Genetics and Reproduction

Review article

Current Status and Prospects of Cattle Production in Cuba

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ABSTRACT

Background: Cattle production in Cuba has experienced declines across all productive indicators, raising questions regarding the effectiveness of the crossbreeding program implemented over the past 60 years. Although the program was conceptually sound, several stress-related factors, together with a technical approach that failed to evolve at the required pace, may explain the observed outcomes. **Aim**: To review Cuban studies on genotype - environment interaction (GEI) and genetic progress (GP), the effects of which were not considered in the statistical models employed, and to explain the biased results reported for all dairy and beef cattle breeds. **Methods**: A more robust statistical model was applied to 537,567 lactation records from 233,082 cows sired by 2,589 bulls belonging to the Siboney, Mambí, and Holstein breeds. This approach enabled the estimation of breeding values (BV) for both males and females, regardless of breed. **Results**: The breeding values of cows and bulls exhibited the same negative trend. During the most critical period, the decline reached the equivalent of −138 kg/year and −68 kg/year in genetic enterprises and in the overall Cuban cattle population, respectively. **Conclusions**: The breeding program used Zebu cattle as the "recipient" component and Bos taurus as the "transforming" component. The resulting crossbred animals became physiologically specialized for milk production but were managed and fed under environmental conditions more closely resembling those suitable for the recipient genotype. Consequently, both productivity and adaptability were adversely affected. A radical change in breeding value estimation models is recommended, together with increased attention to the role of dairy Zebu cattle, for which supporting evidence already exists. **Keywords**: genotype - environment interaction; milk production in Cuba; genetic progress; role of dairy Zebu cattle (Source: *AGROVOC*)

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INTRODUCTION

The genetic breeding program implemented in Cuba has no comparable precedent in any other tropical country. The program's fundamental objective was conceptually sound: to develop a dairy animal capable of adapting to the country's environmental conditions and efficiently converting pasture resources into food for human consumption (Prada, 1984). More than half a century has elapsed, and the current state of the Cuban cattle population remains far from what was originally envisioned, raising the question of whether this genetic strategy failed. The initial answer is that its shortcomings were not due to the program's design or objectives, but rather to multiple contributing factors. Foremost among these were an international context highly unfavorable to Cuba for more than six decades and, additionally, a technical approach that did not evolve at the pace required to effectively implement and sustain the program.

The initial achievements of the breeding program were remarkable, largely due to the heterosis effects expressed in the first crossbred generation. However, as the program progressed, these favorable responses began to diminish. The studies by Pérez (1999), Morales and Suárez (2018), and Betancourt and Fernández (2019) provide a detailed account of more than half a century of this breeding effort. It was during this stage of changing genetic composition that the methods and statistical models employed proved insufficiently dynamic and failed to adapt to the large population of dairy females, which no longer exhibited the same level of heterozygosity as the preceding generation. Breeding objectives were intensified and management guidelines were modified to increase milk production; however, the management practices and nutritional conditions provided did not correspond to the level of genetic specialization attained by these animals. As a result, a pronounced imbalance developed, and its adverse effects gradually began to emerge.

As a consequence of these factors, evidence emerged of both genotype - environment interaction (GEI) and genetic progress (GP) not significantly different from zero, as reported in several scientific publications of the period (references will be presented later). When both of these genetic indicators occur simultaneously, they represent a substantial risk for the deterioration of the original genetic base. Therefore, the purpose of this review is to examine Cuban studies on genotype - environment interaction (GEI) and genetic progress (GP), whose effects were not accounted for in the statistical models employed, and to explain the biased results reported across all dairy and beef cattle breeds.

DEVELOPMENT

General Challenges Facing the Cuban Cattle Industry

Over the past 50 years, the Cuban cattle industry has been affected by multiple factors, including:

– For many years, insufficient attention has been devoted to the growth and development of young animals, a situation that persists to the present day.

- For a period of time, females were introduced into the breeding herd based solely on age, without consideration of their live body weight.
- Widespread use of hormonal treatments in a large proportion of females entering the breeding herd.
- Continued implementation of three-times-daily milking in a substantial proportion of cows with moderate to low production levels.

These factors created a highly stressful environment that substantially affected the physiological functioning of animals with a greater proportion of taurus genes over an extended period. Such conditions may have contributed to increased mortality, reduced reproductive performance, and lower overall milk production. Concurrently, other limiting factors associated with the genetic improvement program also became evident, including:

- Incomplete and poorly coordinated individual animal recording systems.
- Exclusion of records from cows with short lactation periods.
- Use of inappropriate statistical models for breeding value (BV) estimation that failed to account for genotype - environment interaction (GEI).
- Sustained genetic progress close to zero across all breeds over an extended period.

