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Breeding objectives of Brangus cattle in Brazil

Michele R. S. Simões[1] | **Joal J. B. Leal**[2] | **Alessandro P. Minho**[3] | **Cláudia C. Gomes**[2] | **Michael D. MacNeil**[4,5] | **Rodrigo F. Costa**[1] | **Vinícius S. Junqueira**[6] | **Patrícia I. Schmidt**[7] | **Fernando F. Cardoso**[2] | **Arione A. Boligon**[7] | **Marcos J. Yokoo**[2]

[1]Postgraduate Program in Animal Husbandry – UFPEL, CAPES, Pelotas, Brazil

[2]Embrapa South Livestock, Center of Livestock Research of South Brazilian Fields (CPPSul), Brazilian Agricultural Research Corporation, Ministry of Agriculture, Livestock and Food Supply, Bagé, Brazil

[3]Embrapa Southeast Livestock (CPPSE), Brazilian Agricultural Research Corporation, Ministry of Agriculture, Livestock and Food Supply, São Carlos, Brazil

[4]Delta G, Miles City, Montana

[5]Department of Animal, Wildlife and Grassland Sciences, University of the Free State, Bloemfontein, South Africa

[6]Postgraduate Program in Genetics and Improvement by the Federal University of Viçosa, Viçosa, Brazil

[7]Animal Husbandry Department – UFPEL, Pelotas, Brazil

Correspondence
Michele R. S. Simões, Postgraduate Program in Animal Husbandry – UFPEL, CAPES, Pelotas, RS, Brazil.
Email: michelescholantsimoes@gmail.com

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Abstract

Our goal was to define a breeding objective for Brangus beef cattle in Brazil. Bioeconomic models were produced and used to estimate economic values (EVs). The scenarios simulated were typical full-cycle beef production systems that are used in tropical and subtropical regions. The breeding objective contained pregnancy rate (PR), warm carcass weight (WCW), mature cow weight (MCW), number of nematode eggs per gram of faeces (EPG) and tick count (TICK). Two models were used in series to estimate the EV. A deterministic model was used to simulate effects of PR, WCW and MCW on profitability with a constant parasite load. Subsequently, stochastic models were used to estimate economic values for TICK and EPG as consequences of their environmental effects on weight gains, mortality and health costs. The EV of PR, WCW, MCW, EPG and TICK, was US$1.59, US$2.11, −US$0.24, −US$5.35 and −US$20.88, respectively. Results indicate positive emphasis should be placed on PR (12.49%) and WCW (65.07%) with negative emphasis on MCW (13.92%), EPG (2.77%) and TICK (5.75%). In comparison with the indexes usually used, these results suggest a reformulation in the selection indexes of the beef production system in tropical and subtropical regions in order to obtain greater profitability.

KEYWORDS

beef cattle, bioeconomic model, economic value, production system, selection criteria

1 | INTRODUCTION

Production costs are often not fully known for beef cattle production systems in developing countries. This lack of information makes it difficult to determine income, expense and profitability. For genetic improvement of economically relevant traits, farmers and industry (sector) need to know which traits have the greatest impact on their profitability in order to facilitate their selection decisions.

Goal-focused selection decisions aid in efficient production of livestock. In the 1940s, Hazel (1943) and Hazel and Lush (1943) suggested economic merit as a goal of livestock production and developed methods to maximize genetic progress. Ponzoni and Newman (1989) suggested that bioeconomic models describing the complex nature of production could aid in this process. The choice of traits to include in the breeding objective is determined purely by their effect on profitability and not by the ease with which they are measured. Thereafter, a breeding objective is related to the readily measured selection criteria through the genetic covariance structure (Amer, Simm, Keane, Diskin, & Wickham, 2001; Henderson, 1963; Schneeberger, Barwick, Crow, & Hammon, 1992).

Currently, beef cattle producers in tropical and subtropical areas have focused their selection decisions on increasing animal growth using empirical indices weighted based on technical advice, but without formal derivation of economic values. The empirical index that is currently in use by the Brazilian Brangus beef cattle breeding programme (PROMEBO) for yearling bulls is set as follows: weight gain from birth to weaning and weaning to 550 days of age is each weighted 25%, conformation at both weaning and 550 days of age is each weighted 5%, musculature and precocity at weaning and yearling are weighted 8%, and scrotal circumference is weighted 8% (Brangus Bulls Summary, 2017–2018). Thus, the current index places more than 50% of its emphasis directly on growth to 18 months of age. This emphasis has been justified by the recognition that income from the production system is generated from carcass weight. However, because the current index is empirical, cost of production, reproductive rate and herd health are largely ignored. In Brazil, the economic losses associated with animal health, especially those resulting from gastrointestinal nematodes and tick infestations, have an annual impact of US$7.11 billion and US$3.24 billion, respectively (Grisi et al., 2014). Resistance and resilience are traits of low-to-medium heritability (Cardoso et al., 2015; Kim, Sonstegard, Silva, Gasbarre, & Tassell, 2015; Mapholi et al., 2016), and selecting animals genetically resistant to parasites may bring long-term benefits to producers by enabling use of less affected animals. Thus, our objective was to model the beef production systems in the south of Brazil and to estimate economic values for traits having an impact on profitability. Application of these economic values in selection indexes could facilitate increasing profitability through selection decisions focused on a broader array of economically relevant traits relative to current practice.

2 | MATERIAL AND METHODS

2.1 | Bioeconomic models

A socioeconomic questionnaire (in Table S1) of six farms in Rio Grande do Sul state (Southern Brazil) was used to establish a baseline for the bioeconomic modelling of production systems that used Brangus cattle (Table 1). Costs of human resources, depreciation, fuel and maintenance were extracted from Anualpec (2015). An exchange rate of US$1.00 = R$3.24 was assumed.

