LITERATURE REVIEWS

Body-conformation traits and their association with milk yield in *Bos indicus* dairy cattle

Características lineares de conformación y su asociación con producción de leche en Ganado de leche Bos indicus

Características lineares de conformação e a sua associação com produção de leite em gado de leite *Bos indicus*

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Abstract

Background: The search for productive and the reduction of involuntary culling leads to the selection of cows by milk yield and morphological traits, such as body-conformation traits suitable to maintain production and permanence in the herd. Body conformation traits have been targeted in dairy cattle breeding because they are associated with lifetime production and, consequently, influence both the welfare and profitability of dairy cattle, by affecting health and leading to the premature culling of cows. **Objective:** This review aims to explore the genetic importance of linear conformation traits related to "frame", "foot and leg" and "mammary system", explaining their relationship with milk production, with a particular focus on Zebu breeds. **Conclusion:** Heritability estimates for body conformation traits related to the mammary system and structure, as well as for milk production, indicate that changes can be achieved through selection. Some body conformation traits were found to be correlated with milk yield, which suggests that selection to increase milk yield should be approached with caution as it may, in the long term, lead to undesirable changes in conformation traits of the body dimension and mammary system.

Key words: *body structure; dairy cattle; foot and leg; genetic parameters; milk production; type characteristics, traits; udder conformation; zebuine breeds.*

Resumen

Antecedentes: La búsqueda de animales productivos y eficientes en ganado lechero lleva a la selección de vacas con base en la producción de leche y características morfológicas, como la conformación corporal y características de la urbe. Las características de la conformación corporal han sido objeto de estudio en la cría de ganado lechero, ya que están asociadas con la producción a lo largo de la vida y, por lo tanto, influyen en el bienestar y la rentabilidad del ganado, al estar relacionadas con problemas sanitarios y el descarte prematuro de vacas. **Objetivo:** Esta revisión pretende analizar la importancia genética de los rasgos de conformación lineal relacionados con la "estructura", las "pezuñas y patas" y el "sistema mamario", explicando su relación con la

producción de leche, con especial atención a las razas cebuinas. **Conclusion:** las estimativas de heredabilidad para las características de conformación corporal relacionados con el sistema mamario y la estructura, así como para la producción de leche, indican que pueden lograrse cambios mediante la selección. Algunas características de conformación corporal resultaron estar correlacionadas con la producción de leche, lo que sugiere que la selección para aumentar la producción de leche debe abordarse con cautela, ya que, a largo plazo, puede provocar cambios indeseables en los rasgos de conformación de la estructura y del sistema mamario.

Palabras clave: *características de tipo; conformación de ubre; estructura corporal; ganado lechero; parámetros genéticos; patas y pezuña; producción de leche; razas cebuinas.*

Resumo

Antecedentes: A busca por animais produtivos e eficientes em gado leiteiro induz à seleção de vacas com base na produção de leite e características morfológicas, como a conformação corporal e características de úbere. As características de conformação corporal têm sido alvo na criação de gado leiteiro, pois estão associadas à produção ao longo da vida e, portanto, exercem influência no bem-estar e rentabilidade do gado leiteiro, ao estar relacionadas com problemas sanitários e o descarte prematuro das vacas. **Objetivo:** Esta revisão tem como objetivo aprofundar a importância genética das características lineares de conformação relacionadas a "dimensão corporal ", "pés e pernas" e "sistema mamário", explicando sua relação com a produção de leite, com foco particular nas raças zebuínas. **Conclusão:** As estimativas de herdabilidade para características de conformação corporal relacionados com o sistema mamário e a estrutura, bem como para a produção de leite, indicam que podem ser conseguidas mudanças através da seleção. Verificou-se que alguns traços de conformação corporal estavam correlacionados com a produção de leite, o que sugere que a seleção para aumentar a produção de leite deve ser abordada com cautela, uma vez que pode, a longo prazo, conduzir a alterações indesejáveis em características de conformação da dimensão corporal e sistema mamário.

Palavras-chave: *características de tipo; conformação do úbere; estrutura corporal; gado leiteiro; parâmetros genéticos; pés e pernas; produção de leite; raças zebuínas.*

Introduction

In tropical and subtropical dairy farming, where extensive production systems and low-quality pastures are prevalent, taurine breeds (*Bos taurus taurus*) often fail to achieve their productive potential compared to their performance in temperate climates. Conversely, zebuine breeds (*Bos taurus indicus*), having evolved in similar environment, possess adaptations to both the climate and prevailing production systems, making them essential for milk production in these regions (Santana Jr et al., 2014).

Among the zebu cattle, the Gyr and Guzerat breeds stand out for their milk yield. The Gyr breed became important in the production chain of tropical countries due to its hardiness, longevity and milk yield (Santana Jr et al., 2014). Similarly, the Guzerat breed is the second most used zebuine breed (after the Gyr) for milk production in Brazil (Santos et al., 2013). These breeds and their crosses with taurine breeds are established genetic material for sustaining livestock farming in tropical and subtropical countries (Toro-Ospina et al., 2023; Carrara et al., 2022), demonstrating the importance of studying these breeds in order to increase the efficiency of food production for the population.