When considered collectively, the events described above created the conditions necessary for the manifestation of what are known as epigenetic effects, defined as the heritable regulation of gene expression induced by adverse environmental conditions without alterations to the DNA sequence. This biological mechanism links the environment to the expression of genetic merit and contributes to genotype - environment interaction (GEI). Epigenetics is now a well-established scientific field (Zetzsche and Fallet, 2024), and a more comprehensive understanding of its significance and implications is recommended for professionals involved in cattle production and genetic improvement programs in Cuba.

Genotype - Environment Interaction in Cuban Cattle Production

The topic of genotype - environment interaction (GEI) has been extensively studied in Cuba, and there is broad consensus regarding its importance in both dairy and beef cattle production. The importance of GEI is commonly assessed through the correlation (R) between breeding values (BV) estimated under different environmental conditions. Table 1 provides a summary of these results. Under ideal circumstances, R values are expected to equal 1.0; however, the available evidence consistently indicates correlations that are significantly lower than unity, demonstrating that GEI effects are important under Cuban production conditions. Similar findings have been reported in other tropical countries. Comparable conclusions have also been obtained from studies comparing the breeding values of purebred and crossbred sires (Menéndez-Buxadera *et al*., 2022), evaluating the relationship between milk production and heat stress (González Prieto *et al*., 2024), and examining weaning weight in relation to cumulative heat load during the preceding six months (Suárez *et al*., 2022).

Table 1. Selected published results on genotype - environment interaction (GEI) in Cuba

Breed	Period of time	Correlation*	Author
Holstein	1972 to 2006	R = 0.37	Menendez-Buxadera (2005)
Mambi	1981 to 2006	R = 0.66	Hernández *et al*. (2012)
Siboney	1980 to 2000	R = 0.49	
Zebu	1981 to 2009	R = 0.46	Rodríguez and Guerra (2013)
S, Gertrudis	1980 to 2001	R = 0.18	Suarez *et al*. (2019).
Criollo	1981 to 2003	R = 0.63	Suarez *et al*. (2023).

*R represents the correlation between the breeding values (BV) of sires evaluated under high and low environmental conditions. These conditions may refer to herd average milk production in dairy breeds, body weight at 18 months of age in performance tests of beef breeds, or comparisons between periods before and after the Special Period.

The overall implication of these findings is that the highest-ranking sires under one set of environmental conditions are not necessarily the highest-ranking sires under all environmental conditions. Therefore, genetic evaluation models should account for genotype - environment interaction (GEI). Unfortunately, insufficient attention has been given to this issue to date. As a consequence, selection decisions have been based on biased estimates.

When more sophisticated statistical models that incorporate genotype - environment interaction (GEI) effects are applied, valuable information can be extracted from the same available data, providing benefits that should not be overlooked. To illustrate this approach, results reported by Menéndez-Buxadera (2005) were used from a complex reaction norm model applied to 226,048 lactation records from 105,953 Holstein cows sired by 519 bulls under Cuban production conditions. The results are presented in Figure 1. It is noteworthy that, within the same dataset in which a correlation of 0.37 was estimated between low- and high-environment conditions (Table 1), markedly different patterns of genetic response can be identified.

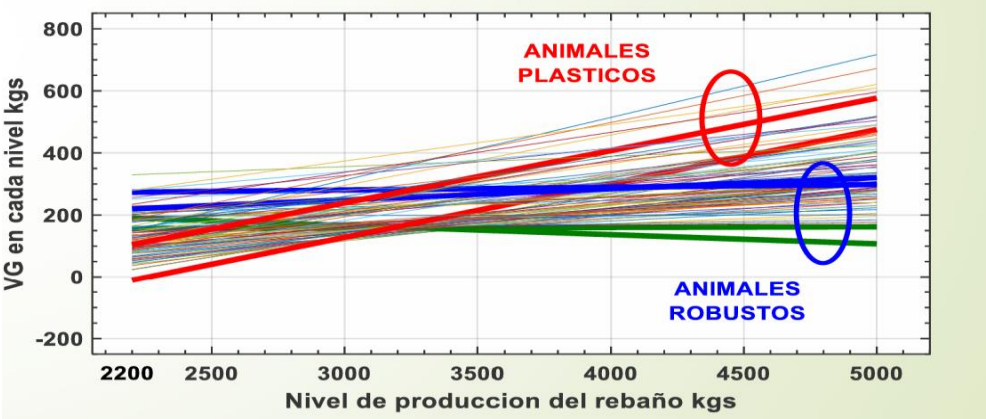


Figure 1. Phenotypic plasticity effects in Holstein cattle under Cuban production conditions