Three discrete components were used to estimate the economic values (EVs). First, a straightforward partial budgeting of income and expense, coded in Excel (version 14.0.6112.5000, Microsoft Office Home Program and Business 2010), was used to simulate a typical farm profit model. In this analysis, the parasite load was considered constant and unknown, consistent with the on-farm environments of respondents to the socioeconomic questionnaire. Parameters and baseline performance levels from this analysis were used as constant inputs to models, coded in R (Anon, 2016), that assess consequences of endoparasites and ectoparasites as measured by effects of tick infestation (TICK) and number of nematode eggs per gram of faeces (EPG) on animal performance. As a consequence of this strategy, economic values for pregnancy rate (PR), warm carcass weight (WCW) and mature cow weight (MCW) were independent of the level of tick infestation and faecal nematode egg count. Economic values for TICK and EPG estimated model were consequences of environmental effects of tick infestation on unrealized weight gains, mortality and health costs, and of nematode from gastrointestinal infestations on weight gains and health costs. Measuring these traits individually is important, so that their EV can be properly calculated, thus avoiding double counting between TICK and EPG with the traits of the deterministic model.

The simulated farm employs 553 hectares of land to provide for 560 animals in total (200 cows) in a full-cycle system (Figure 1). The herd was composed of cows, male calves, female calves, heifers, yearling steers, young and adult steers and bulls. Carcasses from steers, heifers, cows and old bulls, sold for slaughter, are sources of income. Expenses, other than those attributable to management of parasites, were those indicated in the socioeconomic questionnaire. The general mortality rate of the herd represents a loss of 4.41%. Pregnancy rate of the cows was 75.5%, and thus, 75 female calves and 76 male calves were produced annually. Parturition occurred between September and November (spring). Weaning occurred when the calves were, on average, 7 months of age (May). After that age, the animals between 8 and 24 months old were divided into four classes (Figure 1). Annual replacement of the cows was 18%. Thus, 24-month-old heifers are exposed to bulls from which 36 females return to the herd as cows, 30 heifers are sold for slaughter, and 2 heifers die. Yearling steers at 24 months of age were castrated, fattened and slaughtered. Thus, 65 steers are finished and sold for slaughter at 30 months of age, 2 return to the herd as sires, and 2 males die. Dressing percentages of the steers, heifers, old bulls and cows were 50%,

TABLE 1 Characterization of the six farms in Rio Grande do Sul state that provided a baseline for simulations used to estimate breeding objectives for Brangus in southern Brazil

Description	Unit	Quantity
Number of cows	head	200
Total animals	head	560
Production system area	hectare	553.00
Stocking rate	head/hectare	0.71
Pregnancy rate	%	75.50
Replacement rate of cows	%	18.00
General mortality rate	%	4.41
Weight at birth	kg	35.75
Weight of cows	kg	450.00
Weight of fat cows	kg	516.66
Weight of the bulls with 24 months	kg	500.00
Weight of the old bulls	kg	650.00
Weight adult steers kg	kg	500.00
Age at the slaughter of steers in C1	month	30
Age at the slaughter of steers in C2	month	27
Selling price of heifers (carcass) 18–24 months	US$/kg	3.02
Selling price of cow (carcass)	US$/kg	2.90
Selling price of steers above 24 months (carcass)	US$/kg	3.67
Carcass dressing (steers) above 24 months	%	50
Carcass dressing (heifers)	%	50
Carcass dressing (cows)	%	47
Carcass dressing (bulls)	%	54
Arroba (@)	kg	15
Fuel		
Cost of fuel consumption (800 L)	US$	790.12
Human resources		
Salary	US$	335.45
Fixed work unit	unit	4
Office	US$	2,713.05
VET		
Annual veterinary cost	US$	4,693.59
Reproduction		
Cost of AI (cost of semen and materials)	US$/cow	12.34
Andrological cost	US$/bull	18.52
Depreciation and maintenance		
Cost of depreciation and maintenance		12,955.14
Pasture, salt and ration		
Cost of winter pasture	US$/hectare	151.38
Cost of native pasture	US$/hectare	48.28
Production dry matter winter pasture	kg/hectare	6,770
Production dry matter native pasture	kg/hectare	4,100
Consumption of dry matter	%/live weight	3.00
Cost of common salt	US$/kg	0.35
Cost of protected salt	US$/kg	0.51
Cost of ration	US$/kg	0.30
Consumption ration	%/live weight	1.16
Drugs		
Cost of drug *"fluazuron"*	US$/L	20.99
Cost of drug *"fipronil"*	US$/L	15.43
Cost of drug *"ivermectina"*	US$/L	37.04
Cost of drug *"imidogarb"*	US$/L	58.64

50%, 54% and 47%, with carcass prices per kg of US$3.67, US$3.02, US$2.90 and US$3.33, respectively.

Level of tick infestation, animal mortality due to bovine parasites and EPG observed in the Brangus experimental herd at the "Cinco Cruzes" Experimental Station belonging to Embrapa Pecuária Sul were used to develop equations and to estimate their reference parameters in order to quantify the consequences from parasitic infestation. Average seasonal parasite loads and treatments are illustrated in Figure 2.

The genetic parameters used in this work were estimated from the herd database above reported for traits that had measurements available (TICK, EPG, MCW and PR) and derived from related research reported in the literature for carcass traits. The genetic parameters heritability and the genetic standard deviation are shown in Table 2, and the genetic and phenotypic correlation showed in Table S2.

2.2 | Description of scenarios

First, a typical full-cycle system (C1) was considered. Annual production from this system was modelled considering the numbers of animals in each category to reflect the long-term equilibrium. Thus, C1 is a typical full-cycle beef production system in tropical and subtropical regions, without sale of breeding stock. An additional scenario (C2) was simulated in which the steers were slaughtered at 27 months of age rather than at 30 months as in C1.

