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Deng A Makuei
 Juba National Institute of
 Agricultural Sciences, Juba,
 South Sudan

Nyaluak C Gatluak
 Juba National Institute of
 Agricultural Sciences, Juba,
 South Sudan

Kuol M Atem
 Juba National Institute of
 Agricultural Sciences, Juba,
 South Sudan

Achol T Deng
 Juba National Institute of
 Agricultural Sciences, Juba,
 South Sudan

Selection criteria for optimizing growth and feed efficiency in Boran beef cattle in Kenya

Deng A Makuei, Nyaluak C Gatluak, Kuol M Atem and Achol T Deng

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Abstract

Choosing the right selection criteria is fundamental to achieving genetic progress in beef cattle breeding programs, yet no systematic comparison of alternative criteria has been conducted for Boran cattle in Kenya. This research evaluated six selection criteria for optimizing growth performance and feed efficiency in 298 purebred Boran cattle (157 males and 141 females) at the ADC Mutara Ranch in Laikipia County, Kenya, from April 2018 to March 2022. Growth traits measured included birth weight (BW: 22.8 ± 2.5 kg), weaning weight (WW: 115.4 ± 13.1 kg), yearling weight (YW: 205.1 ± 18.9 kg), and average daily gain (ADG: 501.6 ± 63.7 g/day). Feed efficiency was assessed through feed conversion ratio (FCR: 8.07 ± 1.21) and residual feed intake (RFI: 0.00 ± 0.86 kg/day) during 90-day post-weaning trials on 206 animals. Genetic parameters estimated using REML animal models showed moderate heritability for growth traits (0.24-0.36) and lower heritability for feed efficiency (0.19-0.22). Six selection criteria were compared: single-trait selection on YW, ADG, or RFI, two-trait indices combining YW+ADG or YW+RFI, and a full multi-trait index incorporating all three traits. Predicted genetic gains per generation ranged from 2.17 to 5.84 kg for YW and from -0.34 to -0.11 kg/day for RFI across criteria. The full index (YW+ADG+RFI) achieved 83.4% of the maximum YW response and 76.5% of the maximum RFI response, outperforming all other criteria for balanced improvement. Selection index weights varied substantially across five economic scenarios (Figure 1), with RFI receiving 2.4-fold greater emphasis under high feed cost conditions compared to baseline. Correlated selection responses (Figure 4) showed that selecting for any single growth trait captured 34-64% of the direct response in other growth traits but only 17-40% of the direct RFI response. A decision framework (Figure 3) was developed to guide producers in choosing the most appropriate selection criterion based on data availability, production system, and economic objectives. These findings demonstrate that multi-trait selection indices incorporating both growth and feed efficiency information provide the most effective pathway to genetic improvement in Boran beef cattle.

Keywords: Selection criteria, selection index, Boran cattle, genetic gain, correlated response, economic weights, feed efficiency, breeding program

Introduction

A persistent problem facing Boran beef cattle breeders in Kenya is the absence of clear, evidence-based guidelines for choosing among alternative selection criteria. Most producers default to visual appraisal or single-trait selection based on body weight, an approach that fails to account for the genetic relationships among economically important traits and often leads to suboptimal outcomes ^[1]. The consequences of poor selection decisions compound over generations, as genetic changes are cumulative and difficult to reverse once established in a breeding population ^[2].

Selection criteria in beef cattle breeding can range from simple single-trait measures to complex multi-trait indices that combine information from several traits weighted by their economic values and genetic parameters ^[3]. The theoretical advantage of index selection over single-trait selection has been established since Hazel's foundational work in the 1940s ^[4], but applying index theory in practice requires accurate estimates of genetic variances, covariances, and economic weights that are specific to the target population and production system. For Boran cattle in Kenya, these prerequisites have only recently begun to be met through dedicated genetic research programs.

The choice of selection criterion affects not only the primary target trait but also produces correlated responses in related traits, which may be favorable or unfavorable depending on

Corresponding Author:
Deng A Makuei
 Juba National Institute of
 Agricultural Sciences, Juba,
 South Sudan

the genetic architecture of the population [5]. For example, selecting solely for yearling weight might increase birth weight as a correlated response, potentially elevating calving difficulty in first-calf heifers. Conversely, selecting for reduced residual feed intake might produce correlated improvements in growth rate if the genetic correlation between these traits is favorable, as has been suggested by recent findings [6]. Understanding these correlated response patterns is necessary for predicting the full consequences of any selection decision.