In biology, there is a mechanism known as phenotypic plasticity, which can be defined as the biological property of an animal (*i.e*., a genotype) to modify its performance according to its capacity to adapt to environmental conditions. It is noteworthy that this finding was first reported two decades ago and demonstrated that, within the national dairy cattle population, there were sires classified as robust, owing to their ability to produce daughters whose genetic makeup allowed

them to express their genetic potential regardless of environmental conditions. In other words, these sires produced daughters capable of performing across a wide range of production environments. Similar findings have been reported in Zebu cattle (Rodríguez *et al.*, 2015), Creole cattle (Suárez *et al.*, 2022), and Charolais cattle (Suárez *et al.*, 2024) with respect to resistance to accumulated heat stress prior to weaning. Exploiting this phenomenon does not require additional financial resources; rather, it requires a change in the statistical models used for genetic evaluation and a revised scientific interpretation of the results, one that more accurately reflects the biological behavior of the animals and helps mitigate the effects of genotype - environment interaction (GEI).

Genetic Progress in Cuban Cattle Production

Achieving higher levels of productivity over time is an implicit objective of any economic activity, and in genetic improvement programs this objective is assessed through genetic progress (GP). Although several approaches are available for estimating genetic progress, the simplest and most intuitive definition is that animals born in a given year should possess higher breeding values than those born in the preceding year. Results obtained in Cuba for both dairy and beef cattle breeds are presented in Table 2 and indicate that, despite decades of selection efforts, the genetic level of the country's cattle populations has shown little or no improvement. This outcome is attributable, among other factors, to the genotype - environment interaction (GEI) effects discussed previously and to the limited implementation of recommendations derived from the numerous studies conducted on this subject.

Table 2. Results on (GP) published in Cuba

Breed	Period of time	Genetic Progress	
		Estimates	Author
Holstein	1990 to 2014	0.23% 5.7 kg/y	Hernández (2016) Suarez (2016)
Mambi	1990 to 2014	0.25% 4.9 kg/y	
Siboney	1990 to 2015	0.17% 3.4 kg/y	
White Zebu	1981 to 2017	0.11% 0.13 kg/y	Suarez (2016)
Charolais	1981 to 2006	0.01% 0,04kg/y	Suarez (2016)
S Gertrudis	1981 to 2010	0.09% 0,01kg/y	Morales *et al*. (2013).
Criollo	1981 to 2016	0.08% 0,09kg/y	Suarez *et al*. (2023).

***Refers to the year of publication and does not include unpublished periodic reports submitted to the Office of the Vice Minister of Livestock Production between 1986 and 1996, which showed that genetic progress (GP) from 1970 to 1992 was not significantly different from zero.**

With respect to the three dairy breeds represented in Tables 1 and 2, it should be noted that they are genetically related; therefore, a more robust analytical approach is required to account for this relationship. Accordingly, a large dataset was reanalyzed using more sophisticated statistical models (Menéndez-Buxadera, 2022) that incorporated additive genetic effects, heterosis, and recombination loss effects. Consequently, the results refer to a typical dairy animal representative of this population, regardless of the breed designation assigned to individual animals.

To this end, a dataset comprising 537,567 lactation records from 233,082 cows, daughters of 2,589 sires belonging to the Siboney, Mambí, and Holstein breeds, was analyzed. These animals were distributed across 21 dairy breeding enterprises throughout Cuba and had calved between 1984 and

2003. The dataset was subjected to a rigorous editing process to ensure the quality of the analyses, particularly with respect to the variability and frequency distribution of each effect included in the model. The pedigree file incorporated all available ancestors, with the Holstein breed serving as the genetic link connecting the different population groups. This structure allowed direct comparisons among animals and breeds within a unified analytical framework. To date, this represents the largest study conducted on the Cuban dairy cattle population, and its principal findings are summarized in Figure 2.

