

# Genetic selection indices for growth traits in Blanco-Orejinegro cattle

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**ABSTRACT:** Selection indices are used in genetic improvement programs, with the purpose of selecting simultaneously for several economically important traits. The objective of this study was to construct equations for selection indices in the Blanco-Orejinegro (BON) breed and to determine the index that would generate the greatest genetic progress. The information used included birth weight (BW), body weights adjusted to 120, 240, 480, and 720 days old (W120, W240, W240, 480 and W720, respectively), age at first calving (AFC) and interval between first and second calving (IBC) estimated breeding values. Two Smith and Hazel

indices were calculated using variances (I1) and literature (I2), with a part two indices designed using information from experts and breeders (I3 and I4). All the indices favored the reduction of weight at birth. The I1 focused mainly on W120 and I2, I3 and I4 focused on 720. In general, the estimated indices obtained similar reliability and expected genetic differences I1 generated a decrease in direct BW. I2 generated the largest increases in BW and AFC. I3 and I4 generated positive changes in growth and reproductive traits, with I3 generating the greatest genetic gains in the population, especially for W240.

**Key words:** beef cattle, genetic improvement, genomic analysis, variance components

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## INTRODUCTION

Currently, a number of distinct local Creole cattle breeds are found throughout the Americas. Creole cattle show great phenotypic heterogeneity and have adapted to a wide range of environments with few human interventions. Blanco Orejinegro (BON) has been recognized as a

landrace cattle breed with a broad geographical distribution and that has adapted to a wide range of environments, from the high Andean region to the harsh conditions in Colombian tropical regions (Martínez et al., 2013). The animals have a pigmented epidermis and mucous membranes and dark hooves and horns, with hair that is completely white or white evenly combined with some black, while the hairs on the ears are black. There is also a variety of animals with white hair on the body and blond hair on the ears (Gallego et al., 2012).

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The increasing popularity of the BON cattle breed is encouraging farmers to select animals with better productive performance for traits of economic interest, prioritizing the genetic improvement of body weights adjusted to 240, 480, and 720 days (W240, W480, and W720, respectively) and reproductive traits. Therefore, it is necessary to establish adequate selection criteria to identify the individuals that make positive genetic contributions since poor genetic gain have been documented for some growth traits in this breed (Gallego et al., 2006).

Genetic selection in farm animals is a complex process that seeks to generate the greatest genetic progress for several traits in a population based on the identification of superior individuals. The most efficient way to achieve this goal is to use selection indices that allow assessing genetic values for various traits and combining them with their economic values, thus classifying individuals with a single figure and facilitating selection (Marques et al., 2012; Stanojević et al., 2015). For example, Boligon et al. (2018) showed positive and favorable direct genetic changes for the traits growth and reproductive in Nellore cattle when using selection indices.

Smith (1936) and Hazel (1943) introduced the concept of the selection index by combining genetic and economic information. This concept is also referred to as desired gain (Pesek and Baker, 1970). This methodology uses phenotypic and genetic correlations to calculate a single number that represents the added genetic value of each animal (Ochsner et al., 2017), thus simplifying and optimizing selection by multiple characters (Ramirez et al., 2020). The objective of the present study was to propose selection indices with different weights to be used in the BON breed that maximize genetic progress for various productive and reproductive traits.

## MATERIALS AND METHODS

### Animals and Data

Estimated breeding values for birth weight (BW), body weights adjusted to 120, 240, 480, and 720 days old (W120, W240, W480, and W720, respectively), age at first calving (AFC) and interval between first and second calving (IBC) of 13,612 BON animals were used, of which 719 were sires and 3675 were dams. The herds included pure animals from

the Colombian Corporation for Agricultural Research - AGOSAVIA and 24 private farms in several Colombian regions.

The database belongs to the AGROSAVIA National Genetic Improvement Program under the guidelines of the Colombian Ministry of Agriculture and Rural Development (Resolution 000327-2018 and contract 003 of 1994, accepting the Convention on Biological Diversity of 1992). The information provided by the AGROSAVIA databases was obtained from routine farm management activities based on the International Animal Registration Committee.