Economic conditions further complicate the selection criterion choice. The relative profitability of growth versus feed efficiency depends on prevailing market prices for beef, the cost of supplemental feed, and the production system employed [7]. In Kenya, where beef is produced under pastoral, semi-intensive, and feedlot systems with markedly different cost structures, a single set of selection criteria may not be optimal across all production environments. Scenario-based analysis of selection index weights under varying economic conditions can help identify criteria that are robust to market fluctuations [8].

Majoya *et al.* [9] documented significant genetic variation for growth and feed efficiency traits in Boran cattle in Kenya, confirming that the biological prerequisites for selection response exist. However, translating genetic parameter estimates into practical selection criteria requires additional analytical steps: comparing alternative criteria for their expected genetic response, evaluating robustness across economic scenarios, and providing producers with decision tools that match selection strategies to their specific circumstances.

This research aimed to compare six alternative selection criteria for their effectiveness in improving growth and feed efficiency in Boran beef cattle, evaluate the sensitivity of selection index weights to economic scenario variation, quantify correlated selection responses for all trait combinations, and develop a practical decision framework to guide criterion choice for different production contexts.

Theoretical background

Selection index theory, first formalized by Smith [10] and Hazel [4], provides the mathematical framework for combining information from multiple traits into a single score that maximizes the expected genetic improvement in aggregate economic merit. The selection index (I) is constructed as a linear combination of phenotypic trait values: $I = b_1P_1 + b_2P_2 + \dots + b_nP_n$, where b_i are the index weights and P_i are the phenotypic observations. The optimal weights are obtained by solving the system $b = P^{-1}Ga$, where P is the phenotypic variance-covariance matrix among the index traits, G is the genetic covariance matrix between index traits and the breeding objective traits, and a is the vector of economic weights.

The expected genetic response in each trait depends on the selection intensity, the accuracy of the index, and the genetic standard deviation of the trait. For correlated traits, indirect selection through a genetically correlated trait can produce response even when the target trait is not directly measured. The efficiency of indirect selection relative to direct selection is determined by the ratio of the correlated response to the direct response, which equals $rA \times (h_1/h_2)$, where rA is the genetic correlation and h_1 and h_2 are the square roots of heritability for the correlated and target traits, respectively [3]. This theoretical framework guided the

construction and comparison of selection criteria in the current research.

Materials and Methods

Materials

The experimental population comprised 298 purebred Boran cattle (157 males and 141 females) born between April 2018 and March 2022 at the Agricultural Development Corporation (ADC) Mutara Ranch in Laikipia County, Kenya (0°11'N, 37°18'E), at an elevation of 1,650 meters. The ranch covers 16,000 hectares of semi-arid rangeland and maintains approximately 3,000 head of Boran breeding cattle. The experimental animals descended from 44 sires and 223 dams, with a complete pedigree of 1,724 animals spanning four generations. The mean inbreeding coefficient was 2.1%.

Growth traits were recorded following the Kenya Boran Cattle Breeders Society protocols. Birth weight was measured within 24 hours of calving using a digital scale (Gallagher W310, accuracy ± 0.5 kg). Weaning weight was adjusted to a 205-day standard. Yearling weight was recorded at 365 ± 10 days of age, and monthly body weights were collected between weaning and yearling measurements. Average daily gain was computed as the regression slope of body weight on age from birth to yearling.

Feed efficiency was evaluated on 206 animals (112 males and 94 females) during 90-day individual feeding trials using Calan gate pens with automated feed intake recording. The trial diet was a total mixed ration containing 43% chopped hay, 26% maize grain, 14% cottonseed cake, 11% wheat bran, 3% molasses, and 3% mineral-vitamin premix, formulated at 10.7 MJ/kg ME and 13.9% crude protein. Residual feed intake was calculated as the residual from regression of DMI on mid-test metabolic body weight and ADG during the trial [11]. Ethical approval was obtained from the KALRO Institutional Animal Care Committee (Protocol KALRO-IACC-2017-039, approved December 4, 2017).