Initially, breeding programs in dairy zebuine cattle, such as the Gyr breed, were focused on increasing milk yield (Prata et al., 2015). However, to optimize production, including milk yield and productive lifespan, it is necessary for the individual to have the morphological structure and body condition capable of maintaining production and remaining in the herd (Almeida et al., 2017; Saowaphak et al., 2017). According to Saowaphak et al. (2017) and Fernandes et al. (2019), in dairy cattle breeding programs, body-conformation traits are extremely important, as long as they are focused on promoting more efficiently productive animals.

The study of body measurements in cattle has long been recognized for its importance in understanding animal health, productivity, and lifespan (An et al., 2019). These traits, collectively known as body-conformation, are correlated with key economic factors such as calving ease, longevity, laminitis incidence, and productive efficiency (Abo-Ismail et al., 2017). In dairy cattle breeding, the evaluation of body conformation aims to select animals that exhibit a harmonious balance between production capacity and functional soundness, promoting extended herd life and streamlined management. Therefore, the inclusion of body conformation traits or type variables, in breeding programs is essential for identifying and selecting individuals optimally adapted to

the prevailing production system conditions, ultimately reducing the economic burden of frequent animal replacement.

The estimation of genetic parameters and the relationship between body-conformation traits and milk yield can vary across breeds. Most of the available research on these estimates focuses on taurine breeds, with the Holstein breed likely being the most studied. Due to the genetic distance between Holsteins and zebuine breeds, there is concern that the findings may not be directly applicable to zebuine cattle. Therefore, understanding the genetic correlation between body conformation traits and milk production is crucial for breeding programs in zebuine cattle.

This literature review aims to compile information on the importance of body-conformation traits in dairy breeding programs and their association with milk yield, with a primary focus on zebuine breeds selected for milk production.

Body-conformation traits

Milk yield has long been considered the most important trait in dairy cattle breeding programs. However, exclusive selection for this trait can have unfavorable effects on other functional traits, such as fertility and herd health (Pérez-Cabal et al., 2006; Lagrotta et al., 2010).

Body-conformation traits influence economically important traits, such as milk production, health, and longevity. For example, body-conformation traits related to the udder are associated with cow health (Dube et al., 2009). Traits related to body capacity or frame, such as height and heart girth, are linked to feed efficiency and energy balance (Søndergaard et al., 2002). Additionally, the rump angle and udder depth have been associated with longevity (Lund et al., 1994; Vollema et al., 2000). Therefore, measuring body-conformation traits in dairy herds can contribute to herd profitability.

Body-conformation traits evaluation in dairy cattle originated in North America, initially focusing on the Holstein breed. At first, this method involved subjective assessments to identify the most productive animals in the herd based on conformation and body traits. However, greater emphasis was placed on milk recording. Over the years, body-conformation traits evaluation advanced, incorporating scores to describe traits more precisely, and later, it was integrated into breeding programs (Short and Lawlor, 1992; McManus and Saueressig, 1998). In South America, body conformation traits evaluation began in 1994, starting with the dairy Gyr breed in Brazil (Panetto et al., 2023).

Body-conformation traits evaluation in dairy cows is performed on an individual basis, involving observations and body measurements that are compared to a standard considered ideal for each breed. This approach provides significant benefits for breeders and technicians, enabling the assessment of variables that can influence animal welfare, health, and longevity. Body-conformation traits can be classified into: frame, foot and leg, and mammary system (Table 1).

Table 1. Classification and description of body-conformation traits in dairy cattle, including acronyms, measurement units, and trait definitions by category (frame, foot and leg, and mammary system).

Trait	Acronymous	Units	Description
Frame			
Hip height	HH	cm	Length of the animal from the top of the rump to the ground.
Heart girth	HG	cm	The thoracic perimeter
Body length	BL	cm	The distance from the (humeral tuberosity to the ischial tuberosity).
Rump length	RL	cm	Distance between the tip of the ilium and the tip of the ischium in the same side of the animal
Rump width	RW	cm	The distance between the tip of the ischium from the left to the right side
Rump angle	RA	Score	Pin bones should be slightly lower than hip bones (1-high pins and 9-low pins)
Foot and leg			
Foot angle	FA	Score	The angle formed between two imaginary lines, the first parallel to the ground surface and the second to the wall of the hoof (1-low and 9-steep)
Rear legs-side view	RLS	Score	Angulation formed between the tibia and metatarsus bones (1-straight and 9-curved)
Mammary system			
Fore udder attachment	FUA	Score	Firmly attached with moderate length and ample Capacity (1-weak and 9-strong).
Rear udder width	RUW	Score	The distance between the junction of the leg and the udder from the left side to the same junction on the right side (1-narrow and 9-wide)
Udder depth	UD	Score	The distance from the hock to the floor of the udder (1-shallow and 9-deep)
Teat length	TL	Score	Teat size (1-short and 9-long)