### Selection Index

For the construction of the indices, the direct genetic ( $G$ ) and phenotypic ( $P$ ) (co)variance matrices by Ramirez et al. (2020) were considered, which use a polygenic-genomic model for BW, W120, W240, W480, and W720. Ramirez et al. (2020) estimated the variance components by the maximum restricted likelihood method based on a multitrait animal model (Corbeil and Searle, 1976; Harville, 1977) using the AIREMLF90 package (Tsuruta, 2014) of the BLUPF90 program system of the University of Georgia (Misztal, 2006; Misztal et al., 2018), including the genotype information of 917 animals with 50,932 SNPs per animal. The standard errors of the additive variances were low, between 0.03 (for BW) and 4.11 (for W720), and the standard errors of the heritabilities and correlations were close to zero.

The  $G$  and  $P$  matrices for BW, W120, W240, W480, and W720 were:

$$G = \begin{bmatrix} 2.44 & 2.01 & 2.91 & 6.22 & 8.27 \\ & 52.87 & 44.77 & 58.08 & 57.93 \\ & & 123.99 & 148.74 & 154.68 \\ & & & 238.19 & 266.62 \\ & sym & & & 339.54 \end{bmatrix}$$

$$P = \begin{bmatrix} 7.66 & 2.01 & 2.91 & 6.22 & 8.27 \\ & 180.89 & 44.77 & 58.08 & 57.93 \\ & & 432.38 & 148.74 & 154.68 \\ & & & 629.00 & 266.62 \\ & sym & & & 857.76 \end{bmatrix}$$

The indices did not include maternal genetic effects. They also did not take into account reproductive traits because it was not possible to include these

traits in the multitrait model due to convergence problems. The indices were constructed according to the methodology proposed by Hazel (6), where:

$I = b_1X_1 + \dots + b_nX_n$ , with  $X_i$  = genetic values of the animal for BW, W120, W240, W480, and W720.

$b_i$  = regression coefficient for the  $i$ th trait, given by:  $b = P^{-1}Ga$ . The value  $a_i$  = weights of traits, representing the weighting of the relative contribution of each trait to production efficiency, and estimated in four different ways (indicated with asterisks):

$$a^* = \left( \left( \frac{1}{\sigma_{fn}} \right) / \left( \frac{1}{\sigma_{fP240}} \right) \right)$$

$\sigma_{fn}$  = phenotypic standard deviation of the  $n$  trait.  
 $\sigma_{fP240}$  = phenotypic standard deviation of the W240 trait.

The value of the W240 trait was set to one. The values of the other traits were calculated as relative values. W240 was selected because it is a relevant trait for farm systems dedicated to breeding or fattening. In addition, it was considered by farmers and technicians to be the most important trait.

For  $a^{**}$ , parameters estimated in the literature based on bioeconomic models under similar management systems (grazing and extensive systems and full productive life cycle) were used. The economic values obtained by Júnior et al. (2006), Brumatti et al. (2011), Moreira (2015), de Souza (2016), Macneil (2016) were averaged and expressed in US dollars.

$a^{***}$  was constructed from 23 surveys of farmers and experts (researchers who worked on the studied race) familiar with the BON breed who were asked to strictly order (from 1 to 5) the five weight traits by importance for the system production of BON cattle, as follows: 1 for the most important trait and 5 for the least important.  $a^{****}$  was calculated as follows:

$$a^{***} = C_t/C_n$$

$C_t$  = number of traits (5)

$C_n$  = assigned position (1, 2, 3, 4, or 5).

$a^{****}$  was constructed from 23 surveys of farmers and experts familiar with the BON breed who were asked to assign a score between 1 and 10 to the weight traits, where 1 is an unimportant trait and 10 is a very important trait. In this case, the traits could have the same score.  $a^{****}$  was calculated as:

$$a^{***} = A_n/A_t$$

$A_n$  = assigned score (1, 2, 3,... 10)

$A_t$  = total score

The  $a$  estimates for each trait are presented in Table 1.

