Effect of the percentage of *Bos taurus* inheritance on the fertility of Holstein×Zebu and Brown Swiss×Zebu cows in the Mexican tropics

Efecto del porcentaje de herencia Bos taurus sobre la fertilidad de vacas cruzadas Holstein×Cebú y Pardo Suizo×Cebú en el trópico mexicano

Efeito da porcentagem de herança Bos taurus na fertilidade de vacas mestiças Holandês×Zebu e Pardo Suíço×Zebu no trópico mexicano

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Abstract

Background: No dairy breed or crossbreed has superior overall performance in all environments; therefore, it is necessary to determine which crossbreed is the most suitable for the Mexican tropic and what proportion of European breed is optimum for reproduction. **Objective:** To assess the effect of the proportion of *Bos taurus* (Bt) genes on reproductive performance of Holstein×Zebu (HZ) and Brown Swiss×Zebu (BZ) cows, and compare reproductive performance of these genotypes in a dual-purpose production system. **Methods:** Cows were maintained in a rotational grazing system on African star grass (*Cynodon plectostachyus*) in Veracruz, Mexico. Cows were milked twice daily. Calves were kept tied to the side of their dams while the cows were milked. **Results:** The percentage of Bt genes did not affect ($p>0.05$) fertility traits (age at first calving, days to first service after calving, services per conception, conception rate at first service, days open until conception, gestation length, and calving interval) of BZ cows. In contrast, HZ cows with less than 75% Holstein (H) genes were 0.3 years younger ($p<0.05$) at first calving and had 39.8 fewer days open ($p<0.05$) than HZ cows with 75% H genes or more. In addition, the calving interval of HZ cows with less than 75% H genes was 44.8 days shorter ($p<0.05$) than that of HZ cows with 75% H genes or more. The HZ cows had five fewer days pregnant and were 22.8 kg heavier at calving ($p<0.05$) than BZ cows. **Conclusions:** The effect of the percentage of Bt genes on cow fertility depends on the dairy breed used. In general, BZ and HZ cows present similar reproductive performance.

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Keywords: *age at first calving; Bos taurus; Bos taurus×Bos indicus; Brown Swiss×Zebu; calving interval; conception rate; crossbred cows; dual purpose; fertility; first service; Holstein×Zebu; inheritance; production system; tropic.*

Resumen

Antecedentes: Ninguna raza lechera o cruce tiene un desempeño general superior en todos los ambientes; por lo tanto, es necesario determinar cuál cruce lechero es más apropiado en el trópico mexicano y qué proporción de raza europea es óptima para la reproducción. **Objetivo:** Evaluar el efecto de la proporción de genes *Bos taurus* (Bt) en el desempeño reproductivo de vacas cruzadas Holstein×Cebú (HC) y Pardo Suizo×Cebú (PC), y comparar el desempeño reproductivo de estos dos genotipos en un sistema de producción doble propósito. **Métodos:** Las vacas se mantuvieron en un sistema de pastoreo rotacional en zacate Estrella de África (*Cynodon plectostachyus*) en Veracruz, México. Las vacas se ordeñaron dos veces al día. Los becerros se mantuvieron atados, a un costado de sus madres mientras éstas se ordeñaron. **Resultados:** El porcentaje de genes Bt no afectó ($p>0,05$) ninguna característica de fertilidad (edad a primer parto, días a primer servicio después del parto, servicios por concepción, tasa de preñez a primer servicio, días abiertos a la concepción, duración de la gestación, e intervalo entre partos) de las vacas PC. En contraste, las vacas HC con menos de 75% de genes Holstein (H) fueron 0,3 años más jóvenes ($p<0,05$) al primer parto y tuvieron 39,8 días abiertos menos ($p<0,05$) que las vacas HC con 75% de genes H o más. Además, el intervalo entre partos de las vacas HC con menos de 75% de genes H fue 44,8 días más corto ($p<0,05$) que el de las vacas HC con 75% de genes H o más. Las vacas HC tuvieron cinco días de gestación menos y fueron 22,8 kg más pesadas al parto ($p<0,05$) que las PC. **Conclusiones:** El efecto del porcentaje de genes Bt sobre la fertilidad de la vaca depende de la raza lechera usada. En general, las vacas PC y HC tienen similar desempeño reproductivo.