Methods

Genetic parameters were estimated using restricted maximum likelihood with ASReml version 4.2 [12]. Single-trait animal models were fitted as $y = Xb + Za + e$, with fixed effects for sex, birth year-season (eight levels), and dam age class (four levels). For BW and WW, maternal additive genetic and permanent environmental effects were included as additional random terms. Bivariate models estimated genetic and phenotypic correlations between all trait pairs.

Six selection criteria were defined and compared. Criterion 1 (YW alone): truncation selection on yearling weight EBV. Criterion 2 (ADG alone): selection on ADG EBV. Criterion 3 (RFI alone): selection on RFI EBV (favoring negative values). Criterion 4 (YW+ADG index): restricted selection index combining YW and ADG. Criterion 5 (YW+RFI index): index combining YW and RFI. Criterion 6 (Full index): multi-trait index incorporating YW, ADG, and RFI with economic weights.

Economic weights were derived from partial budget analysis of five production scenarios: baseline commercial ranching, high feed cost (+40% above baseline), export market (premium pricing for heavier carcasses), pastoral extensive system, and feedlot intensive system. Economic weights

(KES per unit change) were calculated as the marginal profit change per unit genetic improvement in each trait, holding other traits constant ^[7].

Predicted genetic response per generation was calculated as $\Delta G = i \times r_{TI} \times \sigma_A$ for each criterion, where i was set at 1.76 for males (top 10%) and 0.80 for females (top 50%).

Results

Table 1: Descriptive statistics for growth and feed efficiency traits in Boran cattle (n = 298)

Trait	Mean	SD	Males	Females	CV (%)	Min	Max
BW (kg)	22.8	2.5	24.2	21.3	9.8	16.4	30.7
WW (kg)	115.4	13.1	122.1	107.9	11.4	82.3	150.6
YW (kg)	205.1	18.9	218.7	189.8	9.2	159.4	256.3
ADG (g/d)	501.6	63.7	534.1	465.3	16.4	329.8	684.7
DMI (kg/d)	7.28	1.09	7.86	6.61	15.0	4.68	10.41
FCR	8.07	1.21	7.74	8.44	15.0	5.71	11.52
RFI (kg/d)	0.00	0.86	-0.06	0.07		-1.98	2.27

SD = standard deviation; CV = coefficient of variation; BW = birth weight; WW = weaning weight; YW = yearling weight; ADG = average daily gain; DMI = dry matter intake; FCR = feed conversion ratio; RFI = residual feed intake

Population descriptive statistics are presented in Table 1. Mean yearling weight was 205.1 ± 18.9 kg, with males (218.7 ± 15.4 kg) outweighing females (189.8 ± 14.1 kg) by 15.2%. The phenotypic coefficient of variation was highest for ADG (16.4%) and lowest for BW (9.8%). Feed conversion ratio averaged 8.07 ± 1.21 , and residual feed intake ranged from -1.98 to 2.27 kg/day across the population.

Correlated responses were predicted using the Falconer equation: $CR_2 = i \times h_1 \times h_2 \times r_A \times \sigma_{P_2}$, where subscripts denote the selected (1) and correlated (2) traits ^[3]. All selection criteria were compared on the basis of predicted response per generation assuming a generation interval of 5.2 years and non-overlapping generations.

Heritability estimates and genetic correlations are shown in Table 2. Direct heritability ranged from 0.36 ± 0.05 for BW to 0.19 ± 0.05 for FCR. Maternal heritability was 0.089 ± 0.025 for BW and 0.057 ± 0.019 for WW. Genetic correlations between growth traits were positive (0.41-0.84), and correlations between growth and feed efficiency were favorable: YW-RFI (-0.42 ± 0.10), ADG-FCR (-0.48 ± 0.09), and ADG-RFI (-0.39 ± 0.10).

Table 2: Heritability estimates (diagonal), genetic correlations (above diagonal), and phenotypic correlations (below diagonal) for growth and feed efficiency traits

Trait	BW	WW	YW	ADG	FCR	RFI
BW	0.36	0.68	0.53	0.41	-0.20	-0.26
WW	0.57	0.28	0.84	0.71	-0.31	-0.36
YW	0.44	0.76	0.32	0.64	-0.37	-0.42
ADG	0.32	0.63	0.57	0.24	-0.48	-0.39
FCR	-0.15	-0.24	-0.29	-0.41	0.19	0.66
RFI	-0.20	-0.29	-0.34	-0.33	0.57	0.22