2.3 | Revenue and costs components

The scenarios produce the revenue (Revenue) of the system through sales of cull cows, heifers, steers and old bulls for slaughter. In Brazil, carcasses are valued per arroba (15 kg of carcass weight). Thus:

$$\text{Revenue} = \sum_{i=1}^{4} n_i \times \$ \, @_i \times \left(\frac{\text{LW}_i \times \text{CDP}_i}{15} \right)$$

where n_i = the number of animals slaughter from the ith class (cull cows, heifers, steers and old bulls); $\$ \, @_i$ = the carcass price per arroba of the ith class of animal; and $\text{LW}_i \times \text{CDP}_i$ = the product of live weight and carcass dressing percentage for the ith class of animal.

Annual production costs were accrued for feed (CF), general expenses (CG), maintenance, depreciation and fuel (CMDF) and herd health (CHH). Feed cost was further partitioned into costs for maintenance of native pasture, production of improved pasture for winter grazing, mineral and supplemental feed (protein and energy supplementation to support the desired level of performance). The average production of dry matter (DM) per hectare was evaluated. The cost basis for the improved and native pastures was US$151.38 per hectare and US$48.28 per hectare, respectively, taking into account the purchase of the herbicide, the seed, the fertilizer and the fuel. Labour was also accounted for in the CG. Each animal was assumed to consume 3% of its live weight in DM, and thus, the cost attributable to forage for each animal was calculated for each period during the year.

As the profit equations were separated individually by animal category, when a unit of the selection objective is changed to calculate its respective economic value, the food consumption will be proportional to this change for all categories of animals. In this context, when we set 3% CMS for all categories of animals, all simulated oscillations resulted in a proportional increase in food consumption.

Cows and bulls grazed native pasture for 208 and 305 days and were on improved pasture for 157 and 60 days, respectively. They received common mineral salt (CMS) for 90 and 275 days and protein mineral salt (PMS) for 90 days, during the breeding season. From birth until being weaned at 7 months of age, both male and female calves were kept on native pasture. After weaning, male calves are grazed native pasture for 65 days and sown pasture for 90 days, while female calves only grazed native pasture. During this time, they received CMS for 75 days and PMS for 75 days as supplements. Yearling steers and heifers grazed on native pasture through 18 months of age. Between 19 and 24 months of age, the long-yearling steers grazed 26 days on native pasture and 157 days on improved pasture, while their heifer contemporaries grazed native pasture for 123 days and improved pasture for 60 days. Between 12 and 24 months of age, the yearling cattle were supplemented with CMS. After attaining 24 months of age, the steers spent on native pasture until slaughtered (6 months for C1 and 3 months for C2). Heifers at the end of 24 months entered the cowherd. The native and sown pasture produces 4,100 kg per hectare and 6,770 kg per hectare of dry matter and 11.4% and 20.1% of crude protein, respectively, per season (Conterato, David, Trindade, Maldaner, & Bremm, 2016; Ferreira et al., 2011; Marchesan et al., 2015; Silveira, Velho, Vargas, Genro, & Velho, 2006). The calves and the bulls were provided supplemental feed at 1.16% of their live weight (LW) per day. Thus, CF was the sum of the costs for grazing, mineral supplement and supplemental feed.

The cost of human resources, having four employees, with a basic monthly salary of US$335.45 per employee, including the taxes, was attributed to CG. Total office costs estimated as US$2,713.05 (Anualpec, 2015) were also assigned to CG. For the calculation of CMDF, the expenses with maintenance and depreciation were estimated to be US$12,955.14 (Anualpec, 2015). Annual consumption of diesel oil was 800 litres and, considering US$0.99 the price per litre, resulted in a total fuel cost of US$790.12 (except the fuel spent on the grazing implementation).

Expenses attributed to CHH resulted from vaccinations (VAC) for clostridia, brucellosis, foot-and-mouth disease and vibriosis and for anthelmintic drugs to control internal parasites and acaricides for control of ticks under the management presented in the strategic treatment (Figure 2). Additional costs for maintenance of herd health were related to reproductive management and veterinary doctor remuneration. The reproductive costs were US$12.34 per cow for fixed time artificial insemination (FTAI) and US$18.52 per breeding soundness examination for each bull. The total amount paid to the veterinarian, regardless of the scenarios in one year, was US$4,693.59, with a frequency of two days of service per week to prescribe necessary treatments and make recommendations for health management.

2.4 | Economic values

A deterministic model was first used to obtain the EV of the traits PR (%), WCW (kg) and MCW (kg) independent of parasite load. The total profit of the system (P) was obtained by summation of the revenues and deducting all the costs of the system during one year with each trait at its respective mean value. Then, a new profit figure was calculated, and results (P') were calculated by individually perturbing the mean of each trait by a single unit in separate simulations. For each trait, the difference between the two outcomes ($P' - P$) represents its economic value in the breeding objective (Groen et al., 1997; MacNeil, Newman, Enns, & Stewart-Smith, 1994). Thus, the EVs were approximations of the partial derivatives of profit with respect to PR, WCW and MCW. Each of these economic values was