Palabras clave: *Bos taurus; Bos taurus×Bos indicus; doble propósito; edad al primer parto; fertilidad; herencia; Holstein×Cebú; intervalo entre partos; Pardo Suizo×Cebú; primer servicio; sistema de producción; tasa de concepción; trópico; vacas cruzadas.*

Resumo

Antecedentes: Nenhuma raça ou cruza leiteira tem desempenho geral superior em todos os ambientes; portanto, é necessário determinar qual cruza leiteira é mais apropriada no trópico mexicano e qual proporção da raça europeia é ideal para a reprodução das vacas. **Objetivo:** Avaliar o efeito da proporção de genes *Bos taurus* (Bt) no desempenho reprodutivo de vacas Holandês×Zebu (HZ) e Pardo Suíço×Zebu (PZ), e comparar o desempenho reprodutivo desses dois genótipos em sistema de produção de dupla aptidão. **Métodos:** As vacas foram mantidas em sistema de pastoreio rotacional em capim Estrela de África (*Cynodon plectostachyus*) em Veracruz, México. As vacas foram ordenhadas duas vezes por dia. Os bezerros foram mantidos ao lado de suas mães enquanto eram ordenhadas. **Resultados:** A porcentagem dos genes Bt não afetou ($p>0,05$) nenhuma característica de fertilidade (idade ao primeiro parto, número de dias para o primeiro serviço pós-parto, serviços por concepção, taxa de prenhes no primeiro serviço, dias abertos, período de gestação e intervalo entre partos) das vacas PZ. Em contraste, vacas HC com menos de 75% dos genes Holandês (H) eram 0,3 anos mais jovens ($p<0,05$) no primeiro parto e tiveram 39,8 dias abertos a menos ($p<0,05$) do que as vacas HZ com 75% ou mais dos genes H. Além disso, o intervalo de parto das vacas HZ com menos de 75% dos genes H foram 44,8 dias mais curtos ($p<0,05$) do que as vacas HZ com 75% ou mais de genes H. As vacas HZ tiveram cinco dias de gestação a menos e foram 22,8 kg mais pesadas no parto ($p<0,05$) do que as PZ. **Conclusões:** O efeito da porcentagem de genes Bt na fertilidade da vaca dependeu da raça leiteira utilizada. Em geral, as vacas PZ e HZ tiveram desempenho reprodutivo semelhante.

Palavras-chave: *Bos taurus; Bos taurus×Bos indicus; dupla aptidão; fertilidade; herança; Holandês×Zebu; idade ao primeiro parto; intervalo entre partos; Pardo Suíço×Zebu; primeiro serviço; sistema de produção; taxa de prenhes; trópico; vacas mestiças.*

Introduction

Dual purpose is the main cattle production system in the tropical regions of Mexico. This system is common in several states across the country, such as Sinaloa, Nayarit, Veracruz, Tabasco, Campeche, Chiapas, Oaxaca, Quintana Roo, and Yucatán. From a genetic point of view, this system is based on the use of *Bos taurus*×*Bos indicus* cattle to produce milk and meat (calves); however, technicians and breeders recognize that milk production is the main objective. Therefore, Holstein and Brown Swiss are the breeds predominantly used in crossbreeding due to their exceptional milk aptitude compared to other breeds (*e.g.,* Ayrshire, Jersey, and Simmental). Additionally, crossbred cattle inherit adaptability traits (*e.g.,* tick resistance and heat tolerance) from *Bos indicus* breeds (*e.g.,* Sardo Negro, Indubrazil, Nelore, and Brahman).