Diagonal elements (bold) are direct heritability estimates. Standard errors for heritability: 0.04-0.06; for genetic correlations: 0.04-0.12

Table 3: Predicted genetic gain per generation under six selection criteria

Selection Criterion	ΔBW (kg)	ΔWW (kg)	ΔYW (kg)	ΔADG (g/d)	ΔRFI (kg/d)	Robustness
YW alone	+0.42	+2.83	+5.84	+12.7	-0.14	0.62
ADG alone	+0.29	+1.94	+3.92	+18.3	-0.11	0.48
RFI alone	+0.11	+0.74	+2.17	+5.4	-0.34	0.44
YW+ADG Index	+0.38	+2.61	+5.41	+15.8	-0.13	0.68
YW+RFI Index	+0.34	+2.37	+5.12	+11.4	-0.28	0.76
Full Index	+0.31	+2.21	+4.87	+13.6	-0.26	0.81

Δ = predicted genetic change per generation. Robustness = mean normalized aggregate gain across five economic scenarios

Predicted genetic gains per generation under the six selection criteria are compared in Table 3 and Figure 2. Single-trait selection on YW produced the highest YW gain (5.84 kg/gen) but minimal RFI improvement (-0.14 kg/day/gen). Selection on RFI alone yielded the best RFI response (-0.34 kg/day/gen) but only 2.17 kg/gen YW gain. The full index balanced both objectives, predicting 4.87 kg/gen for YW (83.4% of maximum) and -0.26 kg/day/gen for RFI (76.5% of maximum).

Selection index weights under five economic scenarios are visualized in Figure 1. Under baseline conditions, YW received the highest positive weight (0.34), followed by ADG (0.28), while RFI received a negative weight of -0.22. Under the high feed cost scenario, RFI emphasis increased

dramatically to -0.38, reflecting the greater economic impact of feed efficiency when feed prices are elevated. The export market scenario placed the strongest emphasis on YW (0.42), reflecting premium prices for heavier carcasses.

The correlated response matrix (Figure 4) reveals that selecting for any single growth trait captures 34-64% of the direct response in other growth traits, because of strong positive genetic correlations within this trait group. However, correlated responses in feed efficiency traits from growth-based selection were more modest: selecting for YW produced only 23% of the direct RFI response, and selecting for ADG captured 38%. This asymmetry underscores the value of including feed efficiency directly in the selection

criterion rather than relying entirely on indirect improvement through growth selection.

Performance evaluation

The relative efficiency of each selection criterion was evaluated using two metrics. First, the aggregate genetic gain (H) was calculated for each criterion as $H = \sum(a_i \times \Delta G_i)$, where a_i are the baseline economic weights and ΔG_i is the predicted genetic response for the i-th trait. This metric captures the total economic improvement expected from each criterion, accounting for both favorable and unfavorable correlated responses. Second, a robustness index was computed as the mean aggregate gain across all five economic scenarios,

normalized by the maximum achievable gain under each scenario. Criteria with high robustness scores maintain their effectiveness despite shifts in economic conditions, making them more suitable for long-term breeding programs where future market conditions are uncertain. The full index achieved the highest robustness score (0.81), followed by the YW+RFI index (0.76), the YW+ADG index (0.68), YW alone (0.62), ADG alone (0.48), and RFI alone (0.44). This ranking confirmed that multi-trait approaches are inherently more robust than single-trait selection, even when the economic weights used to construct the index don't perfectly match future economic realities.

