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Belmont Crossbreeding – Phase 1

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1.0 ABSTRACT

Breeds of African, European and Indian origins are being used to investigate how productivity of the northern beef industry may be increased through greater use of heterosis and better matching of genotypes to markets, environments and management systems. Productivity incorporates efficiency of growth and reproduction, survival rates, “easy-care” characteristics, resistance to environmental stresses and meat and carcase qualities. These variables are being measured and used to develop models that predict the productivity of different genotypes over a range of breeding, rearing and finishing environments. Preliminary data indicate that no breed excels in all components of production and that appropriate crossbreds have far higher productivity than any straightbred, without the need for additional inputs. Growth from birth to 18 months and resistance to ticks and worms are the only measurements completed. They show differences between genotypes of over 33% in liveweights at each age and over 100% in resistance to parasites. Crossbred genotypes of high mature size had the highest absolute growth rates but in the presence of parasites, crossbred genotypes of high resistance had higher efficiency of growth. Although objective measurement of meat tenderness favoured the taurine breeds, breed differences were not detected by taste panel tests. Positive identification of the most productive genotypes for each set of conditions will follow completion of measurements of all production variables in 1998.

2.0 EXECUTIVE SUMMARY

Background

For the northern beef industry to maintain long-term profitability in the face of increasing competition and environmental concerns, productivity must be increased in a cost-effective and sustainable manner.

The majority of cattle in northern Australia are either high grade Brahman or 2-breed synthetics based on Brahman and European (British and Continental). Production systems based on these breeds fail to fully capitalise on the benefits of heterosis or the attributes of other breeds. Methods must be found to reduce age and increase weight at turnoff, increase reproductive efficiency and survival rates, and improve meat and carcase qualities while simultaneously maintaining high levels of tropical adaptation. Sale animals must be able to meet the requirements of the market being targeted whether those markets are the South East Asian live cattle trade, the feedlot or grass-fed sectors or any other market. Flexibility to target different markets is highly desirable to reduce the risk of failure of any particular market. Females for use in the breeding herd must be efficient, “easy-care” and highly productive. This project uses breeds of diverse origins to quantify the extent to which these goals might be achieved through greater use of heterosis and by better matching of breeds to markets, environments and management systems.

The long generation interval of cattle, the high cost of maintaining large numbers of animals as a single herd and the requirement for sufficient numbers to detect economically and statistically significant differences dictate that completion of all measurements will take several years. In Phase I of the project, measurement of growth from birth to 18 months and resistance to ticks and worms was completed and measurements of other production variables, including meat and carcase qualities, commenced.

Results

There were differences between genotypes of over 33% in liveweights at each age. Brahman- and Boran-sired calves from *Bos taurus* dams had the highest birthweights of all calves. Tuli-sired calves were of similar birthweights but generally higher weaning and 18 month weight than the corresponding straightbreds. When ticks and worms were controlled, liveweights at all ages for *Bos taurus*-sired progeny from Brahman dams and for *Bos indicus*-sired progeny from *Bos taurus* dams, ranked the same as the mature sizes of the *Bos taurus* and *Bos indicus* sire breeds respectively. Thus, for crosses that generate similar heterosis it is likely that any genetic differences in efficiency of growth are small or non-existent. Within each dam breed, liveweights of crossbreds at all ages were generally higher than those of straightbred contemporaries. Efficiency of growth was also higher for the crossbreds.

The ranking of the straightbreds for resistance to ticks was Brahman (B), Boran (Bo)>Brahman cross (BX)>Belmont Red (AX), Belmont Adaptaur (HS), Tuli (Tu)>Charolais (Ch) and for worms, B>Bo,BX>AX,Ch,HS,Tu. Growth of all genotypes was affected by parasites but at low to moderate levels of parasite challenge, the response of the more resistant genotypes was too low to warrant the cost of chemical treatment. There was significant heterosis for resistance to parasites but only the B×Bo and B×BX were as resistant as the B. However, the difference in response between B and the most resistant F_1’s was such that even at twice the parasite challenge, the F_1’s would be expected to outgain the B.

The data being generated are being used to develop user-friendly predictive models that when complete will allow producers to compare productivity of different genotypes in different environments and make a rational choice of genotype before initiating a crossbreeding program or before continuing with the next step in a crossbreeding program.

The large differences between genotypes in resistance to parasites, growth potentials and in the heterosis generated by particular crosses provide scope for generating crossbreds that have high efficiency of growth over a range of conditions. However, genotypes must be assessed on the basis of total productivity. That cannot be done until completion of the study.

3.0 MAIN RESEARCH REPORT

3.1 Background and Industry Context

The beef cattle industry is of major importance to the economy of northern Australia.. Cattle are reared in a variety of environments ranging from semi-arid subtropics where there is no parasite challenge, to wet, humid tropics where there is continuous challenge from a variety of ecto- and endo-parasites. These parasites can be controlled by chemicals. However, public concerns over the effects on health of any chemical residues in beef, concern over the effect of toxic chemicals on the general environment, the potential use of chemical residues as non-tariff trade barriers and the inevitable development of resistance by the parasites to chemicals used for their control, are sound reasons for minimising their use. There are also considerations of continuing direct costs associated with the use of chemicals and the impracticality of using them in extensive pastoral situations. All of these concerns could be overcome through the use of cattle that have high genetic resistance to parasites. Regardless of the region, the cattle may be grown entirely on pasture or finished in feedlot. They may be destined for the domestic trade or for the quality-conscious markets of Asia. They may be exported live to South East Asia or as manufacturing grade beef to a variety of markets.

For the industry to maintain long-term stability and profitability in the face of ever increasing environmental concerns and competition from other livestock products and other beef exporting countries, productivity must be increased in all sectors of the industry. Improvements in “on-farm” productivity will depend on developing sustainable, cost-effective methods of increasing the efficiency of growth, reproduction and survival, increasing market flexibility and producing the type of product required by the different markets while simultaneously maintaining high levels of tropical adaptation and “easy-care” characteristics in growing and breeding stock.

Experience in temperate regions has shown that no single breed is best suited to all production systems and that the highest productivity depends on an appropriate match between genotype, environment and market, and making best use of heterosis and complementarity (Koch *et al.*, 1989). To be able to achieve these aims, northern Australian beef producers must have access to a range of unrelated genotypes that have desirable production characteristics. There is a wide range of breeds of European origins (*Bos taurus*) in Australia and although they have some desirable production characteristics, they lack the desired resistance to the stresses of the tropics. Until recently, most of the tropically adapted breeds were of Indian origin (*Bos indicus*) with the Brahman being the principal representative of the group. The sole representative of the African breeds was the Africander, a southern African sanga breed (*Bos taurus*). In 1990, the Boran and the Tuli were introduced to Australia from Africa (Frisch, 1990) to expand the range of unrelated, tropically adapted breeds available to northern beef producers.

The first step in the process of identifying the genotypes that are best suited to the diversity of production environments and market outlets available to northern Australian beef producers is to identify the strengths and weaknesses of representative breeds from each of the major breed groups already present in Australia. With this in mind, the total productivity of crossbred and straightbred breeds of African, European and Indian origins is being measured over a range of breeding, rearing and finishing environments. Total productivity incorporates efficiency of growth and reproduction, survival rates, “easy-care” characteristics, resistance to environmental stresses and meat and carcase qualities, and it is total productivity, not any single component of it, that must be considered when assessing the relative merits of breeds and breeding systems.

Although total productivity is being assessed, measurement of growth on pasture to 18 months and resistance to ticks and worms are the only measurements completed. Measurement of other components of production will not be completed till 1998. Interim results, which are the subject of milestone reports, are not reported here. Measurement of meat and carcase qualities of steers that were finished in feedlot or an pasture, is also incomplete. Preliminary results only are reported.

3.2 Project Objectives

(i) To identify genotypes that in stressful environments express maximum heterosis and produce environmentally sustainable increases in overall productivity, measured as the combination of survival, growth, reproduction, “easy-care” characteristics, resistance to environmental stresses and meat and carcase quality, of at least 20% above that of Brahmans.

(ii) Develop model(s) that allow prediction of the productivity of any defined genotype (whether crossbred or straightbred) reared in any defined environment, using any defined management system and targeting any defined market.

3.3 Detailed Methodologies

3.3.1 Breeds and Animals

The study was conducted at the National Cattle Breeding Station, “Belmont”, near Rockhampton, Queensland, on three crops of straightbred and crossbred calves born in 1991, 1992 and 1993. The zebu breeds (*Bos indicus*) used were the Brahman (B) and the Boran (Bo), the sanga breed (African *Bos taurus*) was the Tuli (Tu), and the European breeds (*Bos taurus*) were the Charolais (Ch) and the Belmont Adaptaur (HS), a synthetic breed of nominally ½Hereford (H) × ½Shorthorn (S) derivation. The Belmont Red (AX), a *Bos taurus* synthetic breed of nominally ½Africander ¼H ¼S, and the Belmont BX (BX), a synthetic of nominally ½B ¼H ¼S, were also used.

The same H and S cows were used in the formation of the HS, AX and BX lines, each of which has been closed and *inter se* mated since 1953. The B, AX, BX and HS lines have been selected since the late 1960’s primarily for high growth rates on pasture at Belmont. A description of selection in the lines is available elsewhere (Frisch, 1981; Mackinnon *et al.*, 1990). There had not been any selection within the Boran and Tuli lines in Australia. Most of the B animals were direct samples from industry herds or were the progeny of animals sampled from industry herds. The Ch were sampled as semen from industry herds.

At the end of 1990, 1991 and 1992, females from the AX, B, BX and HS lines were allocated at random within age and previous lactational status, to different sire breeds to produce straightbreds and crossbreds according to the design shown in Table 2.

Except during the 10 weeks breeding season, all of the cows grazed as a single herd. At the end of the breeding season the herd was divided on the basis of sex of calf. From then on, calves of the same sex remained together and were treated alike. Up to weaning, none of the calves was treated to control endo- and ecto-parasites and none was offered supplementary feed. All were vaccinated against calf-hood diseases. None of the dams was treated to control ecto- or endo-parasites. All of the male calves remained entire until the end of the study.

Drought prevailed for the latter half of 1994 and from 9 to 12 months of age, the 1994 crop of males was offered a supplement of a grain-urea-molasses block at the rate of approximately 2kg/head/week. Their heifer contemporaries were reared concurrently on irrigated pasture.

<u>Sires</u>

The 10 AX, 18 B and 10 BX sires in the study were selected for high Estimated Breeding Value (EBV) for 600 day liveweight. The 15 HS sires were selected primarily for high 600 day liveweight and high resistance to cattle ticks (*Boophilus microplus*). Within each of these breeds, the same sires were used to produce straightbred and crossbred calves. The 10 Bo, 10 Tu sires, and 6 Ch were selected at random. At least two bulls of every breed were joined in successive years. The prime purpose of the study was to estimate breed rather than sire effects. Consequently the number of sires/breed was maximised rather than the number of progeny/sire.

3.3.2 Liveweights

Calves born on weekdays were individually identified and weighed within 24 hours of birth. The interval for calves born on weekends was up to 48 hours. All of the calves were weighed at weaning, which occurred on a single day when the mean age of the calves was 180 days, at about 8 months of age and at approximately 18 months of age.

3.3.3 Ticks and worms

At weaning the calves from each crop were allocated at random within sex, breed, sire and age, and age and previous lactation status of the dam, to “treated” and “control” groups.

Every three weeks on three occasions post-weaning, faecal samples were taken from each animal for estimation of resistance to worms. Estimates were determined by one experienced person by counting the number of eggs (“worm egg counts”) per gram of fresh faeces (Roberts and O’Sullivan, 1950). At the same time, all of the calves were assessed for resistance to cattle ticks (*Boophilus microplus*) by counting the number of engorging females ≥4.5mm long on one side of each animal and doubling the count (“tick counts”). All counting was conducted by 3 or 4 experienced observers. Tick counts were highest during this period.

Every three weeks thereafter, all of the “treated” animals were treated with antihelmintic (Nilverm injection, Pitman-Moore, Australia). On each occasion, 10 treated animals were sampled at random to check the efficacy of the antihelmintic. Worm egg counts of these animals were generally fewer than 10/g. They were also inspected for cattle ticks and if any were found, all of the “treated” animals were dipped in acaricide (Tactic, Hoechst, Australia). Tick counts were recorded on the controls. Tick counts on the treated animals were zero throughout the period of treatment.

Prior to this, none of the calves or their dams had been treated to control ticks or worms. Part way through the treatment period a few control animals from the 1992 calf crop became heavily infested with cattle ticks and were treated to prevent possible deaths. They were included in the estimates of tick resistance but were excluded from analyses of liveweight responses. Treatment for control of parasites ceased at about 17 months of age. The combined effect of ticks and worms was estimated as the difference in gains of treated and control groups over the entire period of treatment (about 10 months).

3.3.4 Statistical analysis

Liveweights of the calves at birth, weaning and 18 months and liveweight gains from 8 to 18 months, were analysed using mixed-model least squares procedures (Harvey, 1987; SAS, 1992). The total variance in liveweights at birth and weaning was partitioned into that due to years, breed and sex of calf, combined age and previous lactation status of the dam (called here AGEPLS), the interactions between main effects, and residual. Only first order interactions were included in the final model as all higher order interactions were non-significant ($P>0.05$). Covariance was used to adjust birthweights and weaning weights of calves for differences between them in date of birth. The mean squares for main effects were tested against the residual mean square unless there was a significant interaction involving the main effect. In the latter case, the main effect was tested against the interaction. The ‘F’ values shown in the analysis of variance tables were calculated from the appropriate mean squares. For the analysis of liveweights at 18 months and gains from 8 to 18 months, the effect of treatment to control parasites and its interaction with genotype of calf were included as additional sources of variation. Liveweights at 18 months were estimated from birthweights and daily gains from birth to the age of final weighing. Preliminary analysis of 18 months liveweight had shown that sex × treatment and breed × sex × treatment effects were not statistically significant ($P>0.40$). Sex differences in 18 month liveweight were therefore estimated from the data for both treatments combined.

For parasite burdens, the interaction between sex of calf and treatment was not significant for any of the variables analysed. Since it is breed effects that are the main focus of this project, sex effects have not been presented.

Brahman, Bo and Tu were used as common sire breed on HS, AX, BX and B dams. This subset of data was used to estimate the effect of sire breeds, dam breeds, their interaction, and calf sex and its interaction with sire and dam breeds on liveweight at different ages, response to treatment, and tick and worm egg counts. The average effect of dam breed was calculated across the three common sire breeds. Comparisons of the seven sire breeds were valid only across B dams.

To reduce the non-normality of the data for parasite counts, the data for tick counts were first transformed to $\log_{10}$ (1 + tick count) and worm egg counts were transformed to $\log_{10}$ (10 + worm egg count) before analysis. The variance in parasite counts was partitioned into the same components as those used for liveweight gains. Parasite counts recorded after treatment began were analysed within the controls only. In all cases, tests of significance were conducted on the transformed data but for convenience, arithmetic means are also presented.

Relationships between tick counts and liveweight gains were estimated over the period before treatment began and over the entire period of treatment. In each case the data for corresponding tick counts and liveweight gain were used. Preliminary analysis had shown that there was no significant different between the regressions within each breed and for the final analysis, the common regression was used as the best estimate of the relationship.

Preliminary analyses had shown that for log tick count, there were no significant first order interactions between main effects and these interactions were therefore deleted from the final analysis. Since the intention of the study was to rank the breeds for resistance to ticks, only the least squares means for breeds and their back transformation have been presented.

In each of the above analyses for parasite resistance, the data for all calf genotypes were included in the model (the “full model”). In addition, liveweight gains, tick counts and worm egg counts were analysed within common sire and dam breeds (the “partial” model). In each case the total variance was partitioned into that due to year, calf sex, dam breed, sire breed, AGEPLS of the dam and the first order interactions between sire breed, dam breed and treatment.

Heterosis for liveweight gains, tick counts and worm egg counts was estimated for each of the reciprocal crosses between HS and B, AX and B and BX and B as the deviation of the F_1 from the mid parent mean.

Purebred Bo and Tu calves were born on Belmont to maiden or primiparous heifers that were reared as a separate herd. Their birthweights, corrected using the constants for AGEPLS, calculated from the other breeds, were used to estimate heterosis for birthweights for the Bo and Tu crossbreds. Prior to weaning, the purebreds were transferred to another location. Heterosis for liveweights at weaning and 18 months have therefore not been calculated. For the AX, B and HS, the linear functions of the means for liveweights of each sex at each age, tick counts, worm egg counts and response to treatment, were used to estimate heterosis as the deviation of the F_1 from the mean of the parents. Straightbred Ch were not included in the comparisons and heterosis effects were not estimated. The approximate difference required for statistical significance between breed-sex means and for statistical significance from zero were then calculated using Studentized Range (Snedecor and Cochran, 1980).

3.4 RESULTS

3.4.1 Liveweights

3.4.1.1 Analysis of variance

Table 1 shows the summary of the analyses of variance for liveweights at birth, weaning and 18 months when all calf genotypes were included in the model (the “full” model) and when only those from the three common sire breeds were included in the model (the “partial” model).

For the full model, all of the main effects, first order interactions and the regression of calf liveweight on day of birth were highly significant ($P<0.01$) sources of variation at each age. For the partial model for birthweight, all of the main effects, sire breed × calf sex and the regression of calf birthweight on day of birth were highly significant sources of variation, dam breed × sire breed approached significance ($P<0.07$) and dam breed × calf sex was not a significant source of variation ($P>0.10$). Most of the main effects, first order interactions and the regression were highly significant sources of variation for the partial model for weaning weights but sire breed and sire breed × calf sex were not ($P>0.10$). All of the main effects, and first order interactions except sire breed × calf sex were significant sources of variation in the partial model for 18 month liveweight. The regression of calf birth day approached significance ($P<0.10$).

3.4.1.2 Birthweights

The least squares estimates for birthweights adjusted for day of birth for calves of each sex in each genotype are shown in Table 2.

Within each dam breed, birthweights of male and of female calves by Tu sires were similar to those of their straightbred contemporaries and consistently lower than those of their B- and Bo-sired contemporaries. The difference between sexes was also consistently less for Tu-sired than for B- and Bo-sired calves. Birthweights of B- and Bo-sired male calves from HS, AX and BX dams were consistently heavier than those of their straightbred contemporaries. The corresponding females were significantly heavier only from HS dams. B-sired crossbred calves were consistently heavier than Bo-sired contemporaries.

There were large, significant differences between birthweights of each of the reciprocal crosses with the greatest difference (9.1kg) between male AX/B reciprocals and the least (2.2kg) between female B/BX reciprocals.

Within B dams, straightbred B males were significantly heavier than males sired by Tu or BX bulls, and significantly lighter than Ch-sired males. Females sired by AX, Ch and HS were significantly heavier than females sired by the other breeds. Ch-sired calves were significantly heavier than all other calves and only Ch- and AX-sired calves were significantly heavier than straightbred B calves.

Over all breeds the heaviest calves were AX×B males and the lightest were B×Tu females. The greatest difference between sexes (5.6kg) was for B sired calves from AX and BX dams.

For straightbreds and crossbreds, the birthweights of calves from the different dam breeds ranked AX>HS>BX>B with the difference between each dam breed being statistically significant ($P<0.01$).

Birthweights (kg) adjusted for AGEPLS for the purebred Bo and Tu males were 31.2±0.61 (10 calves) and 32.6±2.29 (8) respectively and for the corresponding females were 27.6±0.90 (13) and 29.3±1.45 (11) respectively.

3.4.1.3 Heterosis for birthweights

The estimates of heterosis for birthweights of live calves of each sex are shown within dam breed in Table 3. For each dam breed (except B) and sex, heterosis generally exceeded 13% for B-sired calves and 11% for Bo-sired calves and was generally less than 6% for Tu-sired calves. The greatest absolute (7.1kg) and proportionate (20.6%) estimate of heterosis was for B-sired males from AX dams while the lowest estimates were for Tu-sired males from B dams (-2.6kg and -8% respectively).

For the HS and B dams, heterosis for females of each genotype consistently exceeded that of their male contemporaries while for all dam breeds, the heterosis for Tu-sired females consistently exceeded that of Tu-sired males. For male calves born to B dams, most of the estimates of heterosis were significantly negative and for the female calves, generally not significantly different from zero.

3.4.1.4 Weaning weights

Table 4 shows the least squares estimates for weaning weights of calves of each sex in each genotype, the mean weaning weights of the calves by B, Bo and Tu sires from the four dam breeds and the mean weaning weights of calves from the four dam breeds mated to the three common sire breeds.

Over all genotypes, the B×Ch calves were the heaviest (209kg), 38% heavier than the lightest genotype, the HS (151kg). Over the common sire breeds, the progeny of HS dams were significantly lighter than their contemporaries from the other dam breeds. Males from B dams were significantly lighter than males from AX and BX dams but the differences between their female contemporaries were small and non-significant.

B×HS calves were significantly heavier of HS×B calves, but the differences between reciprocal AX/B and between reciprocal BX/B crosses were small and not statistically significant.

Crossbred males by B, Bo and Tu sires were significantly heavier than straightbred males within HS, AX and BX dams but crossbred female contemporaries were consistently heavier only within HS dams.

The ranking of these sire breeds depended on the dam breeds to which they were mated ($P<0.07$). B-sired calves were heavier than Bo- and Tu-sired calves from HS and AX dams but were lighter than Bo- and Tu-sired calves from BX dams and lighter than Tu-sired calves from B dams.

Within B dams, Ch-sired females were significantly heavier than all other females and B- and Bo-sired females were significantly lighter than all other females except BX-sired females. Overall, Ch-sired calves were significantly heavier than all other calves, AX-sired calves were significantly heavier than all but the Ch-sired calves, HS- and Tu-sired calves were of similar weights and heavier than calves sired by BX, Bo and B bulls.

3.4.1.5 Heterosis for weaning weights

Table 5 shows estimates of heterosis for weaning weights of calves of each sex for reciprocal crosses between HS and B, AX and B and BX and B. For calves from B dams, heterosis was significantly highest for HS-sired progeny and significantly lowest for BX-sired progeny of each sex. Heterosis did not differ significantly between sexes within any sire breed. However, this pattern was not repeated for calves by B sires. There was significant positive heterosis for both sexes only within AX dams.

There was significantly more heterosis for B×HS progeny than for HS×B progeny, significantly less heterosis for AX×B females than for AX×B and B×AX males, and significantly more heterosis for BX×B males than for BX×B females or for B×BX males and females.

3.4.1.6 Liveweight at 18 months

Table 6 shows liveweights at 18 months of age for males and females of each genotype. For each genotype, males were consistently heavier than females with the difference varying within genotypes from about 24kg for the BX to about 55kg for the BX×B ($P<0.01$).