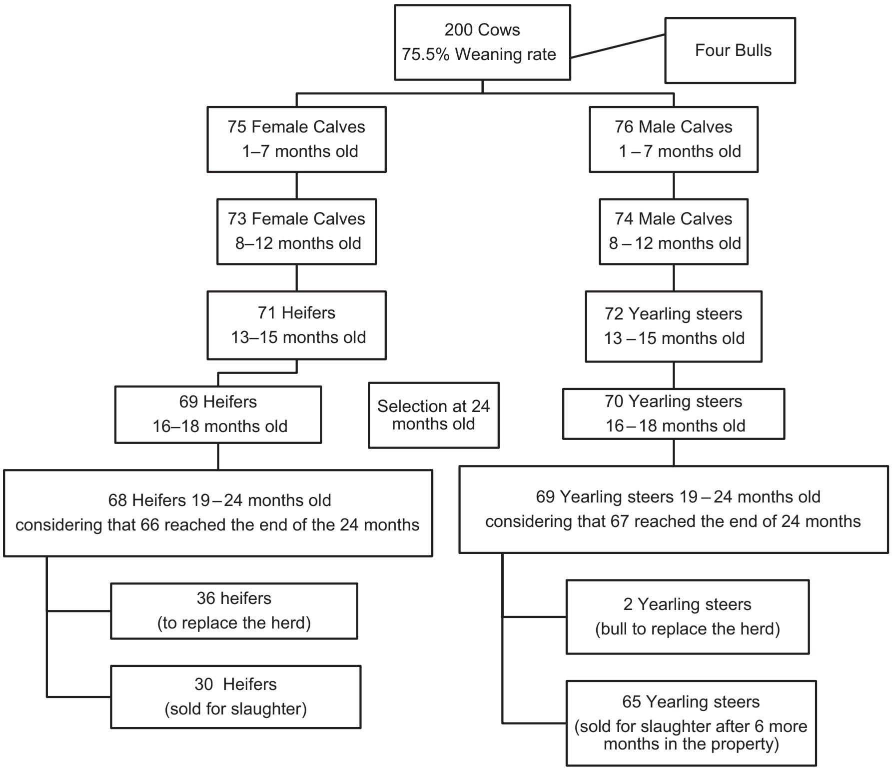

FIGURE 1 Herd structure simulated in the bioeconomic model for Brangus breed and flow chart of the animal categories in Scenario 1

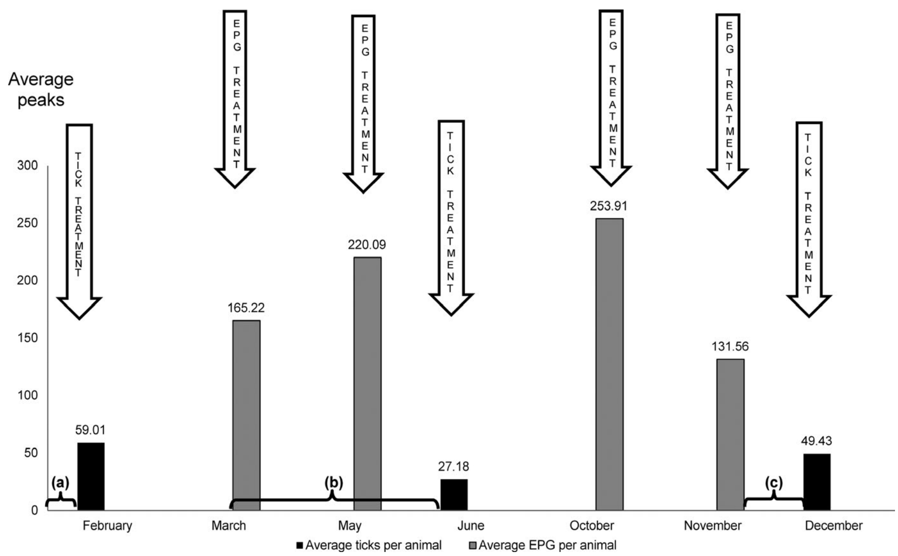

FIGURE 2 Average peaks of ticks and EPG (*y*-axis) and months of peaks (*x*-axis). Annual treatment of tick and endoparasites and previous periods of tick peaks that occurs weight loss. (a) Previous of second peak of 19 days of weight loss; (b) previous of third peak of 78 days of weight loss; and (c) previous of first peak of 21 days of weight loss

rescaled by dividing by the number of cows in the herd; thus, EV = $(P' - P)$/number of cows.

Additionally, two stochastic sub-models were used to obtain the EVs of TICK and EPG using functions developed in R. The parameters and scenarios described above remained unchanged; however, random parasite loads and consequent losses and probabilities of mortality were simulated in 18,000 iterations around their means and standard deviations. The EVs for TICK and EPG were their respective average deviations from the baseline estimate of profitability calculated as described below.

2.5 | Economic value for tick count

In order to estimate the EV of tick count, a curve describing tick load (number of ticks/months of the year) was developed from tick count data of 794 Brangus animals belonging to the experimental herd of Embrapa Pecuária Sul (Yokoo et al., 2016). Over a three-year period of evaluation, there were 1,989 measures of tick load resulting from natural infestation with each animal (cows, yearling steers and heifers), having between 1 and 4 tick counts. However, to the opportunity cost of weight gains that was

TABLE 2 Economic values (EVs), heritability (h^2), additive standard deviation (σ_a), relative economic value (REV) and relative emphasis (%) for component traits of breeding objectives estimated for a commercial Brangus herd in southern Brazil that markets steers and surplus heifers at 30 months of age

Breeding objectives	EV/enterprise (US$)	EV (US$)	REV	Emphasis (%)	h^2	σ_a
PR	318.38	1.59	7.71	12.49	0.01[a]	4.85[a]
WCW	421.72	2.11	40.17	65.07	0.58[b]	19.04[b]
MCW	−48.71	−0.24	−8.59	13.92	0.26[a]	35.80[a]
EPG	−1,070.00	−5.35 (±0.04)	−1.71	2.77	0.12[a]	0.32[a]
TICK	−4,176.00	−20.88 (±0.28)	−3.55	5.75	0.13[a]	0.17[a]

Abbreviations: EPG, number of nematode eggs per gram of faeces ($\log_{10}$); MCW, mature cow weight (kg); PR, pregnancy rates (%); TICK, tick count ($\log_{10}$); WCW, warm carcass weight (kg).