Teat diameter	TD	Score	The teat thickness (1-thin and 9-thick)

Frame

The body-conformational traits, such as hip height (HH), heart girth (HG), body length (BL), rump length (RL), rump width (RW), and rump angle (RA), are part of a group of variables related to frame. HH refers to the animal's length from the top of the rump to the ground (Figure 1a). An average height is preferred, although it may vary between breeds, with cows having sufficient height to keep the udder off the ground (Carvalho et al., 2021). Very tall animals tend to have higher nutritional requirements for maintenance (Dominguez-Castaño et al., 2024). HG and BL are related to the thoracic and abdominal capacity (Figure 1b), involving vital organs such as the heart, lungs, and digestive system, which are crucial for the animal's performance. For Gyr breed, animals with HG greater than 102 cm and BL greater than 175 cm are desirable (Panetto et al., 2023).

The traits related to the rump, such as RW, are associated with ease of calving (Bruneli et al., 2022; Panetto et al., 2023). Animals with larger measurements (greater distance in centimeters) for these traits tend to have a lower likelihood of calving difficulties. On the other hand, RA is measured based the difference between the height of the pin and the hip bones (Figure 1c). Pin bones should be slightly lower than hip bones. Intermediate values are preferred.

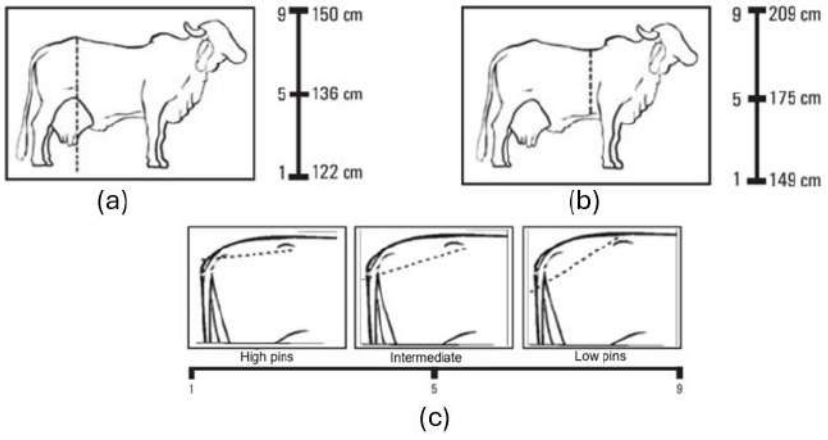

Figure 1. Body-conformation traits related to frame: hip height (HH, a), heart girth (HG, b), and rump angle (RA, c). Adapted to Panetto et al. (2023).

Foot and leg

Within the category of foot and leg, the traits of foot angle (FA) and rear legs-side view (RLS) can be included. Both traits are evaluated using scores. Steep angle and deep heel with short, well-rounded closed toes is desirable (Figure 2a). RLS refers to the angle to the hock (Figure 2b). Intermediate values are preferred for the feet and legs category. These traits have been associated with hoof injuries and longevity (Sewalem et al., 2004; Chapinal et al., 2013). Additionally, since most Zebu breeds are raised on pasture in extensive production systems, where the animals must move to find food, proper foot and leg conformation is especially important to ensure they can move and therefore feed without difficulty.

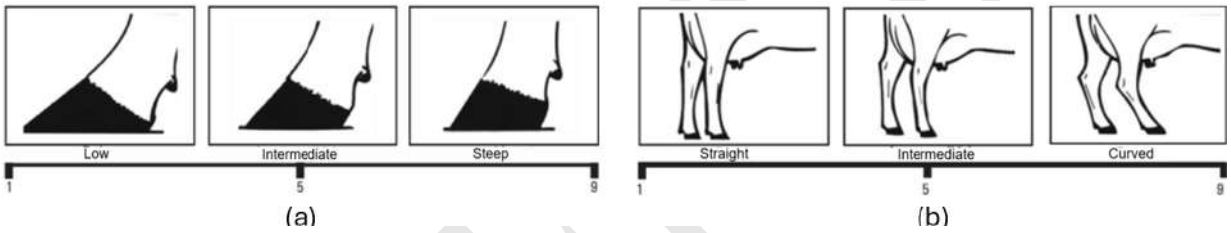

Figure 2. Body-conformation traits related to foot and legs: foot angle (FA, a) and rear legs-side view (RLS, b) (Panetto et al., 2023)

Mammary system

The mammary system category includes traits related to the udder and teats. Relevant traits for udder conformation include fore udder attachment (FUA), rear udder width (RUW), udder depth (UD), teat length (TL), and teat diameter (TD). FUA describes the strength of the attachment of the fore udder to the abdominal wall, ideal scores for this trait are intermediate (close to 5; Figure 3a). A wide rear udder with uniform width from top to bottom is desirable (Figure 3b). An appropriate measure to UD is moderate depth relative to the hock, with adequate capacity and clearance. The ideal UD has its floor approximately 10 cm above the hock (Panetto et al., 2023).