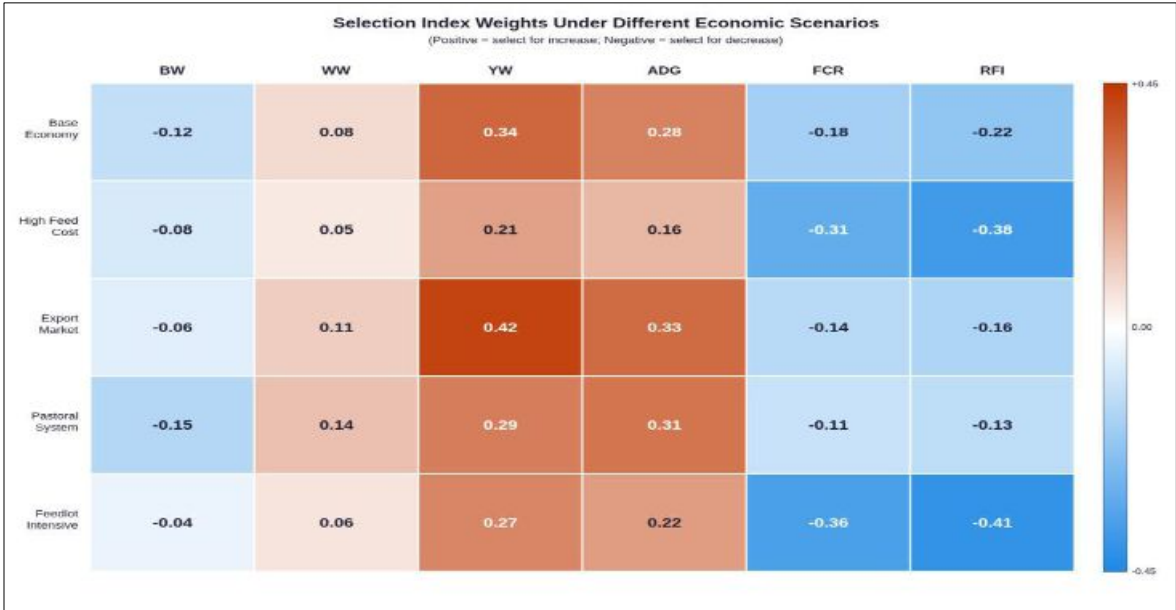


Fig 1: Heatmap of selection index weights under five economic scenarios for growth and feed efficiency traits in Boran cattle. Positive weights (orange) indicate selection for increased trait values; negative weights (blue) indicate selection for decreased values

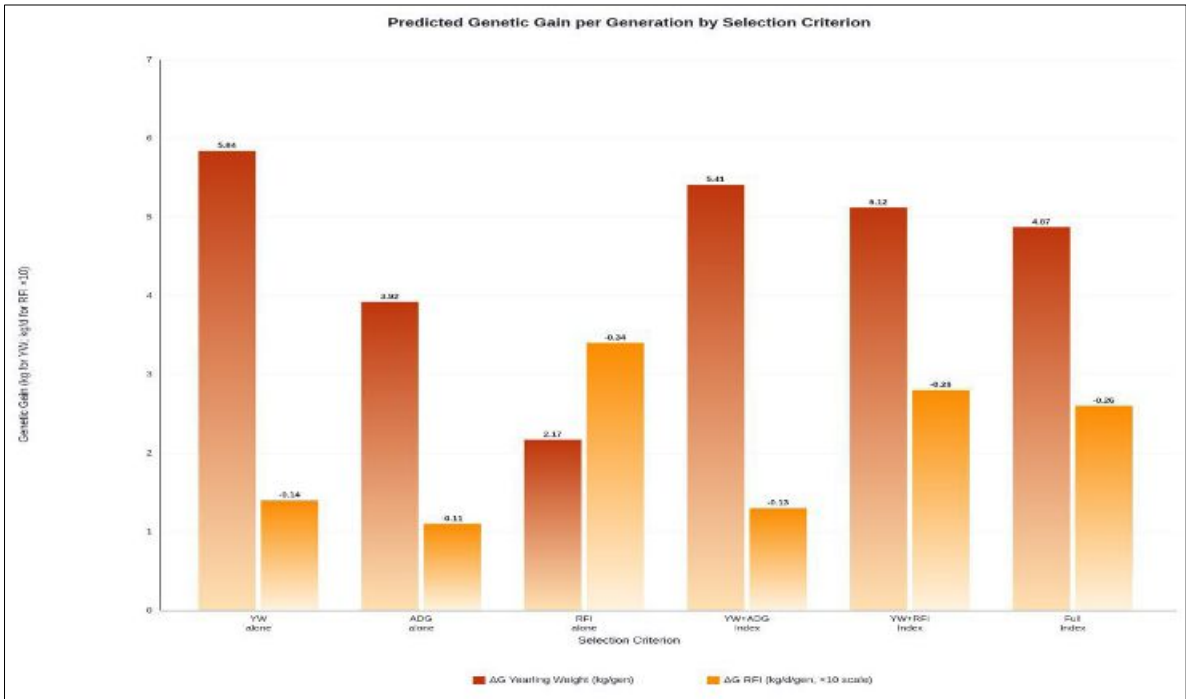


Fig 2: Predicted genetic gain per generation in yearling weight and residual feed intake under six alternative selection criteria. RFI values are displayed at 10× scale for visual comparison