[a]Genetics parameters estimated from Brangus-Ibagé database of the Experimental Facility "Cinco Cruzes."

[b]Costa, Teixeira, Yokoo, and Cardoso (2017).

unattained due tick infestation, only data from animals between 12 and 30 months old were used. As these phenotypes resemble an exponential distribution, the function $f(x;\lambda)=\begin{cases}\lambda e^{-\lambda x} & ,x \geq 0,\\ 0 & ,x < 0.\end{cases}$ was used in the simulation, where x is the random variable (tick load) and λ is the exponential distribution rate of the tick count, and thus, $E[x]=\frac{1}{\lambda}$. Linear regression indicated an estimated cost of 1.18 ± 0.21 g live weight/tick/day (Jonsson, 2006).

In southern Brazil, there are 3 tick infestation peaks (beginning and end of the summer and beginning of the fall), totalling 119 days over which weight may be lost (Figure 2; Evans, 1992). The first peak occurs in summer (between December and February) and lasts approximately 19 days. The second peak occurs between in autumn (between February and June) with duration of approximately 78 days. The third peak occurs in winter or spring (June and December) and may last for approximately 21 days. These periods result from a lack of complete synchrony between the tick life-cycle and acaricide treatment. The average tick loads (on one side of the animal's body) for the first, second and third peaks were 49.43 ± 58.54, 59.01 ± 56.67 and 27.18 ± 41.71. Thus, three curves of tick count were simulated following an exponential distribution with λ equal to 0.02023063, 0.01694628 and 0.03679176, respectively.

Costs of drugs for tick control were calculated according to the schedule of interventions shown in Figure 2. Use of "*fluazuron*" and "*fipronil*" was proposed, with dorsal application ("pour-on") of 10 ml every 40 kg of LW, and costing US$20.99 and US$15.43 per litre, respectively. In addition, "*ivermectin*" (Iv) was used at a cost of US$37.04 per litre and dosage of 1 ml every 20 kg of LW. For bulls and cows, prophylactic treatment of drugs based on "*imidocarb*" was used at a cost of US$58.64 per litre and dosage of 1 ml every 50 kg of LW.

Death loss attributable to ticks was estimated from the Brangus experimental herd of Embrapa Pecuária Sul. Given the tick count and incidence of death, a survival analysis was performed to estimate the probability of death (Figure 3) using the package "survival" of the R program (Therneau, 2015; Therneau & Grambsch, 2000). To estimate survival time as the area under the survival curve, the Kaplan–Meier or product-limit estimator was used to estimate the survival function $S(t)$.

$$\hat{S}(t_i)=\prod_{j:t_j\leq t_i}\hat{p}_j=\prod_{j:t_j\leq t_i}\left(1-\frac{d_j}{n_j}\right)$$

where p_j = the conditional probability of surviving during the jth interval; d_j = the number of deaths; and n_i = the size of the population at risk during the jth interval. The variance of Kaplan–Meier estimator at time point t_i can be expressed by the formula below (also known as Greenwood's formula):

$$\hat{V}\left[\hat{S}(t_i)\right]=\hat{S}(t_i)^2\sum_{j:t_j\leq t_i}\frac{d_j}{n_j(n_j-d_j)}$$

A uniform random variable (v) on the interval 0–1 was compared to the probability of survival (p) to simulate the potential mortality of each animal, with $v \leq p$ = live, and $v > p$ = dead. Dead animals were replaced reducing the number of animals available to be sold.

To estimate the EV of TICK, the effect of the tick infestation was used given the costs with treatments (medication), labour and losses due to loss of weight that was attributable to the level of tick infestation and incidence of death incident resulting from tick-borne disease (Eyo et al., 2014). Thus:

$$\text{Operational TICK}=\left(\left(\prod_{i=1}^{7}X_iY_i\right)+\left(\prod_{i=1}^{7}K_iL_iM_i\right)+\left(1.18\prod_{j=1}^{5}Z_jW_jT_j\right)+\text{Labor}\right)\times -1$$

where X_i = the number of deaths due tick-borne disease in the ith class (all classes during the year); Y_i = the value of the

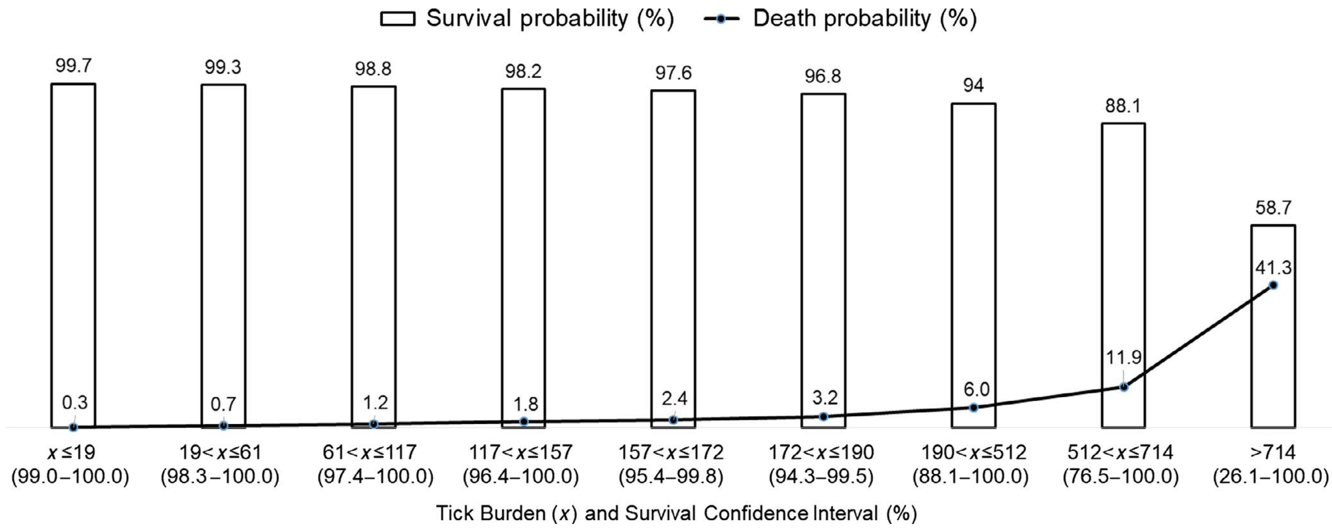

FIGURE 3 Probabilities of death and survival according to the tick burden in Brangus breed