Within HS, AX and BX dams, all crossbred males except AX×Tu were significantly heavier than their corresponding straightbred male contemporaries. However, the crossbred females were consistently heavier than their straightbred contemporaries only within HS dams. Within HS and AX dams, B-sired progeny were the heaviest and Tu-sired progeny were the lightest, but within B and BX dams, the differences between the progeny of B, Bo and Tu sires were generally small and not significant.

Within B dams there were significant differences between sire breeds such that Ch>AX>HS>BX, Bo, Tu>B with a 15% (49kg) weight range between the Ch- and B-sired progeny. Although Ch-sired males were heavier than AX-sired males, the difference was small and not significant. Likewise, although the HS-sired males were heavier than Bo-sired males, the difference was not significant.

Over the three common sire breeds, there were significant differences between dam breeds with AX>BX,B> HS and a 6% (22kg) range between the mean liveweights of progeny born to AX and HS dams. Straightbred HS males and females were significantly lighter than all other straightbreds of either sex. B and AX males were of similar weights and each was significantly heavier than the BX males. The difference between B and BX females was small and not significant. Both were lighter than AX females although only the B was significantly so.

3.4.1.7 Heterosis for 18 month weight

Table 7 shows estimates of heterosis for liveweight at 18 months for reciprocal crosses between HS and B, AX and B, and BX and B.

Within sex, heterosis was generally significantly highest for HS/B genotypes and significantly lowest for BX/B genotypes and was significant for all genotypes except BX×B females. Although there were significant differences between reciprocal crosses, there was no consistent pattern as to which genotype had the higher estimate.

3.5 DISCUSSION

3.5.1 Liveweights

3.5.1.1 Birthweights

Within the straightbreds, birthweights were markedly higher for the AX than for the other breeds (Table 2). Kennedy and Chirchir (1971) reported mean values of 31.8, 31.0 and 29.7kg for the unselected HS, AX and BX lines respectively. Since that time (1964-68) mean birthweights have changed by 1.0, 5.1 and 1.9kg for the HS, AX and BX lines respectively. There is strong circumstantial evidence that the change in ranking of the AX and HS lines is the result of selection for different traits in the two lines. From 1984 onwards, all AX sires were selected for high EBV for 550 day liveweight (Mackinnon *et al.*, 1990) while HS sires have been selected mainly for increased resistance to the stresses of the tropics, particularly cattle ticks. Selection for high EBV for growth within the AX line has increased mature size and in consequence, birthweight, relative to the mature size of the HS. In the unselected populations (1970), mature AX cows were 6% heavier than HS contemporaries. In 1995, the AX cows were 18% heavier than the HS cows which in turn were 4% heavier than their 1970 compatriots (see later). Continued selection within the AX line for high EBV for 550 day liveweight can be expected to further increase mature size and its components, including birthweight.

Birthweights of reciprocal crosses were markedly higher when the B was used as the sire breed rather than as the dam breed with the greatest difference occurring between males. Sanders (1995) has reported similar results. The respective differences between males and females were 9.1 and 4.9, 6.6 and 2.2 and 6.2 and 4.9 kg for the B/AX, B/BX and B/HS reciprocal crosses respectively. All values are for live calves only which, because of the disproportionately high mortality of HS×B male calves of disproportionately high birthweight (Frisch and O’Neill, unpublished data) deflates the actual difference between male B/HS reciprocal cross calves. It has long been recognised that growth of the foetus in the uterine environment of *Bos taurus* dams of European origins is superior to that in the uterine environment of Brahman dams (Cartwright, 1973). The differences in favour of the AX line suggest that the uterine environment provided by *Bos taurus* dams of mixed sanga-European origins is at least as favourable for growth of the foetus as that of European dams.

For each of the dam breeds, birthweights of Tu-sired progeny were consistently lower than those of B-sired or Bo-sired progeny and were similar to those of the respective straightbreds. There was also no significant positive heterosis for Tu-sired male calves from any of the dam breeds (Table 3). Relatively low birthweights and lack of heterosis for birthweights identifies the Tu as a potential sire breed for use in those situations where an increase in birthweight is undesirable. The mean differences between birthweights of male and female calves sired by B, Bo and Tu bulls from the four dam breeds were 4.1, 3.8 and 1.4 kg respectively (Table 2). Thus, on the basis of birthweights, it can be expected that there would be no increase in dystocia above that of the straightbreds if Tu sires were used and that the incidence of dystocia for Tu-sired male calves would be significantly lower than the corresponding incidence for B- or Bo-sired males. Cundiff *et al.* (1995) reported that the mean birthweight of Tu-sired calves was lower, for B-sired calves significantly higher and for Bo-sired calves higher but not significantly so, than for reciprocal Hereford-Angus cross calves. The incidence of dystocia corresponded closely with these mean birthweights. Similar rankings for dystocia and birthweights of calves by the same sire breeds mated to Hereford cows were reported by Rowan and Josey (1995).

Within B dams, the only marked increase in birthweights occurred for Ch-sired calves indicating that dystocia arising from high birthweights is unlikely in any of the crosses except perhaps those where European breeds of high mature size are used as sires.

Birthweights of female B×Tu calves were similar to those of corresponding B females. However, the B×Tu males were 7% lighter than B males. Plasse *et al.* (1995) in summarising results from crosses between Brahman and several South American Criollo breeds reported a similar phenomenon for birthweights of the F_1B×Criollo calves. Their birthweights were similar to or up to 8% below those of straightbred B contemporaries. The reasons for this phenomenon and for the similarity of response of the Criollo breeds and the Tuli are unclear. However, the latter may indicate that the sanga and Criollo breeds are more closely related than their recent origins would suggest. The relatively greater difference between birthweights of the reciprocal B/AX crosses compared to the other reciprocal crosses may be associated with the same phenomenon. The Africander component of the AX line when interacting with the B uterine environment may have resulted in a relatively lower birthweight of the F_1B×AX calves than would be predicted from the birthweight of the straightbred AX.

For both sexes, heterosis was consistently greatest for B-sired calves from HS and AX dams and consistently least for Tu-sired calves (Table 3). As a general principle, this indicates that the genetic distance between the Brahman and the two taurine breeds is greater than that between the Bo and the two taurine breeds and that the Tu is more closely related than either of the zebu breeds to the two taurine breeds. Similarly, the lack of significant heterosis for Bo-sired calves from B dams suggests that the B and Bo are relatively closely related. These results are not unexpected given the likely evolutionary history of the breeds (Frisch *et al.*, 1996).

3.5.1.2 Weaning weights

Within each dam breed, weaning weights of crossbreds (with the exception of B×Bo calves) were consistently higher than those of the corresponding straightbreds with the advantage ranging from 1% for Tu-sired calves from AX dams to 16% for B-sired calves from HS dams.

Within HS and AX dams, breed and heterosis effects can be expected to favour B sires over Bo and Tu sires. Weaning weights ranked accordingly (Table 4). However, within BX dams, heterosis effects are likely to have been least for B sires. Weaning weights then favoured Bo- and Tu-sired calves. Within B dams, heterosis effects were zero for B-sired calves and could be expected to be less for Bo- than for Tu-sired calves. In this case, weaning weights favoured Tu-sired calves. Despite the marked morphological differences between the Bo and Tu, the weaning weights of their calves within HS, within AX and within BX dams were essentially the same. However, the weaning weights were over 9% and 4% lighter than those of the Ch-sired and AX-sired calves respectively, differences attributable mainly to the higher mature size of the Ch and AX (discussed later).

Cundiff *et al.* (1995) have reported a similar ranking for weaning weights of B-, Bo- and Tu-sired calves from Hereford and Angus females. However, in the temperate environment of Nebraska, the Hereford-Angus reciprocal cross calves had higher weaning weights than the Bo- or Tu-sired calves and the advantage of the B-sired calves over the Bo- or Tu-sired calves was greater than in the present study. For the HS×B males, the estimate of heterosis for weaning weight was not significantly different from zero which, when the estimate for the reciprocal cross is considered, indicates that realised growth of the HS×B males had been substantially restricted. Within HS dams, male calves of genotypes other than the HS×B were at least 10kg heavier than their female compatriots further suggesting that the weaning weight of the HS×B males is anomalous. This anomaly accounts for the smaller difference between weaning weights of B- and Bo-sired calves in the present study compared to that of Cundiff *et al.* (1995).

The small differences in weights within AX/B reciprocals and within BX/B reciprocals indicate that milk yield of the AX, B and BX is likely to be similar. This is further supported by the similarity of the weaning weights of straightbred AX, B and BX calves, each of which has moderate to high resistance to the stresses of the tropics. Conversely, the 10% advantage of the B×HS over the HS×B for weaning weights indicates that milk yield of the HS is at least 10% less than that of the other breeds. The relatively lower weaning weight of the HS straightbreds reflects not only a lower milk yield of their dams but also their relatively lower resistance to the stresses of the tropics.

Weaning weights for F_2 and F_3 generation AX and BX calves were 9% and 17% higher than those of their HS contemporaries (Kennedy and Chirchir, 1971). Current differences were 21% and 20% respectively (Table 4). Any environmental improvement or deterioration over the interval can be expected to favour the least resistant (HS) and most resistant (BX) breeds respectively. Thus it is likely that most or all of the upward trend within the AX, relative to the BX and HS, is genetic and a direct result of selection of sires for high EBV for 550 day weight.

The AX and BX are both nominally 50% HS and were derived from the same base population as the straightbred HS. Estimates of heterosis for B sires crossed to B dams should therefore be half that of B×HS. However, for both males and females, heterosis for B×BX was significantly lower than half of the B×HS estimate both at weaning and at 18 months. This could occur if selection in the BX had concentrated genes originating from the B. If this was so, estimates of heterosis for the reciprocal crosses should be similar to one another, which they were not. No logical explanation for the lack of conformity with expectation can be offered.

The difference in heterosis between the B×AX [i.e. B×(A×HS)] and the B×HS should depend mainly on the degree of commonality of genes between A and HS. At 18 months, the average heterosis calculated over both sexes of B/HS reciprocals was 40kg. The average heterosis for the AX/B reciprocals of both sexes was 34kg of which nominally 20kg was from the HS. The expected heterosis for an A/B reciprocal is therefore 28kg [(2(34-20)]. This indicates that there is at least 70% (28/40) commonality between the HS and A of the genes that influence heterosis for growth. This is not unexpected given that both are taurine breeds but that each has evolved in a markedly different environment.

Where the B was used as a dam, heterosis for weaning and 18 month weights was closely dependent on the expected degree of relationship between the parental breeds. However, where the B was used as a sire, there were exceptions between breeds, reciprocal crosses and sexes and the general rule could not be applied to accurately predict the heterosis likely to occur between specific crosses. Empirical estimation appears to be the most accurate method.

When the B was used as a dam breed, heterosis within each sex and sire breed was proportionately very similar at weaning and at 18 months indicating that within each genotype, the same genes influenced growth to both ages. However, when the B was used as a sire breed, heterosis increased from zero to 10% between weaning and 18 months for HS×B males and 10% to 13% for HS×B females. This marked change indicates that the cause of the restriction of their growth to weaning, particularly for the males, was removed at weaning.

3.5.1.3 Liveweight at 18 months

Within the two taurine dam breeds (AX and HS), progeny of B sires were heavier than those of Bo or Tu sires, within the "*taurindicus*" dam breed (BX), progeny from the three sire breeds were of similar weights, and within B dams, progeny from Bo and Tu sires were heavier than those from B sires. These interactions are the result of differences between the sire breeds in growth potentials and resistance to environmental stresses, and differences in the amount of heterosis for growth potential and resistance to environmental stresses produced by the various combinations of sire and dam breeds. Thus, provided the sire breeds have similar resistance to environmental stresses and produce similar heterosis when crossed to the same dam breed, comparative growth rates of the resulting crossbred progeny, free from maternal and other environmental effects, are estimates of comparative growth potentials of the sire breeds.

The only estimates of heterosis for Bo and Tu are for birthweights (Table 3). The heterosis produced by each of the zebu breeds, the Bo and B crossed to the HS, was similar. Comparison of growth rates achieved by HS×B and HS×Bo in a stress-free environment should therefore provide an estimate of comparative growth potentials of the B and Bo. Gestation lengths of Bo- and B-sired calves are similar (Cundiff *et al.*, 1995) and the uterus provides a relatively stress free environment. The 5% difference in birthweights of the HS×B and HS×Bo calves (Table 2) should therefore reflect differences in growth potentials of the sire breeds. If it is assumed that heterosis for growth potential maintains the same relativity at 18 months as at birth, the 4% difference in 18 month liveweight of the crossbreds (from Table 6) is mainly a reflection of a difference in growth potential. Liveweights of heifers at 365 days of age presented by Cundiff *et al.* (1995) were 330kg and 314kg for B-sired and Bo-sired progeny respectively, a 5% difference in favour of the B-sired progeny. From these three estimates, growth potential of the Brahman is estimated to be about 5% higher than that of the Boran.

Likewise, the taurine breeds can be ranked for growth potential from the comparative growth rates of their respective crossbred progeny from a common indicine breed, in this case, the Brahman. Each of the crossbred groups inherits high overall resistance from the Brahman (Frisch and O'Neill, unpublished data) and estimates of heterosis for birthweights are similar for each of the taurine sire breeds (Table 3). On this basis and assuming that heterosis for growth potential maintains the same relativity between breeds at 18 months as at birth, growth potential of the Tuli is estimated to be about 3%, 8% and 12% less than that of the HS, AX and Ch respectively.

Although none of the dam breeds provide an appropriate link between indicine and taurine breeds, the BX is likely to be the breed that is least related to both the Bo and the Tu. Using the BX as the reference breed, growth potential of the Tu estimated from 18 month liveweight is about 1% less than that of the Bo. However, small differences in resistance may have affected this estimate. Cundiff et al. (1995) measured growth rates of Bo- and Tu crosses in feedlot where differences in growth are mainly a reflection of differences in growth potentials. At 365 days of age for heifers and 440 days for steers, Tu-sired progeny were about 1% heavier than Bo-sired progeny. On this basis, growth potential of the Tuli is estimated to be about 6% below that of the Brahman. In the present study, liveweights at 18 months for HS×Bo animals (Table 6) were about 7% higher than those of their HS×Tu contemporaries. This difference is mainly a reflection of differences between the Bo and Tu in resistance to some of the stresses of the tropics (Frisch and O'Neill, 1996).

Thus, the ranking for growth potential of the sire breeds used in the present study is estimated to be B>Bo=Tu<HS<AX<Ch. However, of critical importance is whether these differences in growth potential arise from differences in efficiency of growth or from differences in mature size.

Comparative mature sizes of some of the genotypes used in the present study can be estimated from the liveweights of 5-10 year old cows at "Belmont". At weaning in May 1995, the mean liveweights were HS=456, B=479, F_1B×HS=496, AX=537 and F_1B×Ch=567kg. For these genotypes, there is complete correspondence between the ranking of the sire breeds for growth potentials and the ranking of the cows for mature size. Other genotypes used in the study are not yet represented as mature cows. Purebred Bo and Tu cows were reared elsewhere and were not directly comparable to the other cow genotypes. However values for absolute liveweights suggests that the cows of both breeds have lower mature sizes than the HS.

Because of the general relationship between growth potential and mature size, any increase in progeny growth rates that is achieved through the use of sire breeds of high mature size must be balanced against the higher maintenance requirements of those progeny if they enter the breeding cow herd. Mature cow weights (W) are available for F_1B×Ch and F_1B×HS. Comparative maintenance requirements can be calculated from comparative metabolic body weights ($W^{.75}$). On this basis 111 mature F_1B×HS cows could be maintained on the same amount of feed as 100 F_1B×Ch cows. At 18 months, the relativity between the liveweights of F_1B×Ch and F_1B×HS females was 112.5 (from Table 6). The similarity of these estimates suggests that the difference in liveweights at 18 months is a direct reflection of differences in mature size of the HS and Ch, not a difference in efficiency of growth of the crossbreds.

For any given environment (particularly the nutritional environment) and market, there will be a particular size of animal that is most efficient and most profitable. Real improvements in efficiency of production will be achieved, not through increasing mature size beyond the desired optimum, but through increasing the rate at which the optimum size is attained. This is particularly so where the progeny are slaughtered at a constant liveweight and fatness. An estimate of this rate (referred to here as relative growth rate) can be derived from the present data as the proportion of mature cow weight that has been attained by 18 months. From the values for liveweights of heifers at 18 months (Table 6) and for mature cows (previous paragraph), the estimates are HS=58.0%, AX=59.8%, B=64.8%, F_1B×Ch=65.6% and F_1B×HS=67.0%. Thus, although the AX females were significantly heavier than the HS at 18 months and at maturity, their relative growth rate was only marginally higher than that of the HS. This further suggests that selection within the AX for high EBV for 550 day liveweight has been selection for increased mature size, not for increased rate of maturation. A similar result can be expected if the same sort of selection policy was imposed on any "tropically adapted" genotype. When an increase in mature size is undesirable, methods for increasing relative growth rates need to be considered. For the few genotypes for which relative growth rates could be estimated, the highest value was achieved by the F_1B×HS, which at maturity were 9% lighter than the mature AX cows. At 18 months, the F_1B×HS heifers were 3.6% heavier than their AX contemporaries and had attained 67% of their mature size, a marked improvement in relative growth rate compared to that of the AX. The advantage in relative growth rates of the F_1B×HS over that of the B and the HS parents was 2 and 9 percentage units respectively. The principal reason for the larger difference between the HS and F_1B×HS than between the B and F_1B×HS arises from the relatively low resistance of the HS compared to the B or F_1B×HS and the similarity of resistance of the B and F_1B×HS. In the presence of environmental stresses, the HS animals express a lower proportion of their growth potential than do the B or F_1B×HS (Frisch and Vercoe, 1984), i.e. their relative growth rate is lower. The small difference in relative growth rate between the HS and AX suggests that any difference in their resistance to the stresses of the tropics is relatively small compared to the difference between the HS and B or between the AX and B. This is borne out in practice (Frisch and O'Neill, 1996). Improvements in relative growth rate of the less resistant straightbreds, in this case the AX and HS, could therefore be achieved by selecting for increased growth rate that results from increased resistance to the stresses of the tropics rather than selecting for increased growth rate that results from increased mature size.

This is the selection policy implemented in the HS line. There is no evidence that mature size of the HS has changed significantly (see earlier) while overall resistance to the stresses of the tropics has increased markedly (Frisch, 1981; Frisch and O'Neill, 1996). However, their relative growth rate is still well below that of the most resistant breed, the Brahman. The evidence from the F_1B×HS is that the quickest way to increase relative growth rate and hence, productivity, is to cross the HS to an unrelated highly resistant breed. Similar considerations apply to the AX. An additional 5.9% increase in liveweight at 550 days was achieved by crossing the AX to B (Table 6) presumably without the proportionate increase in mature size that has accompanied selection in the AX.

With the exception of the AX×Tu, which was slightly, though not significantly lighter at 18 months than the straightbred AX, all of the crossbreds had higher absolute growth rates than their respective straightbreds. However, to differentiate between breeds on the basis of biological efficiency, it is their ranking on relative growth rates, not on absolute growth rates, that is required. Since estimates of mature size are not yet available for most of the genotypes, direct estimation of their relative growth rates is not possible. The best indirect estimate of mature size available from the current data is birthweight, which is growth achieved in the absence of environmental stresses (i.e. growth potential). The indirect estimate of relative growth rate is then 18 month liveweight / birthweight. In this case, valid comparisons can only be made between genotypes with similar heterosis for birthweights within a given dam breed (Table 3). This implies comparisons between genotypes within the same evolutionary group. Thus, B- and Bo-sired progeny can be compared within AX, within BX and within HS dams, and sanga- and European-sired progeny can each be compared within B dams. However, progeny from B dams cannot be validly compared to progeny from other dam breeds and straightbreds (for which there is no heterosis) cannot be valid compared to crossbreds. For B- and Bo-sired progeny, values for 18 month liveweight/birthweight within AX dams were AX×B=9.4 and AX×Bo=9.3, within BX dams, BX×B=10.1 and BX×Bo=10.1, and within HS dams, HS×B=9.3 and HS×Bo=9.4. The similarity of these estimates within each dam breed supports the hypothesis that despite the significant differences in absolute growth rates to 18 months, there is little or no difference in relative growth rates of the B- or Bo-sired progeny. The relative constancy of these values (within dam breed) has occurred despite the comparisons being between progeny of randomly selected Bo bulls and progeny of B bulls that were selected for high EBV for 550 day liveweight. This strongly indicates that firstly, EBV for 550 day liveweight is a direct reflection of mature size, not of efficiency of growth, and secondly, the differences in absolute growth rates of the B- and Bo-sired progeny are direct reflections of a difference in mature size of the purebred B and Bo, not a reflection of differences in efficiency of growth of the B- or Bo-sired progeny.

The values for the progeny of taurine sires from B dams were B×AX=11.6, B×Tu=11.7, B×HS=11.3 and B×Ch=10.9. Because of the suppression of birthweights of the Tu- and possibly AX-sired calves noted previously, comparisons of relative growth rates are valid only within sanga-sired progeny and within European-sired progeny. Within the sanga sires the difference was <1% and within the European sires about 3.5%. The ranking of the Ch- and HS-sired progeny corresponds with the previous direct estimate and suggests that in the tropics, the high absolute growth rates of Ch-sired progeny may not be matched by equally high relative growth rates.

Nevertheless, at maturity the F_1B×Ch and F_1B×HS females had each multiplied their birthweights 16.1 times (567/35.3 and 469/30.9). The similarity of these estimates combined with the small differences in relative growth rates within each dam breed, again support the hypothesis that the differences in absolute growth rates of the progeny of the taurine sires are direct reflections of differences in mature size of those sire breeds, not reflections of any differences in efficiency of growth of the crossbred progeny.

Thus, as a general principle, differences in absolute growth rates of F_1 crossbreds of equal resistance to environmental stresses and from the same dam breed are mainly a reflection of differences in mature sizes of the sire breeds. Conversely, in stressful environments, differences in absolute growth rates of F_1 crossbreds sired by breeds of the same mature size from the same dam breed, are mainly a reflection of differences in resistance of the sire breeds to the stresses of those environments.