The equation proposed by Cameron (1997) was used to calculate the reliability of the ( $r_I$ ) index, where  $r_I = \sqrt{\frac{b'Ga}{a'Ga}}$ . The expected genetic differences for each trait ( $\nabla G$ ; kg) were also estimated as follows:  $\nabla G = \frac{b'G}{\sqrt{b'Pb}}$ . The relative efficiency (ER) of each index was estimated based on the value relative to I1. For all the indices, the BW was considered negative because it seeks to reduce birth weight.

### Pseudosimulation Processes

Pseudosimulation processes of mating between sires and dams with a uniform distribution were carried out to observe, under seven possible selection scenarios, the changes in the traits included in the index and the maternal genetic effects of BW, W120 and W240 and the AFC and IBC traits. The breeding values were estimated, and the genetic values were estimated using the variance components of Ramírez et al. (2020). The variance components, heritabilities, and genetic values AFC and IBC were previously estimated in a bitrait model. The fixed effects for each trait were contemporary groups: farm, season, and year of birth for AFC or year of parity for IBC. The seasons were formed according to the region's rainfall regime as follows: Dry = December, January, February, June, July, and August; Rainy = March, April, May, September, October, and November. The heritability estimated was  $0.13 \pm 0.05$  for two-trait and

**Table 1.** Economic weighting (a) for growth traits in BON cattle

Trait	$1/\sigma_{fn}$	$a^*$	$a^{**}$	$a^{***}$	$a^{****}$
Birth weight	0.361	-7.51	-0.48	-1.57	-0.53
Weight adjusted to 120 days	0.074	1.55	0.11	2.39	0.50
Weight adjusted to 240 days	0.048	1.00	0.33	4.39	0.73
Weight adjusted to 480 days	0.040	0.83	0.25	3.30	0.72
Weight adjusted to 720 days	0.034	0.71	0.94	3.30	0.76

$\sigma_{fn}$ , Phenotypic deviation;  $a^*$ , relationships of variances;  $a^{**}$ , bioeconomic references and information from experts ( $a^{***}$  and  $a^{****}$ ).

genetic and phenotypic correlations of  $-0.92$  and  $-0.24$ , respectively.

The seven scenarios were no selection (S0), the best animals with a breeding value for W240 only (I240) and W720 only (I720), and scenarios where selection was performed from the proposed indices (I1, I2, I3, and I4).

For this, the individuals in the simulated generation were chosen for each index using selection intensities of 5% for males and 50% for females. The pairings were simulated by randomly assigning a bull to each cow. Genetic values were generated for the progeny as the average of their parents' breeding values for all traits (productive and reproductive). The pseudosimulation process for each scenario was repeated 200 times.

The indices were then compared by means of a duality diagram relating the genetic values for each trait in each index using the `ade4` library (Dray and Dufour, 2007) of the R-project statistical program (R Core Team, 2018). This allowed us to predict the variation in genetic values, in terms of standard deviations for each trait from the application of each selection criterion.

## RESULTS

In the case of the survey of producers and experts for  $a^{**}$ , the descending order of importance was W240, W480, W720, W120, and BW. In the surveys for  $a^{***}$ , the average scores of the producers and experts in descending order were  $7.58 \pm 1.89$  (W720),  $7.33 \pm 3.29$  (W240),  $7.20 \pm 2.2$  (W480),  $5.33 \pm 2.82$  (BW), and  $4.95 \pm 2.25$  (W120) points.

The estimated regressors for the different  $a$  values are presented in Table 2, and the  $\nabla G$  values are presented in Table 3. The estimated ERs were 100.21, 99.15, and 99.40 for I2, I3, and I4, respectively. The I2 index had the highest estimated ER (100.2), while I3 had the lowest ER (99.15).  $r_I$  was 0.66 for the four proposed indices.

