnson DD, Butts WT Jr (1998) Preweaning growth traits for Senepol, Hereford, and reciprocal crossbred calves and feedlot performance and carcass characteristics of steers. *Journal of Animal Science* **76**, 2967–2975. doi:10.2527/1998.76122967x

Crouse JD, Cundiff LV, Koch RM, Koohmaraie M, Seideman SC (1989) Comparisons of *Bos indicus* and *Bos taurus* inheritance for carcass beef characteristics and meat palatability. *Journal of Animal Science* **67**, 2661–2668. doi:10.2527/jas1989.67102661x

Davis GP (1993) Genetic parameters for tropical beef cattle in northern Australia: a review. *Australian Journal of Agricultural Research* **44**, 179–198. doi:10.1071/AR9930179

Fordyce G, Holroyd RG (2003) Management of extensive northern beef breeding herds. In 'Proceedings of the Australian cattle veterinarians conference', May 2003, Cairns. pp. 16–30. (Australian Association of Cattle Veterinarians: Brisbane)

Fordyce G, Barnes TS, McGowan MR, Perkins NR, Smith DR, McCosker KD (2021) Defining the primary business measure of liveweight production for beef cows in northern Australia. *Animal Production Science*. doi:10.1071/AN20096

Frisch JE (1987) Physiological reasons for heterosis in growth of *Bos inducus* × *Bos taurus*. *Journal of Agricultural Science* **109**, 213–230. doi:10.1017/S0021859600080631

Frisch JE, Vercoe JE (1984) An analysis of growth of different cattle genotypes reared in different environments. *Journal of Agricultural Science* **103**, 137–153. doi:10.1017/S0021859600043409

Hearnshaw H, Arthur PF, Barlow R, Kohun PJ, Darnell RE (1994) Evaluation of *Bos indicus* and *Bos taurus* straightbreds and crosses. II. Postweaning growth, puberty and pelvic size of heifers. *Australian Journal of Agricultural Research* **45**, 795–805. doi:10.1071/AR9940795

Hothorn T, Bretz F, Westfall P (2008) Simultaneous inference in general parametric models. *Biometrical Journal* **50**(3), 346–363. doi:10.1002/bimj.200810425

Johnson ER (1987) Comparison of twelfth rib and rump fat thickness measurements for predicting commercial beef yield in local market carcasses. *Australian Journal of Experimental Agriculture* **27**, 613–617. doi:10.1071/EA9870613

Johnson DD, Huffman RD, Williams SE, Hargrove DD (1990) Effects of percentage Brahman and Angus breeding, age-season of feeding and slaughter end point on meat palatability and muscle characteristics. *Journal of Animal Science* **68**, 1980–1986. doi:10.2527/1990.6871980x

Johnston DJ, Barwick SA, Corbet NJ, Fordyce G, Holroyd RG, Williams PM, Burrow HM (2009) Genetics of heifer puberty in two tropical beef genotypes in northern Australia and associations with heifer- and steer-production traits. *Animal Production Science* **49**, 399–412. doi:10.1071/EA08276

Kosmidis I (2021) brglm2: Bias Reduction in Generalized Linear Models. R package version 0.8.0. Available at https://CRAN.R-project.org/package=brglm2

Kosmidis I, Kenne Pagui EC, Sartori N (2020) Mean and median bias reduction in generalized linear models. *Statistics and Computing* **30**, 43–59. doi:10.1007/s11222-019-09860-6

Kuznetsova A, Brockhoff PB, Christensen RHB (2017) lmerTest Package: Tests in Linear Mixed Effects Models. *Journal of Statistical Software* **82**(13), 1–26. doi:10.18637/jss.v082.i13

Lenth R (2021) emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.6.1. Available at https://CRAN.R-project.org/package=emmeans

McGowan MR, McCosker KD, Fordyce G, Smith DR, Perkins NR, O'Rourke PK, Barnes T, Marquart L, Menzies D, Newsome T, Joyner D, Phillips N, Burns BM, Morton JM, Jephcott S (2013) Insights from Cash Cow. *Proceedings of the Northern Beef Research Update Conference*, 12–15 August 2013. Cairns Qld. pp 61–66.

O'Rourke PK, Entwistle KW, Arman C, Esdale CR, Burns BM (1991). Fetal development and gestational changes in *Bos taurus* and *Bos indicus* genotypes in the tropics. *Theriogenolgy* **36,** 839–853.

O'Connor SF, Tatum JD, Wulf DM, Green RD, Smith GC (1997) Genetic effects on beef tenderness in *Bos indicus* composite and *Bos taurus* cattle. *Journal of Animal Science* **75**, 1822–1830. doi:10.2527/1997.7571822x

Olson TA, Lucena CC, Chase CC Jr, Hammond AC (2003) Evidence of a major gene influencing hair length and heat tolerance in *Bos taurus* cattle. *Journal of Animal Science* **81**, 80–90. doi:10.2527/2003.81180x

Prayaga KC (2003) Evaluation of beef cattle genotypes and estimation of direct and maternal genetic effects in a tropical environment. 1. Growth traits. *Australian Journal of Agricultural Research* **54**, 1013–1025. doi:10.1071/AR03071

R Core Team (2021) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at https://www.R-project.org/

Rudder TH, Seifert GW, Bean KG (1975) Growth performance of Brahman and Charolais × Brahman cattle in a tropical environment. *Australian Journal of Experimental Agriculture and Animal Husbandry* **15**, 156–158. doi:10.1071/EA9750156

Schatz TJ (2017) A comparison of the growth of Brahman and F1 Senepol × Brahman steers in an Indonesian feedlot. *Animal Production Science* **57**, 2096–2099. doi:10.1071/AN16211

Schatz TJ, Thomas S, Geesink G (2014) Comparison of the growth and meat tenderness of Brahman and F1 Senepol × Brahman steers. *Animal Production Science* **54**, 1867–1870. doi:10.1071/AN14243

Schatz T, Thomas S, Reed S, Hearnden M (2020) Crossbreeding with a tropically adapted *Bos taurus* breed (Senepol) to improve meat quality and production from Brahman herds in Northern Australia. 1. Steer performance. *Animal Production Science* **60**, 487–491. doi:10.1071/AN18609

Wildeus S (1999) Performance of Senepol cows at two locations on St Croix. In 'Senepol Cattle. Proceedings, international senepol research symposium'. (Ed. S Wildeus) pp. 15–23. (University of the Virgin Islands: St. Croix)

Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

Conflicts of interest. The authors declare no conflicts of interest.

Declaration of funding. Funding for this research was provided by NT DITT.

Acknowledgements. The assistance of NT DITT research station staff at Katherine Research Station (Will Mathers, Steven Rose, David Hancock and Dylan Williams) and Victoria River Research Station (Tony Moran, Cameron Heeb and Alison Haines) with herd management; and the assistance of Katherine DITT Livestock Industries staff, especially Whitney Dollemore, Jodie Ward, Jo Miller and Melissa Wooderson, with data collection is gratefully acknowledged.

Author affiliations

[A]NT Department of Industry Tourism and Trade, GPO Box 3000, Darwin, NT 0801, Australia.

[B]NT Department of Industry Tourism and Trade, Katherine Research Station, Katherine, NT 0850, Australia.