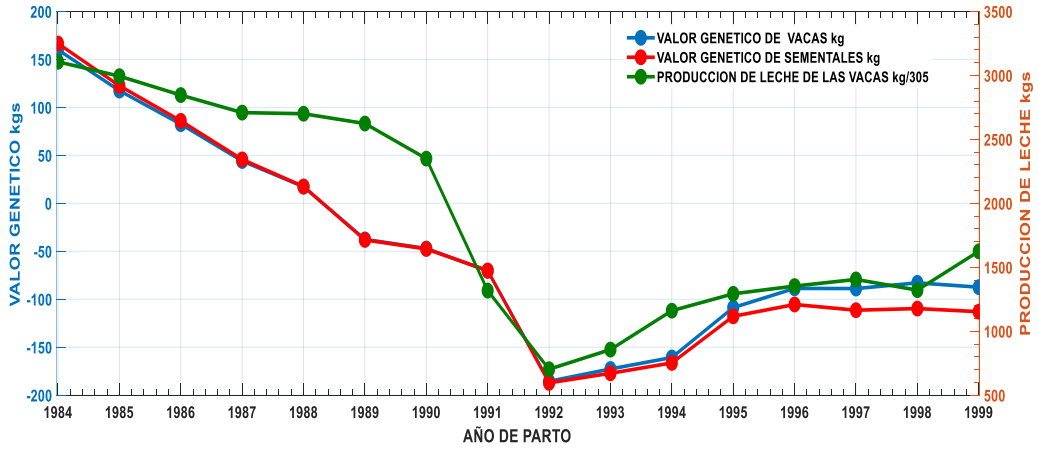


Figure 2. Annual trends in 305-day milk yield and breeding values (BV) of cows (n = 233,082) and sires (n = 2,589) during the period 1984-1999.

The trends of all three indicators followed the same pattern, showing a pronounced negative response that was consistent with the results presented in Table 2. During the period from 1984 to 1992, genetic progress (GP) averaged −19.3 kg/year. Beginning in 1992, however, a modest but positive recovery was observed in the breeding values (BV) of both sires and cows, as well as in average milk production. Notably, a parallel trend emerged between genetic merit and phenotypic performance expressed as milk yield. This response indicates that, even under relatively poor environmental conditions, selection can still produce genetic gains, although the magnitude of such gains may be limited. In this case, the average milk production of the three dairy breeds was approximately 1,560 kg per 305-day lactation, yet a measurable increase in productivity was achieved. The key point is that positive genetic change remained possible despite the unfavorable production environment. A potential criticism of this analysis is that the study period is considerably removed from current conditions. While this observation is valid, the primary objective of the study was to assess the temporal evolution of breeding values. Consequently, the results should be interpreted as describing the development of the new genetic base that emerged from, and subsequently evolved beyond, the genetic resources introduced through the initial cattle importations.

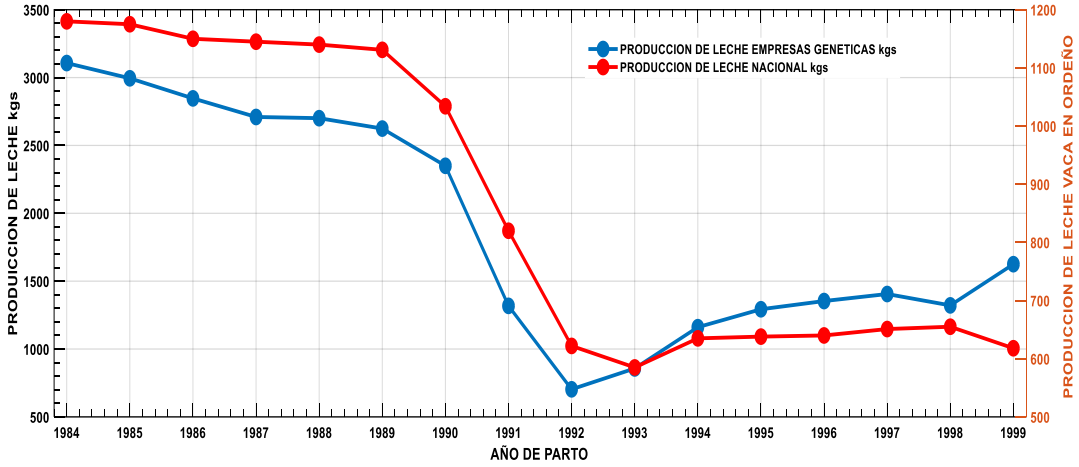
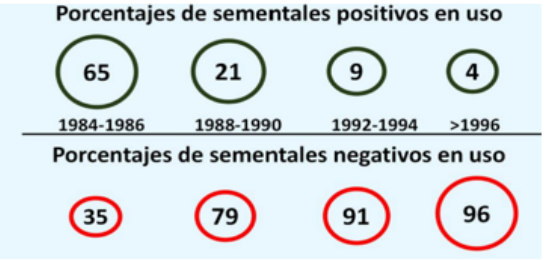