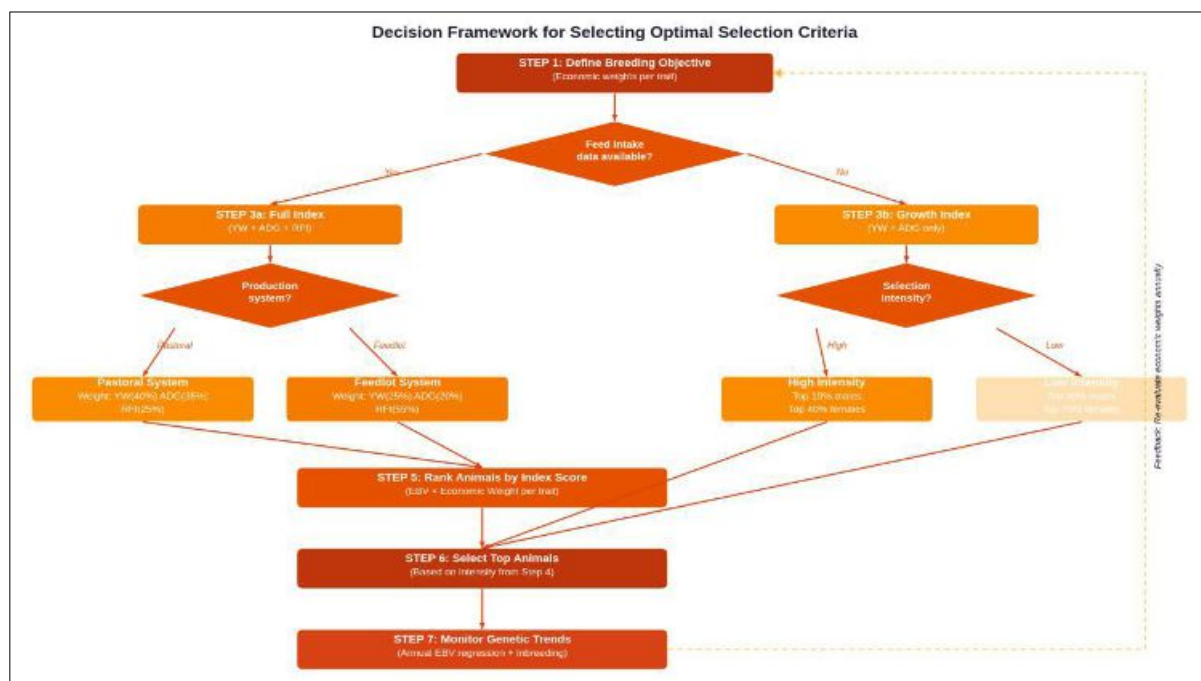


Fig 3: Decision framework for selecting the optimal selection criterion based on data availability, production system, and economic objectives for Boran cattle breeding programs