In the comparisons of the seven simulated scenarios in the genetic changes caused after the simulation process, only I3 and I4 were not significant ( $P > 0.05$ ) for AFC, IBC, BWm, and W480. The

duality diagram (Figure 1) shows growth and reproductive trait changes (in standard deviations) resulting from the application of selection criteria. When no selection (S0) was conducted, growth traits and both direct and maternal effects decreased and reproductive traits increased.

## DISCUSSION

The weight obtained in the BW characteristic for I1, I3, and I4 were similar to those obtained by Faid-Allah and Ghoneim (2012) using different methodologies. Brumatti et al. (2011), using a bioeconomic model with five characteristics, weighted weight at weaning and the weight at 18 months as the least relevant within the index. In the Beefmaster breed, Ochsner et al. (2017) weighted the weaning weight as the most important within the index and found that W720 represented a negative economic impact for the evaluated systems. In Colombia, Amaya et al. (2020), using a bioeconomic index, found that the W240 and IBC were the most important in the Simmental production systems. These results show how the importance of the growth characteristics varies due to the selection objectives, the characteristics, and economic values, indicating the importance of the estimation of the indices according to the production systems.

All the indices favor the reduction of weight at birth. I1 focuses mainly on weight gain at 120 days, contrary to I2, I3, and I4, since these indices prioritize weight at 720 days. I1 could be used in herds where the main objective is the rearing of calves or the production of dams with good maternal aptitude. In accordance with what was proposed by Emanoela et al. (2015), the early relationships between the dam and calf have an important effect on the survival of the calf, in addition to being a good indicator of the production ability of the cow due to the high effect that this has on the weight of the calf at this stage (Kamei et al., 2017). I2, I3, and I4 prioritized increases in W480 and W720 and a reduction in CFA, aspects related to sexual precocity and entry to reproductive life (De León et al., 2019), although the IBC was increased.

**Table 2.** Estimated regressors for growth traits used in the construction of selection indices in BON cattle

Trait	I1	I2	I3	I4
Birth weight	-3.73	-0.22	-2.16	-0.48
Weight adjusted to 120 days	0.77	-0.07	0.56	0.12
Weight adjusted to 240 days	0.32	0.14	1.55	0.26
Weight adjusted to 480 days	0.37	0.25	1.54	0.34
Weight adjusted to 720 days	0.34	0.33	1.69	0.37

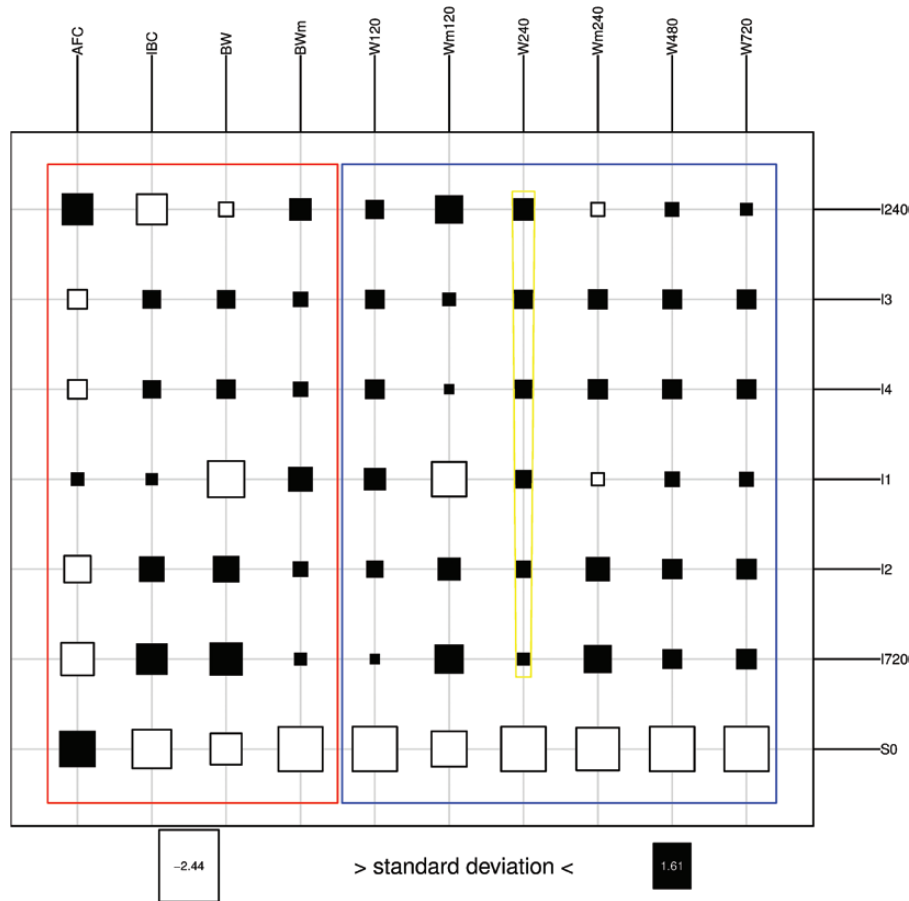
I1...I4 = selection index with four desired changes.