Figure 3. Trends in milk production of 233,082 cows from dairy breeding enterprises between 1984 and 1999 and the average milk yield per cow in milk for the entire Cuban cattle population

To assess the broader relevance of the patterns shown in the previous figure, official statistics published by the National Office of Statistics of Cuba for the same period were used to obtain the average milk yield per cow in milk at the national level. These data were then compared with the average milk production of cows from the dairy breeding enterprises included in the study. The resulting trends are presented in Figure 3. The patterns observed in both datasets were remarkably similar, indicating that the trends derived from the records of the dairy breeding enterprises are representative of those observed in the Cuban dairy cattle population as a whole.

Regression analysis showed that between 1984 and 1992 (or 1993), milk yield declined at a rate of −138 kg/cow/year in the dairy breeding enterprises, whereas the corresponding decline for the Cuban cattle population as a whole was −68 kg/cow/year. Considering that the commercial population reflects the gene frequencies transmitted by sires produced in the breeding enterprises, it is noteworthy that the productive response observed in the national herd represented approximately one-half of that recorded in their genetic source population. Consistent with the trends described above, an upward phase began after 1992, characterized by gradual improvements in milk production. This recovery suggests an improvement in environmental conditions affecting both the dairy breeding enterprises and the national cattle industry as a whole.

The results presented here are consistent with those previously reported in several scientific publications and summarized in Table 2. However, a detailed discussion of the underlying causes falls beyond the scope of the present review. Nevertheless, it is worth presenting an additional indicator that may help explain the negative genetic trends observed in the three dairy breeds and may also be of practical value for decision-making at higher administrative levels within the Ministry of Agriculture. This indicator is shown in Figure 4 and represents the percentage of daughters sired by bulls with positive and negative breeding values (BV) during the same period.



En las casi dos décadas estudiadas decreció 16 veces el uso de sementales con VG positivos mientras que los de VG negativos aumento cerca de tres veces. Las consecuencias explican las figuras previas.

Figure 4. Percentage of daughters produced by sires with positive and negative breeding values (BV) during the study period

CONCLUSIONS

The results obtained are genuine and indicate a decline in both milk production and the genetic merit of the cattle population. Reversing this trend represents a complex but unavoidable challenge. The findings are consistent with a breeding scheme in which Zebu cattle functioned primarily as the recipient genotype, whereas Bos taurus served as the transforming genotype. The generations derived from this crossbreeding strategy gave rise to animals that were physiologically more specialized for milk production. Under such conditions, a greater proportion of the nutrients consumed is preferentially allocated to milk synthesis. Consequently, when nutrient supply becomes inadequate, less energy remains available for other essential biological functions, such as disease resistance and reproduction, both of which may be adversely affected. This principle is described in the fundamental theory of animal nutrition known as the Resource Allocation Theory (Rauw, 2007). Within the context of the Cuban breeding program, the contribution of the Zebu component became increasingly limited. Its attributes of hardiness and environmental adaptation were constrained by the functional predominance of taurine genes, reinforced by the program's central objective of increasing milk yield. In other words, these animals were expected to perform according to the physiological demands imposed by the transforming genotype, while being managed under environmental and production conditions that more closely resembled those suitable for the recipient genotype.

Based on the evidence presented, greater emphasis should be placed on the training of professionals involved in animal breeding and genetic improvement programs, enabling them to apply more advanced statistical models for the estimation of breeding values (BV). Under the current and foreseeable economic conditions of the country, it may be advisable to orient breeding objectives toward animals with a more moderate milk production potential that better reflects the realities of the production environment. At the same time, efforts should focus on preserving the hardiness, adaptability, and environmental resilience characteristic of Zebu cattle while progressively improving their dairy performance. Preliminary results obtained from dairy Zebu populations in Sancti Spíritus revealed an average milk yield of approximately 1,400 kg per lactation, with individual records ranging from 830 to 2,420 kg, in addition to producing calves with an average weaning weight of 170 kg. The incorporation of this genetic resource does not compromise the original objectives of the breeding program; rather, it complements them

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AUTHOR CONTRIBUTION STATEMENT

Research conception and design: AMB; data analysis and data interpretation: AMB; redaction of the manuscript: AMB.

CONFLICT OF INTEREST STATEMENT

The authors state there are no conflicts of interest whatsoever.