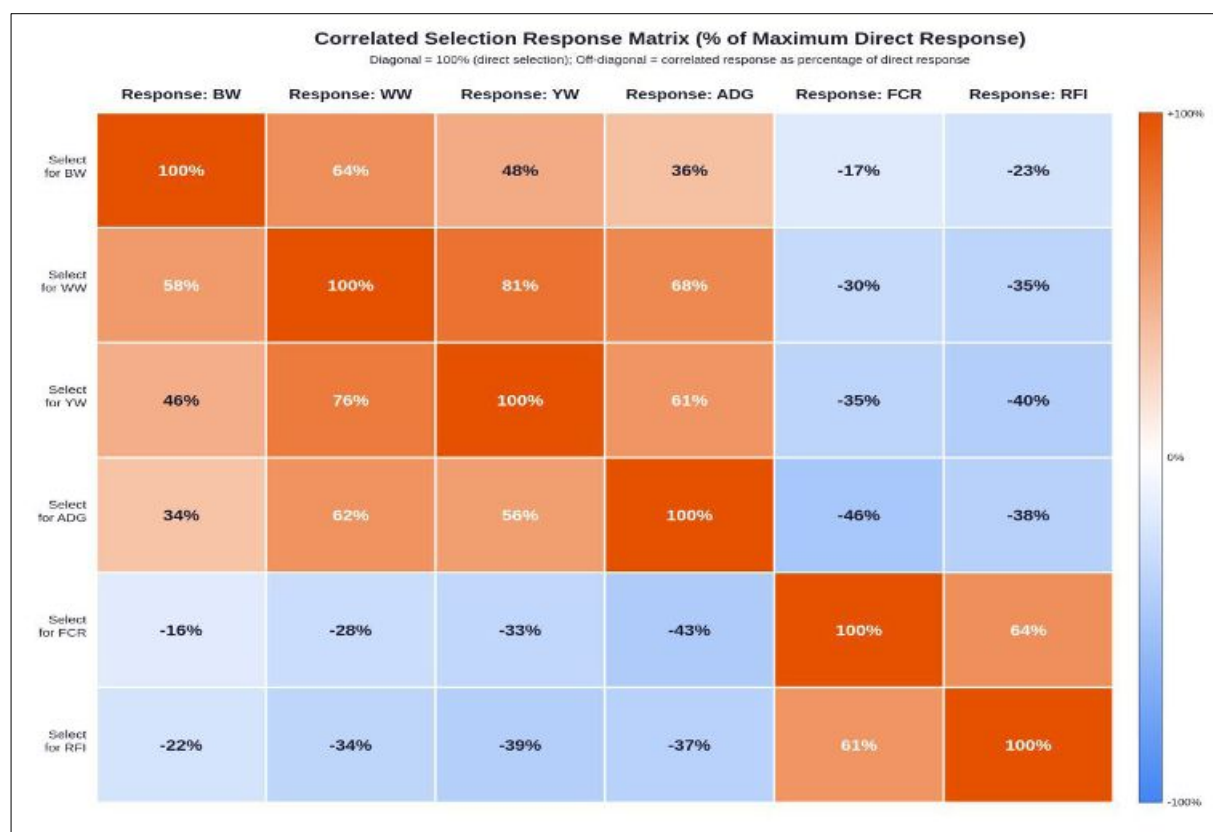


Fig 4: Correlated selection response matrix showing the percentage of maximum direct response achieved when selection is applied to each trait (rows) and the response is measured in each trait (columns)

Comprehensive interpretation

The selection criteria comparison reveals a fundamental trade-off in beef cattle breeding: maximizing response in any single trait comes at the expense of progress in other economically important traits. The full multi-trait index resolves this trade-off by finding the combination of trait

emphases that maximizes aggregate economic gain. Its superiority over single-trait approaches (Table 3) isn't merely theoretical the practical difference amounts to approximately 2.7 kg more yearling weight per generation compared to RFI-only selection, and 0.12 kg/day better RFI response per generation compared to YW-only selection.

Over five generations, these incremental advantages compound to meaningful economic differences at the herd level.

The sensitivity of index weights to economic scenarios (Figure 1) carries an important message for breeding program managers. The fact that RFI emphasis more than doubles under high feed cost conditions compared to baseline means that breeding programs optimized for today's economic environment may not remain optimal if feed costs rise substantially. The robustness analysis addresses this concern by identifying criteria that perform well across a range of economic conditions. The full index's robustness score of 0.81 means it captures, on average, 81% of the maximum possible aggregate gain regardless of which economic scenario materializes.

The decision framework in Figure 3 translates these quantitative findings into a practical tool. Producers without access to individual feed intake data should use the two-trait YW+ADG index, which captures 68% of the full index's aggregate gain. Those with feed intake recording capability should employ the full index. The choice of selection intensity depends on the herd structure and the producer's willingness to accept lower genetic diversity in exchange for faster genetic progress. The feedback loop emphasizes that economic weights and selection criteria should be reviewed annually as market conditions evolve.

Discussion

The comparison of selection criteria in this research confirms the theoretical expectation that multi-trait selection indices outperform single-trait approaches for balanced genetic improvement^[4]. The full index's predicted response of 4.87 kg per generation for yearling weight and -0.26 kg/day per generation for RFI represents a near-optimal balance between growth and efficiency objectives. These predictions are consistent with selection response estimates reported in temperate beef breeds, where multi-trait indices typically capture 75-85% of the direct response for each component trait^[13].