3.5.1.4 Implications for crossbreeding

Absolute growth rates of the progeny of each of the straightbred dams could be significantly increased by crossing to the appropriate breed. At 18 months, the liveweights of the heaviest crossbreds within each dam breed were 21, 9, 5 and 16% above those of the straightbred HS, AX, BX and B respectively. In some cases the increase has arisen mainly from an increase in relative growth rate and therefore efficiency of growth has increased (e.g. HS×B vs. HS), while in others the increase has arisen mainly from an increase in mature size without necessarily improving the efficiency of growth (e.g. B×Ch vs. B). In those situations where high absolute growth rate is the prime consideration and can be supported by the environment, crosses between B and Ch (and in principle, any European breed of high mature size) are unsurpassed. However, in the stressful tropics it is not always desirable to increase mature size and it is not always feasible to use European breed bulls. Where an increase in mature size is undesirable, relative growth rates could be increased by crossing breeds that are unrelated, of similar mature sizes, and at least one of which has high resistance to environmental stresses. In the present study, the difference in mature sizes of the HS, B, Bo and Tu is likely to be less than 6%, and they differ in resistance (Frisch and O'Neill, unpublished data) and degree of relationship (Frisch *et al.*, 1996). Where the existing herd was Brahman, the greatest increases in growth rates could be achieved by crossing to the HS, or by inference, to any British breed of similar mature size to the HS, rather than to a Bo or a Tu. Likewise, using the AX as a sire breed on F_1B×Ch females is less likely to change mature size than if a HS, Tu or Bo was used as the sire breed.

Where lack of resistance precludes the use of straightbred European breed bulls, European x African or straightbred African provide a more resistant alternative. In the case of the AX, significant increases in absolute growth rate (Table 6) and significant heterosis for growth (Table 7) can be expected if they are crossed to B dams. The AX may also have advantages in terms of growth rates of their male progeny and mature sizes of their female progeny relative to those of Ch-sired progeny. At 18 months, the liveweights of B×AX males were only 3kg lighter than those of B×Ch males but the B×AX females were 20kg lighter than the B×Ch females. An even larger difference occurred between liveweights of males and females in the reciprocal cross. The AX is the only sanga-derived synthetic breed in Australia. However, on the basis of the present results, there is obvious scope for using other sanga crossbreds as a vehicle for the incorporation of desirable European genes into Brahman and Brahman crossbred herds in northern Australia and presumably in other tropical regions of the world.

Thus, for example, where the environment was unsuitable for straightbred Angus or Charolais sires, Angus × sanga or Charolais × sanga sires could be used instead. If the sanga was a randomly selected Tuli, 18 month liveweight of the progeny (relative to those in Table

6) of the Ch×Tu sires could be expected to be about 360kg, about 9% higher than that of selected straightbred B sires and similar to that of selected AX sires. Similarly, where a British × African bull was used, compensation for the relatively small size of the Boran and the Tuli could be achieved if desired by using a British breed of relatively high mature size.

In those regions where high resistance is of prime consideration, there is scope for achieving smaller increases in absolute growth rates by crossing between the African and Indian breeds. However, since the increases are relatively small, it is likely that any decision to cross will be governed mainly by the size of any increases in other production variables. These variables are currently being assessed for the genotypes used in the present study.

The Bo and Tu bulls provide a link between breeds in the USA and in Australia. They allow other breeds ranked at USMARC, Clay Center, and elsewhere in the USA to be compared directly with the breeds ranked at the Tropical Beef Centre, Rockhampton and elsewhere in Australia. Similar considerations apply to other locations where the same Bo and Tu bulls or other link bulls have been used. Since all Australian Brahmans have originated from American Brahmans, including from recent importations, it is not surprising that the difference in growth potential between the Bo and B is essentially the same at Clay Center as at Rockhampton. The Brahman could therefore be used as the basis for additional links between locations. Use of this technique between countries allows direct ranking of a far greater range of breeds for a far greater range of characteristics than could be achieved within any single country.

3.6 RESULTS

3.6.1 Resistance to ticks and worms

3.6.1.1 Analysis of variance

Table 8 shows a summary of the analyses of variance for the full and partial models for log transformed mean tick and worm egg counts for all animals over the period before treatment began (6-8 months) and for liveweight gains of all animals over the entire period of treatment (8-18 months).

For the full model, calf genotype was a significant source of variation for liveweight gains, tick counts and worm egg counts (P<0.001). Treatment had a significant effect on liveweight gain of all genotypes (P<0.001) though some breeds responded more to treatment than did others (P<0.001). For tick count and worm egg count, both of which were measured before treatment began, there were no significant effects of treatment, its interaction with sire or dam breed, or the interaction between sire and dam breed. Thus, the random allocation of animals to treatments did not bias the mean resistance of either treatment, or the sire or dam breeds. Calf genotype was a significant source of variation for tick count and for worm egg count.

For the partial model there were significant effects of sire breed and dam breed on liveweight gains, tick counts and worm egg counts. For liveweight gain there were significant interactions between sire and dam breeds, and between treatments and sire and dam breeds.

3.6.1.2 Effect of parasites on gains

Gains of treated and control animals and the response of each breed to treatment to control parasites is shown in Table 9.

3.6.1.2.1 Liveweight gains

Within every breed, the treated animals gained more than the control animals. However, within the B×BX and B×Bo, the difference was not significant. Over all breeds significantly higher gains were achieved by treated B×Ch, and significantly lower gains were achieved by control HS, than by any other breed. Within the straightbreds, gains of the treated AX were significantly higher than the gains of any other treated group. However, in the controls, gains of the B were highest although not significantly higher than those of the control BX. Gains of control B and treated HS were similar to one another.

For treated animals, the HS×Bo, AX×B, B×AX and B×Ch had significantly higher gains than the treated AX, the straightbred with the highest gains. However, all treated crossbreds with the exception of HS×Tu had higher gains, though not always significantly so, than treated straightbred B and HS, the treated straightbreds with the lowest gains. For controls, gains of the HS×B, AX×B, B×HS, B×AX and B×Ch were significantly higher than those of control B, the straightbred control with the highest gains.

Within HS dams, gains of B- and of Bo-sired progeny did not differ significantly within treated or within control groups. Tu-sired progeny gained significantly less than their B- and Bo-sired contemporaries within both treated and control groups. Control HS×Tu gained significantly more than control HS but the corresponding treated animals had similar gains to one another.

Within AX dams, gains of treated progeny of B and of Bo sires were similar to one another and higher than those of treated progeny by AX and Tu sires. The difference between AX- and Bo-sired progeny was not significant. In the controls, gains of progeny ranked B>Bo>AX,Tu with the differences between the sire breeds being significant. Gains of the control progeny of the B sires were similar to those of treated progeny of AX and Tu sires.

Within BX dams, the gains of treated progeny of each of the sire breeds were similar to one another. However, in the control, gains were significantly higher for the progeny of B sires than for the progeny of BX and Tu sires. Gains of control progeny of Bo sires were intermediate between those of B and BX sires and not significantly different to either.

Within B dams, gains of treated progeny ranked Ch>AX>HS,Tu>BX,Bo,B. However, the differences between Tu, Bo and BX were not significant. Gains of the Ch- and AX-sired controls were significantly higher than those of all other controls. In addition, gains of straightbred B controls were significantly lower than those of the HS and BX sired controls.

Over the four dam breeds, gains of treated progeny of B and Bo sires were similar and significantly higher than the gains of treated progeny of Tu sires. Gains of control progeny of B sires were significantly higher than those of Bo sires which in turn were significantly higher than those of Tu sires.

Over the three common sire breeds, gains of treated progeny from AX and HS dams were similar to one another and significantly higher than those of B and BX dams. Differences between gains of control progeny were small although the difference between HS and BX dams was significant.

3.6.1.2.2 Response to treatment

Over all breeds, response to treatment was significantly highest for HS and AX×Tu and significantly lowest for B×BX, B, B×Bo and BX×B. Over all dam breeds, response to treatment was significantly least for B-sired progeny and significantly greatest for Tu-sired progeny. These sire differences were generally consistent within each of the dam breeds. Over the common sire breeds, responses were significantly least for the progeny of B dams and significantly greatest for the progeny of AX dams.

Responses of B- and Bo-sired progeny from each dam breed were consistently significantly lower than those of their straightbred contemporaries. However, responses of Tu-sired crossbreds, with the exception of HS×Tu, were consistently significantly higher than those of the corresponding straightbreds. Within the straightbreds, responses were significantly highest for HS, significantly lowest for B and significantly higher for AX than for BX.

The difference in response of the genotypes within reciprocal crosses were significant for B/AX and B/BX but the differences were small and not consistently in favour of either the B sire or the B dam.

Over the four dam breeds, the ranking of responses of B-sired progeny corresponded with the ranking of responses of the straightbreds. With a single exception in each case, the same was true within the Bo and Tu sires. The response of B×Ch was significantly greater than that of all other progeny from B dams and there was no significant difference between the response of B×AX and B×Tu progeny.

Table 10 shows estimates of heterosis for liveweight gains over the treatment period for treated and control animals of each reciprocal cross genotype. For HS/B and AX/B genotypes there was significant positive heterosis for gains of both treatments but in the B/BX genotypes, heterosis was significant only for gains of control animals.

3.6.1.3 Tick counts

Table 11 shows the log and the arithmetic mean tick counts for each genotype, the dam breed means calculated over the three common sire breeds, and the sire breed means calculated over the four dam breeds.

Over all genotypes, tick counts were significantly higher for straightbred AX and HS than for all other genotypes except AX×Tu. Within each dam breed, tick counts for B- and for Bo-sired progeny were not significantly different from one another and were consistently significantly lower than for Tu-sired progeny and for the respective straightbred progeny (other than B). Tu-sired progeny had significantly lower counts than the corresponding respective straightbreds from HS dams, similar counts to those for straigthtbred AX and BX, and significantly higher counts to those for straightbred B. Within the straightbreds, tick counts were significantly higher for AX and HS than for the B and BX and significantly lowest for B.

Within B dams, tick counts for Ch-sired progeny were significantly higher than those of all other progeny except Tu-sired progeny. Tick counts of progeny of HS and Tu sires were significantly higher than those of straightbred B. The tick counts of progeny sired by AX, BX HS and Bo bulls were not significantly different from one another.

Over the three common sire breeds, the tick counts of the progeny of AX dams were significantly higher than those of the progeny of B and BX dams. Over the four dam breeds, tick counts of B- and of Bo-sired progeny were similar and significantly lower than those of Tu-sired progeny.

Table 12 shows heterosis for mean tick counts for reciprocal cross genotypes over the period before treatment to control of ticks began.

There was generally significant positive heterosis for tick counts for all genotypes. Heterosis was generally significantly higher for HS/B and AX/B genotypes than for BX/B genotype. The exception in both cases was that heterosis for the B×HS was significantly lower than that of AX/B genotypes and did not differ significantly from that of the BX/B genotypes.

3.6.1.4 Worm egg counts

Table 13 shows the log and arithmetic mean worm egg counts for each genotype, the dam breed means calculated over the common sire breeds and the sire breed means calculated over the four dam breeds.

Over all genotypes, worm egg counts were highest for HS×Tu and lowest for B. However, the differences between worm egg counts of Tu-sired progeny from HS, AX and BX dams, Bo-sired progeny from HS and AX dams, and straightbred HS, AX and BX were not significant. Likewise, worm egg counts of the B did not differ significantly from those of HS×B, B×HS, B×BX, B×Ch and B×Bo. Within each dam breed and over the four dam breeds, worm egg counts were consistently lowest for B-sired progeny, intermediate for Bo-sired progeny and generally highest for Tu-sired progeny. The exception was that within B dams, the worm egg counts of AX-sired progeny were higher, though not significantly so, than those of Tu-sired progeny.

Within the straightbreds, worm egg counts were significantly lower for B than for the other straightbreds. Within B dams, worm egg counts of AX- and of Tu-sired progeny were significantly higher than those of straightbred B, B×BX and B×HS, and higher, but not significantly so, than the progeny of the other sire breeds. The differences between progeny sired by HS, BX, B, Bo and Ch were small and not significant.

Over the common sire breeds, worm egg counts of progeny of B dams were significantly lower than those of the other dam breeds while the differences between the progeny of AX and BX dams approached significance ($P<0.08$). Within each reciprocal cross the difference between worm egg counts was small and not significant.

Table 14 shows estimates of heterosis for reciprocal cross genotypes for worm egg counts recorded on all animals before treatment began.

There was significant positive heterosis of similar magnitude for both B/HS reciprocals but no significant heterosis for either B/AX reciprocals. Although there was positive heterosis for both B/BX reciprocals, only that for B×BX was significantly different from zero.

3.7 DISCUSSION

3.7.1 Liveweight gains

In the treated group, differences in liveweight gains of the different genotypes are mainly a reflection of differences in growth potentials of the parental breeds used to produce each cross and the amount of heterosis generated by each cross. Estimates of these variables are presented elsewhere (Frisch and O'Neill, 1996). In the present study it is the effect that ticks and worms have on the expression of these variables and the consequent changes in the ranking of the genotypes for growth rates that are being considered.

Despite the relatively low burdens of ticks and worms experienced throughout the study, the gains of the controls of every genotype were depressed. Across breeds, the depression in gains was closely related to the numbers of parasites carried by any given genotype. Across breeds the correlation between worm egg counts and response to treatment was 0.78 ($P<0.01$). The corresponding value for tick counts and response to treatment was 0.61 ($P<0.01$). Thus, the combined effect of both parasites effectively accounted for all of the variation between breeds in response to treatment, with worms accounting for about twice as much variation as did ticks. However, neither the total parasite burdens nor the relative burdens of ticks and worms can be expected to remain constant either between years or regions. The comparative rankings of the breeds for growth rates can be expected to change accordingly. The extreme case is demonstrated by the B and HS straightbreds. As treateds, there was very little difference in their growth rates, but as controls, growth rate of the B exceeded that of the HS by about 26%. Likewise, as tick challenge increased, growth rates of the B- and Bo-sired progeny could be expected to maintain the same relativity but as worm challenge increased, the difference in gains in favour of B-sired progeny could be expected to increase. The effects of parasites shown in Table 9 must therefore be interpreted, not as absolute values, but as comparative values for the different genotypes exposed to low to moderate burdens of both ticks and worms. At higher levels of challenge, correspondingly greater responses to treatment can be expected.

In a previous study (Frisch and Vercoe, 1984) responses of B, BX and HS to treatment to control ticks and worms were about 4 times those of the same breeds used in the present study. Under conditions where parasite loads were 4 times those experienced in the present study, it can be expected that there would be an upward shift in the ranking of the more resistant breeds relative to the less resistant breeds. Predicted gains for control B×Bo, B and B×HS would then be 115, 110 and 105kg respectively compared to 97, 91 and 77kg for the B×AX, B×Tu and B×Ch respectively. In general, at higher levels of parasite challenge, the B could be expected to have markedly higher gains than any other straightbred, and B-sired progeny from dam breeds of lower resistance than B dams, could generally be expected to have higher growth rates than Bo- or Tu-sired progeny. All crossbreds from HS dams could be expected to have higher growth rates than straightbred HS. Likewise, B- and Bo-sired crossbreds from AX, BX and B dams could be expected to have higher growth rates than the corresponding straightbreds. However, Tu-sired progeny from AX, BX and B dams could be expected to have lower growth rates than the corresponding straightbreds.

The responses of the HS×Tu and B×BX are anomalous. Consider the HS×Tu. From the comparisons of tick counts and worm egg counts of B-, Bo- and Tu-sired progeny from HS and AX dams, responses of the HS×Tu should be similar to that of the AX×Tu. If it is assumed that the heterosis for response is directly proportional to the breed contribution to the cross (which, as explained later, it is likely to be), the response of the HS×Tu can be predicted from the response of the BX×Tu. The BX is nominally ½B½HS. Thus, the predicted response of a BX×Tu = ½[(B×Tu)+(HS×Tu)]. From this, the predicted response of HS×Tu = 2(BX×Tu)-(B×Tu) = 26.7kg. The response of HS×B and AX×B, and HS×Bo and AX×Bo, differ by only 1kg. The estimate of 26.7kg for the HS×Tu is consistent with the estimate for the AXxTu (26.5kg). It also corresponds closely with the tick and worm egg counts of the HS×Tu compared to Bo- and B-sired contemporaries. Using the same method, the predicted response of the B×BX = 7.3kg.

If these "predicted" values of responses for the HS×Tu and B×BX are used, the correlation across breeds between worm egg counts and liveweight responses is 0.88 ($P<0.01$) and between tick counts and liveweight responses is 0.65 ($P<0.01$). Regardless of which value is used, the high correlation demonstrates that across breeds, worm egg counts are a good, though not perfect, measure of comparative resistance to worms.

Although the gains of the controls of all genotypes were depressed, the response to treatment of those genotypes with the highest resistance was insufficient to warrant treatment. For the B, the response was equivalent to 6.7kg/year or about AU$7/animal/year (1996 prices) extra liveweight value for the treated animals. Any cost of treatment to control parasites would therefore have to be below $7 annually to break even. For the HS, the genotype with the greatest response, the corresponding value was $36. Likewise, at 4 times the present parasite challenge, the break-even costs would be four times the present values. Thus, as the potential for parasite challenge increases, the benefit from using genotypes of high resistance also increases.

Heterosis for liveweight gains (Table 10) arises from heterosis for growth potential and for resistance to environmental stresses (Frisch, 1987). Growth potential of the F_1 approaches that of the parent with the higher growth potential while resistance approaches that of the parent with the higher resistance. The consistently higher heterosis for gains of the controls is a reflection of the high levels of heterosis for resistance to ticks and worms. Environmental stresses other than ticks and worms also had differential effects on growth rates of F_1's and straightbreds. This accounts for the relatively high heterosis for the treated animals. The growth rate advantage of the F_1 over the less resistant parent can be expected to increase as parasite challenge increases because of the higher resistance of the F_1. However, it was only for crosses between breeds of similar, high resistance that the F_1 also maintained a growth rate advantage, albeit small, over the more resistant parent. The resistance of the various F_1's was consistently lower than or similar to that of the more resistant parent suggesting that the same genes control resistance in each of the breeds. Any additional advantage arising from crossing resistant breeds must therefore come from effects on components of production other than growth. These are currently being assessed.

3.7.2 Ticks

The mean 3-weekly tick count averaged over all controls over the entire treatment period was 4.3±1.0 ticks/animal/day. This low level of infestation presumably resulted from conditions that were unfavourable for the establishment of higher burdens. However, despite the low level of infestation, liveweight gains over the corresponding 10 month period were significantly depressed by ticks ($r=-0.46$, $P<0.001$). The regression, $b=-0.42\pm0.113$ ($P<0.001$) equates to a depression of liveweight gain of about 0.5kg/tick/year regardless of genotype. The total effect of ticks on liveweight gains of any breed is therefore a function of the number of ticks carried by that breed. Accordingly, breeds have been ranked for resistance on the basis of tick counts.

The straightbreds can be compared directly and ranked B>BX>HS,AX in order of decreasing resistance. However, the Bo, Tu and Ch can only be ranked from tick counts of their crossbred progeny.

Because of possible differences in heterosis for tick resistance between different crosses (Table 12), sire breeds should be compared for resistance only within crosses likely to generate the same degree of heterosis. Thus, the two indicine breeds, the B and Bo, can be compared within HS dams, the two sanga breeds, the AX and Tu, can be compared within B dams, the two European taurine breeds, the HS and Ch, can be compared within B dams, and the Bo and BX can be compared within B dams. There is no entirely satisfactory dam breed to use as the basis for comparing Bo and Tu. However, the BX is the breed likely to be least related to both the Bo and Tu and it is therefore used. More detailed reasons for using these comparisons are presented elsewhere (Frisch and O’Neill, 1996).

On the basis of tick counts for HS×B and HS×Bo, the B and Bo have similar resistance to ticks. This hypothesis is supported by the similarity of tick counts for the progeny of both sire breeds irrespective of dam breed. Comparisons of tick counts of B×AX and B×Tu suggest that the AX may have slightly higher resistance than the Tu. However, comparisons of tick counts of AX and AX×Tu suggest that the AX and Tu have similar resistance to ticks. This is further supported by the similarity of liveweight responses of the B×AX and B×Tu. Comparisons of tick counts of B×HS and B×Ch indicate that the HS has higher resistance than the Ch. This is supported by the difference in response to treatment in favour of the B×HS, which had similar worm egg counts to the B×Ch. Comparisons of tick counts for BX×Bo and BX×Tu suggest that the Tu has lower resistance to ticks than does the Bo. This is supported by the consistently higher tick counts for Tu-sired progeny compared to Bo-sired progeny regardless of dam breed.

On the basis of these comparisons, the breeds have been ranked in order of decreasing resistance to ticks as B,Bo>BX>AX,HS,Tu>Ch.

It has long been recognised that the B has high resistance, the HS has low resistance, and the AX and BX did not differ significantly in resistance (Seifert, 1971; Turner and Short, 1972). Turner and Short (1972) reported that when their F_2 and F_3 generations of AX and BX carried about 40 ticks/animal, their HS contemporaries carried about 150 ticks per animal. It is likely that the change in relativity of the HS, AX and BX lines over time is the result of the different selection policies used in the different lines. The small change in resistance of the AX relative to the BX is presumably related to the absence of direct selection for tick resistance in the AX line. The large change in resistance of the HS line is associated mainly with an increase in the frequency of a major gene for tick resistance (Frisch, 1994; Kerr *et al.*, 1994). HS animals, particularly those that are carriers of the major gene, are therefore not typical Hereford×Shorthorns and are not typical of other breeds of European origins. The comparatively high resistance of the F_1B×HS in the present study is therefore unlikely to be repeated if lowly resistant Hereford×Shorthorns (or any other lowly resistant breed of European origins) were crossed to B dams. An indicator of the likely result is provided by the tick count for the F_1B×Ch which was significantly higher than that of the F_1B×HS and over twice that of the straightbred B.

In regions where the tick challenge was higher than that experienced in the present study, it could be expected that the progeny of Ch sires (and by inference, any lowly resistant sire breed) would be significantly more affected by ticks than would straightbred B. The factors that affect resistance have a multiplicative rather than an additive effect on tick counts (Wharton et al., 1970). Thus, from values for liveweight gains of treated animals (Table 9), tick loads (Table 11) and the effect of ticks on liveweight gain (-0.5kg/tick/year), it is possible to calculate the tick load on B controls at which annual liveweight gains of contemporary B×Ch controls can be expected to be the same as that of the control B. In the absence of worms, this value was 50 ticks/day. Thus, the straightbred B would have to carry a consistent tick load of >50 ticks/day (and no worms) before their gain exceeded that of the B×Ch. The corresponding values for other genotypes derived from B dams were B×BX=15, B×Tu=23, B×HS=38, B×Bo=42 and B×AX=102 ticks/day. At low to moderate levels of tick infestation (<20 ticks/day on B controls), liveweight gains of the crossbreds will exceed those of the B. Values for any other genotype could be calculated and their relative suitabilities assessed for particular regions. These values can be expected to apply after the breeds have acquired high resistance to worms and growth was no longer affected by them. However, up to that time, the combined effects of ticks and worms must be considered.