Regarding the traits of the teats, intermediate-length teats (TL; approximately 7.5 cm; Figure 3d) and intermediate-to-small teat diameter (TD; Figure 3e) are preferred. The teats traits play an important role in mechanical milking, calf feeding and udder health. Long and thicker teats can cause difficulties during mechanical milking, calf suckling, and are more susceptible to injuries, which can compromise udder health (Dube et al., 2009). Due, most of the zebuine are raised in

extensive production systems, it is difficult to provide individual care for the calf before birth. Therefore, the maternal ability of the cow, along with the udder and teat conformation, plays a crucial role. Deep udders and long, thick teats can make it difficult for the calf to suckle, which may compromise the calf's health if it is unable to consume colostrum in the first hours after birth.

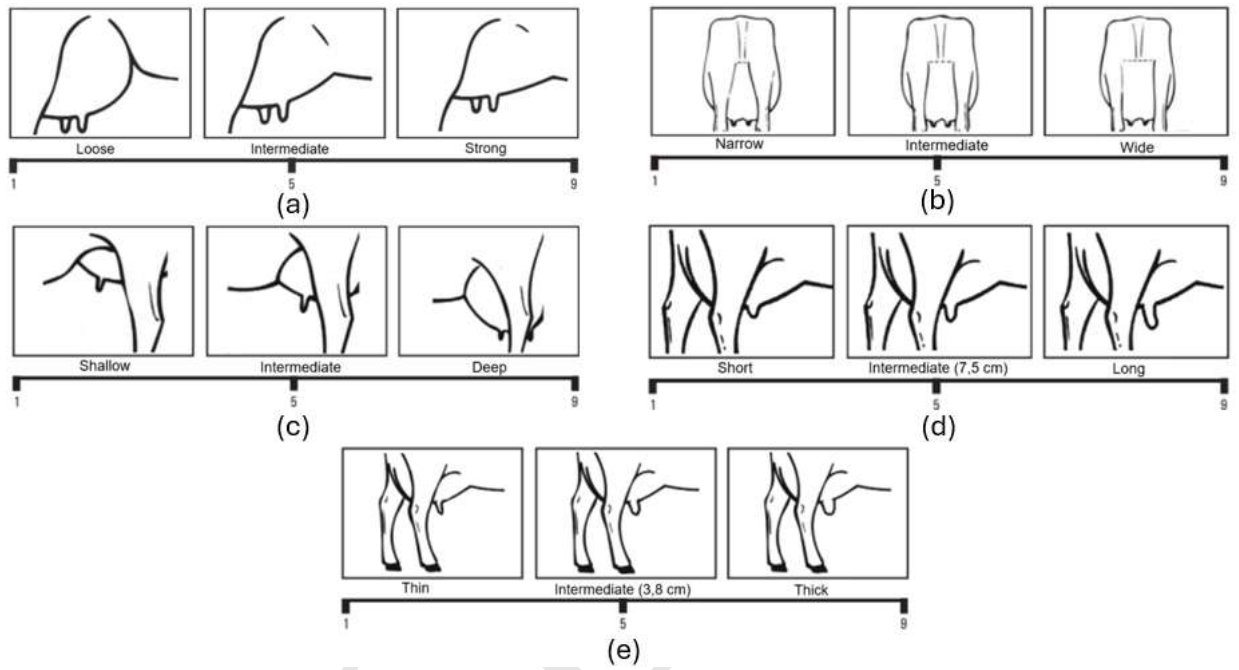

Figure 3. Body conformation traits related to mammary system: Fore udder attachment (FUA, a), rear udder width (RUW, b), udder depth (UD, c), teat length (TL, d) and teat diameter (TD, e) (Panetto et al., 2023)

Genetic parameters for body-conformations traits and milk yield

Understanding how body-conformation traits respond to selection and how they are associated with milk yield is crucial for the breeding programs. For this purpose, genetic parameters such as heritability and genetic correlation are estimated. These estimates can vary considerably depending on the breed, population, and statistical model used.

The majority of studies investigating genetic parameters for body-conformation traits and milk yield have focused on taurine breeds, particularly the Holstein breed (DeGroot et al., 2002; Berry et al., 2004; Campos et al., 2015), followed by the Brown Swiss (De Haas et al., 2007; Samoré et al., 2010), and Jersey breeds (Dube et al., 2009). However, literature regarding these traits in zebuine cattle is scarce, with the Gyr breed being the primary breed used in such research (Lagrotta

et al., 2010; Carvalho et al., 2021; Dominguez-Castaño et al., 2024). Therefore, evaluating these parameters within the target population is essential for determining the selection criteria in breeding programs.