In Mexico, reproductive characterization of *Bos taurus*×*Bos indicus* crossbred cows raised under dual-purpose system have revealed contrasting results, which could be due to differences in climate (humid tropical, dry tropical, and humid subtropical) and/or microclimate differences among locations in the same region. For example, in a study conducted in Centro, Tabasco, pure *Bos indicus* cows had better reproductive performance (days to first service after calving, days open, calving interval) than ½ *Bos taurus*×½ *Bos indicus* and ¾ *Bos taurus*×¼ *Bos indicus* cows (López *et al.*, 2010). In contrast, in a more recent study conducted in the same state (Teapa municipality) other researchers (Arce *et al.*, 2017) found that cows with 0 to 25%, 37.5 to 50%, and 62.5 to 75% Holstein inheritance had similar reproductive performance (calving interval). Results by López *et al.* (2010) could be unexpected as fertility traits are positively affected by heterosis (McDowell *et al.*, 1968; Dechow *et al.*, 2007), which reach its maximum expression (100%) in F1 animals. However, Rege (1998) mentioned "no one breed or crossbred will have superior aggregate performance in all environments"; in addition, he emphasized that "one needs to determine which exotic breed is most economical and what level of exotic inheritance is optimum".

Therefore, the objectives of this study were to assess the effect of the proportion of *Bos taurus* genes on the reproductive performance of Holstein×Zebu and Brown Swiss×Zebu cows, and compare the reproductive performance of these genotypes in a dual-purpose production system.

Materials and Methods

The study was conducted from 2010 to 2018 at Campo Experimental La Posta, which belongs to Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). The research station is located at Paso del Toro, Medellín, Veracruz, Mexico, at 15° 18' N and 96° 10' W, at 12 m above sea level. The region has dry tropical climate (Aw1), with maximum, average, and minimum temperature of 35.2, 25.0, and 15.0°C, respectively, and average pluvial precipitation and relative humidity of 1,461 mm and 77.4%, respectively (García, 1988).

Fertility records of 37 Brown Swiss×Zebu and 62 Holstein×Zebu cows with different Brown Swiss (B) and Holstein (H) breed proportions were analyzed. The Brown Swiss×Zebu cows were daughters of 16 sires and 27 dams, while the Holstein×Zebu cows were daughters of 20 sires and 55 dams. Cows were mainly mated to sires by artificial insemination; however, there were some natural mating. The percentage of *Bos taurus* genes varied from 34.4 to 75.0% and from 37.5 to 79.7% in the Brown Swiss×Zebu and Holstein×Zebu cows, respectively.

Cows were maintained in a rotational grazing system on African star grass (*Cynodon plectostachyus*). In addition, they were offered 2 kg animal^{-1} d^{-1} of a commercial supplement with 16% crude protein and 70% total digestible nutrients at each milking throughout lactation. During the dry season (December to May) cows were supplemented with 20 kg animal^{-1} d^{-1} of sorghum (*Sorghum vulgare*) silage.

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Females were first bred when they reached about 350 kg. Heat detection was performed in the morning (06:00-07:00 AM) and in the afternoon (05:00-06:00 PM). Breeding was conducted as follows: females showing estrus in the morning were served in the afternoon, and those detected on estrus in the afternoon were served the next morning, approximately 12 hours after visual observation of estrus. Cows were confirmed pregnant by rectal palpation 45 d into pregnancy. Cows were culled mainly for poor fertility and health problems.

Cows were milked twice daily (06:00-08:00 and 14:00-16:00) after a brief suckling by their calves to stimulate milk ejection. Calves were kept tied on one side of their dams, while the cows were milked. Milk yield per cow was recorded at each milking. Only three quarters of the udder were milked during the first three months of lactation, leaving one quarter for calf consumption plus the residual milk of the three milked quarters. All four quarters of the udder were milked from day 91 of lactation to weaning (210 d of age), leaving just the residual milk for the calf.

After milking, calves were allowed to suckle for about one hour. Later, they were separated from their dams until the next milking. After weaning, calves were used just to stimulate milk ejection of their dams until drying off. Cows were dried off when they were seven months pregnant or produced less than 3 kg milk per day.