Regardless of the resistance of the dam breed, tick counts for each of the B-sired crosses was similar to that of the B and never exceeded that of the more resistant parent. This suggests that resistance is controlled entirely, or almost entirely, by dominant genes, that all of these dominant genes were present in the B, and that there were no additional dominant genes for tick resistance in the other parent. For these hypotheses to be correct, all F_1 B crossbreds should have the same resistance as the B parent. The reason they did not is uncertain. Nor is it clear why there was lack of consistency in the heterosis expressed by the different reciprocal crosses (Table 12). However, what is certain is that the progeny of lowly resistant sire breeds and B or other indicine dams (e.g. Lemos *et al.,* 1985) will have markedly lower resistance than the straightbred indicine breed and resistance will be maintained at high levels only if sire breeds of high resistance are used.

The BX is the product of at least 8 generations of *inter se* matings of an original HS×B cross. The tick count of the current F_1 HSxB was 17.4 ticks (Table 11). The present tick count of the BX was 28.8 ticks, which corresponds with the mid-parent mean of the current HS and B (28.7 ticks). This suggests that all of the F_1 heterosis for tick resistance has been lost in subsequent generations. However, this conclusion is biased by the effects of selection for high tick resistance in both the HS and the BX. These data are therefore unsuitable for determining the extent of retention of heterosis for tick resistance.

The BX is nominally ½B½HS. If it is assumed that heterosis is directly proportional to the breed contribution, the average heterosis for tick count for a BX×Tu should be ½[(B×Tu)+(HS×Tu)]. The expected tick count for a BX×Tu is then ½(26.5+28.4)=27.5 ticks. The observed value was 27.1 ticks. Using the same reasoning for a BX×Bo, the predicted value for tick count is 16.5. The observed value was 17.6. For the B×BX, the predicted value is 19.2 ticks, compared to an observed value of 19.8 ticks. For the BXxB, the predicted and observed values were 16.1 and 15.5 respectively. The close correspondence between observed and predicted values supports the hypothesis that the same amount of heterosis is produced by the same proportion of B and Bo genes, and HS and Bo genes regardless of the source of those B and HS genes. Similarly for the B and Tu, and HS and

Tu. These breeds are of very diverse origins which suggests that as a general principle, F_1 heterosis for tick count is directly proportional to the breed contribution to the cross regardless of which breeds are crossed. Thus, predicted tick count for an (F_1 B×HS)×Tu and an (F_1 B×HS)×Bo will be the same as that for a BX×Tu and a BX×Bo respectively. Likewise, tick count for a B×A predicted from B×AX is 13.8 ticks suggesting that the B and Africander (A) have similar tick resistance. This hypothesis agrees with the results of direct comparisons of the two breeds (Frisch and O'Neill, unpublished). Thus, comparative tick resistance of other crosses not produced in the present study may be predicted and from these results their suitability for particular regions assessed. The possibility that maternal effects may sometimes be important should not be ignored.

3.7.3 Worms

Unlike the situation for ticks where their effect on growth was the same irrespective of breed, the effect of worm egg counts on growth was not consistent across breeds. Comparisons of the worm egg counts of the straightbreds indicate that the B had the highest resistance to worms and that any differences in resistance between the HS, AX and BX were small. However, the within breed regressions of liveweight at the start of the treatment and mean worm egg count were -0.015±0.005 and -0.021±0.008kg/egg for the HS and AX respectively but 0.000±0.009 and 0.015±0.008kg/egg for the BX and B respectively. Thus, the effect of a similar worm burden will be greatest for HS and AX and least for B. It has long been recognised that equal worm egg counts are not always reflected in equal effects on liveweight gains. Turner and Short (1972) reported that the BX had similar worm egg counts to the HS and AX, but markedly lower liveweight responses to treatment. Likewise, B animals have failed to show liveweight responses to drenching when worm egg counts have been low (Frisch and Vercoe, 1984; Frisch, 1987). Thus, at least where B animals are involved, the ranking of breeds for resistance must consider both worm egg counts and responses to treatment. On this basis, the ranking of the straightbreds for resistance to worms in order of decreasing resistance is B>BX>AX,HS. This ranking is consistent with that established previously (Turner and Short, 1972; Frisch and Vercoe, 1984; Frisch, 1987).

The same rationale as that used to rank the breeds for tick resistance can be used to rank them for worm resistance. On the basis of comparisons of worm egg counts and liveweight gain responses for the HS×B and HS×Bo, the B has higher resistance to worms than does the Bo. This hypothesis is supported by the consistent difference in both worm egg count and response to treatment in favour of the B-sired progeny irrespective of dam breed. Similar comparisons of B×AX and B×Tu indicate that the AX and Tu have similar resistance to worms. This hypothesis is supported by the comparisons of worm egg counts and responses to treatment of the AX and AX×Tu. Comparisons of worm egg counts of the B×HS and B×Ch suggest that the HS and Ch have similar resistance to worms. The greater response of the B×Ch to treatment compared to the B×HS is likely to have arisen from differences in tick resistance (Table 4). Comparisons of BX×Bo and BX×Tu indicate that the Bo has higher resistance to worms than does the Tu. Again, this is supported by the consistently higher worm egg counts and generally higher responses to treatment for Tu-sired compared to Bo-sired progeny.

On the basis of these comparisons, the breeds are ranked in order of decreasing resistance to worms as B>Bo,BX>Ch,HS,AX,Tu. However, because of differences between breeds in the relationship between worm egg counts and growth rates it was not possible to use worm egg counts to quantify the differences in resistance of the different breeds.

If it is assumed that as for tick counts, heterosis for worm egg counts is directly proportional to the breed contribution in the cross, mean worm egg counts for a BX×Bo should be ½[(B×Bo)+(HS×Bo)]. The predicted worm egg count is then ½(260+381)=321. The observed value was 317 (Table 13). Using the same reasoning for the BX×Tu, the predicted value for worm egg count is 427. The observed value was 421. For the B×BX, the predicted value is 238 compared to an observed value of 240. The complete correspondence between predicted and observed values indicates that a similar amount of heterosis is produced by the same proportion of B and Bo genes, and HS and Bo genes, regardless of the source of those B and HS genes. Similarly for the B and Tu, and HS and Tu. This suggests that, as for tick resistance, F_1 heterosis for worm egg count is directly proportional to the breed contribution to the cross regardless of which breeds are crossed. As for tick count, the predicted worm egg count for an (F_1 B×HS)×Bo and an (F_1 B×HS)×Tu will then be the same as that for a BX×Bo and BX×Tu respectively. Again however, the possibility that maternal effects may be important should not be ignored.

The mean worm egg count for the BX was similar to the mid parent mean of the B and HS (338 eggs). This suggests that all of the F_1 heterosis for worm egg count is lost in subsequent generations, a conclusion reached previously (Frisch, 1987). If this holds for the AX (nominally ½A½HS), the predicted egg count for the Africander (A) is 401 eggs suggesting that the Africander is far less resistance to worms than is the B. This hypothesis agrees with results of direct comparisons of the two breeds (Frisch and O'Neill, unpublished). Worm egg counts can also be predicted for A×Tu, A×Bo and A×B. In this way, worm egg counts for multiple crosses between breeds of African, European and Indian origins could be predicted. Given the high correlation between worm egg counts and responses to treatment across breeds, the resistance of multibreed crosses to the species of worms present in the current study should then be predictable with a high degree of accuracy.

In the B-sired crosses, tick counts, and therefore resistance to ticks, was likely to be controlled mainly by dominant genes. The same effect was again evident for worm egg count of the HS×B, less so for AX×B and BX×B. However, the responses to treatment of the AX×B and BX×B suggest that although there may not have been significant heterosis for worm egg count, there was substantial heterosis for the effect of worms, again suggesting that the factors that control resistance to worms are controlled mainly by dominant genes. As for tick counts, the worm egg count of the F_1 was never less than that of the B.

Although A and Tu have other attributes that are advantageous in the tropics and subtropics, they have the disadvantage of low resistance, compared to the B, to the worm species present in the current study. Any advantages associated with their use either as crossbreds or straightbreds, can therefore be expected to decrease as challenge from worms increases. For crossbreeding to reach its full potential in areas of high worm challenge, there is a need to have access to other tropically adapted breeds that not only have high worm resistance but are also unrelated to the Indian zebus. There is a need to determine whether such breeds exist.

3.7.4 Implications for crossbreeding

None of the breeds in the present study was outstanding for both high resistance and high growth rates at all levels of challenge from ticks and worms. None of the breeds could equal the B for resistance to both ticks and worms. However, at low levels of parasite challenge, the B could not equal the growth rates of some of the less resistant crossbreds. While the Bo could match the B for resistance to ticks, it had lower resistance to worms. There is therefore scope for improving productivity through appropriately combining breeds for particular environments, defined in the present study by the level of challenge from ticks and worms. In regions of high challenge from both ticks and worms and in the absence of other equally resistant breeds, the B (and by inference, other Indian zebus) is therefore likely to remain as an essential component of any crossbreeding program. Where the B is already the major breed, potentially the greatest increase in absolute growth rates could be obtained by crossing to Ch (or by inference, to any other large breed of European origins). However, because of comparative lack of resistance of the B×Ch, the cross has limited application in regions of high challenge from ticks and worms unless those parasites are controlled by chemical or other means. In such regions, the AX, HS and Tu offer real advantages over the Ch both from the standpoint of ease of use of bulls and in terms of efficiency of growth of their F_1 progeny. At the highest levels of parasite challenge, only B×BX and B×Bo could be expected to match the growth rates of the straightbred B. However, any advantage in growth rate is likely to be small and, as for any F_1 , the magnitude of advantages in other components of production will therefore have a major influence on any decisions relating to crossbreeding.

The comparatively high resistance but low growth potential of the B×Bo compared to the B×Ch suggests that in regions of moderate to high tick challenge, use of F_1 Ch×Bo bulls over B cows offers potential advantages over the use of a straightbred Ch (or other breeds of European origins). Resistance of F_1 Ch×Bo bulls to the stresses of the tropics can be expected to be similar to that of F_1 B×Ch bulls and at levels of parasite challenge up to twice that experienced in the present study, growth rates of the 3-way cross progeny can be expected to exceed that of straightbred B. In regions where parasite challenge was similar to that experienced in the present study, there is no real advantage in terms of absolute growth rates in using Ch rather than AX bulls over B cows. Rather, these are advantages in using AX bulls because of their higher resistance to ticks.

In terms of increasing resistance to parasites and growth rates in the presence of these parasites, there are potential advantages to be gained by crossing AX, BX or HS females (or females of similar genotypes) to other, more resistant breeds. At low levels of parasite challenge, use of a B or Bo sire will produce a similar effect regardless of which dam breed is used, though since the B has larger mature size than the Bo, differences in absolute growth rates of the B- and Bo-sired progeny can be expected (see Frisch and O’Neill, 1996). The improvement in growth of the AX that could be achieved by treatment to control ticks and worms could also be achieved by crossing to B, without the need to implement chemical control measures. The crossbreeding approach represents a simple, low cost, sustainable strategy for improving productivity. The crossbreeding option offers even greater improvements in productivity where the dam breed was HS. Tu-sired progeny would match B- and Bo-sired progeny only if crossed to breeds of at least similar resistance to the BX. As challenge from parasites increases, the comparative advantage of using B sires increases, and of using Tu sires decreases, relative to the Bo.

At the low to moderate levels of parasite challenge experienced in the present study, use of any of the B crossbreds in place of the B could be expected to increase growth rates without the need to use chemical control measures. However, as the level of parasite challenge increased, efficiency of growth of the less resistant crossbreds, particularly the B×Ch, could be expected to decrease more rapidly than that of the B×Bo or the more resistant crossbreds.

In the present study, only straightbreds and F_1's have been considered. However, formation of the F_1 is only the first step in any systematic crossbreeding program and the question of which breeds are best suited for the production of subsequent generations must be addressed. Consider the case where the F_1 was an F_1 B×HS. While back-crossing to the B (ie. BX×B) will maintain high resistance and slightly increase growth rates, effects on reproduction, meat quality and other components of production may preclude its use. Back-crossing to the HS (or other breeds of European origins) will reduce resistance and growth rates (independent of maternal effects) though may produce advantages in other components of production. Crossing to an AX, Bo or Tu or combinations of these breeds (e.g. AX×Bo) or combinations with other breeds of European origins (e.g. Ch×Bo) can be expected to reduce resistance and hence efficiency of growth and absolute growth rate (independent of maternal effects) to a lesser extent than back-crossing to the HS (or other breeds of European origins).

The use of crossbred bulls has merit only if those crossbreds are also more productive than the straightbreds from which they were formed. The data presented here do not allow this assessment to be made. Crosses may be compared only on the basis of resistance to ticks and worms and its likely impact on growth. In the case of AX×Bo, there are advantages to be gained in terms of both increased resistance to ticks and increased growth irrespective of the level of challenge from ticks and worms. For an AX×Tu, there is likely to be a small decrease in both resistance and growth rates irrespective of the level of challenge from ticks and worms. The merits of other crosses in terms of resistance to ticks and worms and growth rates at various levels of challenge could be predicted by reference to the relevant tables.

While systematic crossbreeding between the more resistant breeds could be used to maintain moderate to high levels of resistance and growth in the presence of ticks and worms, it is not always a feasible system to use. The formation of multibreed synthetics from these same breeds offers a potential solution. However, whichever breeds are used to form the synthetic, it can be expected that, as for the BX, at least half of the F_1 heterosis for resistance will be lost on interbreeding and growth in the presence of ticks and worms can be expected to decline relative to the F_1. The significance of any loss cannot be estimated without knowing the total productivity of the different breed types. This is being measured. However, from the values for the AX and BX, it can be expected that losses in resistance, and hence efficiency of growth in the presence of parasite challenge, can be expected to be significant for any multibreed synthetic based on combinations of "resistant" and "susceptible" breeds. Those losses could be avoided if only resistant breeds were used. While the AX, HS, Tu and Bo have high resistance relative to the Ch, they are far less resistant than the B for resistance to one or both parasites. Identification of breeds that have high resistance to ticks and worms and are unrelated to B is another step towards improving productivity in those regions where tick and worm challenge are high. This task remains to be undertaken.

3.8 Meat and carcase qualities

This section of the study is far from complete. To avoid confusion and allow the section to be extracted as a single entity, it has been included as appendix 3.15.3.

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3.11 Tables

Table 1 Summary of analyses of variance for liveweights at birth, weaning and 18 months (a) over all calf genotypes and (b) within common sire breeds

		Birthweights		Weaning weights		18 months weights	
	Source of variance	DF	'F'	DF	'F'	DF	'F'
(a) all calf genotypes	Year	2	16.2^{***}	2	6.6^{***}	2	156.1^{***}
	Calf genotype	18	10.5^{***}	18	12.6^{***}	18	37.8^{***}
	Calf sex	1	34.6^{***}	1	49.7^{***}	1	389.0^{***}
	Dam AGEPLS	4	12.4^{***}	4	19.5^{***}	4	5.0^{***}
	Year × Genotype	36	2.3^{***}	36	2.2^{***}	36	2.1^{***}
	Genotype × Sex	18	2.3^{**}	18	2.0^{**}	18	2.1^{**}
	Regression calf birth day	1	15.5^{***}		109.7^{***}		12.7^{***}
	Residual	1094	---	1050	---	1021	---
(b) common sire and dam breeds	Year	2	29.8^{***}	2	10.3^{***}	2	126.8^{***}
	Dam breed	3	36.8^{***}	3	8.0^{**}	3	17.5^{***}
	Sire breed	2	12.6^{**}	2	0.5	2	16.3^{***}
	Calf sex	1	75.2^{***}	1	89.8^{***}	1	348.5^{***}
	Dam AGEPLS	4	6.1^{***}	4	11.6^{***}	4	2.7^{*}
	Dam breed × sire breed	6	$2.0^{\dagger}$	6	4.0^{***}	6	11.1^{***}
	Dam breed × calf sex	3	1.7	3	4.4^{**}	3	3.2^{*}
	Sire breed × calf sex	2	6.0^{**}	2	0.4	2	1.8
	Regression calf birth day	1	14.5^{***}		648^{***}		3.6†
	Residual	701	---	678	---	650	---

† P<0.07
* P<0.05
** P<0.01
*** P<0.001

Table 2 Least squares estimates of birthweights (means±SEM) for live calves of each sex in each genotype

		Sire breeds							
Dam breed	Sex	HS*	AX	BX	B	Bo	Tu	Ch	Dam breed mean[a]
HS	M	34.5±0.68 (44)(c)	---	---	37.5±0.92 (24)	36.8±1.14 (15)	33.8±0.95 (21)	---	36.1±0.61 (60)
	F	31.1±0.63 (52)	---	---	35.8±0.73 (38)	33.4±0.98 (20)	31.9±0.85 (28)	---	33.9±0.54 (86)
	Breed mean	32.8±0.47	---	---	36.7±0.61	35.1±0.76	32.9±0.65	---	34.9±0.43
AX	M	---	36.9±0.78 (32)	---	41.6±0.73 (36)	39.4±0.93 (22)	35.5±0.76 (34)	---	38.9±0.51 (92)
	F	---	35.2±0.82 (31)	---	36.0±0.73 (37)	34.4±0.84 (29)	34.7±0.76 (36)	---	34.9±0.49 (102)
	Breed mean	---	36.1±0.57	---	38.8±0.53	36.9±0.63	35.1±0.55	---	36.9±0.38
BX	M	---	---	32.7±0.78 (32)	36.6±0.85 (26)	35.6±0.92 (25)	32.4±0.87 (26)	---	34.9±0.54 (77)
	F	---	---	30.5±0.78 (32)	31.0±0.86 (26)	32.2±0.84 (27)	30.1±0.83 (28)	---	31.1±0.52 (81)
	Breed mean	---	---	31.6±0.55	33.8±0.60	33.9±0.63	31.2±0.61	---	33.0±0.39
B	M	31.3±0.92 (26)	32.5±0.75 (35)	30.2±0.78 (32)	32.0±0.53 (72)	31.7±1.25 (17)	29.7±0.75 (34)	34.6±0.98 (22)	31.1±0.49 (123)
	F	30.9±0.74 (37)	31.1±0.80 (30)	28.8±0.97 (20)	28.3±0.54 (72)	29.0±1.06 (18)	28.5±1.21 (15)	35.3±0.90 (24)	28.6±0.54 (105)
	Breed mean	31.0±0.62	31.9±0.56	29.5±0.63	30.1±0.39	30.3±0.86	29.1±0.72	35.0±0.68	29.9±0.40
Regression of calf birthweight on day of birth b_1=0.020±0.005				M	37.0±0.41 (158)	35.9±0.55 (79)	32.8±0.46 (115)		
				F	32.9±0.39 (173)	32.1±0.51 (94)	31.4±0.49 (107)		
				Sire breed mean[a]	34.9±0.30	34.1±0.40	32.1±0.36		

* see text for description of breeds

a calculated within common sire and dam breeds only

c number of animals

Table 3 Estimates of heterosis (kg,%) for birthweights of live calves of each sex in each genotype

		Dam breed HS		Dam breed AX		Dam breed BX		Dam breed B				Dam breed B	
Sire breed	Heterosis	M	F	M	F	M	F	M	F	Sire breed	Heterosis	M	F
B	kg	4.2^{**}	6.1^{**}	7.1^{**}	4.2^{**}	4.2^{**}	1.6^{*}	0	0	HS	kg	-2.2^{**}	1.2^{*}
	%	12.6	20.5	20.6	13.2	13.0	5.4	0	0		%	-6.6	4.0
Bo	kg	3.9^{**}	5.7^{**}	5.3^{**}	3.0^{**}	3.6^{**}	3.1^{**}	0.1	1.0	AX	kg	-2.0^{**}	-0.5
	%	11.9	13.6	15.5	9.6	11.3	10.7	0.3	3.6		%	-5.8	-1.6
Tu	kg	0.2	1.7^{*}	0.7	2.4^{*}	-0.3	0.2	-2.6^{**}	-0.3	BX	kg	-2.2^{**}	-0.6
	%	0.6	5.6	2.0	9.1	-0.9	2.0	-8.0	-1.0		%	-6.8	-2.0

*, ** means are significantly different from zero * P,0.05, ** P<0.01
Differences between means of >0.8kg are significant (P<0.05)

Table 4 Least squares estimates of weaning weights (means±SEM) for calves of each sex in each genotype

		Sire breeds							
Dam breed	Sex	HS*	AX	BX	B	Bo	Tu	Ch	Dam breed mean[a]
HS	M	157.8±3.0	---	---	173.6±3.8	172.2±5.3	171.6±4.4	---	172.5±2.6
		(43)(c)			(26)	(14)	(19)		(59)
	F	143.7±2.8	---	---	174.8±3.2	162.3±4.5	160.1±3.8	---	165.7±2.3
		(50)			(37)	(18)	(27)		(82)
	Breed mean	150.7±2.1	---	---	174.2±2.6	167.2±3.5	165.9±2.9	---	169.1±1.8
AX	M	---	185.8±3.5	---	204.6±3.2	193.2±4.0	190.6±3.6	---	196.1±2.2
			(31)		(36)	(23)	(30)		(89)
	F	---	178.5±3.7	---	186.6±3.2	177.9±3.7	178.5±3.4	---	181.0±2.1
			(29)		(37)	(29)	(35)		(101)
	Breed mean	---	182.2±2.6	---	195.6±2.3	185.5±2.7	184.5±2.5	---	188.6±1.6
BX	M	---	---	185.4±3.8	199.4±3.7	199.9±4.1	200.0±3.9	---	199.8±2.3
				(26)	(27)	(24)	(25)		(76)
	F	---	---	176.5±3.5	172.5±3.8	180.7±3.7	180.4±3.8	---	177.9±2.2
				(31)	(26)	(27)	(26)		(79)
	Breed mean	---	---	181.0±2.6	186.0±2.6	190.3±2.8	190.2±2.7	---	188.8±1.6
B	M	197.0±4.1	205.9±3.3	190.9±3.3	191.6±2.3	188.6±5.5	194.5±3.3	205.6±4.6	191.6±2.0
		(25)	(35)	(35)	(75)	(17)	(33)	(20)	(121)
	F	184.5±3.3	191.2±3.3	179.0±4.5	174.4±2.5	174.4±4.8	185.3±5.4	213.2±4.2	178.0±2.3
		(36)	(28)	(18)	(65)	(17)	(14)	(21)	(96)
	Breed mean	190.8±2.8	198.6±2.5	185.0±2.8	183.0±1.8	181.5±3.8	189.9±3.2	209.4±3.2	184.8±1.7
Regression of calf weaning weight on day of birth b_2=0.020±0.005				M	192.3±1.7	188.5±2.3	189.2±2.0		
					(160)	(78)	(107)		
				F	177.0±1.7	173.8±2.2	176.1±2.1		
					(165)	(91)	(102)		
				Sire breed mean[a]	184.7±1.3	181.2±1.7	182.6±1.6		

* see text for description of breeds
a calculated within common sire and dam breeds only
c number of animals in each cell

Table 5 Estimates of heterosis (kg,%) for weaning weights of calves of each sex in each reciprocal cross genotype