animal in the ith class; K_i = the total live weight of animals in the ith class; L_i = the number of treatments for the ith class; M_i = cost of the medication per unit weight for the ith class; Z_j = the total number of days afflicted with ticks for the jth class (all classes during the year except for cows and bulls); W_j = the value of the animal live weight for the jth class; and T_j = the total number of ticks for the jth class.

2.6 | Economic value of EPG

To determine the economic value for trait EPG, one obtains the costs associated with for this trait, resulted from treatments with drugs, labour, laboratory examination and the opportunity cost of unattained growth. Each of 4 peaks of EPG (Hoffmann, 1987) was simulated based on a negative binomial distribution with parameter $\mu = (1-\rho)/\rho$, where μ in number of nematode eggs per gram of faeces for each peak were 165.22 ± 252.95, 220.09 ± 330.56, 253.91 ± 301.98 and 131.48 ± 252.3, and ρ = 0.006089, 0.004564, 0.003954 and 0.007664, respectively (Molento & Miller, 2018). These parameters were consistent with the occurrence of EPG in Brangus animals from the experimental herd of Embrapa Pecuária Sul. The opportunity cost incurred from infestation with helminths was limited to those animals with faecal loads >299 EPG and was simulated as occurring between weaning and 30 months of age. Melo and Bianchin (1977) found this effect to cause a 20% reduction in weight. Thus:

$$\text{Operational EPG} = \left(\left(\prod_{i=1}^{7} K_i L_i M_i \right) + \left(\prod_{j=1}^{5} (Z_j \times 0.2) W_j L_j \right) + \text{Labor} \right) \times -1$$

where K_i = the animals total live weight with more than 299 EPG in the ith class (all classes during the year); L_i (L_j) = the number of treatments for the ith(jth) class; M_i = value of the medication per weight for the ith class; Z_j = the animals total live weight with more than 299 EPG for the jth class (all classes during the year except for the cows and bulls); and W_j = the value of the animal live weight for the jth class.

2.7 | Sensitivity analysis and emphasis

Herds of 200, 400 and 1,000 cows were modelled to evaluate the sensitivity of the EVs to herd size. Additional sensitivity analyses were conducted to evaluate changes in prices for grazing and feed supplements on the EVs of all traits in the breeding objective, with prices of those inputs varied ±20% of their original costs.

For each trait in the breeding objective, a relative economic value was calculated from its EV by multiplication times the genetic standard deviation (σ_a) for that trait. The emphasis of a trait in the breeding objective (expressed as a percentage) was determined by dividing the absolute value (b_i) of the relative economic value by the sum over all traits (t) of the absolute values of the relative economic values. Thus:

$$\text{Emphasis} = \frac{|b_i| \times \sigma_{a(i)}}{\sum_{i=1}^{t} |b_i| \times \sigma_{a(i)}} \times 100,$$

2.8 | Genetic correlations

Genetic correlations were calculated between the current index of the PROMEBO (Brangus Bulls Summary, 2017–2018) and the values of the traits used in this study.

The different breeding goals were compared using estimates of the genetic correlations (r) (Table S2), between them:

$$r = \frac{\mathrm{EV}_i \mathrm{GEW}_j}{\sqrt{\mathrm{EV}_i \mathrm{GEV}_i \times \mathrm{EW}_j \mathrm{GEW}_j}}$$

where EV_i = the vector of economic values for the ith breeding objective, EW_j = is the vector of PROMEBO empirical weights for the jth breeding objective, and G = the genetic variance–covariance matrix for traits in the breeding objective.

2.9 | Expected changes in the breeding objectives

After the breeding objectives were defined, the weight factors (b) were estimated (in matrix notation) by: $b = P^{-1}{}_{11}G_{12}V$, where: $P^{-1}{}_{11}$ = inverse phenotypic (co)variance matrix among the selection criteria by PROMEBO empirical; G_{12} = genetic (co)variance matrix among the selection criteria (row) and the breeding objective (column); V = vector of economic values for the breeding objectives, expressed as monetary unit (dollar) per unit improved in each trait (Schneeberger et al., 1992).

The genetic superiority expected in the breeding objectives (S_{ESI}) for one standard deviation in the selection using the economic selection index (ESI) is given by $S_{\mathrm{ESI}} = i \times R_{\mathrm{IH}} \times \sigma_H = i \times \frac{\sigma_{\mathrm{ESI}}}{\sigma_H} \times \sigma_H = i \times \sigma_{\mathrm{ESI}}$, where i is the selection intensity and H is aggregated genotype of the breeding objectives (Pimentel & König, 2012). If i equals the unit (1), then $S_{\mathrm{ESI}} = \sigma_{\mathrm{ESI}}$. Subsequently, it also used the empirical weights of the PROMEBO and the gain in the selection objectives was calculated to be able to compare the differences.

3 | RESULTS

Baseline profits per cow in scenarios C1 and C2 were US$77.90 and US$73.49, respectively. Although in C2 the yearling steers are slaughtered earlier, C2 was less profitable due to the increased nutritional cost required to attain the prescribed carcass weight at 27 months. While the profitability of C1 and C2 differed, the EVs were similar for both scenarios.