Records for age at first calving, days to first service after calving, services per conception, conception rate at first service, days open until conception, gestation length, calving interval, and calving weight were analyzed. Age at first calving was calculated as the difference between date of first calving and birth date. Days to first service after calving was calculated as the difference between date of first service after calving and corresponding calving date. Days open until conception was defined as the difference between conception date after calving and corresponding calving date; this trait reflects both conception rate and the female capability to cycle and express estrus. Gestation length was defined as the difference between calving date and conception date. Calving interval was the period between calving dates. Conception rate at first service was defined as a binary variable; therefore, if a female became pregnant after first service, a value of 1 was assigned; otherwise, a value of 0 was assigned.

Two sets of analyses were performed. In the first set, data of Brown Swiss×Zebu and those of Holstein×Zebu cows were analyzed separately to assess the effect of percentage of *Bos taurus* genes within each type of cows. In the second set, data of Brown Swiss×Zebu and those of Holstein×Zebu cows were combined and then analyzed together to compare reproductive performance of Brown Swiss×Zebu with Holstein×Zebu cows.

Age at first calving was analyzed with the GLM procedure of SAS version 9.3 software (SAS Institute Inc., Cary, NC, USA; 2011) with a simple model that included calving year (2010 thru 2018), calving season (dry, rainy), and percentage of *Bos taurus* genes (<75%, ≥75%) or cow genotype (Brown Swiss×Zebu, Holstein×Zebu) as fixed effects. The dry season was from October to May, while the rainy season was from June through September. Preliminary analyses of age at first calving indicated that the random effects of cow nested within genetic group of the cow, and sire of the cow nested within genetic group of the sire were not significant (p>0.05).

The remaining traits were analyzed with a repeated measures model that included cow nested within genetic group of the cow, and sire of the cow nested within genetic group of the sire as random effects (except for services per conception and conception rate at first service), and year of calving, season of calving, age of cow at calving (covariable; in days), and percentage of *Bos taurus* genes or cow genotype as fixed effects. When random effects and age of cow at calving were not significant (p>0.05) in preliminary analyses, they were not included

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in the final model. Sire of the cow nested within genetic group of sires was not significant for days to first service after calving, days open until conception, gestation length, calving interval and calving weight. In addition, for conception rate at first service, the statistical model included stage of lactation (Stage 1: from 1 to 50 d; Stage 2: from 51 to 100 d; Stage 3: from 101 to 150 d; and Stage 4: ≥151 d postpartum).

Days to first service after calving, days open, gestation length, calving interval and calving weight were analyzed with the MIXED procedure of SAS (2011). The model to analyze days to first service after calving, days open until conception, gestation length, calving interval and calving weight was preliminarily fitted testing different covariance structures (ante-dependence, first-order autoregressive, heterogeneous autoregressive, compound symmetry, heterogeneous compound symmetry, simple, Toeplitz, heterogeneous Toeplitz, and unstructured) to provide the best fit to the data. The selection of the appropriate covariance structure for days to first service after calving, days open until conception, gestation length, calving interval and calving weight was based on Akaike's, second order, and Schwarz's Bayesian information criteria fit statistics.

Services per conception and conception rate at first service were analyzed with the GENMOD procedure of SAS (2011). For services per conception, a Poisson distribution was specified in the model statement; in the analysis of conception rate at first service, a binomial distribution was specified, and a logit link function was used. The covariance structures tested to analyze services per conception and conception rate at first service were first-order autoregressive, compound symmetry, independent, Toeplitz, and unstructured. For services per conception and conception rate at first service the appropriate covariance structure was selected based on the quasi-likelihood information criterion fit statistic.

Results

Table 1 summarizes characteristics of the data for fertility traits. Raw means of age at first calving, days to first service after calving, services per conception, days open until conception, conception rate at first service, calving interval, and calving weight were: 1,101.1 d, 119.5 d, 2.1 services, 162.1 d, 43.9%, 447.5 d, and 482.4 kg, respectively.