Heritability estimates

In the category of traits related to frame, studies have indicated higher heritability estimates compared to other groups of body-conformation traits. Within this category, HH shows the highest heritability estimate, although the estimate varies considerably between studies (ranging from 0.31 to 0.74) (De Haas et al., 2007; Campos et al., 2015; Carvalho et al., 2021). Another trait that shows variability in the estimates reported in the literature is the RA, with values ranging from 0.13 to 0.36 (Abo-Ismail et al., 2017; Olasege et al., 2019; Wu et al., 2013). On the other hand, low variation has been observed in heritability estimates when comparing results from previous studies investigating HG in the Gyr breed (heritability estimates of 0.26 and 0.30; Carvalho et al., 2021; Dominguez-Castaño et al., 2024). These values suggest that heritability estimates for frame-related traits tend to be moderate to high, indicating that these traits should respond more quickly to selection.

The heritability estimates of the foot and leg traits have low magnitudes, with values ranging from 0.06 to 0.14 for FA (Abo-Ismail et al., 2017; Carvalho et al., 2021; Olasege et al., 2019) and from 0.08 to 0.16 for RLS (Carvalho et al., 2021; Čítek et al., 2022; Dominguez-Castaño et al., 2024), indicating a strong influence of environmental effects on their expression.

For the traits in the mammary system category, there is variability in heritability estimates in the literature. For example, UD and TL show a broader range of variation, with values ranging from 0.15 to 0.41 and from 0.18 to 0.44, respectively (Abo-Ismail et al., 2017; Carvalho et al., 2021; Dominguez-Castaño et al., 2024; Olasege et al., 2019). Regards RUW, although variability exists, the range is narrower, with estimates between 0.13 and 0.21 (Carvalho et al., 2021; Olasege et al., 2019; Wu et al., 2013). Since TD is not a major trait of interest in taurine breeds, limited information is available in the literature on this variable. However, for the zebuine breed Gyr, heritability estimates for TD ranged from 0.07 to 0.27 (Carvalho et al., 2021; Dominguez-Castaño et al., 2024; Wenceslau et al., 2000), highlighting the wide variation in the estimates reported for this trait.

Traits related to milk yield have been emphasized in the selection of dairy cattle due to their economic importance. Heritability estimates for accumulated milk yield at 305 days (MY) in zebuine breeds are moderate. For example, the estimates in studies with Gyr cattle range from 0.24 to 0.45 (Lagrotta et al., 2010; Toro-Ospina et al., 2023; Wenceslau et al., 2000), and from 0.23 to 0.32 in Guzerat cattle (Brito et al., 2020; Carrara et al., 2022; Paiva et al., 2020). These estimates suggest that selecting individuals with high genetic value for MY will lead to an increase in its phenotypic expression in the next generation.

It should be noted that even when considering the same breed, heritability estimates can vary among studies according to the classification system (i.e., how traits are measured), sample size and the statistical models used in the analyses. Therefore, comparisons among studies should be undertaken with caution.

Regarding zebuine cattle, the Gyr breed have been more studied. Heritability estimates for MY and body-conformation traits related to the mammary system and frame, indicate that changes can be achieved through selection. On the other hand, for traits in the foot and leg category, due to their low heritability estimates (~0.09; Carvalho et al., 2021; Djedović et al., 2023, Dominguez-Castaño et al., 2024), the changes resulting from selection would be less pronounced. Therefore, for these variables, environmental managements would likely have a greater impact than genetic selection.

Genetic correlation between body-conformation traits and milk yield

Estimates of genetic correlation between MY and frame group traits in taurine breeds reveal positive coefficients that vary in magnitude. For example, genetic correlations range from 0.21 to 0.61 for MY and HH, from 0.16 to 0.39 for MY and HG, and from 0.12 to 0.62 for MY and RA (Campos et al., 2015; DeGroot et al., 2002; De Haas et al., 2007; Dominguez-Castaño et al., 2024). These findings suggest that animals with larger frame measurements (higher values for HH and HG) tend to produce more milk. It is important to note that selecting for height in cattle can lead to an increase in adult size, which may not necessarily be beneficial. Changes in the adult size may, consequently, influence nutritional requirements.

On the other hand, studies in Holstein and Gyr cattle reported no genetic correlations between MY and the traits HH (values between -0.08 and -0.02) and HG (values between -0.17 and -0.11)

(Campos et al., 2015; Lagrotta et al., 2010), suggesting that genes related to frame do not influence MY.