Presented in Table 2 are the EVs, relative economic values and emphasis for the breeding objectives that are applicable to both scenarios. Warm carcass weight receives the greatest emphasis in the breeding objectives followed in order by MCW, PR, TICK and EPG, with the negative emphasis on MCW in part counterbalancing the positive emphasis on WCW when considering the impacts of these objectives on growth.

Considering the magnitude of the SE of the estimated EVs for TICK and EPG, the selection pressure to be applied to these traits appears independent of herd size (Table 3). Thus, results that were derived from the simulated 200 cow herd are discussed hereafter. Estimated losses from TICK and EPG were US$ 29,882.97 and US$17,923.60 per year, respectively. For ticks, the financial loss resulted from deaths (64%), cost of insecticidal drugs (28%) and unrealized gain in weight (8%) due to increased infestation. For helminths, financial loss resulted from cost of anthelmintic drugs (27%) and unrealized gain in weight (73%) due to increased infestation.

Sensitivity of the economic values to changes in availability of feed resources is shown in Table 4 with the breeding objectives estimated herein being relatively insensitive to the modelled differences in availability of feed.

The correlation between these breeding objectives and the PROMEBO empirical index that is currently in use was 62%. Thus, these indices are different than the selection criterion that is currently advanced.

A new selection index using the economic weights proposed in this work would increase the overall genetic economic gain to US$ 19.66 in contrast to US$ 12.93 when using the empirical weights of PROMEBO. The individual genetic economic gain for economic and empirical weights, respectively, was US$ 2.45 and US$ 1.02 for PR, US$ 22.46 and US$ 16.36 for WCW, −US$ 6.03 and −US$ 5.40 for MCW, −US$ 0.22 and US$ 0.02 for EPG and US$ 1.00 and US$ 0.94 for TICK (Figure 4).

Thus, migration from the current PROMEBO index to an economic index may be financially beneficial for beef producers.

4 | DISCUSSION

Similar estimates of profitability from the presented scenarios have been reported for Nelore breed (Jorge Junior, Cardoso, & Alburquerque, 2006). In all of the studied scenarios, supporting the cow herd was the greatest single cost, mainly due to the cost of feedstuffs. Opportunities to reduce this cost are limited because the cow herd is also the basis for the system productivity.

For the C2, become more profitable than C1, it is necessary to genetically improve growth (i.e., weaning weight, yearling weight and carcass weight) without increasing production costs. Breaking this genetic antagonism is unlikely since increased growth requires feed to support it as indicated by the large positive estimated genetic correlation between feed intake and growth (MacNeil, Lopez-Villalobos, & Northcutt, 2011; MacNeil, Scholtz, & Maiwashe, 2013; Rolf et al., 2012).

The relative trait importance found in this work is similar to that found by the Ochsner, MacNeil, Lewis, and Spangler

TABLE 3 Sensitivity of tick count (TICK) and number of nematode eggs per gram of faeces (EPG) to number of cows in bioeconomic simulation of Brangus herds

Cows	200		400		1,000	
	651		1,302		3,255	
Total of Animals	Tick	EPG	Tick	EPG	Tick	EPG
Death loss (US$)	19,175.56	–	38,268.85	–	95,260.80	–
Drug cost (US$)	8,417.80	4,843.20	16,807.70	9,686.58	42,034.02	24,215.63
Unrealized weight (US$)	2,289.61	13,080.40	4,574.66	26,156.44	11,442.72	65,437.75
Total economic loss (US$)	29,882.97	17,923.60	59,651.22	35,843.02	148,737.54	89,653.38

Note: Death loss and Financial loss resulting from deaths due to infestation by ticks; drug cost: cost of acaricide and anthelmintic drugs; unrealized weight: economic opportunity cost of parasitism resulting from decreased growth.

(2017), who reported that the order of importance begins with maintenance, followed by growth and lastly by reproduction in a grass-based system. Studies in rearing and fattening beef cattle production systems found that carcass yield was the most important trait for the profitability followed by feed intake (Peripolli et al., 2016). Jorge Junior, Cardoso, and Alburquerque (2007), studying a production system that was similar to C1, also found that breeding objectives related to carcass traits and weaning rate (a reproductive trait) have greatest influence on profit. Åby, Aass, Sehested, and Vangen (2012), analysing a system similar to C1, obtained an order of importance of the ability of a bull's daughter to enter the breeding herd and remain productive (stayability), followed by carcass and other reproduction traits. These studies demonstrate that the emphasis of importance of the traits group (reproduction, maintenance, growth and carcass) depends very much on each production system and each situation (level). However, relative importance of traits included in a breeding objective depends not only on the economic values, but also on the estimates of additive genetic variance. Particularly for PR, the estimates of additive genetic variance may be wide-ranging (Glaze, 2011) and this variation may rerank traits as to their relative importance in multiple trait selection.

Results that were found herein indicating positive emphasis for PR in the breeding objective are supported by the findings of Jorge Junior et al. (2006). Improvement in PR results in increased number of animals that are born and, consequently, in increased off-take that is available to generate income. Amer et al. (2001) and Pravia, Ravagnolo, Urioste, and Garrick (2014) described that reproductive traits have higher relative importance when compared to growth and carcass traits. In this study, the emphasis on PR would increase if the additive genetic variance increased, the current mean for PR decreases or the value of the progeny increases, but the costs of production remained the same. For example, Splan, Cundiff, and Vleck (1998) estimated the additive genetic variance of PR to be 168.7 with a corresponding heritability estimate of 0.09. If this value is used to replace the corresponding 0.01 estimate in the present study, the PR would receive 53.5% of the emphasis in the breeding objective, followed by WCW (33.8%), MCW (7.9%), EPG (1.5%) and TICK (3.3%). In this case, additional income will be derived directly from increased PR and as correlated selection response in weight gains from birth to weaning and weaning to yearling, due to the positive genetic correlation between PR and weight traits (Table S2).