		Dam breed B				Sire breed B	
Sire breed	Units	M	F	Dam breed	Units	M	F
HS	kg	23.3***	25.4**	HS	kg	-1.1	15.7**
	%	13.3	16.0		%	-0.6	9.9
AX	kg	17.2**	14.7**	AX	kg	15.9**	10.1**
	%	9.1	8.3		%	8.4	5.7
BX	kg	2.4	3.5	BX	kg	10.9**	-3.0
	%	1.3	2.0		%	5.8	-1.7

** means are significanlty different from zero (P>0.01)
Differences between means of >4.7kg are significant (P>0.05)

Table 6 Adjusted liveweights at 18 months of age for males and females of each genotype

		Sire breeds							
Dam breed	Sex	HS*	AX	BX	B	Bo	Tu	Ch	Dam breed mean[a]
HS	M	297.8±4.5	---	---	357.3±6.0	345.3±7.6	320.6±6.5	---	340.8±3.8
		(42)[c]			(23)	(14)	(19)		(56)
	F	264.7±4.4	---	---	324.7±4.8	312.6±6.9	293.0±5.6	---	310.2±3.3
		(44)			(35)	(17)	(27)		(79)
	Breed mean	281.2±3.2	---	---	341.0±3.9	328.9±5.2	306.8±4.3	---	325.5±2.6
AX	M	---	350.6±5.3	---	392.6±4.8	368.1±6.0	345.1±5.1	---	369.6±3.1
			(29)		(36)	(23)	(32)		(91)
	F	---	320.9±5.3	---	339.7±4.8	320.5±5.5	317.4±5.0	---	325.9±3.0
			(30)		(36)	(28)	(34)		(98)
	Breed mean	---	335.8±3.8	---	366.2±3.5	344.3±4.1	331.3±3.7	---	347.8±2.3
BX	M	---	---	336.9±5.8	367.5±5.6	362.9±5.9	365.4±5.7	---	364.9±3.2
				(24)	(26)	(24)	(25)		(75)
	F	---	---	312.8±5.3	312.0±5.7	319.9±5.5	312.5±6.1	---	314.8±3.2
				(29)	(25)	(27)	(22)		(74)
	Breed mean	---	---	324.8±4.0	339.7±4.0	341.4±4.1	339.0±4.2	---	339.8±2.4
B	M	369.9±6.0	385.8±5.0	352.9±4.8	353.2±3.5	359.3±6.8	358.5±5.0	388.4±6.5	355.7±2.9
		(23)	(33)	(35)	(71)	(18)	(33)	(20)	(122)
	F	332.3±5.0	357±5.7	320.7±6.7	310.3±3.9	315.0±7.1	322.0±7.7	372±6.3	316.5±3.4
		(34)	(25)	(18)	(55)	(16)	(14)	(21)	(85)
	Breed mean	351.1±3.9	368.9±3.9	336.8±4.2	331.7±2.7	337.1±5.0	340.2±4.6	380.2±4.6	336.1±2.4
Regression of 18 months liveweight on day of birth b_3=-0.1163±0.0340				M	367.2±2.5	358.0±3.2	348.0±2.8		
					(156)	(79)	(109)		
				F	321.7±2.4	316.8±3.1	312.1±3.0		
					(151)	(88)	(97)		
				Sire breed mean[a]	344.4±1.8	337.4±2.4	330.1±2.2		

* see text for description of breeds
a calculated within common sire and dam breeds only
c number of animal in each cell

Table 7 Estimates of heterosis (kg,%) for liveweights at 18 months of age for males and females in each reciprocal cross genotype

Dam breed B				Sire breed B			
Sire breed	Units	M	F	Dam breed	Units	M	F
HS	kg	44.4^{**}	44.8^{**}	HS	kg	31.8^{**}	37.2^{**}
	%	13.6	15.6		%	9.8	12.9
AX	kg	33.9^{**}	36.4^{**}	AX	kg	40.7^{**}	24.1^{**}
	%	9.6	11.5		%	11.6	7.6
BX	kg	7.8^{*}	9.1^{*}	BX	kg	22.4^{**}	0.4
	%	2.3	2.9		%	6.5	0

Means are significantly different from zero * $P<0.05$ ** $P<0.01$
Differences between means of >7.1kg are significant ($P<0.05$)

Table 8 Summary of analyses of variance for liveweight gains over the entire treatment period, and for log transformed mean tick and worm egg counts for all animals before treatment began (a) over all calf genotypes and (b) within common sire and dam breeds

			Liveweight gain		Log Tick count		Log Worm egg count	
		DF	DF	"F"	DF	"F"	DF	"F"
(a) all calf genotypes	Year	2		879^{***}		40.0^{***}		11.5^{***}
	Calf genotype	18		16.7^{***}		7.5^{***}		6.6^{***}
	Calf sex	1		27.2^{***}		6.6^{***}		31.6^{***}
	Dam AGEPLS	4		2.5^{*}		5.6^{***}		NS
	Treatment	1		58.0^{***}		NS		NS
	Genotype × Treatment	18		3.2^{***}		NS		NS
	Regression :							
	Calf birth day	1		4.6^{*}		---		---
	Residual		998		754		810	
(b) within common sire and dam breeds	Year	2		697^{***}		41.3^{***}		18.9^{***}
	Calf sex	1		3.6^{*}		NS		22.6^{***}
	Dam breed	3		6.5^{***}		3.8^{**}		8.3^{***}
	Sire Breed	2		19.3^{***}		26.9^{***}		21.0^{***}
	Dam AGEPLS	4		NS		4.1^{***}		NS
	Treatment	1		17.9^{*}		NS		NS
	Sire breed × Dam breed	6		8.4^{***}		NS		NS
	Dam breed × Treatment	3		2.6^{*}		NS		NS
	Sire breed × Treatment	2		6.6^{**}		NS		NS
	Residual		656		484		513	

*	$P<0.05$
**	$P<0.01$
***	$P<0.001$

Table 9 Liveweight gains (kg) for each treatment group (T,C) from 8 to 18 months of age

		Sire breed							
Dam breed		HS*	AX	BX	B	Bo	Tu	Ch	Dam breed mean[a]
HS	T	128.5±2.7	---	---	148.1±3.3	151.9±4.4	129.7±3.6	---	142.9±2.1
	C	100.2±2.5	---	---	137.4±3.1	132.5±4.1	116.0±3.4	---	128.8±2.0
	Response	28.3[aa] (90)[+]	---	---	10.7 (59)	19.4 (32)	13.7 (48)	---	14.1[bb]
AX	T	---	143.4±3.2	---	150.5±2.9	147.9±3.4	141.8±3.1	---	146.3±1.8
	C	---	119.7±3.2	---	140.9±2.8	127.5±3.3	115.3±3.0	---	127.6±1.8
	Response	---	23.7 (58)	---	9.6 (71)	20.4 (51)	26.5 (63)	---	18.7
BX	T	---	---	136.0±3.2	135.6±3.3	135.9±3.4	138.6±3.3	---	136.7±1.9
	C	---	---	122.0±3.2	129.0±3.3	124.8±3.4	119.2±3.3	---	124.0±1.9
	Response	---	---	14.0 (56)	6.6 (52)	11.1 (52)	19.4 (53)	---	12.7
B	T	141.3±3.4	153.8±3.2	135.9±3.5	131.9±2.1	135.9±4.5	139.6±3.6	161.0±3.9	136.0±1.9
	C	132.3±3.3	139.7±3.1	132.4±3.3	126.3±2.2	130.7±4.5	127.5±3.6	140.1±3.8	126.4±1.9
	Response	9.0 (57)	14.1 (48)	3.5 (52)	5.6 (129)	5.2 (32)	12.1 (49)	20.9 (41)	9.6
			Sire breed mean[a]	T	141.3±1.4	142.5±2.0	137.6±1.7		
				C	132.9±1.5	128.2±1.9	118.9±1.7		
				Response	8.4[cc]	14.3	18.7		

\+ numbers of animals in each cell
* see text for description of breeds
a calculated within common sire and dam breeds only
aa Differences between calf genotypes in response (aa) of > 2.6, between dam breeds in response (bb) of > 2.9 and between sire breeds in response (cc) of > 2.7 kg are significant P<0.05.

Table 10 Heterosis for liveweight gains of treated and control animals for each reciprocal cross genotype

		Dam breed B				Sire breed B	
Sire breed	Units	Treated	Control	Sire breed	Units	Treated	Control
HS	kg	11.1^{**}	19.0^{**}	HS	kg	17.9^{**}	24.1^{**}
	%	8.5	16.8		%	13.7	21.3
AX	kg	16.1^{**}	16.7^{**}	AX	kg	12.8^{**}	17.9^{**}
	%	11.7	13.6		%	9.3	14.6
BX	kg	1.9	8.2^{**}	BX	kg	1.6	4.8^{*}
	%	1.4	6.6		%	1.2	3.9

Means are significantly different from zero * $P<0.05$
** $P<0.01$

Differences between means > 3.9kg are significant ($P<0.05$)

Table 11 Log and arithmetic mean tick count (per animal/day) for each breed before treatment began

		Sire breed							
Dam breed		HS*	AX	BX	B	Bo	Tu	Ch	Dam breed mean[a]
HS	Log	1.629±0.050	---	---	1.241±0.063	1.171±0.082	1.453±0.069	---	1.347±0.040
	Arith	42.6	---	---	17.4	14.8	28.4	---	22.2
		(66)[+]	---	---	(45)	(25)	(38)	---	(108)
AX	Log	---	1.635±0.060	---	1.260±0.058	1.360±0.066	1.594±0.060	---	1.419±0.038
	Arith	---	43.1	---	18.2	22.9	39.2	---	26.2
		---	(45)	---	(49)	(37)	(48)	---	(134)
BX	Log	---	---	1.460±0.066	1.191±0.064	1.246±0.066	1.433±0.065	---	1.321±0.037
	Arith	---	---	28.8	15.5	17.6	27.1	---	20.9
		---	---	(44)	(37)	(37)	(39)	---	(113)
B	Log	1.372±0.069	1.270±0.060	1.296±0.067	1.170±0.042	1.258±0.094	1.424±0.070	1.545±0.084	1.277±0.036
	Arith	23.6	18.6	19.8	14.8	18.1	26.5	35.1	18.9
		(37)	(40)	(38)	(89)	(22)	(33)	(30)	(144)
			Sire breed mean[a]	Log	1.245±0.031	1.275±0.038	1.503±0.035		
				Arith	17.6	18.8	31.8		
					(220)	(121)	(158)		

+ number of animals in each cell
* see text for description of breeds
a calculated within common sire and dam breeds only

Table 12 Heterosis for mean tick counts before treatment began for each reciprocal cross genotype

		Dam breed B			Sire breed B
Sire breed	Units	Treated	Dam breed	Units	Treated
HS	ticks	5.1^{*}	HS	ticks	11.3^{**}
	%	17.8		%	39.4
AX	ticks	10.4^{**}	AX	ticks	10.8^{**}
	%	35.9		%	37.2
BX	ticks	2.0	BX	ticks	6.3^{*}
	%	9.2		%	29.8

means are significantly different from zero	*	P<0.05
	**	P<0.01

Differences between means >4.3 ticks are significant (P<0.05)

Table 13 Log and arithmetic mean worm egg count for each genotype before treatment began

Dam breed		Sire breed							
		HS*	AX	BX	B	Bo	Tu	Ch	Dam breed mean[a]
HS	Log	2.66±0.045	---	---	2.39±0.052	2.58±0.064	2.72±0.057	---	2.57±0.037
	Arith	455	---	---	245	381	522	---	372
		(69)	---	---	(45)	(27)	(37)	---	(109)
AX	Log	---	2.63±0.053	---	2.48±0.048	2.62±0.055	2.68±0.049	---	2.59±0.034
	Arith	---	428	---	302	412	479	---	389
		---	(44)	---	(58)	(40)	(53)	---	(151)
BX	Log	---	---	2.59±0.052	2.45±0.054	2.50±0.053	2.62±0.051	---	2.53±0.034
	Arith	---	---	387	279	317	421	---	339
		---	---	(45)	(41)	(42)	(43)	---	(126)
B	Log	2.41±0.056	2.53±0.052	2.38±0.055	2.34±0.039	2.42±0.071	2.48±0.056	2.42±0.058	2.43±0.034
	Arith	255	342	240	221	260	302	266	269
		(38)	(47)	(39)	(101)	(23)	(38)	(36)	(162)
			Sire breed mean[a]	Log Arith	2.43±0.030 269 (245)	2.53±0.035 339 (132)	2..63±0.032 427 (171)		

* see text for description of breeds

a calculated within common sire and dam breeds only

Table 14 Heterosis for mean worm egg counts before treatment began for each reciprocal cross genotype

		Dam breed B			Sire breed B
Sire breed	Units	Treated	Dam breed	Units	Treated
HS	eggs	83^{*}	HS	eggs	93^{**}
	%	24.6		%	27.5
AX	eggs	-17	AX	eggs	23
	%	-5.2		%	7.1
BX	eggs	64^{*}	BX	eggs	25
	%	21		%	8.2

means are significantly different from zero * $P<0.05$

Differences between means of >62 eggs are significant ($P<0.05$)

Table 15 Least squares means for rectal temperature (°C) for each genotype

	Sire breed							
Dam breed	HS*	AX	BX	B	Bo	Tu	Ch	Dam breed mean[a]
HS	39.69±0.034	---	---	39.39±0.043	39.42±0.058	39.40±0.048	---	39.40±0.029
	(91)	---	---	(62)	(32)	(47)	---	(141)
AX	---	39.38±0.043	---	39.41±0.039	39.34±0.046	39.30±0.042	---	39.35±0.024
	---	(57)	---	(71)	(51)	(63)	---	(185)
BX	---	---	39.34±0.044	39.31±0.045	39.37±0.047	39.29±0.045	---	39.32±0.026
	---	---	(54)	(53)	(50)	(52)	---	(155)
B	39.26±0.044	39.23±0.041	39.26±0.044	39.25±0.028	39.25±0.064	39.28±0.047	39.24±0.053	39.25±0.027
	(62)	(62)	(54)	(136)	(31)	(49)	(41)	(216)
			Sire breed mean[a]	39.34±0.019	39.34±0.026	39.32±0.023		
				(322)	(164)	(211)		

* see text for description of breeds

a calculated within common sire and dam breeds only

3.12 Success in achieving objectives

Objective 1 *To identify genotypes that in stressful environments express maximum heterosis and produce environmentally sustainable increases in overall productivity, measured as the combination of survival, growth, reproduction, "easy-care" characteristics, resistance to environmental stresses and meat and carcase quality, of at least 20% above that of Brahmans.*

Overall productivity cannot be assessed until completion of measurements of all components of production. However, on the basis of preliminary data, there is little doubt that the objective will be achieved. For the variables for which measurements are complete :

1. Growth on pasture - Demonstrated that in the absence of ticks and worms, increases in absolute growth rates above that of Brahmans of about 22% can be achieved by crossbreeding. However, preliminary data indicate that any differences in efficiency of growth are likely to be <1%. Demonstrated that in the presence of low to moderate levels of ticks and worms, differences between the same genotypes as above declined to about 11%. Efficiency of growth then favoured the more resistant genotypes.

2. Resistance to ticks and worms - Demonstrated large differences between genotypes in resistance to ticks and worms and that the combined effect of these parasites on growth of the more resistant crossbreds was similar to or only marginally more than that of the straightbred Brahmans.

3. Meat Quality (incomplete) - Demonstrated that objective measurement of tenderness favoured the taurine breeds but these breed differences were not detected by taste panel assessment.

Objective 2 *Develop model(s) that allow prediction of the productivity of any defined genotype (whether crossbred or straightbred) reared in any defined environment, using any defined management system and targeting any defined market.*

A prototype of a crossbreeding decision support aid has been developed by Dr. Scott Newman of the Meat Quality CRC. The software runs on a Windows platform. He has formed a series of producer focus groups around Queensland to trial the software. Only growth data (birth to 550 days) from CS183 has been available and analysed to yield a larger number of genetic parameters than from previous analyses. These results form a portion of the genetics database which, along with an environmental database with stress information, forms the basis for prediction of the performance of genotypes. Experimental results from all over the world have been included in the genetics database.

3.13 Impact on beef industry

1. Immediate : The study provides sufficient information to allow producers to identify likely changes in absolute and/or relative growth rates, resistance to ticks and worms, and meat and

carcase qualities before initiating a crossbreeding program based on particular types of breeds in particultr types of environments. The potential exists to increase *Bos taurus* content and with that, increase growth rates and meat tenderness without incurring any significant loss of resistance to ticks and worms.

2. 5 years' time : Crossbreeding is quick and simple to implement and operate, is low cost and does not have to disrupt established management practices. Preliminary data indicate that the benefit/cost ratio for crossbreeding is so large that within 5 years, commercial beef producers who want to remain viable will use crossbreeding as part of their production system. Within 5 years, measurement of total productivity of the different genotypes and model development will have both been completed. A rational choice of genotypes can then be made for each particular set of circumstances.

3.14 Conclusions and recommendations

On the basis of the measurements so far completed or partially completed, there is no doubt that the potential advantages of crossbreeding are large. It is the quickest and simplest way to change resistance to environmental stresses, meat quality, absolute growth rates, and in some cases, relative growth rates. The zebu breeds (Brahman, Boran) and sanga breeds (Africander, Tuli) have similar resistance to heat but differ in resistance to ticks and worms. The sanga and European breeds have similar resistance to worms but differ in resistance to ticks and heat. The Brahman and Boran have similar resistance to ticks and heat but differ in resistance to worms. Within each breed group there are differences between breeds in growth potentials. The sanga and European breeds appear to have similar meat quality characteristics.

The large differences between genotypes in growth potentials, resistance to environmental stresses and meat quality characteristics allow F_1 crossbreds to be assemebled according to the requirements of the market and the production environment. Heterosis for growth occurs between all of the breed groups suggesting that high levels of heterosis and, on the basis of preliminary data, high productivity, can be expected from more complex crosses, including those combining African, European and Indian breeds, than those generated in Phase I.

The moderately high resistance of the African breeds identifies them as useful vehicles for the incorporation of taurine genes into herds of high *Bos indicus* content and as partial substitutes for Indian and European breeds.

While growth is a significant component of production, preliminary data indicate that the greatest increases in productivity arising from crossbreeding are associated with other components of production. Categorical identification of the most productive genotype for each set of conditions or over a wide range of conditions is therefore dependent on completion of measurement of total productivity (Phase II).

While crossbreeding can be commercially exploited by almost any producer, it is unlikely that all producers who want to use crossbreeding fully understand the principles and procedures involved. The benefits obtained from crossbreeding may therefore be less than is potentially possible. The development of user-friendly predictive models will allow producers to compare productivity of different genotypes, including straightbreds and crossbreds, in different environments and make a rational choice of genotype before initiating a crossbreeding program, or before continuing with the next step in a crossbreeding program. This would remove much of the guess-work that currently surrounds the choice of appropriate breeds and breeding systems. However, these models must predict total productivity, not just of the parental and F_1 generations, but of advanced generations of crossbreds as well. This requires access to data on the productivity of these advanced generations. These are functions of Phase II of the project.

Despite the relatively low parasite burdens for all genotypes, the efficiency of growth of all genotypes was depressed by ticks and worms. This, in regions that are moderately to heavily infested with ticks and worms, significant improvements in productivity are potentially available through the use of genotypes of higher resistance than those used in the current study. The greatest improvement lies in increasing the tick and worm resistance of the taurine breeds, none of which could match the resistance of the Brahman. Ways by which this could be achieved most efficiently should be thoroughly investigated.

3.15 Appendices

3.15.1 Resistance to heat

3.15.1 Results

The least squares means for rectal temperatures of each genotype recorded on three occasions during summer are shown in Table 15.

The HS had significantly higher mean rectal temperatures than any other genotype ($P<0.01$). Within the straightbreds, rectal temperatures were significantly lowest for B and highest for HS while BX and AX did not differ significantly from one another. Within each dam breed and over all dam breeds, differences in rectal temperatures of B-, Bo- and Tu-sired progeny were small and not significant. Over the three common sire breeds, rectal temperatures were significantly lowest for progeny of B dams and significantly higher for progeny of HS dams than for progeny of B or BX dams. Rectal temperatures of progeny of BX dams were intermediate to those from B and HS dams and similar to those of progeny from AX dams. The difference between HS and AX dams was not significant. Within each dam breed except HS, differences in rectal temperatures of straightbreds and crossbreds were small and not significant.

3.15.1.2 Discussion

The straightbreds can be ranked directly for resistance to heat and ranked B>BX,AX>HS. The same reasoning as that used to estimate comparative resistance of B, Bo and Tu to ticks and worms has been used to estimated rankings for resistance to heat. Comparisons of progeny of B and Bo within HS and AX dams and Bo and Tu within BX dams indicate that the B, Bo and Tu have similar resistance to heat. This hypothesis is supported by the similarity of values for each of the sire breeds regardless of dam breed.

The reasons for the remarkable consistency of values for all genotypes from B dams have not been determined. The most likely explanation is that the values are too close to normal rectal temperature to allow differentiation between genotypes. However, that does not explain the consistently higher rectal temperatures of B-sired progeny from HS, AX and BX dams than for their respective reciprocal crosses. The reasons for the differences are quite enigmatic. Because of the similarity of rectal temperatures of all genotypes within B dams, it was not possible to use the values to rank the sire breeds for resistance to heat. Further exploration of the data is required to see if differentiation between genotypes can be achieved. However, the present data indicate that at ambient temperatures below 35°C, all genotypes based on B dams are likely to be equally resistant to heat.

If it is assumed that, as for ticks and worms, heterosis for rectal temperature is directly proportional to the breed contributions, the average heterosis for rectal temperature for a BX×Bo should be ½ (B×Bo + HS×Bo). The predicted rectal temperature for a BX×Bo is then $(39.25 + 39.42) / 2 = 39.34^{o}$C. The observed value was 39.37°C. Similarly, the predicted and observed values for BX×Tu were 39.34 and 39.29°C respectively. For the B×BX the observed and predicted values were 39.26 and 39.26°C respectively. The close correspondence between each set of values within a genotype indicates that heterosis for rectal temperature is directly proportional to the breed contribution to the cross. Prediction of rectal temperatures of more complex crosses should therefore be quite accurate.

The predicted and observed values for the BX×B were 39.31 and 29.32^{o}C respectively. These values are not significantly differenct to those of the reciprocal cross but when combined with the significant differences between the other reciprocal crosses, indicate that maternal effects may need to be considered if prediction of rectal temperatures of more complex crosses is required.

3.15.2 Milestone 23

"Wean approximately 400 straightbred and crossbred two-way cross calves from the fourth calf crop and allocate to treatment groups."

(i) *Analysis of liveweights at birth and weaning of fourth crop*
Approximately 540 straightbred, 2-, 3- and 4-way cross calves were weaned in May 1995 and allocated to treatment groups. All are being assessed for resistance to ticks and worms before treatment begins in mid-July.