**Table 3.** Expected genetic differences in selection indices for growth traits in BON cattle

Trait	$\nabla G$			
	I1	I2	I3	I4
Birth weight	-0.15	0.24	0.21	0.21
Weight adjusted to 120 days	4.24	2.01	2.83	2.84
Weight adjusted to 240 days	6.45	6.59	7.04	6.89
Weight adjusted to 480 days	8.74	10.04	9.89	9.94
Weight adjusted to 720 days	9.77	11.99	11.48	11.59

I1...I4 = selection index with four desired changes.  $\nabla G$  = Genetic change (kg).



**Figure 1.** Duality diagram between birth, 120, 240, 480, and 720 days’ weight (BW, W120, W240, W480, and W720, respectively), age at first calving (AFC), the interval between first and second calving (IBC), and the maternal genetic effects of BW (BWm), W120 (Wm120), and W240 (Wm240), with genetic values of progeny obtained by no selection (S0), W240 only (I240), W720 only (I720), and Hazel selection indices (I1 to I4) in Blanco Orejinegro cattle pairings. Genetic gain order for W240 (red color). Blue features require positive deviations and red features require negative deviations to be improved in the genetic program of the breed.

In general, the estimated indices obtained similar  $r_I$  and ER values. The  $\nabla G$  results were similar for I3 and I4. I1 was the only index that generated a decrease in BW. The I2, I3, and I4 indices resulted in a positive  $\nabla G$  for all traits. I2 generated the largest  $\nabla G$  for BW, W480, and W720. I3 generated the greatest change in W240. The contrasts in  $\nabla G$  with the different indices were small. The  $\nabla G$  generated by the different indices in W120, W240, W480, and W720 agreed with what is desired in bovine production systems, where it is important to identify breeders that transmit greater

growth capacity since it has a direct relationship with farm income (Verde, 2008; Urdaneta, 2009; Quiceno et al., 2012). Higher-income results in improved business profitability by producing animals with a higher weight in a shorter time at lower costs (Brown et al., 1976; Bergamasco et al., 2001).

Our results show a small  $\nabla G$  for BW; therefore, this trait is expected to remain with little variation. There is a high and positive genetic correlation between BW and calving difficulty. According to Inoue et al. (2017), the risk of calving difficulty increases by 1% for every kg increase in calf weight at

birth. Therefore, maintaining BW can eliminate the risks of calving problems.

According to our results, the least favorable scenario was S0, in which the genetic values of all traits were unfavorably modified. In scenario S0 (without the selection of breeders), the progeny showed a reduction in growth traits and increases in AFC and IBC. In the scenario where breeders were selected considering the genetic value at W240, increases in AFC and IBC were observed, indicating that if selection is conducted only for weight at 8 months (weaning age), reproduction will be affected, even if greater genetic gain at W240 and BW reduction are achieved.