In the analyses of Brown Swiss×Zebu data, appropriate covariance structures used in the definitive statistical model were simple for days to first service after calving, gestation length, calving interval and calving weight; compound symmetry, for services per conception; and first-order autoregressive, for days open until conception (Table 2). Conception rate at first service was not calculable for Brown Swiss×Zebu cows.

In the analyses of Holstein×Zebu data, appropriate covariance structures were simple for days to first service after calving, gestation length, calving interval, and calving weight; compound symmetry for number of services per conception; independent for conception rate at first service; and heterogeneous autoregressive for days open until conception (Table 3).

In the analyses of combined data (Brown Swiss×Zebu plus Holstein×Zebu data), appropriate covariance structures were simple for days to first service after calving, days open, gestation length, calving interval and calving weight; and compound symmetry for services per conception and conception rate at first service (Table 4).

The percentage of *Bos taurus* genes did not affect ($p>0.05$) any fertility trait of Brown Swiss×Zebu cows; in contrast, age at first calving, days open, and calving interval of Holstein×Zebu cows were affected ($p<0.05$) by percentage of H genes. Cow genotype was a significant source of variation for gestation length and calving weight. Stage of lactation did not account for variation in conception rate at first service (Table 5).

Table 1. Descriptive statistics for fertility traits.

Data/Variable[a]	N	Mean	Standard deviation	Minimum	Maximum
Brown Swiss×Zebu (BZ)					
AFC (years)	42	3.3	0.57	2.3	4.9
DFS	75	146.1	83.5	26.0	479.0
SPC	97	1.7	1.1	1.0	5.0
CR (%)	97	58.8	49.5	0	1
DO	69	182.1	93.7	29.0	479.0
GL (days)	93	286.5	5.3	270.0	296.0
CI (days)	83	485.7	102.4	315.0	866.0
CW (kg)	132	484.9	70.3	295	662
Holstein×Zebu (HZ)					
AFC (years)	60	3.4	0.6	2.2	4.9
DFS	128	123.3	75.9	17.0	474.0
SPC	164	2.0	1.5	1.0	8.0
CR (%)	164	54.9	49.9	0	1
DO	115	181.9	122.6	22.0	624.0
GL (days)	158	281.4	5.3	270.0	295.0
CI (days)	133	476.0	126.1	303.0	896.0
CW (kg)	208	510.2	73.7	258.0	672
BZ and HZ					
AFC (years)	102	3.4	0.6	2.2	5.0
DFS	203	131.7	79.4	17.0	479.0
SPC	261	1.9	1.4	1.0	8.0
CR (%)	261	56.3	49.7	0	1
DO	184	181.9	112.4	22.0	624.0
GL (days)	251	283.3	5.8	270.0	296.0
CI (days)	216	479.7	117.4	303.0	896.0
CW (kg)	340	500.4	73.4	258.0	672.0

[a]AFC=age at first calving; DFS=days to first service after calving; SPC=services per conception; CR= conception rate at first service; DO=days open; GL=gestation length; CI=calving interval; CW=calving weight.

Least squares means and their standard errors for response variables of Brown Swiss×Zebu and Holstein×Zebu cows are presented in Table 6. Brown Swiss×Zebu cows with less than 75% of B inheritance and Brown Swiss×Zebu cows with 75% or more of B inheritance had similar reproductive performance (p>0.05).

Holstein×Zebu cows with less than 75% H genes, and Holstein×Zebu cows with 75% H genes or more were similar in days to first service after calving, services per conception, conception rate at first service, gestation length and calving weight. In contrast, Holstein×Zebu cows with less than 75% H inheritance were 0.3 years younger (p<0.05) at first calving and had 39.8 fewer days open (p<0.05) than Holstein×Zebu cows with 75% H inheritance or more. In addition, the calving interval of Holstein×Zebu cows with less than 75% H genes was 44.8 days shorter (p<0.05) than that of Holstein×Zebu cows with 75% H inheritance or more.

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Table 2. Akaike's (AIC), second order (AICC), Schwarz's Bayesian (BIC) and quasi-likelihood (QIC) information criteria fit statistics for fertility traits of Brown Swiss×Zebu cows.