Birth weights
There are insufficient 3-way and 4-way cross calves of any genotype to allow meaningful analysis of birth weights. Additional information will become available from the calf crop expected in October-December 1995. Birth weights of straightbreds and 2-way cross calves were reported in Milestone 14.

Weaning weights
Many of the genotypes represented as maidens are not yet represented as mature cows. To avoid confounding, the weaning weights of calves from the two classes of females have been analysed separately.

Tables 1 and 2 show weaning weights of straightbred, 2-way, 3-way and 4-way crossbred calves from maiden heifers. It must be realised that the numbers of calves in individual cells are too few to provide reliable estimates of weights for particular genotypes. However, as generalities :

1. The straightbreds and the 2-way crossbreds rank the same as in previous years with the weights of the 2-way cross calves exceeding those of the respective straightbred contemporaries.

2. Most of the 3-way and 4-way cross genotypes had higher weaning weights than the straightbred B.

3. The mean weaning weight of calves sired by AXxBo bulls was intermediate to that of calves sired by AX and Bo bulls suggesting that epistatic effects for growth to weaning are not important.

4. The difference between most reciprocal crosses was small.

Table 1. **1995 Weaning Weights (kg) of the straightbred and 2-way crossbred calves from maiden heifers.**

Straightbreds	
Breed	**WWT**
B	192±6[a] (12)[+]
AX	192±9 (5)
HS	157±4 (29)

2-way cross		
Dam breed	**Sire breed**	**WWT**
B	HS	202±10 (4)
B	AX	216±6 (11)
B	Ch	228 (1)

a SEM

\+ number of animals

Table 2. **1995 Weaning Weights (kg) of the 3- and 4-way crossbred calves from maiden heifers.**

	Sire breed			Dam breed
Dam breed	**AX**	**AXxBo**	**Bo**	**Mean**
HSx B	205±9 (5)	205±12 (3)	173±12 (3)	194±11 (11)
BXx Tu	186±10 (4)	185±14 (2)	205±12 (3)	192±7 (9)
BxHS	216±9 (5)	198±8 (6)	205±9 (5)	206±5 (16)
BxCh	227±14 (2)	221±14 (2)	198±14 (2)	215±9 (6)
BxTu	209±12 (3)	192±12 (3)	204±14 (2)	202±5 (8)
Sire breed Mean	209±7 (19)	200±6 (16)	197±6 (15)	
AXxB	---	206±6 (11)	---	
BxAX	---	202±7 (9)	---	

Dam breed	**Sire breed HSxTu**
BXxB	187±6 (10)
BXxBo	187±8 (6)
BxBX	208±12 (3)
BxBo	169±12 (3)
	Sire breed BxCh
HSxBo	196±9 (5)
HSxTu	195±7 (8)
AXxBo	214±6 (13)
AXxTu	198±6 (10)

Table 3 shows weaning weights of straightbred and crossbred calves from mature cows. The straightbred and 2-way cross calves ranked the same as their contemporaries born to maidens with the HS and F_1BxCh calves being lightest and heaviest respectively. In the 3- and 4-way crosses, there was a complete reversal of ranking of calves by AX and Bo sires between F_1BxCh and F_1B/HS dams. However, although some of the differences between genotypes were statistically significant, at this stage the biological significance of the differences is uncertain. The weaning weights of calves by AXxBo bulls were intermediate to those by AX and Bo bulls again suggesting that epistatic effects for growth to weaning are not important.

The differences between sire breed means and between dam breed means were small indicating that over the same range of dam breeds, the three sire breeds would produce calves of similar weaning weights, and over the same range of sire breeds, the two dam breeds would produce calves of similar weaning weights.

The weaning weights of the 3- and 4-way cross calves by each of the sire breeds were significantly heavier than those of straightbred HS and B calves but not all were significantly heavier than that of straightbred AX calves. F_1BxHS calves were lighter than all other 2-, 3- and 4-way cross calves. Weaning weights of (F_1B/HS), (F_1BxCh)x(F_1AXxBo) and (F_1BxCh)xBo were similar to, or not significantly different from, the weaning weight of the F_1BxCh, the 2-way cross with the highest weaning weight.

(ii) *Analysis of calf survival/mortality figures from pregnancy test to weaning by genotype.*

Pregnancy rates

Tables 4, 5 and 6 show pregnancy rates for maidens, first calf heifers and mature cows respectively. The data refer to pregnancy rates of females for each dam breed of origin x sire breed of origin. Thus, where the sire and dam breeds of origin are shown, e.g. as Adaptaur, the pregnancy rates refer to straightbred Adaptaurs. Where the dam breed of origin is Adaptaur and the sire breed of origin is, e.g. Brahman, the pregnancy rates refer to females that are F_1Adaptaur x Brahman mated to HS, B, AX, AXxBo and Bo bulls. In tables 4, 5 and 6, Adaptaur = HS, and Belmont Red = AX.

The data for the straightbreds, reciprocal HS/B and BxCh are based on pregnancy rates over 3 years. Data for crossbred maidens and first calf heifers refer to pregnancy rates over 2 years and 1 year respectively. Sire breed and dam breed means have been calculated within common dam breed and sire breed respectively.

The numbers in some cells are too few to provide reliable estimates of pregnancy rates while numbers in other cells are adequate.

In the maidens, the pregnancy rate for each genotype was high. The differences between straightbreds were small and within each dam breed of origin, the differences between crossbred genotypes were also small. Within each dam breed of origin, pregnancy rates of the crossbreds generally exceeded that of the straightbred. Within each sire breed of origin, pregnancy rates of females from a B dam of origin had a lower pregnancy rate (88%) than females originating from an HS (98%), AX (99%) or BX (100%) dam.

Within the first calf heifers, pregnancy rates were generally high. The exceptions were for BX, B and F_1BxCh, all of which were below 60%. The straightbreds differed markedly, with the HS and AX higher than the B and BX. Within dam breed of origin, pregnancy rates of crossbreds generally exceeded that of the straightbred. Over the four common dam breeds, females that originated from Bo and Tu sires had higher pregnancy rates than those that originated from B sires. Over the three common sire breeds, females that originated from HS and AX dams had higher pregnancy rates than those that originated from BX or B dams.

Within the mature cows, pregnancy rates of the crossbreds were high and at least 20 percentage units above that of the B. In the straightbreds, HS and AX were higher than BX and B. Within dam breed of origin, the crossbred exceeded the straightbred.

Over the three classes of females, pregnancy rates of the B and BX were consistently and sometimes markedly lower than those of the HS, AX and the reciprocal F_1B/HS crossbreds. The latter consistently maintained high pregnancy rates while there is an indication that pregnancy rate of 1st calf F_1BxCh heifers was depressed relative to that of F_1B/HS contemporaries.

Table 3. **1995 Weaning Weights (kg) of straightbred, 2-, 3- and 4-way crossbred calves from mature cows.**

		2-way crosses		
Straightbreds		**Dam breed**	**Sire breed**	**WW**
B	199±4 (33)	B	HS	204±4 (29)
AX	205±5 (26)	B	AX	215±4 (32)
HS	166±3 (67)	B	Ch	230±5 (24)

3- and 4-way crosses

	Sire breed			
Dam breed	**AX**	**AXxBo**	**Bo**	**Dam breed mean**
B/HS[+]	228±5 (25)	219±5 (22)	218±5 (25)	222
BxCh	216±8 (8)	223±8 (7)	233±7 (9)	224
Sire breed mean	222	221	226	

[+] reciprocal crosses

Table 4. **Pregnancy rates (%) of maidens.**

	Sire Breed of origin							
Dam breed of origin	**Adaptaur**	**Belmont Red**	**Belmont BX**	**Brahman**	**Boran**	**Tuli**	**Charolais**	**Dam breed mean**[a]
Adaptaur	93(87)[+]	---	---	95(19)	100(11)	100(21)	---	98
Belmont Red	---	92(48)	---	96(25)	100(23)	100(17)	---	99
Belmont BX	---	---	90(52)	100(15)	100(18)	100(18)	---	100
Brahman	94(48)	94(16)	80(10)	90(98)	83(12)	92(13)	100(21)	88
			Sire breed mean	95	96	98		

\+ number of animals

a calculated within common sire breeds only

Table 5. Pregnancy rates (%) of lactating 1st calf heifers.

	Sire Breed of origin							
Dam breed of origin	**Adaptaur**	**Belmont Red**	**Belmont BX**	**Brahman**	**Boran**	**Tuli**	**Charolais**	**Dam breed mean[a]**
Adaptaur	91(44)[+]	---	---	91(11)	100(6)	89(9)	---	93
Belmont Red	---	85(26)	---	85(13)	100(14)	100(11)	---	95
Belmont BX	---	---	48(29)	90(10)	88(8)	80(10)	---	86
Brahman	85(41)	89(9)	67(3)	57(42)	100(5)	100(8)	54(24)	86
			Sire breed mean	81	97	92		

[+] number of animals

[a] calculated within common sire breeds only

Table 6. Pregnancy rates (%) of lactating mature cows.

	Sire Breed of origin							
Dam breed of origin	**Adaptaur**	**Belmont Red**	**Belmont BX**	**Brahman**	**Boran**	**Tuli**	**Charolais**	**Dam breed mean**
Adaptaur	79(140)[+]	---	---	96(49)	---	---	---	---
Belmont Red	---	77(115)	---	---	---	---	---	---
Belmont BX	---	---	73(62)	---	---	---	---	---
Brahman	94(51)	---	---	72(258)	---	---	92(24)	---
			Sire breed mean	---	---	---		

[+] number of animals

Mortality

Table 7 shows mortality rates of straightbred and 2-way cross calves from birth to weaning over the years 1992-1994. Mortalities arising from twin births have been excluded but all other causes including dingo attack or losses arising from the death of drought weakened cows have been included.

In the straightbreds, mortalities were lowest for the AX and highest for the BX. In the 2-way crosses, mortalities were highest for the F_1HSxBo and lowest for the F_1BxTu.

Within HS dams, mortalities of calves by the two zebu breeds were high and exceeded those of the straightbred HS. Calves by the Tu sires had low mortalities. Most of the mortalities of the zebu-sired calves were associated with dystocia in maiden heifers or losses of drought affected maidens weakened further by calving. Tu sires have a marked advantage over the zebu and HS sires in terms of lack of dystocia and calf survival.

Within the AX dams, mortalities of all crossbred genotypes were lower than that of the straightbreds with the lowest mortalities in Bo sired calves.

Within BX dams, mortality of straightbreds was higher than that of each of the crossbreds with the lowest mortalities in the Bo and B sired calves.

Within B dams, mortalities of straightbreds exceeded that of each of the crossbreds with the lowest and highest mortalities in the crossbreds being for Tu and Ch sired calves respectively.

Over all dam breeds, mortalities were lower for Tu sired calves than for Bo or B sired calves which were similar to one another. Over the three common sire breeds, mortalities were highest in calves born to HS dams. Mortalities of calves from the other dam breeds were similar to one another.

There was a marked difference in the mortality rate of reciprocal cross B/HS but little differences between reciprocal cross B/AX. A difference in dystocia rates between reciprocal B/HS was the main reason for the difference in mortality rates.

Table 8 shows mortality rates from birth to weaning of back-cross and 3-way cross calves born to F_1 dams over the years 1992-94. Numbers of animals in individual cells are too few to allow accurate assessment of any real differences between genotypes. However, of the 178 calves born to F_1 cows, only 1 calf died (0.6%). This low value compares highly favourably with the 9.5 and 10.6% (Table 7) for straightbred B and BX respectively, the two most common genotypes in northern Australia.

Table 7. **Mortality rates (%) of straightbred and 2-way cross calves from birth to weaning (1992-1994).**

	Sire breed							
Dam breed	**Adaptaur**	**Belmont Red**	**Belmont BX**	**Brahman**	**Boran**	**Tuli**	**Charolais**	**Dam breed mean**[a]
Adaptaur	8.7 (103)[+]	---	---	13.9 (72)	20.5 (39)	2.0 (49)	---	12.1
Belmont Red	---	6.1 (66)	---	4.0 (75)	1.9 (53)	4.2 (71)	---	3.4
Belmont BX	---	---	10.6 (66)	1.9 (54)	1.9 (53)	5.4 (56)	---	3.1
Brahman	3.1 (63)	5.8 (69)	5.4 (56)	9.5 (158)	2.9 (34)	0 (50)	6.8 (44)	4.1
			Sire breed mean	7.3	6.8	2.9		

[+] total number of calves born

[a] calculated within common sire breeds only

Table 8. Mortality rates (%) from birth to weaning for back-cross and 3-way cross calves from F_1 dams (1992-1994).

	Sire breed					
Dam breed	**Adaptaur**	**Belmont Red**	**Brahman**	**Boran**	**Tuli**	**Dam breed mean**[a]
F_1BxHS	0 (15)[+]	0 (11)	0 (13)	7.7 (13)	0 (20)	1.4
F_1BxCh	---	---	0 (10)	0 (10)	0 (12)	0
F_1SxB	0 (13)	0 (12)	0 (15)	0 (13)	0 (19)	0
		Sire breed mean	0	2.6	0	

[+] total number of calves born

[a] calculated within common sire breeds only

(iii) *Analysis of body weight, condition score and genotype on conception percentages.*
Table 9 shows liveweights of first calf heifers at weaning of their calves in May 1995. The AX, BX and B heifers were the progeny of sires selected for high EBV for 550 day weight. The Bo and Tu sired progeny were by randomly selected bulls. The HS were progeny of bulls selected mainly for increased resistance to ticks.

The number of animals in some cells is too few to allow accurate assessment of genotype differences. This must be borne in mind when considering any of the following comments.

The straightbred HS and F_1BxCh were the lightest and heaviest of any of the genotypes. Straightbred AX were the heaviest of the straightbreds. The HS were the only genotype that was lighter than the B.

Within HS dams, all of the crossbreds were heavier (though the Tu, not significantly so) than the straightbreds with the crossbreds ranked B>Bo>Tu.

Within AX dams, straightbred AX were heavier, though not significantly so, than each of the crossbreds. B and Tu sired crossbreds were of similar weight.

Within BX dams, none of the differences between BX and crossbreds was significant.

Within B dams, all crossbreds were significantly heavier than straightbred B.

Table 10 shows liveweights of mature straightbred cows with straightbred calves at foot, for B dams that weaned crossbred calves, and for F_1 dams that weaned 3-way and 4-way crossbred calves.

The AX were significantly heavier than the other straightbreds and although B cows were heavier than the HS the difference was not significant. B cows that weaned crossbred calves did not differ significantly from B cows that weaned B calves. Reciprocal cross B/HS cows were significantly lighter than AX and F_1BxCh cows and significantly heavier than HS and B cows that weaned B calves. Within F_1 genotype there was no significant difference between weights of cows that weaned calves by AX, AXxBo or Bo bulls. Thus, although these crossbred calves were significantly heavier than straightbred B calves (Tables 1 and 2) they had no greater effect on the liveweight of the dam than did the straightbred B calves.

Table 9. Liveweight (kg) of first calf heifers at weaning of their calves in May 1995.

	Sire breed of origin							
Dam breed of origin	**Adaptaur**	**Belmont Red**	**Belmont BX**	**Brahman**	**Boran**	**Tuli**	**Charolais**	**Dam breed mean**[a]
Adaptaur	390±8 (28)	---	---	454±13 (10)	428±18 (5)	408±14 (8)	---	430
Belmont Red	---	480±18 (5)	---	472±12 (11)	451±11 (13)	470±13 (10)	---	464
Belmont BX	---	---	438±13 (9)	447±12 (10)	413±16 (6)	430±13 (9)	---	430
Brahman	474±10 (16)	472±13 (9)	435±23 (3)	402±7 (28)	458±23 (3)	433±14 (8)	528±16 (6)	431
			Sire breed mean	444	438	435		

a calculated within common sire breeds only

Table 10. Liveweights of mature straightbred and 2-way cross cows at weaning of their calves in May 1995.

Straightbreds	
HS	456±7 (66)
AX	537±10 (24)
B	471±9 (31)

	Bull breed			
Cow breed	**AX**	**AX/Bo**	**Bo**	**Dam breed mean**
B/HS	496±10 (26)	495±11 (22)	498±10 (25)	496
BxCh	569±18 (7)	552±18 (7)	581±16 (9)	567

	HS	**AX**	**Ch**	
B	478±9 (29)	478±9 (31)	481±10 (23)	479

Table 11 shows the mean weaning weight/cow joined for straightbred and F_1 cows from those breeds for which there are sufficient numbers of animals to provide reliable estimates for each of the variables. The data were from 1992-1995. Estimates of calving rates and calf weaning weights are based on the assumption that the herd structure is 15% maidens, 15% first calf heifers and 70% mature cows with all non-pregnant females culled each year.

There were marked differences between genotypes in calf mortalities, calving rate of cows and calf weaning weights. Values for each variable favoured the F_1 genotypes over the straightbreds. In the straightbreds the B and BX had higher calf mortalities and lower calving rates than the HS and AX but had similar calf weaning weights to the AX. Of the straightbreds, the HS had the highest net calving rate but the lowest calf weaning weight. The net effect of genotype differences in the different variables was that the measure of productivity, weaning weight/cow joined, was over 80kg/cow higher for the F_1 cows with 3-way cross calves at foot than for straightbred B cows with straightbred B calves at foot. In the straightbreds, the productivity index was highest for the AX, with little difference between the HS, BX and B. Although the productivity index was 36kg higher for B cows that weaned F_1BxCh calves that for B cows that weaned B calves, the index was still 46kg lower than that of F_1BxCh cows that weaned calves sired by Bo bulls. Similarly, the index for B cows that reared a calf sired by an HS bull was 27kg higher than that of the straightbred B calf but 59kg lower than that of the F_1BxHS cows that weaned calves by Bo bulls.

The index, WW/cow joined, does not take into consideration the differences between genotypes in liveweights of the cows at weaning. The larger cows (e.g. AX and F_1BxCh) require more feed for maintenance than do smaller cows (e.g. B, F_1BxHS). To account for these differences in maintenance and mature size, a productivity index WW/100kg of cow joined, has also been calculated. This index is a measure of biological efficiency that takes into consideration differences in cow size, reproduction rates, weaning weights and calf mortality rates. Other indices would need to be calculated for economic efficiency but that is at present outside the scope of this report. Values for cow weights have been estimated from the weights of 1st calf heifers (Table 9) and mature cows (Table 10).

The value for this index was similar for each of the straightbreds indicating little or no difference in biological efficiency. The value for B cows that weaned crossbred calves was higher indicating an increase in biological efficiency. The index further increased for F_1BxCh cows that weaned Bo cross calves. However the highest value was for moderately sized F_1B/HS cows that weaned Bo cross calves.

Thus, the greatest advantage of crossbreeding arises from using F_1 cows rather than straightbred cows to produce the next generation. The next generation must in turn have the high productivity of the F_1. Indications from the weaning weights (Tables 1, 2 and 3) are that the higher growth of the F_1's compared to straightbreds will be maintained by the appropriate 3- or 4-way cross. The high pregnancy rates of F_1's of diverse origins (Tables 4 and 5) indicate that the reproductive potential of 3- and 4-way crosses based on the same genotypes used to form the F_1's will also be high. Provided breeds that are well adapted to the environment and have the characteristics required for the intended markets are used to produce those crosses, there is every reason to believe that the high productivity achieved by the F_1 generation will be maintained in subsequent generations of crosses.

Table 11. **Liveweight of calf weaned/cow joined for straightbred, 2-way and 3-way cross calves.**

Cow breed	Bull breed	Calf Mortality (%)	Calving rate (%)	Net Reproduction (%)	Calf Weaning Weight (kg)	WW/cow (kg)	WW/100kg of cow joined (kg)
HS	HS	8.7	82.9	74.2	151	112	25.2
AX	AX	6.1	80.5	74.4	182	135	25.6
BX	BX	10.6	71.8	61.2	181	111	---
B	B	9.5	72.5	63.0	183	115	25.1
B	Ch	6.8	72.5	65.7	230	151	32.9
B	HS	3.1	72.5	69.4	204	142	30.9
F_1BxHS	Bo	0.6[+]	93.8	93.2	216	201	40.9
F_1BxCh	Bo	0.6[+]	87.5	86.9	227	197	35.2

[+] average mortality of all calves combined from all F_1 dams combined

Implications for the Future

There is clear evidence that reproduction (Table 6), survival (Table 7) and growth (Table 10) can be markedly increased, without the need for additional inputs, by using F_1Brahman x European rather than straightbred Brahmans or interbred Brahman x European. However, the F_1 is a unique generation and the important question to address is “Where to after the F_1?” Interbreeding will result in a loss of reproductive capacity (Table 6) and overall productivity (Table 11). However, the high rebreeding performance of the F_1s sired by AX, Bo and Tu (Table 5), suggests that the breeds of African origin can be used to maintain high reproductive performance in systematic crossbreeding programs. Rebreeding performance of Bo and Tu crosses with HS, AX, BX and B and of the AX cross to B, were all higher than that of the respective straightbred.

Growth rates (Table 2) and survival rates (Table 8) of the 3-way cross calves of African origin and growth rates of the 2-way cross cows of African origin (Table 9) relative to the values for the respective straightbreds indicate that the level of each of these production variables can be maintained at that of the F_1 by crossing the F_1 to a breed of African origin. However, the results are indications only. Confirmation or otherwise will depend on the accumulation of results from greater numbers of animals over Phase II of the study. Likewise, there are strong indications (Tables 2 and 3) that epistatic effects are not important for growth to weaning. If this is shown to be true for all of the major components of productivity, the performance of any multibreed synthetic formed from any particular breeds can be predicted directly from the performance of those breeds. Again, confirmation of these current indications is dependent on the accumulation of additional results during Phase II.

Other questions remain to be answered during Phase II, including those relating to meat and carcase qualities, but discussion of those questions is outside the scope of Milestone 23.

3.15.3 Effects of breed and environment on carcass attributes and eating quality of Japanese ox steers.

Contents

1. Summary of notable outcomes - Preliminary data

- Breed-group differences were found in both the myofibrillar component of toughness and the connective tissue component of toughness but these opposed each other, thereby minimizing the overall differences in toughness due to breed-group. Panellists could not detect these breed-group differences.

- Objectively, connective tissue toughness contributed between 1/4 to 1/3 of the total toughness of aged, electrically stimulated striploin from japanese ox type steers.

- Method of finishing, ie. feedlot or pasture, had no direct effect on eating quality.

- While, overall, ageing produced a tenderization of meat, the decrease in the positive contribution of toughness of the myofibrillar component was lessened by an increase in the contribution of the connective tissue component of toughness possibly due to increased cooking loss in aged meat.

- There were no breed-group differences in the changes produced by ageing of meat when all environmental factors were taken into account.