The I3 and I4 scenarios resulted in the greatest balance for the traits, with the I3 index having the greatest change in W240. For this reason, I3 is the recommended index for use in genetic programs aimed at improving the BON breed.

## CONCLUSION

The selection index with desired change values of  $-1.57$ ,  $2.39$ ,  $4.39$ ,  $3.30$ , and  $3.30$  for BW, W120, W240, W480, and W720, respectively, allows us to obtain the best genetic gains in a genetic improvement program for the BON breed. This information will allow BON cattle producers to compare breeders with a single value, selecting the breeder with the greatest genetic progress.

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*Conflict of interest statement:* None declared.

## LITERATURE CITED

- Amaya, A., D. Garrick, R. Martínez, M. Cerón-Muñoz. 2020. Economic values for index improvement of dual-purpose Simmental cattle. *Liv. Sci.* 240:104224. doi: [10.1016/j.livsci.2020.104224](https://doi.org/10.1016/j.livsci.2020.104224)
- Bergamasco, A. F., H. L. De Aquino, and J. A. Muniz. 2001. Ajuste De Modelos Não-Lineares a Dados De Crescimento De Fêmeas Da Raça Holandesa. *Ciênc. agrotec.* 25(2):235–241.
- Boligon, A. A., I. D. S. Vicente, V. M. Roso, and F. P. De Souza. 2018. Direct and maternal annual genetic changes for selected traits at weaning and yearling in beef cattle. *Acta Sci. Anim. Sci.* 41(1):42572. doi:[10.4025/actascianimsci.v41i1.42572](https://doi.org/10.4025/actascianimsci.v41i1.42572)
- Brown, J. E., H. A. Fitzhugh, and T. C. Cartwright. 1976. A comparison of nonlinear models for describing weight-age relationships in cattle. *J. Anim. Sci.* 42(4):810–818.
- Brumatti, R. C., J. B. Ferraz, J. P. Eler, and I. B. Formigoni. 2011. Desenvolvimento de índice de seleção em gado corte sob o enfoque de um modelo bioeconômico. *Arch Zootec.* 60(230):205–213.
- Cameron, N. D. 1997. Selection index methodology. In: *Selection indices and prediction of genetic merit in animal breeding*. Wallingford (UK): CAB International; p. 65
- Corbeil, R. and S. Searle. 1976. Restricted Maximum Likelihood (REML) estimation of variance components in the mixed model. *Technometrics.* 18(1):31–38. doi:[10.2307/1267913](https://doi.org/10.2307/1267913)
- De León, C., C. Manrique, R. Martínez, and J. F. Rocha, 2019. Genomic association study for adaptability traits in four Colombian cattle breeds. *Genet. Mol. Res.* 18(3):gmr18373. <https://doi.org/10.4238/gmr18373>.
- de Souza, F. M. 2016. Valores E Índices Bioeconômicos Para Um Sistema De Produção De Bovinos Nelore No Bioma Cerrado [Doutorado em Zootecnia]. Goiânia, Brasília (Brazil): Universidade Federal de Goiás. Escola de Veterinária e Zootecnia.
- Dray, S., and A. B. Dufour. 2007. The ade4 package: implementing the duality diagram for ecologists. *J. Stat. Softw.* 22(4):1–20. doi:[10.18637/jss.v022.i04](https://doi.org/10.18637/jss.v022.i04)
- Emanoela, S.-C. A. L., V. A. María, L. M. Conde, J. Delgado-Mendez, F. C. Souza, P. M. da Costa, T. C. B. De Bittencourt Dos, and K. N. de Oliveira, 2015. Maternal-calf relationships and their influence on calves up to 120 days. *Rev. Mvz. Córdoba.* 20(1):4436–4446. <https://doi.org/10.21897/rmvz.73>
- Faid-Allah, E., and E. Ghoneim. 2012. Comparing different methods for estimating economic values in selection index for pre-weaning body weights of Friesian heifers in Egypt. *Egyptian J. Anim. Prod.* 49:73–80. [https://journals.ekb.eg/article\\_100891\\_00120b6fcecb9f05b31c3bab4ad0fb35.pdf](https://journals.ekb.eg/article_100891_00120b6fcecb9f05b31c3bab4ad0fb35.pdf)
- Gallego, J. L., R. A. Martínez, and F. L. Moreno. 2006. Índice de consanguinidad y caracterización fenotípica y genética de la raza bovina criolla Blanco Orejinegro. *Corpoica Cienc. y Tecnol. Agropecu.* 7(1):16–24.
- Gallego, G. J., R. A. Martínez, and F. L. Moreno. 2012. Características fenotípicas y morfométricas de la raza En: Estrategias de conservación y mantenimiento de la variabilidad genética de la raza BON. En: S. R. Martínez, R. R. Vásquez, and G. J. Gallego. *Eficiencia reproductiva de la raza BON en el trópico colombiano*. Bogotá (Colombia): Corporación Colombiana de Investigación Agropecuaria, Corpoica; p. 17–30. [https://repository.agrosavia.co/bitstream/handle/20.500.12324/19528/45425\\_62083.pdf?sequence=1&isAllowed=y](https://repository.agrosavia.co/bitstream/handle/20.500.12324/19528/45425_62083.pdf?sequence=1&isAllowed=y)
- Harville, D. 1977. Maximum Likelihood approaches to variance components estimation and to related problems. *J. Am. Stat. Assoc.* 72(358):320–37. doi:[10.2307/2286796](https://doi.org/10.2307/2286796)
- Hazel, L. N. 1943. The genetic basis for constructing selection indexes. *Genetics.* 28:476–490.