Regarding the traits related to foot and leg group, the literature indicates that genetic correlation estimates with MY vary considerably. For example, in Holstein cattle, estimates ranged from -0.05 to 0.39 for MY and FA, and from 0.04 to 0.83 for the correlation between MY and RLS (Campos et al., 2015; DeGroot et al., 2002; Djedović et al., 2023). In zebuine breeds, studies have focused particularly on the Gyr breed. For instance, Lagrotta et al. (2010) and Dominguez Castaño et al. (2024) reported estimates ranging from -0.16 to 0.11 for MY and FA, and from -0.31 to 0.30 for MY and RLS.

Similarly, the genetic correlation between MY and body-conformation traits related to the mammary system varies across studies, with values ranging from -0.46 (between MY and UD) to 0.61 (between MY and RUW), as shown in studies on Holstein and Sahiwal breeds (Campos et al., 2015; Khan and Khan, 2016). In Gyr cattle, correlation estimates between MY and teat traits range from 0.13 to 0.22 for MY and TL, and from 0.26 to 0.29 for MY and TD (Dominguez-Castaño et al., 2024; Lagrotta et al., 2010). Likewise, Dominguez-Castaño et al. (2024) reported a strong positive genetic association between MY and UD (0.63) and RUW (0.61) in Gyr cattle. In general, these genetic associations are undesirable (with the exception of the association between MY and RUW), as they suggest that continued emphasis on selecting animals for MY could result in cows with deep udders (closer to the ground), which are more prone to mastitis and may compromise their longevity. Additionally, thick and elongated teats could make milking and suckling calves difficult.

The observed genetic correlations between some of the body-conformation traits and MY highlight the importance of considering conformation traits in breeding programs for zebuine cattle, such as the Gyr breed. Focusing solely on MY may lead to unfavorable changes in body-conformation, such as increased stature and udder depth. Incorporating both body-conformation and MY in breeding programs, would permit the breeders to select animals to enhance MY while preserving desirable conformation, promoting both productivity and reducing the involuntary culling.

Declarations

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Conflicts of interest

The authors declare they have no conflicts of interest with regard to the work presented in this report.

Author contributions

All authors contributed to the conception and design of this work. The first draft of the manuscript was written by PDC. The critical revision was performed by JAIIVC. All authors read and approved the final manuscript.

Use of artificial intelligence (AI)

No AI or AI-assisted technologies were used during the preparation of this work.

References

Abo-Ismail MK, Brito LF, Miller SP, Sargolzaei M, Grossi DA, Moore SS, Plastow G, Stothard P, Nayeri S, Schenkel FS. Genome-wide association studies and genomic prediction of breeding values for calving performance and body conformation traits in Holstein cattle. Genet Sel Evol. 2017;49:82. https://doi.org/10.1186/s12711-017-0356-8

Almeida TP, Kern EL, Daltro DDS, Braccini Neto J. Mcmanus C, Thaler Neto A, Cobuci JA. Genetic associations between reproductive and linear-type traits of Holstein cows in Brazil. R Bras Zootec. 2017;46(2):91-98. https://doi.org/10.1590/S1806-92902017000200002

An B, Xia J, Chang T, Wang X, Xu L, Zhang L, Gao X, Chen Y, Li J, Gao H. Genome-wide association study reveals candidate genes associated with body measurement traits in Chinese Wagyu beef cattle. Anim Genet. 2019;50(4):386-390. https://doi.org/10.1111/age.12805

Berry DP, Buckley F, Dillion P, Evans RD, Veerkamp RF. Genetic relationships among linear type traits, milk yield, body weight, fertility and somatic cell count in primiparous dairy cows. Ir J Agric Food Res. 2004;43(2):161-176. https://www.jstor.org/stable/25562515

Brito LC, Peixoto MGCD, Carrara ER, Silva FF, Ventura HT, Bruneli FAT, Lopes PS. Genetic parameters for milk, growth, and reproductive traits in Guzerá cattle under tropical conditions. Trop Anim Health Prod. 2020; 52:2251–2257. https://doi.org/10.1007/s11250-020-02255-0

Bruneli FAT, Peixoto MGCD, Santana Júnior ML, Pereira RJ, Arbex WA, Penna VM, Zadra LF, Verneque RS, Lôbo RB, Carvalho MRS. Programa Nacional de Melhoramento do Guzerá para Leite: resultados do Teste de Progênie, do Arquivo Zootécnico Nacional e do Núcleo MOET [Internet]. Juiz de Fora: Embrapa Gado de Leite; 2022 [cited 01-12-2024] 96 p. https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1144948/programa-nacional-de-melhoramento-do-guzera-para-leite-resultados-do-teste-de-progenie-do-arquivo-zootecnico-nacional-e-do-nucleo-moet

Campos RV, Cobuci JA, Kern EL, Costa CN, McManus CM. Genetic parameters for linear type traits and milk, fat, and protein production in Holstein cows in Brazil. Asian-Australas J Anim Sci. 2015;28(4):476-484. https://doi.org/10.5713/ajas.14.0288