- Environmental factors such as method of finishing and backgrounding were much more important than breed-group in effects on growth and fat deposition during finishing.

- Rump fat deposition could be minimized relative to marbling fat deposition during finishing by having animals undergo compensatory growth during this period.

2. Abbreviations

ADG	Average daily gain during the last month before slaughter (kg/day)
ADH	Adhesion (kg)
AGE	Classified animal age at slaughter
BREED	Breed class (TT, F1, IX, II)
TT	Pure Bos taurus
F1	First cross
IX	Indicus-taurus cross
II	Pure Bos indicus
CL	Cooking loss (%)
FINISH	Pasture finished (PA) or feedlot finished (FA)
HCWT	Hot carcase weight (kg)
IC	Instron compression (kg)
IMFAT	Intramuscular fat %
IY	Warner-Bratzler initial yield (kg)
LWT	Liveweight (kg)
MARB	Marbling score
P8FAT	P8 fat thickness (mm)
PF	Warner-Bratzler peak force (kg)
PF_{24}	Classified PF values measured on samples frozen 24 hours after slaughter
PFIY	PF minus IY (kg)
pH_u	Classified ultimate pH values measured on samples frozen 24 hours after slaughter
REMA	Rib eye muscle area (cm^2)
RFAT	Rib fat thickness (mm) taken at the quartering point (10-11 rib)
TREATMENT	Parasite treatment given during backgrounding phase (CON, TRT)

3. Methods

3.1 Animals

The breeding and production of 278 steers used in this study are described in section 3.3.1 of this report. Age at slaughter and average daily gain during the last month prior to slaughter were calculated from production records. Breed, treatments and finish were also noted from production records. Prior to finishing, steers received either no treatments for parasites (Con) or were treated for parasites according to current industry practice (Trt). Finish describes either a completely pasture fed animal (PA) or an animal finished for 120 days on grain in a feedlot (FL).

For slaughter, cattle were weighed off feed on the evening prior to transport and left overnight with water only. They were transported early the next day for slaughter the following day. When coming from a feedlot, all the steers except for one ‘tester’ were kept an extra day at the abattoir while the ‘tester’ was slaughtered and samples tested for contaminating residues. Cattle were slaughtered at several abattoirs; AMH, Rockhampton, Teys Bros., Biloela, Borthwicks, Mackay and CMG, Rockhampton. All animals were kept together with production contemporaries and not mixed with other cattle. Note was taken of extreme weather conditions prior to slaughter and any other potential stressors.

3.2 Slaughter

Slaughter was done according to the abattoir routine except that carcases were electrically stimulated by low voltage stimulation[1]. Hot carcase weight, dentition and P8 fat thickness measurements were collected by abattoir staff. Left hand sides were chilled together overnight under commercial conditions which were monitored using thermocouples placed within muscles.

Rib eye muscle area and rib fat thickness at the 10-11 rib quartering point were measured prior to boning. Abattoir staff performed Ausmeat chiller assessments at the same time. The striploin and the eye round were collected. The first 10 cm of striploin closest to the quartering point were immediately frozen for objective measurements. The next 15 cm were vacuum packed and aged for 8 days at 6°C prior to freezing. When thoroughly frozen, four 2 cm steaks were cut off the butt end of this piece for use in taste panel measurements and the remaining piece was used for objective measurements. Care was taken in panel testing to use only samples of the longissimus dorsi muscle. The eye rounds were cut into three pieces. The end pieces were frozen for objective measurements and the central piece aged, then frozen, for taste panel measurements with care being taken to avoid tendon in the tasting samples.

3.3 Meat measurements

Objective measurements, Warner-Bratzler forces, Instron compression, adhesion, ultimate pH, sarcomere length, cooking loss and Minolta light measurements (L, a, b) were performed at Division of Food Science and Technology, CSIRO, Brisbane Laboratory, as previously described[1]. Myofibrillar fragmentation index was measured as described by Culler *et al.*[2] Collagen solubility was measured similarly to the method used by Hill[3] .

Taste panel measurements of tenderness, juiciness, flavour and acceptability were performed by panels composed of staff from the Tropical Beef Centre who attended an initiation program aimed at raising their awareness of sensory attributes of food. Tasters were compared using standard samples and outliers were removed from the taste panel. Tasting was done during three sessions, before lunch, in 8 booths, under green lights in an air conditioned environment. Four, 1 cm cube samples with tooth picks inserted for handling and to indicate the direction of muscle fibres, were presented on aluminium trays labelled with four positions; A, B, C and D. Statistical analyses of the training results showed that there were no effects due to session, booth or sample position. For each session, 8 frozen steaks were moist roasted in a Rational CM6 oven (Rational, Landsberg/Lech, Germany) to an internal temperature of 70°C. Cubes were cut from the steaks and randomly served to panellists while warm. Each steak was tasted four times by four different panellists. The

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[1] Harris, P.V. and Shorthose, W.R. (1988). Meat texture. In “Developments in meat science”. Ed. R. Laurie. pp. 245-295. Elsevier Applied Science: London.

[2] Culler *et al.* (1978). Relationship of myofibril fragmentation index to certain chemical, physical and sensory characteristics of bovine longissimus dorsi. *J. Food Science* **43**, 1177.

[3] Hill, F. (1966). The solubility of intramuscular collagen in meat animals of various ages. *J. Food Science* **31**, 161-166.

panellists recorded results on sheets provided (sample enclosed) by marking a position on a 100 mm scale. The distance of the mark from the low value end of the line was measured and the median of the four evaluations was taken as the result for the sample[4].

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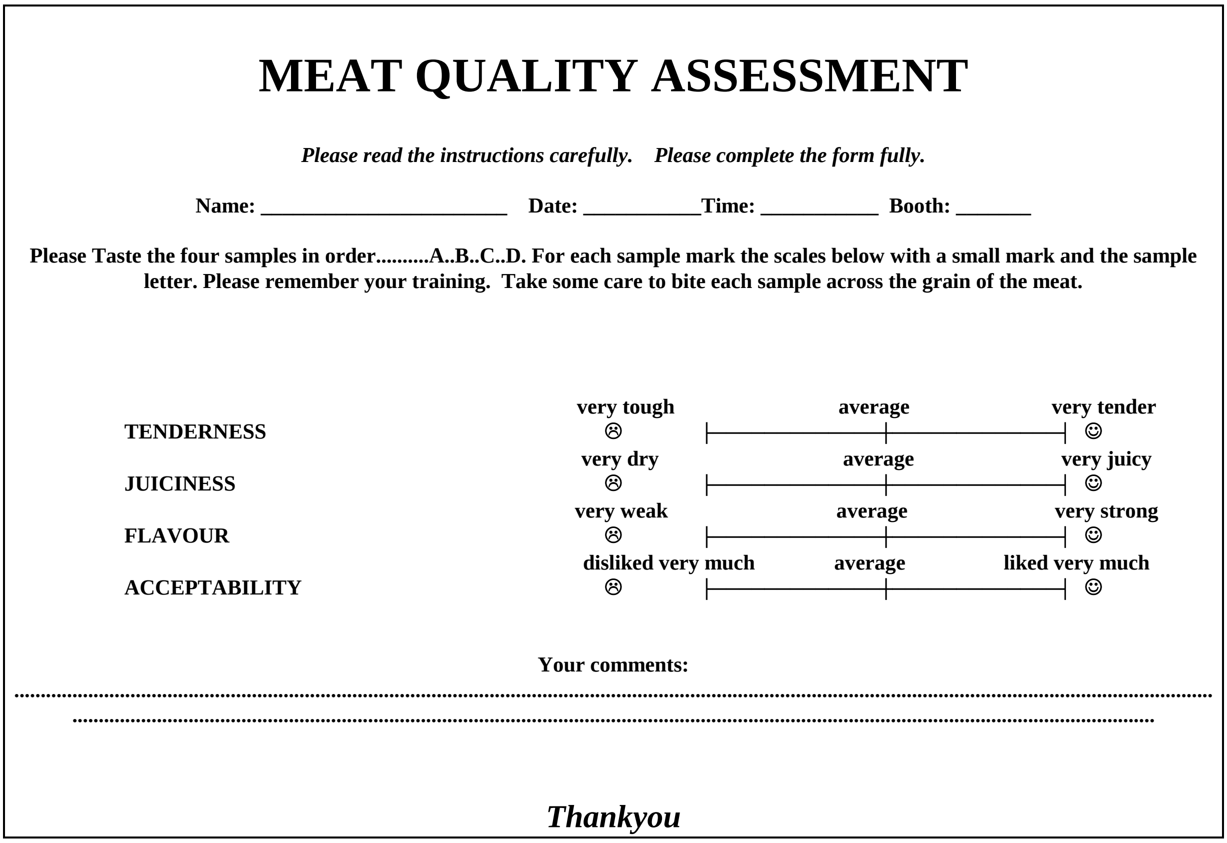

MEAT QUALITY ASSESSMENT

Please read the instructions carefully.   Please complete the form fully.

Name: ______________________   Date: __________Time: __________ Booth: _______

Please Taste the four samples in order..........A..B..C..D. For each sample mark the scales below with a small mark and the sample letter. Please remember your training. Take some care to bite each sample across the grain of the meat.

	very tough		**average**	**very tender**
TENDERNESS	☹	├──────────┼──────────┤		☺
	very dry		**average**	**very juicy**
JUICINESS	☹	├──────────┼──────────┤		☺
	very weak		**average**	**very strong**
FLAVOUR	☹	├──────────┼──────────┤		☺
	disliked very much		**average**	**liked very much**
ACCEPTABILITY	☹	├──────────┼──────────┤		☺

Your comments:

....

....

Thankyou

3.4 Analysis

Data were analysed using the general linear regression model of the SAS program (SAS Institute Inc, Cary, NC, USA). After preliminary analyses, which showed no effects due to TREATMENT and most interactions, a model consisting of the main effects, BREED, FINISH and AGE and the interactions, BREED x FINISH and FINISH x AGE was used throughout. Although it may be expected on biological grounds that some covariates, for example ADG, may have had effects on carcase attributes or eating quality measures, this experimental design resulted in all such factors being confounded with effects such as FINISH. Therefore only the model mentioned above was valid except in the case of the analysis of ageing where PF_{24} and pH_u were each independently affected by the ageing process. AGE and FINISH are confounded to some extent but subsets of data were found where this was not so and these were analysed for effects of one independent of the other. Due to this confounding and the unbalanced nature of the data collected from this project, the results of most measurements could not be analysed in a straight forward manner.

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[4] Dean, R.B. and Dixon, W. J. (1951). Simplified statistics for small numbers of observations. *Analytical Chemistry* **23**, 636-638.

Consequently, data were selected and analysed in such a way that specific questions could be answered using reliable subsets of the total data bank.

Generally speaking there were insufficient numbers of animals of each of the pure bred and cross bred types to analyse each breed individually. Therefore breeds were grouped as pure *Bos taurus* breeds which included Belmont Adaptaurs and Belmont Reds and Tuli crosses, pure *Bos indicus* which comprised Brahmans and Boran-Brahman crosses, first crosses which included all the first crosses between the named breeds except for the Boran-Tuli cross, and *indicus* cross which included the Belmont Brahman cross and back crosses of the named breeds so that these animals had between 1/4 and 3/4 indicus content. Aggregation of breeds into breed-groups is likely to have reduced the differences between individual breeds for most variables. This must be considered when interpreting the current results.

Age at slaughter was classified into age three main age groups, 2.0-2.5 years, 2.5-3.0 years and >3.0 years. The middle group, 2.5-3.0 years was further divided into three classes, <940 days, 940-980 days and >980 days. Liveweight was also classified into three groups, <550 kg, 550-650 kg and >650 kg.

For analysis of the effects of breed and environment on carcase attributes and eating quality, a subset of data comprising 68 steers was selected. These steers were all in the middle AGE and LWT classes (2.5-3.0 years and 550-650 kg). These data were reasonably balanced with respect to breed, finish, treatment and age (Tables 3.1-3.6).

For analysis of the effects of breed and environment on the ageing of striploin, the results from samples from 213 steers were analysed. These were the steers from which both a 24 hour frozen sample of striploin and an 8 day aged sample of striploin were collected. Since only a very small number, <6 depending on which group of samples was analysed, of samples were stressed or cold shortened, samples which had a pH >5.8, indicating stress, or a sarcomere length <1.6μm for striploin and <2.2μm for eye round, indicating cold shortening, were removed. Peak force at 24 hours after slaughter was classified into four PF_{24} classes such that $PF<4$, $4 \leq PF<5$, $5 \leq PF<6$, $6 \leq PF$. pH was also divided into classes (pH_u) so that $pH<5.60$, $5.60 \leq pH<5.65$, $5.65 \leq pH<5.70$, $5.70 \leq pH$.

Table 3.1. Counts of BREED and FINISH

	FINISH		
BREED	Feedlot	Pasture	Total
TT	10	5	15
F1	4	10	14
IX	6	24	30
II	4	5	9
Total	24	44	68

Table 3.2. Counts of BREED and TREATMENT

	TREATMENT		
BREED	Control	Treated	Total
TT	6	9	15
F1	7	7	14
IX	17	13	30
II	3	6	9
Total	33	35	68

Table 3.3. Counts of BREED and AGE

BREED	AGE <940 days	 940-980	 >980 days	Total
TT	3	6	6	15
F1	5	2	7	14
IX	15	8	7	30
II	3	3	3	9
Total	26	19	23	68

Table 3.4. Counts of FINISH and AGE

FINISH	AGE <940 days	 940-980	 >980 days	Total
Feedlot	12	8	4	24
Pasture	14	11	19	44
Total	26	19	23	68

Table 3.5. Counts of TREATMENT and AGE

TREATMENT	AGE <940 days	 940-980	 >980 days	Total
Control	14	9	10	33
Treated	12	10	13	35
Total	26	19	23	68

Table 3.6. Counts of FINISH and TREATMENT

FINISH	TREATMENT Control	 Treated	Total
Feedlot	12	12	24
Pasture	21	23	44
Total	33	35	68

4. Effects of Breed and Environment on the Carcase Attributes of 2.5-3.0 year-old Japanese Ox Steers

4.1 Effects of BREED on growth and carcase attributes

Analysis of the effects of BREED, FINISH, TREATMENT and their interactions, produced no significant effect due to BREED on LWT, HCWT, ADG, REMA, MARB, P8FAT, RFAT or IMFAT (Table 4.1). The data show trends towards expected effects such as increased dressing percentage for indicus steers and higher growth rates for first cross steers but these trends were small compared to the very large differences due to environmental factors such as finish. A larger number of animals, to be produced in the second phase of this project, could make these trends statistically significant.

Table 4.1. Effects of BREED during finishing (MEANS (Standard Errors)

	BREED			
	TT	**F1**	**IX**	**II**
LWT (kg)	607 (5)	607 (5)	609 (4)	601 (6)
HCWT (kg)	310 (3)	317 (4)	320 (3)	321 (4)
ADG (kg/day)	0.71 (0.08)	0.80 (0.08)	0.67 (0.06)	0.76 (0.10)
REMA (cm^2)	69 (3)	77 (3)	74 (2)	68 (3)
MARB (score)	1.8 (0.1)	1.7 (0.1)	1.6 (0.1)	1.7 (0.1)
P8FAT (mm)	14 (1)	15 (1)	16 (1)	15 (2)
RFAT (mm)	8.4 (0.9)	11.1 (1.0)	10.6 (0.7)	10.4 (1.1)
IMFAT (%)	2.2 (0.3)	2.2 (0.3)	2.5 (0.2)	2.4 (0.3)

4.2 Environmental effects on growth during finishing

Since the experimental design was to produce steers for the Japanese ox market (ie. all finished to a liveweight of about 620 kg), it was expected that LWT would be independent of FINISH (Table 4.2) and TREATMENT (Table 4.3). However because of the need to slaughter animals in drafts of 22 or 42 steers, an artefact seen in Table 4.4 was produced. It can be seen that the older animals have a lower LWT than the younger, earlier turnoff animals. This is due to the slower growing animals or stragglers being left for the later drafts. Feedlot finished steers had less gut fill and more fat content than pasture finished steers resulting in higher HCWT for the same LWT (ie. dressing percentages were higher). There were no significant effects on REMA.

ADG, which was the average daily gain during the last month of finishing, was higher for untreated animals (Con) than for treated animals (Trt). This, and an associated effect on fat deposition, were the only effects due to treatment seen in the whole study. The effect of TREATMENT on ADG suggests that the untreated animals were undergoing compensatory growth during finishing. As expected ADG was much higher in the feedlot compared to pasture. There was also an effect of AGE on ADG (Table 4.4) but only in the pasture finished steers (Table 4.5). This was simply related to the slower growing animals taking longer to finish at pasture with the differences between animals being minimized in the feedlot.

Table 4.2. Effects of FINISH on growth during finishing

	FINISH		
	Feedlot	**Pasture**	**significance**
LWT (kg)	606 (4)	606 (3)	NS
HCWT (kg)	322 (3)	311 (2)	0.006
ADG (kg/day)	1.17 (0.07)	0.30 (0.05)	<0.0001
REMA (cm^2)	74 (2)	70 (3)	NS

Table 4.3. Effects of TREATMENT on growth during finishing

	TREATMENT		
	Con	**Trt**	**significance**
LWT (kg)	605 (3)	607 (3)	NS
HCWT (kg)	315 (2)	319 (2)	NS
ADG (kg/day)	0.81 (0.06)	0.66 (0.05)	0.04
REMA (cm^2)	71 (2)	72 (2)	NS

Table 4.4. Effects of AGE on growth during finishing

	AGE (days)			
	<940	**940-980**	**>980**	**significance**
LWT (kg)	612 (4)	607 (4)	599 (4)	a,ab,b
HCWT (kg)	319 (3)	317 (3)	315 (3)	NS
ADG (kg/day)	0.75 (0.07)	0.91 (0.08)	0.28 (0.08)	a,a,b
REMA (cm^2)	71 (2)	74 (2)	71 (2)	NS

Different letters beside rows indicate significant differences within the row in the pattern indicated. Significant differences by LSD method, P<0.05. NS, no significant differences.

Table 4.5. Effects of FINISH x AGE on ADG (kg/day)

	AGE (days)			
FINISH	**<940**	**940-980**	**>980**	**significance**
Feedlot	0.97 (0.08)	1.23 (0.10)	1.30 (0.15)	NS
Pasture	0.50 (0.08)	0.61 (0.09)	-0.21 (0.07)	a,a,b
significance	a,b	a,b	a,b	

Different letters beside rows indicate significant differences within the row in the pattern indicated. Different letters below columns indicate significant differences within the column in the pattern indicated (top to bottom). Significant differences by LSD method, P<0.05. NS, no significant differences.

4.3 Environmental effects on fat deposition

For these animals of similar age and mature size, the main factor determining fatness was the method of finishing. Feedlot finished animals had more intramuscular fat (MARB, IMFAT) and subcutaneous fat (P8FAT, RFAT) than pasture finished animals (Table 4.6).

Untreated animals which were undergoing compensatory growth during finishing deposited less rump fat than treated animals but there were no differences in the other fat depots (Table 4.7). This could be a useful strategy for enhancing marbling over rump fat deposition.

Within the age range of 2.5-3.0 years there was no effect of AGE on fat deposition (Table 4.8).

Table 4.6. Effects of FINISH on fat deposition

	FINISH		
	Feedlot	**Pasture**	**significance**
MARB (score)	1.87 (0.10)	1.48 (0.08)	0.006
IMFAT (%)	3.1 (0.2)	1.6 (0.2)	<0.0001
P8FAT (mm)	18.4 (1.0)	11.8 (0.8)	<0.0001
RFAT (mm)	11.7 (0.7)	8.6 (0.6)	0.002

Table 4.7. Effects of TREATMENT on fat deposition

	TREATMENT		
	Con	**Trt**	**significance**
MARB (score)	1.68 (0.09)	1.68 (0.08)	NS
IMFAT (%)	2.4 (0.2)	2.3 (0.2)	NS
P8FAT (mm)	13.8 (0.9)	16.4 (0.8)	0.03
RFAT (mm)	10.4 (0.6)	9.9 (0.6)	NS

Table 4.8. Effects of AGE on fat deposition

		AGE (days)		
	<940	**940-980**	**>980**	**significance**
MARB (score)	1.60 (0.10)	1.73 (0.11)	1.70 (0.11)	NS
IMFAT (%)	2.3 (0.2)	2.4 (0.3)	2.3 (0.2)	NS
P8FAT (mm)	15.2 (1.0)	15.3 (1.1)	14.8 (1.1)	NS
RFAT (mm)	9.8 (0.7)	11.4 (0.8)	9.2 (0.8)	NS

Different letters beside rows indicate significant differences within the row in the pattern indicated. Significant differences by LSD method, P<0.05. NS, no significant differences.

5. Effects of Breed and Environment on the Eating Quality of 2.5-3.0 year-old Japanese Ox Steers

5.1 Results

Measurements of eating quality attributes on the balanced subset of data described above were analysed using a model containing the main effects, AGE, FINISH and BREED and the interactions BREED x FINISH and FINISH x AGE. The interaction between breed and finish was not significant in any instance but was retained in the model because the original experimental design incorporated the idea that feedlot finish would allow animals to more fully express their genetic potential while the pasture finished animals would more closely demonstrate the interaction between environment and genetics. In terms of eating quality attributes, breeds ranked similarly irrespective of the finish used.

It should be noted that when a small number of animals which had been stressed or cold shortened were removed from the analysis, all meat samples were of "acceptable" eating quality according to the commonly used Australian standard for acceptability which is a peak force less than 6. However, if one uses a more stringent standard such as a value of PF<4.1 which is the value which provides for a 98% satisfaction rating in Texan (USA) restaurants[5], then breed differences emerge. The major interest is not the mean peak force but rather the proportion of samples which fall into the 'acceptable' or 'unacceptable' categories. These questions will be answered after analysis of further samples from phase two of the project.

AGE produced some significant effects (Table 5.1 and 5.2). It should be remembered that the total age range here is only 2.5-3.0 years (912 -1095 days). Therefore, differences due to age were detected when the age difference between animals was as short as 1-2 months. For striploin, there were no detectable differences due to age in the objective force measurements (PF, IY, PFIY, IC). However, panellists rated the younger animals less tender than older animals which was surprising. Their ranking of juiciness was similar, though not significant. Acceptability followed a similar pattern. An explanation can be seen in the cooking loss result where the younger animals had a greater cooking loss thus indicating that panellists were sensitive to the juiciness of the meat when rating tenderness. Alternatively, there may have been an actual increase in toughness in the younger animals which was perceptible to panellists and was due to increased connective-tissue related shrinkage in these samples during cooking. While the perception of panellists was one of decreased toughness with age, the result using MFI, the only measurement taken on uncooked meat, indicates that in fact, the older animals were the toughest before cooking.