TABLE 4 Sensitivity of economic values for traits in a breeding objective for Brangus cattle to quantities of feed resources

	Feed supplement				Grazing			
	More 20%		Less 20%		More 20%		Less 20%	
Breeding objective	EV (US$)	REV	EV (US$)	REV	EV (US$)	REV	EV (US$)	REV
PR (%)	1.54	7.47	1.64	7.95	1.52	7.37	1.67	8.10
WCW (kg)	2.11	40.17	2.11	40.17	2.11	40.17	2.11	40.17
MCW (kg)	−0.24	−8.59	−0.24	−8.59	−0.27	−9.67	−0.22	−7.88
EPG (log)	−5.35 (±0.04)	1.71	−5.35 (±0.04)	1.71	−5.35 (±0.04)	1.71	−5.35 (±0.04)	1.71
TICK (log)	−20.88 (±0.28)	3.55	−20.88 (±0.28)	3.55	−20.88 (±0.28)	3.55	−20.88 (±0.28)	3.55

Abbreviations: EPG (log), number of nematode eggs per gram of faeces in base-10 log; MCW, mature cow weight; PR, pregnancy rates; TICK (log), tick count in base-10 log; WCW, warm carcass weight.

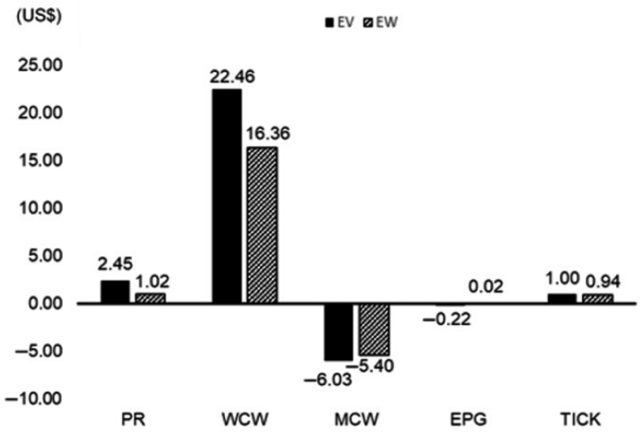

FIGURE 4 Expected economic gains (US$) in breeding objectives using economic values (EVs) and empirical weights (EW). EPG, number of nematode eggs per gram of faeces ($\log_{10}$); MCW, mature cow weight (kg); PR, pregnancy rates (%); TICK, tick count ($\log_{10}$); WCW, warm carcass weight (kg)

Lara (2014), studying a system that was similar to the ones modelled herein, found negative emphasis should be placed on MCW in tropical areas. MacNeil and Newman (1994), studying an integrated terminal sire crossing system, likewise found that MCW should receive negative pressure in maternal strains. Pereira, Alencar, and Barbosa (2007) estimated the positive genetic correlation between adult cow weight and calf weights. Arthur and Herd (2008) described the relationship of producing progeny with high slaughter weight (trait that is sought in production system) with the increase in the size of the cows, which results in an increase in the cost of maintenance in breeding cows. These results indicate that heavier cows generate more expense than is offset by the associated increase in revenue, and thus, controlling mature size of the cows is anticipated to have desirable effects on profit.

Jonsson (2006) estimated that cattle lost 1.37 g per tick, per day of infestation, and that strategies of genetic improvement to control ectoparasites were needed to increase productivity. In addition, death losses resulting from parasitism resulted in approximately 13 fewer animals being available for sale from the simulated 200 cowherd. Death losses attributable to ectoparasitic infestation may be upwards of 2.68% per year (Gottschall, Canellas, Almeida, Magero, & Bittencourt, 2010).

According to Gomes, Koller, and Barros (2011), and Fortes and Molento (2013), one way to minimize that cost would be to prioritize the strategic treatments, wherein only animals with established infestations are treated with an endectocide that had been previously established as being efficacious. Incorporation of TICK and EPG in the selection index would be a long-term alternative. Here, TICK and EPG receive approximately 10% of the emphasis in breeding objectives in the scenarios studied. Previous estimates of heritability for tick resistance and EPG range between 0.04 and 0.39 (Cardoso et al., 2015; Coppieters et al., 2009; Fraga, Alencar, Figueiredo, Razook, & Cyrillo, 2003; Mackinnon, Meyer, & Hetzel, 1991; Passafaro et al., 2015). Thus, selection may reduce chemical treatment and provide positive economic return to the system. Additional benefits may include decreased chemical waste products in meat and in the environment and an environmental increase in weight gains due to reduced parasite burden in the herds. However, because these benefits do not have direct costs attributable to them, they were not considered in calculating the present EVs.

Warm carcass weight is of necessity measured postmortem and thus may be treated as proprietary information and not be readily available for use in genetic evaluation. Often live weight prior to slaughter (SW) may have greater heritability than WCW (Gordo et al., 2016; Riley et al., 2002) and can be measured on the farm. Thus, use of an EBV for SW in a genetic improvement programme as an indicator of WCW may be both sensible and more practical. Here, genetic correlation of breeding objectives containing WCW with those containing SW in the scenarios studied was 1.00. Based on these results, it is concluded that genetic improvement would not be affected, whether based on a breeding objective that included WCW or one containing SW.

In conclusion, given the bioeconomic model studied in this paper, adoption of a new breeding objective for Brangus cattle raised in southern Brazil appears to be warranted. New features of the resulting paradigm would include positive emphasis on reproduction and resistance to parasitism.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest associated with this publication.

ORCID

Michele R. S. Simões https://orcid.org/0000-0001-7909-9725
Cláudia C. Gomes https://orcid.org/0000-0001-7675-7921

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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