Carrara ER, Peixoto MGCD, Veroneze R, Silva FFE, Ramos PVB, Bruneli FAT, Zadra LEF, Ventura HT, Josahkian LA, Lopes PS. Genetic study of quantitative traits supports the use of Guzerá as dual-purpose cattle. Anim Biosci. 2022;35(7):955-963. https://doi.org/10.5713/ab.21.0458

Carvalho NS, Daltro DS, Machado JD, Camargo EV, Panetto JD, Cobuci JA. Genetic parameters and genetic trends of conformation and management traits in Dairy Gir cattle. Arq Bras Med Vet Zootec. 2021;73(4):938-948. https://doi.org/10.1590/1678-4162-12341

Chapinal N, Koeck A, Sewalem A, Kelton DF, Mason S, Cramer G, Miglior F. Genetic parameters for hoof lesions and their relationship with feet and leg traits in Canadian Holstein cows. J Dairy Sci. 2013;96(4):2596-2604. https://doi.org/10.3168/jds.2012-6071

Čítek J, Brzáková M, Bauer J, Tichý L, Sztankóová Z, Vostrý L, Steyn Y. Genome-Wide Association Study for Body Conformation Traits and Fitness in Czech Holsteins. Animals. 2022; 12(24):3522. https://doi.org/10.3390/ani12243522

DeGroot BJ, Keown JF, Van Vleck LD, Marotz EL. Genetic Parameters and Responses of Linear Type, Yield Traits, and Somatic Cell Scores to Divergent Selection for Predicted Transmitting Ability for Type in Holsteins. J Dairy Sci. 2002;85(6):1578-1585. https://doi.org/10.3168/jds.S0022-0302(02)74227-6

De Haas Y, Janss LLG, Kadarmideen HN. Genetic and phenotypic parameters for conformation and yield traits in three Swiss dairy cattle breeds. J Anim Breed Genet. 2007;124(1):12-19. https://doi.org/10.1111/j.1439-0388.2007.00630.x

Djedović R, Vukasinovic N, Stanojević D, Bogdanović V, Ismael H, Janković D, Gligović N, Brka M, Štrbac L. Genetic Parameters for Functional Longevity, Type Traits, and Production in the Serbian Holstein. Animals. 2023;13(3):534. https://doi.org/10.3390/ani13030534

Dominguez-Castaño P, Fortes M, Toro-Ospina AM, Silva JAIIV. Genetic parameters for milk production and body-conformation traits in Dairy Gir cattle. Anim Prod Sci. 2024;64(4):1-9. https://doi.org/10.1071/AN23207

Dube B, Dzama K, Banga CB, Norris D. An analysis of the genetic relationship between udder health and udder conformation traits in South African Jersey cows. Animal. 2009;3(4):494-500. https://doi.org/10.1017/S175173110800390X

Fernandes AR, Faro L E, Vercesi Filho AE, Machado CHC, Barbero LM, Bittar ER, Igarasi MS. Genetic evolution of milk yield, udder morphology and behavior in Gir dairy cattle. R Bras Zootec. 2019;48:1-10. https://doi.org/10.1590/rbz4820180056

Khan MA, Khan MS. Genetic and phenotypic correlations between linear type traits and milk yield in Sahiwal cows. Pak J Agric Sci. 2016;53(2):483-489. https://www.researchgate.net/publication/304925934

Lagrotta MR, Euclydes RF, Verneque RDS, Santana JML, Pereira RJ, Torres RDA. Relação entre características morfológicas e produção de leite em vacas da raça Gir. Pesqui Agropecu Bras. 2010;45(4):423-429. https://doi.org/10.1590/S0100-204X2010000400011

Lund T, Miglior F, Dekkers J, Burnside E. Genetic relationships between clinical mastitis, somatic cell count, and udder conformation in Danish Holsteins. Livest Prod Sci. 1994;39(3):243-251. https://doi.org/10.1016/0301-6226(94)90203-8

Mcmanus C, Saueressig MG. Estudo de características lineares de tipo em gado Holandês em confinamento total no Distrito Federal. R Bras Zootec. 1998;27(5):906-915. https://www.researchgate.net/publication/267414891

Olasege BS, Zhang S, Zhao Q, Liu D, Sun H, Wang Q, Ma P, Pan Y. Genetic parameter estimates for body conformation traits using composite index, principal component, and factor analysis. J Dairy Sci. 2019;102(6):5219-5229. https://doi.org/10.3168/jds.2018-15561

Paiva JT, Peixoto MGCD, Bruneli FAT, Alvarenga AB, Oliveira HR, Silva AA, Silva DA, Veroneze R,Silva FF, Lopes PS. Genetic parameters, genome-wide association and gene networks for milk and reproductive traits in Guzerá cattle. Livest Sci. 2020;242:104273. https://doi.org/10.1016/j.livsci.2020.104273