The eye round results, where significant, showed an increase in toughness with age. This trend, usually attributed to increases in collagen crosslinking with increasing age, was apparent in all measurements including IY which is normally regarded as a measurement of myofibrillar toughness. PFIY, normally associated with connective tissue toughness, showed no difference with age. However both these measures produced an AGE x FINISH interaction (Table 5.3). IY increased with age in the feedlot but not at pasture while PFIY increased at pasture but not the feedlot. The explanation for these results is not known but

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[5] Huffman, K.L. *et al.* (1996). Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. *J. Animal Science* **74**, 91-97.

may be related to the rate of growth during finishing or the level of physical activity during finishing. These effects may act through changes in muscle fibre type or increased load bearing connective tissue (see comment on MFI below). If the perceptions of human consumers disproportionately emphasise the connective tissue component of meat then these results may point to a reason why feedlot finished meat is preferred by consumers.

The only other significant effect of finish was on the MFI of striploin. Feedlot finished samples were tougher than pasture finished samples by this measure ($P<0.0005$). The mean (standard error) for feedlot finished samples was 106 (7) and for pasture finished samples, 140 (5). The significance of this result is not understood but it may indicate the promotion of different fibre types during the finishing phase.

In general terms, objective measurements of overall tenderness and of the myofibrillar component of tenderness in striploin consistently demonstrated Bos taurus breeds to be more tender than Bos indicus breeds, with crosses being intermediate and first crosses demonstrating no heterosis. Consumers however did not detect these differences. These outcomes are consistent with conclusion already drawn that consumers were biased towards the connective tissue component of toughness. The objective measurement PFIY had the reverse trend to the myofibrillar measurements with Bos indicus being the least tough.

Results obtained for striploin are detailed in Table 5.4. Apart from one, possibly spurious, result for juiciness of the F1 type, panellists did not detect any differences between breeds. PF, IY, IC and MFI consistently placed TT as the most tender and II as the toughest with F1 and IX, intermediate and equal. PFIY which measures the connective tissue component of toughness gave the reverse trend. Cooking loss measurements also found the same pattern with Bos taurus meat losing least during cooking.

The eye round results enphasize the difference between the myofibrillar component and the connective tissue component even more. There were no differences between breeds in PF, IC or ADH which measure overall toughness but IY found TT as most tender while PFIY found TT most tough.

The contribution of connective tissue to toughness is a matter of some interest since American scientists tend to dismiss its importance. In striploin, using Warner-Bratzler forces as the measure, PFIY was 19-33% of the total force and in eye round which has a higher content of connective tissue, PFIY was 25-38% of the total force depending on breed. These were not insignificant contributions to the total force and if as indicated above, consumers disproportionately emphasise the connective tissue component of meat, then connective tissue is worthy of further study.

Table 5.1. Effect of AGE on Eating Quality Attributes of Aged Striploin

AGE	Sensory Panel Scores Tenderness	Juiciness	Flavour	Acceptability	Peak Force (kg)	Initial Yield (kg)	PF-IY (kg)	Instron Compression (kg)	MFI	Cooking Loss (%)
<940 days	52 (3)	55 (3)	57 (2)	54 (3)	4.3 (0.2)	3.3 (0.2)	1.0 (0.1)	2.22 (0.06)	138 (6)	31.6 (0.3)
940-980 days	65 (3)	61 (3)	64 (2)	66 (3)	4.4 (0.2)	3.3 (0.2)	1.1 (0.1)	2.09 (0.06)	126 (7)	30.0 (0.4)
>980 days	62 (4)	59 (4)	62 (3)	60 (2)	4.4 (0.2)	3.3 (0.2)	1.2 (0.1)	2.13 (0.09)	105 (9)	29.9 (0.5)
significance	a,b,ab	NS	a,b,ab	a,b,ab	NS	NS	NS	NS	a,ab,b	a,b,b

Means (Standard Errors). Different letters below columns indicate significant differences within the column in the pattern indicated (top to bottom). Significant differences; P<0.05. NS; no significant differences. Panel scores range from 0 - 100 with 0 indicating low levels of the attribute. PF-IY is the difference between peak force and initial yield. MFI is myofibrillar fragmentation index.

Table 5.2. Effect of AGE on Eating Quality Attributes of Unaged Eye Round

AGE	Peak Force (kg)	Initial Yield (kg)	PF-IY (kg)	Instron Compression (kg)	Adhesion (kg)
<940 days	5.6 (0.2)	3.7 (0.1)	1.9 (0.2)	2.46 (0.06)	0.62 (0.03)
940-980 days	6.1 (0.2)	4.2 (0.1)	1.9 (0.2)	2.53 (0.06)	0.65 (0.04)
>980 days	6.5 (0.2)	4.6 (0.2)	1.9 (0.2)	2.82 (0.09)	0.64 (0.05)
significance	a,b,b	a,b,b	NS	a,a,b	NS

Means (Standard Errors). Different letters below columns indicate significant differences within the column in the pattern indicated (top to bottom). Significant differences; P<0.05. NS; no significant differences. PF-IY is the difference between peak force and initial yield.

Table 5.3. Effect of AGE and FINISH on IY and PFIY of Unaged Eye Round

	Initial Yield (kg)		PFIY (kg)	
AGE	Feedlot	Pasture	Feedlot	Pasture
<940 days	3.5 (0.2)	3.9 (0.2)	2.1 (0.2)	1.6 (0.2)
940-980 days	4.3 (0.2)	4.2 (0.2)	1.8 (0.3)	2.0 (0.2)
>980 days	5.2 (0.3)	4.0 (0.1)	1.4 (0.4)	2.4 (0.2)
significance	a,b,c	NS	NS	a,ab,b

Means (Standard Errors). Different letters below columns indicate significant differences within the column in the pattern indicated (top to bottom). Significant differences; $P<0.05$. NS; no significant differences. PF-IY is the difference between peak force and initial yield.

Table 5.4. Effect of BREED on Eating Quality Attributes of Aged Striploin

	Sensory Panel Scores									
Breed	Tenderness	Juiciness	Flavour	Acceptability	Peak Force (kg)	Initial Yield (kg)	PF-IY (kg)	Instron Compression (kg)	MFI	Cooking Loss (%)
pure taurus(TT)	61 (4)	60 (4)	63 (3)	60 (3)	4.0 (0.2)	2.7 (0.2)	1.3 (0.1)	2.09 (0.07)	140 (8)	30.1 (0.4)
first cross(F1)	59 (4)	51 (4)	61 (3)	59 (4)	4.4 (0.2)	3.3 (0.2)	1.1 (0.1)	2.07 (0.08)	117 (9)	30.3 (0.5)
indicus cross(IX)	61 (3)	61 (3)	62 (3)	61 (3)	4.4 (0.2)	3.3 (0.2)	1.1 (0.1)	2.09 (0.07)	123 (7)	30.2 (0.4)
pure indicus(II)	57 (5)	61 (5)	58 (4)	60 (4)	4.7 (0.2)	3.8 (0.3)	0.9 (0.2)	2.34 (0.09)	112 (10)	31.5 (0.5)
significance	NS	ab,a,b,ab	NS	NS	a,a,a,b	a,b,b,b	a,b,b,b	a,a,a,b	a,ab,ab,b	a,ab,a,b

Means (Standard Errors). Different letters below columns indicate significant differences within the column in the pattern indicated (top to bottom). Significant differences; $P<0.05$. NS; no significant differences. Panel scores range from 0 - 100 with 0 indicating low levels of the attribute. PF-IY is the difference between peak force and initial yield. MFI is myofibrillar fragmentation index.

Table 5.5. Effect of BREED on Eating Quality Attributes of Unaged Eye Round

Breed	Peak Force (kg)	Initial Yield (kg)	PF-IY (kg)	Instron Compression (kg)	Adhesion (kg)
pure taurus(TT)	6.0 (0.2)	3.7 (0.1)	2.3 (0.2)	2.49 (0.07)	0.60 (0.04)
first cross(F1)	6.0 (0.2)	4.2 (0.2)	1.8 (0.2)	2.64 (0.08)	0.63 (0.05)
indicus cross(IX)	5.9 (0.2)	4.1 (0.1)	1.8 (0.2)	2.65 (0.07)	0.66 (0.04)
pure indicus(II)	6.4 (0.2)	4.7 (0.2)	1.6 (0.3)	2.62 (0.09)	0.67 (0.06)
significance	NS	a,b,ab,c	a,b,b,b	NS	NS

Means (Standard Errors). Different letters below columns indicate significant differences within the column in the pattern indicated (top to bottom). Significant differences; $P<0.05$. NS; no significant differences. PF-IY is the difference between peak force and initial yield.

6. Effects of Breed and Environment on the Ageing of Striploin

6.1 Results

All of the eating quality attributes which were measured changed with ageing (Table 6.1). PF, IY and IC all decreased; indicating a tenderization due to ageing. However PFIY increased; indicating a rise in the connective tissue contribution to toughness. This increase in connective tissue related toughness may have been associated with a rise in CL which was also observed. There were increases in all the light reflectance factors indicating that ageing caused an increased disruption to the myofibrillar structure; ie. tenderization.

Table 6.1. Changes in striploin attributes due to ageing

	Unaged sample (frozen at 24 hr)	**Aged sample (8 days at 6°C)**	**significance**
PF (kg)	5.28 (0.08)	4.65 (0.07)	<0.01
IY (kg)	4.63 (0.07)	3.65 (0.07)	<0.0001
PFIY (kg)	0.65 (0.03)	1.00 (0.03)	<0.0001
IC (kg)	2.39 (0.02)	2.16 (0.02)	<0.0001
CL (%)	30.1 (0.1)	31.1 (0.1)	<0.0001
L (lightness)	33.9 (0.2)	36.4 (0.20	<0.0001
a (redness)	20.3 (0.2)	21.5 (0.2)	<0.0001
b (yellowness)	8.3 (0.2)	9.7 (0.2)	<0.0001

The changes due to ageing for each attribute were calculated as the differences in values for the paired unaged and aged samples. Preliminary analyses indicated that there were no effects on any changes due to TREATMENT or any of the LWT-related factors. There were no significant effects on any of the light reflectance measures (L, a, b) and none on PFIY, possibly due to the large coefficient of variation of this calculated variable. BREED was not a significant factor for any changes during ageing but was retained in the model because of the interest in breed effects on ageing. Therefore the model which was applied to all changes due to ageing was composed of the main effects; BREED, AGE, PF_{24}, and pH_u. It was found that if either PF_{24} or pH_u were removed from the model then there were significant effects due to BREED. If either of these classes was confounded with BREED then BREED could not be excluded as a possible cause of the variation in changes due to ageing between individuals. Table 6.2 shows that the distributions of BREED within each PF_{24} and pH_u class corresponds reasonably well to the overall distribution of all breeds within PF_{24} and pH_u classes. Therefore all effects on ageing which might be attributed to BREED were accounted for by effects due to these other factors.

Table 6.2. Distribution of steers of each BREED type within PF_{24} and pH_u classes

	pH_u class				PF_{24} class			
BREED	1	2	3	4	1	2	3	4
TT	9	11	3	4	7	12	6	1
F1	17	33	12	4	6	22	26	10
IX	22	37	21	8	6	27	35	21
II	5	11	9	7	3	5	15	11
All Breeds	53	92	45	23	22	66	82	43

pH_u classes 1, 2, 3 and 4 correspond to $pH<5.60$, $5.60 \le pH<5.65$, $5.65 \le pH<5.70$, $5.70 \le pH$ respectively. PF_{24} classes 1, 2, 3 and 4 correspond to $PF<4$, $4 \le PF<5$, $5 \le PF<6$, $6 \le PF$.

6.2 Effects on Warner-Bratzler measurements

Changes in PF and IY occurring during ageing showed effects due to AGE ($P<0.03$ and $P<0.04$ respectively) and PF_{24} ($P<0.0001$ in both cases). IY also showed an effect of pH_u ($p<0.02$). Quantitatively the effects on the two variables indicate that the primary effect is on IY since the change in IY is greater than that for PF even though IY is a component of PF. The residual change in force is seen as an increase in PFIY. Since IY represents the contribution of myofibrils to toughness the conclusion drawn here is that there was a reduction in myofibrillar toughness due to ageing and an increase in the relative contribution of connective tissue toughness after ageing. The latter effect is discussed in the next section.

The effect of AGE on Warner-Bratzler forces (Table 6.3) was that the meat from younger animals aged more than that from older animals. This difference was totally within the myofibrillar component of toughness. It suggests that younger animals have higher levels of ageing-related enzymes or lower levels of inhibitors.

PF_{24} was the major determinant of degree of ageing. The higher the rigor toughness the more myofibrillar tenderization occurred post rigor (Table 6.4). This was best demonstrated by the IY results since the PF changes also included a opposing trend in connective tissue toughness (PFIY). Changes related to pH_u were more complex. Myofibrillar changes increased with increasing pH_u as might be expected from the pH dependency of ageing enzymes (Calpain is most active at neutral pH).

Table 6.3. Effect of AGE on Warner-Bratzler forces

Age	**Change in peak force (kg)**	**Change in initial yield (kg)**	**Change in PF-IY (kg)**
2.0 to 2.5 years	-0.85	-1.18	+0.32
2.5 to 3.0 years	-0.60	-1.04	+0.41
> 3.0 years	-0.49	-0.85	+0.38
significance	a,b,b	a,b,b	NS

Different letters below columns indicate significant differences within the column in the pattern indicated (top to bottom). Significant differences by LSD method, $P<0.05$. NS, no significant differences.

Table 6.4. Effect of PF_{24} on Warner-Bratzler forces

PF_{24}	Change in peak force (kg)	Change in initial yield (kg)	Change in PF-IY (kg)
PF<4	+0.17	-0.58	+0.71
4≤PF<5	-0.39	-0.81	+0.41
5≤PF<6	-0.93	-1.17	+0.25
6≤PF	-1.44	-1.54	+0.10
significance	a,b,c,d	a,a,b,c	a,b,bc,c

Different letters below columns indicate significant differences within the column in the pattern indicated (top to bottom). Significant differences by LSD method, P<0.05. NS, no significant differences.

Table 6.5. Effect of pH_u on Warner-Bratzler forces

pH_u	Change in peak force (kg)	Change in initial yield (kg)	Change in PF-IY (kg)
pH<5.60	-0.68	-0.90	+0.25
5.60≤pH<5.65	-0.54	-0.93	+0.37
5.65≤pH<5.70	-0.77	-1.29	+0.48
5.70≤pH	-0.60	-0.98	+0.36
significance	NS	a,a,b,b	a,a,b,a

Different letters below columns indicate significant differences within the column in the pattern indicated (top to bottom). Significant differences by LSD method, P<0.05. NS, no significant differences.

6.3 Effects on Instron compression and cooking loss

AGE was the significant main effect for IC and CL (P<0.0002 and P<0.0001 respectively). Samples from older animals improved considerably more than those from younger animals with respect to IC (Table 6.6). A matching trend is seen in CL with younger animals suffering more cooking loss than older animals.

Table 6.6. Effect of AGE on IC and CL

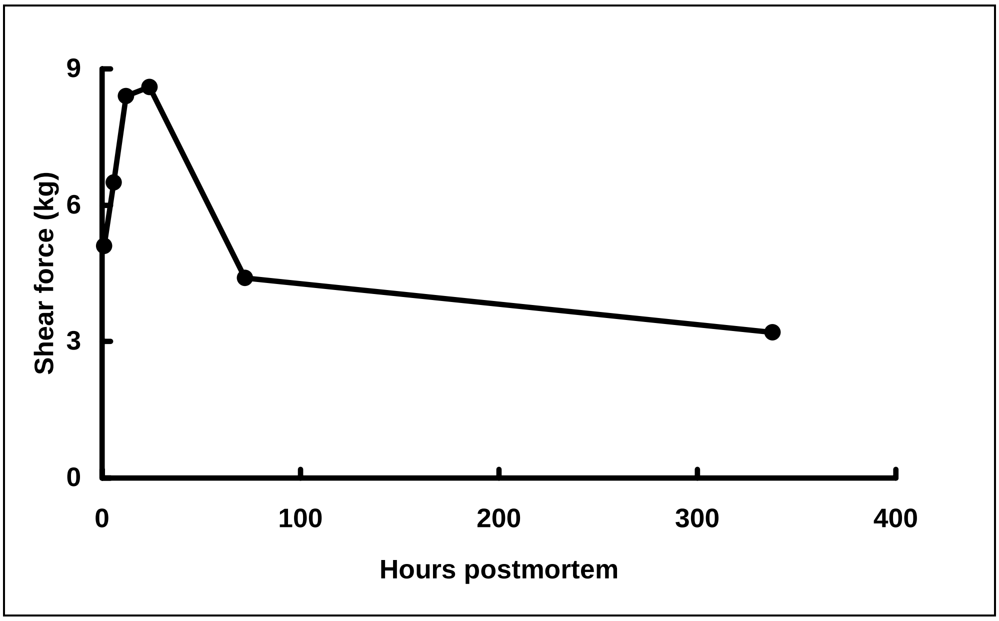
Age	Change in IC (kg)	Change in CL (%)
2.0 to 2.5 years	-0.130	+2.41
2.5 to 3.0 years	-0.168	+0.76
> 3.0 years	-0.320	+0.83
significance	a,a,b	a,b,b

Different letters below columns indicate significant differences within the column in the pattern indicated (top to bottom). Significant differences by LSD method, P<0.05. NS, no significant differences.

6.4 Discussion

Changes in toughness after slaughter without electrical stimulation are classically depicted as progressing through a postmortem peak at about 24 hours followed by a reduction which is substantially complete by 72 hours as shown by a plot of data for sheep taken from a publication by Koohmaraie *et al.* at the Clay Centre, USA (Figure 6.1)[6].

Figure 6.1 Change in shear force post mortem



Koohmaraie has suggested that the factor controlling the ageing response is the level of the calpain inhibitor, calpastatin. This conclusion fits well with ideas regarding breed differences in ageing ability since the level of calpastatin is known to differ between breeds. However no breed differences were found in the present study and Koohmaraie's own data show that any individual differences can be overcome by the infusion of calcium. This suggests that the limiting factor is the availability of calcium and no breed differences have been demonstrated for this component of the system. Detailed observations of individual meat samples show a more complicated picture than the average result shown above (Koohmaraie *et al.*[7], Figure 6.2)

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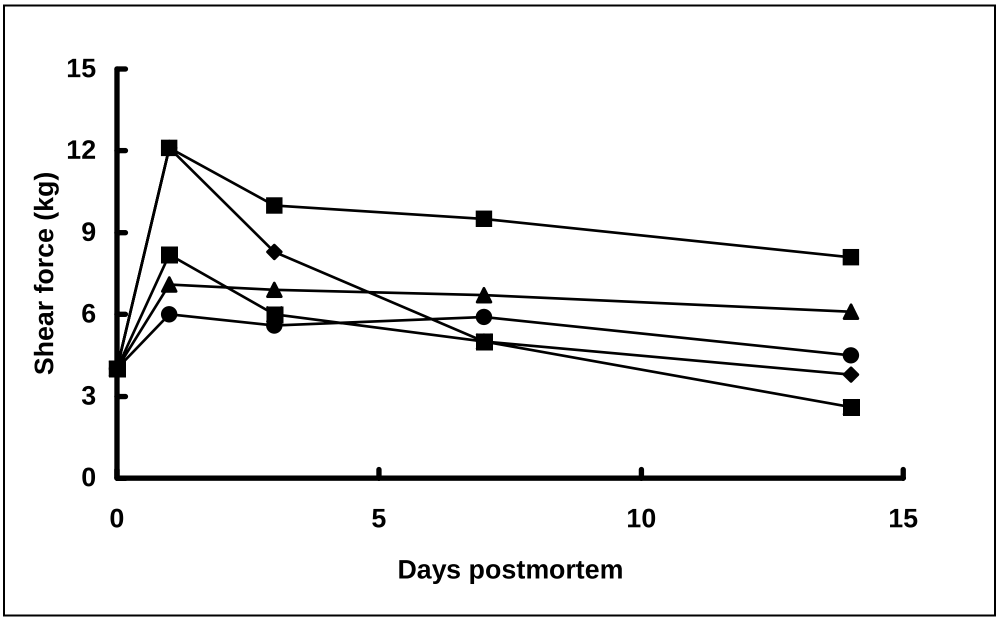
[6] Taylor *et al.* (1995). Is Z-disc degradation responsible for postmortem tenderization. *J. Animal Science* **73**, 1351-1367.

[7] Koohmaraie *et al.* (1995). Beef tenderness: Regulation and prediction. *Proceedings Meat'95*, pp.4A1-4A10, CSIRO, Australia.

Figure 6.2 Change in shear force post mortem for individual samples



It is not known what factors control free calcium levels in meat. Electrical stimulation would be expected to release calcium from within muscle structures so that it is available to activate calpain. Therefore factors related to events during rigor and to electrical stimulation are possibly more relevant to the ageing process than breed. This view was supported by the results presented here. Note that in 4/5 examples shown by Koohmaraie in Figure 6.2 it is also true that the degree of ageing depended on PF_{24}. An additional finding in the present experiment was that by some measures, notably those that correspond most closely to the myofibrillar component, IY and PF, younger animals aged more than older animals. Further research would need to establish whether these animals had higher enzyme activity or more free calcium to produce this effect.

Changes in the connective tissue component of toughness during ageing are not widely recognized. PFIY increased with ageing in parallel with rises in cooking loss. Increased IC changes in older animals correspond to a lower rise in cooking loss. IC measures both myofibrillar toughness and connective tissue toughness but is more biased towards the connective tissue component than PF. These observation could be explained by a decreased water holding capacity during ageing reflected as a decreased resistance to shrinkage during cooking. Therefore aged meat would be drier than unaged meat and would, in terms of the connective tissue component be tougher, because the shrinkage would concentrate the connective tissue. Perhaps the degree of crosslinkage of the connective tissue, an age related factor, determines the degree to which the connective tissue will shrink and therefore determine the degree of toughness produced and the amount of cooking loss which results. Nevertheless, because the major contributor to meat toughness is the myofibrillar component, the predominant effect of ageing is the well recognized tenderization which occurs.

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3.15.4 Adminstrative Details Report

CS183 : Maximising heterotic advantage using systematic crossbreeding

EQUITY POSITION

	92/93	**93/94**	**94/95**	**95/96**	**TOTAL**	**PERCENT**
CSIRO	$98019	$99583	$103085	0	$300687	68.23
MRC	$29000	$39000	$42000	$30000	$140000	31.77
TOTAL	$127019	$138583	$145085	$30000	$440687	100.00

Ratio of Investment per year

CSIRO	77.17%	71.86%	71.05%	0.00%	68.23%
MRC	22.83%	28.14%	28.95%	100.00%	31.77%

Intellectual Property Arising - Nil

Commercial Exploitation of the Project - Report on Progress - Nil