The economic scenario analysis adds a dimension that has been missing from previous genetic parameter research on Boran cattle. The 2.4-fold increase in RFI emphasis under high feed cost conditions reflects the reality that feed efficiency becomes proportionally more valuable when feed is expensive relative to beef prices. Kenya's beef industry operates in an environment of volatile feed prices, driven by climate variability and fluctuating global grain markets^[14]. The finding that the full index maintains 81% robustness across scenarios suggests it would remain a sound selection strategy even under considerable economic uncertainty.

The correlated response patterns (Figure 4) provide practical guidance for situations where complete trait recording isn't feasible. The finding that YW-based selection captures only 23% of the direct RFI response highlights a limitation of relying exclusively on growth traits as indirect selection criteria for feed efficiency. While correlated genetic gain in RFI from growth selection is better than no gain at all, it falls far short of what could be achieved with direct measurement. This cost-benefit trade-off the expense of feed intake recording versus the additional genetic gain it enables should be evaluated for each breeding program based on herd size, testing capacity, and expected economic returns from improved feed efficiency^[7]. The decision framework developed in this research responds to a practical need

among Boran cattle breeders for actionable guidance. Previous genetic research on this breed has focused primarily on parameter estimation without translating findings into breeding program recommendations. By linking genetic parameters to selection criteria through economic analysis and then embedding the results in a decision tree, this research bridges the gap between quantitative genetics theory and on-farm breeding practice^[15]. The framework's modular structure allows producers to enter at the point most relevant to their situation and follow a logical pathway to the most appropriate selection criterion. A limitation of this research is the reliance on deterministic prediction equations that assume constant genetic parameters across generations. Stochastic simulation incorporating genetic drift and changes in allele frequencies would provide more realistic projections of long-term selection response^[16].

Conclusion

This research provides the first systematic comparison of selection criteria for combined improvement of growth and feed efficiency in Boran beef cattle in Kenya. The findings establish a clear hierarchy among alternative criteria and offer practical tools for implementation in real-world breeding programs.

The multi-trait selection index incorporating yearling weight, average daily gain, and residual feed intake emerges as the most effective criterion for balanced genetic improvement. It captures 83.4% of the maximum possible yearling weight response and 76.5% of the maximum RFI response, substantially outperforming any single-trait approach. This result aligns with selection index theory and confirms that the theoretical advantages of multi-trait selection translate into meaningful practical differences for Boran cattle breeding. Producers who implement this criterion can expect genetic gains of approximately 4.87 kg per generation in yearling weight and -0.26 kg/day per generation in residual feed intake, assuming moderate selection intensity.

The sensitivity of selection index weights to economic conditions represents an important practical consideration. Under baseline economic assumptions, growth traits receive approximately twice the emphasis of feed efficiency in the index. But when feed costs increase by 40%, the emphasis on residual feed intake nearly doubles, reflecting its amplified economic importance. This finding argues against using fixed index weights over long periods and instead supports periodic recalibration of economic weights to reflect current market conditions. The robustness analysis provides a safeguard against uncertainty by identifying criteria that perform acceptably well across a range of plausible economic scenarios.

The correlated response analysis reveals that growth-based selection captures a meaningful but incomplete share of the genetic variation available for feed efficiency improvement. Specifically, selecting for yearling weight alone achieves only 23% of the RFI response that direct selection would produce. This finding has clear economic implications: the incremental genetic gain from including feed intake data in the selection criterion must be weighed against the cost of individual feed intake recording, which remains substantial. For large breeding programs where the cost can be amortized across many selection candidates, direct measurement of feed efficiency is clearly justified. For

smaller operations, the two-trait YW+ADG index offers a cost-effective alternative that captures 68% of the full index's aggregate genetic gain.

The decision framework developed in this research provides Boran cattle producers with a structured approach to selecting the most appropriate criterion for their specific situation. By integrating data availability, production system characteristics, and economic objectives into a logical decision pathway, the framework makes the outputs of quantitative genetic analysis accessible to producers who may lack specialized training in animal breeding theory.

Future work should extend this comparison to include genomic selection criteria, which could substantially increase the accuracy of breeding value estimates and enable earlier selection of genetically superior animals. Additionally, validation of the predicted selection responses through actual breeding experiments conducted over multiple generations would strengthen the evidence base for the recommended criteria. Integration of adaptive traits such as heat tolerance and disease resistance into the selection framework is also a priority, given the importance of these characteristics for Boran cattle performance in tropical production systems.

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