Panetto JCC, Silva MVG, Verneque RS, Machado MA, Fernandes AR, Teixeira RB, Machado CHC, Martins MF, Reis DDL, Borges CAV, Oliveira JC, Ventura HT, Pereira MA, Machado MS,

Moura GM. Programa Nacional de Melhoramento do Gir Leiteiro – Sumário Brasileiro de Touros – 6ª Avaliação Genômica de Touros - Resultado do Teste de Progênie – abril/2023 [Internet]. Juiz de Fora: Embrapa Gado de Leite; 2023 [cited: 07-12-2024] 126 p. https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1153450/programa-nacional-de-melhoramento-do-gir-leiteiro-sumario-brasileiro-de-touros-6-avaliacao-genomica-de-touros-resultado-do-teste-de-progenie---abril-2023

Pérez-Cabal MA, García C, González-Recio O, Alenda R. Genetic and phenotypic relationships among locomotion type traits, profit, production, longevity, and fertility in Spanish dairy cows. J Dairy Sci. 2006;89(5):1776-1783. https://doi.org/10.3168/jds.S0022-0302(06)72246-9

Prata MA, Faro LE, Moreira HL, Verneque RS, Vercesi Filho AE, Peixoto MGCD, Cardoso VL. Genetic parameters for milk production traits and breeding goals for Gir dairy cattle in Brazil. Genet Mol Res. 2015;14(4):12585-12594. https://pubmed.ncbi.nlm.nih.gov/26505409/

Samoré AB, Rizzi R, Rossoni A, Bagnato A. Genetic parameters for functional longevity, type traits, somatic cell scores, milk flow and production in the Italian Brown Swiss. Ital J Anim Sci. 2010;9(e28):145-152. https://www.researchgate.net/publication/44122037

Santana Jr, M, Pereira, R, Bignardi, A, El Faro, L, Tonhati, H, Albuquerque, L. History, structure, and genetic diversity of Brazilian Gir cattle. Livest Sci. 2014;163:26-33. https://doi.org/10.1016/j.livsci.2014.02.007

Santos DJA, Peixoto MGCD, Borquis RRA, Verneque RS, Panetto JCC, Tonhati H. Genetic parameters for test-day milk yield, 305-day milk yield, and lactation length in Guzerat cows. Livest Sci. 2013;152(2-3):114-119. https://doi.org/10.1016/j.livsci.2012.12.012

Saowaphak P, Duangjinda M, Plaengkaeo S, Suwannasing R, Boonkum W. Genetic correlation and genome-wide association study (GWAS) of the length of productive life, days open, and 305-days milk yield in crossbred Holstein dairy cattle. Genet Mol Res. 2017;16(2):1-11. https://www.researchgate.net/publication/318119345

Sewalem A, Kistemaker GJ, Miglior F, Van Doormaal BJ. Analysis of the Relationship Between Type Traits and Functional Survival in Canadian Holsteins Using a Weibull Proportional Hazards Model. J Dairy Sci. 2004;87(11):3938-3946. https://doi.org/10.3168/jds.S0022-0302(04)73533-X

Short T, Lawlor T. Genetic parameters of conformation traits, milk yield, and herd life in Holsteins. J Dairy Sci. 1992;75(7):1987-1998. https://doi.org/10.3168/jds.S0022-0302(92)77958-2

Søndergaard E, Sørensen M, Mao I, Jensen J. Genetic parameters of production, feed intake, body weight, body composition, and udder health in lactating dairy cows. Livest Prod Sci. 2002;77(1):23-34. https://doi.org/10.1016/S0301-6226(02)00023-4

Toro-Ospina, AM, Faria, RA, Dominguez-Castaño, P, Santana, ML, Gonzalez, LG, Espasandin, AC, Silva, JAIIV. Genotype–environment interaction for milk production of Gyr cattle in Brazil and Colombia. Genes Genomics. 2023;45(2):135-143. https://doi.org/10.1007/s13258-022-01273-6

Vollema, A, Van Der Beek, S, Harbers, A, De Jong, G. Genetic evaluation for longevity of Dutch dairy bulls. J Dairy Sci. 2000;83(11):2629-2639. https://doi.org/10.3168/jds.S0022-0302(00)75156-3

Wenceslau AA, Lopes OS, Teodoro RL, Verneque RS, Euclydes RF, Ferreira WJ, Silva MA. Estimação de parâmetros genéticos de medidas de conformação, produção de leite e idade ao primeiro parto em vacas da raça Gir Leiteiro. R Bras Zootec. 2000;29(1):153-158. https://doi.org/10.1590/S1516-35982000000100021

Wu X, Fang M, Liu L, Wang S, Liu J, Ding X, Zhang S, Zhang Q, Zhang Y, Qiao L, Lund MS, Su G, Sun D. Genome wide association studies for body conformation traits in the Chinese Holstein cattle population. BMC Genomics. 2013;14:897. https://doi.org/10.1186/1471-2164-14-897