- Inoue, K., M. Hosono, and Y. Tanimoto. 2017. Inferring causal structures and comparing the causal effects among calving difficulty, gestation length and calf size in Japanese Black cattle. *Animal* 11:2120–2128. doi:[10.1017/S1751731117000957](https://doi.org/10.1017/S1751731117000957)
- Júnior, J. J., V. L. Cardoso, and L. G. De Albuquerque. 2006. Modelo bioeconômico para cálculo de custos e receitas em sistemas de produção de gado de corte visando à obtenção de valores econômicos de características produtivas e reprodutivas. *Rev. Bras. Zootec.* 35(5):2187–2196. doi:[10.1590/S1516-35982006000700040](https://doi.org/10.1590/S1516-35982006000700040)
- Kamei, L. M., de A. E. L. Ribeiro, N. N. A. Fonseca, D. S. D. A. C. Muniz, V. T. Camiloti, A. N. Koritiaki, and de S. A. P. Fortaleza, 2017. Genetic parameters of growth traits in Nelore cattle. *Semina Ciênc. Agrár.* 38(3):1503–1510. <https://doi.org/10.5433/1679-0359.2017v38n3p1503>
- Macneil, M. D. 2016. Value of genomics in breeding objectives for beef cattle. *Rev. Bras. Zootec.* 45(12):794–801. <https://doi.org/10.1590/s1806-92902016001200010>
- Marques, E. G., C. U. Magnabosco, and F. B. Lopes. 2012. Selection indices for Nelore beef cattle from performance test weight in confinement. *Rev. Bras. Saúde Prod. Anim.* 13(3):669–681. doi:[10.1590/s1519-99402012000300007](https://doi.org/10.1590/s1519-99402012000300007)
- Martínez, R., A. P. Llinás, and J. F. M-Rocha. 2013. Genetic variability in Blanco Orejinegro breed cattle populations in Colombia. *Genet. Mol. Res.* 12:1083–1094. doi:[10.4238/2013.April.10.4](https://doi.org/10.4238/2013.April.10.4)
- Misztal, I. 2006. BLUPF90 – a flexible mixed model program in Fortran 90. Athens (GA, USA): University of Georgia. [https://pdfs.semanticscholar.org/77ab/71e247fa61ce7100b6c3094a7737c6ab9755.pdf?\\_ga=2.160304957.14444617945.1585070130-342929735.1585070130](https://pdfs.semanticscholar.org/77ab/71e247fa61ce7100b6c3094a7737c6ab9755.pdf?_ga=2.160304957.14444617945.1585070130-342929735.1585070130)
- Misztal, I., S. Tsuruta, D. Lourenco, I. Aguilar, A. Legarra, and Z. Vitezica. 2018. Manual for BLUPF90 family of programs. Athens (GA, USA): University of Georgia; p. 125. [http://nce.ads.uga.edu/wiki/lib/exe/fetch.php?media=blupf90\\_all7.pdf](http://nce.ads.uga.edu/wiki/lib/exe/fetch.php?media=blupf90_all7.pdf)
- Moreira, H. L. 2015. Objetivos de seleção e valores econômicos para bovinos Nelore em sistema de ciclo completo [Doutor em ciências]. Ribeirão Preto (São Paulo, Brazil): Faculdade de medicina de Ribeirão Preto, Universidade de São Paulo.
- Ochsner, K. P., M. D. MacNeil, R. M. Lewis, and M. L. Spangler. 2017. Economic selection index development for Beefmaster cattle I: terminal breeding objective. *J. Anim. Sci.* 95:1063–1070. doi:[10.2527/jas.2016.1231](https://doi.org/10.2527/jas.2016.1231)
- Pesek, J., and R. J. Baker. 1970. An application of index selection to the improvement of self-pollinated species. *Can. J. Plant Sci.* 50:267–276.
- Quiceno, A. J., S. R. Martínez, H. Mateus, G. J. Gallego, and P. Medina. 2012. Crecimiento en pastoreo rotacional de toretes de razas criollas Romosinuano y Blanco Orejinegro en Colombia. *Rev. MVZ Córdoba.* 17(1):2891–2899.
- Ramírez, T. E., P. W. Burgos, M. A. Elzo, S. R. Martínez, and M. Cerón-Muñoz. 2020. Genetic parameters and trends for growth traits in Blanco Orejinegro cattle. *Transl. Anim. Sci.* 4(3):1–9. Doi:[10.1093/tas/txaa084](https://doi.org/10.1093/tas/txaa084)
- R Core Team. 2018. R: The R Project for Statistical Computing Vienna, Austria; Available from <https://www.r-project.org/>
- Smith, H. F. 1936. A discriminant function for plant selection. *Ann. Eugen.* 7(3):240–250. doi:[10.1111/j.1469-1809.1936.tb02143.x](https://doi.org/10.1111/j.1469-1809.1936.tb02143.x)
- Stanojević, D., R. Đedović, V. Bogdanović, M. Popovac, P. Perišić, R. Beskorovajni, and M. Lazarević 2015. The potentials of using selection index in the assessment of breeding values of Holstein breeds in Serbia. *Biotech. Anim. Husbandry.* 31(4):523–532. doi:[10.2298/BAH1504523S](https://doi.org/10.2298/BAH1504523S)
- Tsuruta, S. 2014. Average Information REML with several options including EM-REML and heterogeneous residual variances. Available from <http://nce.ads.uga.edu/wiki/doku.php?id=readme.aireml>
- Urdaneta, F. 2009. Mejoramiento de la eficiencia productiva de los sistemas de ganadería bovina de doble propósito (Taurus-Indicus). *Arch. Latinoam. Prod. Anim.* 17(3):109–120.
- Verde, O. 2008. Sistema de producción con bovinos de carne en la estación experimental “La Cumaca” IV. caracteres reproductivos. *Rev. Fac. Cienc. Vet.* 49(2):113–120. [http://ve.scielo.org/scielo.php?pid=S0258-65762008000200006&script=sci\\_abstract](http://ve.scielo.org/scielo.php?pid=S0258-65762008000200006&script=sci_abstract)