	Fit statistic[a]			
Variable/Covariance structure[b]	**AIC**	**AICC**	**BIC**	**QIC**
Days to first service after calving				
AR	762.6	763.0	768.8	
CS	764.0	764.3	770.1	
SP	**762.0**	**762.1**	**766.1**	
UN	831.4	852.9	874.6	
Services per conception				
AR				118.50
CS				**118.42**
ID				118.51
TOEP				118.50
Days open				
AR	707.5	707.9	**713.7**	
HAR	706.4	709.2	722.8	
CS	713.1	713.5	719.3	
HCS	725.4	728.3	741.9	
SP	711.1	711.3	715.2	
UN	766.1	791.0	809.3	
Gestation length				
AD	535.1	538.9	557.8	
AR	530.9	531.0	535.0	
HAR	532.1	533.6	546.5	
CS	530.6	530.7	534.7	
HCS	531.2	532.7	545.6	
SP	532.5	532.6	**534.6**	
TOEP	534.8	536.0	547.2	
Calving interval				
Ante-dependence	890.2	895.4	915.0	
AR	893.7	894.0	899.8	
HAR	885.4	887.7	901.9	
CS	893.9	894.3	900.1	
HCS	889.8	892.0	906.3	
SP	891.9	892.1	**896.0**	
TOEP	898.5	899.8	910.9	
HTOEP	895.4	900.6	920.1	
Calving weight				
AR	1,296.0	1,296.2	1,302.2	
HAR	1,302.4	1,303.7	1,318.9	
CS	1,296.1	1,296.3	1,302.3	
SP	**1,294.1**	**1,294.2**	**1,298.2**	
TOEP	1,295.5	1,296.3	1,307.9	

[a]Smaller values indicate better adjustment. [b]For each trait, several covariance structures were tested; however, not all of them were calculable. AR=first-order autoregressive; CS=compound symmetry; SP=simple; UN=unstructured; ID=independent; TOEP=Toeplitz; HAR=heterogeneous autoregressive; HCS=heterogeneous compound symmetry; AD=ante-dependence; HTOEP=heterogeneous Toeplitz.

Table 3. Akaike's (AIC), second order (AICC), Schwarz's Bayesian (BIC) and quasi-likelihood (QIC) information criteria fit statistics for fertility traits of Holstein×Zebu cows.

	Fit statistic[a]			
Variable/Covariance structure[b]	**AIC**	**AICC**	**BIC**	**QIC**
Days to first service after calving				
AD	1,353.9	1,356.4	1,381.3	
AR	1,365.2	1,365.3	1,370.2	
HAR	1,362.5	1,363.5	1,379.9	
CS	1,365.4	1,365.5	1,370.4	
HCS	1,362.4	1,363.4	1,379.8	
SP	1,365.4	1,365.4	**1,367.9**	
HTOEP	1,364.6	1,367.1	1,392.0	
Services per conception				
AR				95.89
CS				**95.12**
ID				98.22
TOEP				97.08
Conception rate at first service				
AR				230.80
CS				230.76
ID				**230.75**
TOEP				230.81
Days open				
AR	1,311.5	1,311.7	1,319.0	
HAR	**1,289.2**	**1,290.7**	**1,309.1**	
CS	1,313.5	1,313.8	1,321.0	
HCS	1,295.9	1,297.4	1,315.8	
SP	1,309.5	1,309.6	1,312.0	
TOEP	1,315.2	1,316.0	1,330.1	
HTOEP	1,296.8	1,299.8	1,324.3	
UN	1,417.4	1,428.5	1,469.6	
Gestation length				
AR	931.9	932.1	939.4	
CS	934.6	934.7	942.0	
HCS	936.2	937.2	956.2	
SP	932.6	932.6	**937.5**	
Calving interval				
AD	1,548.2	1,550.6	1,575.6	
AR	1,545.0	1,545.1	1,550.0	
HAR	1,545.4	1,546.3	1,562.8	
CS	1,545.4	1,545.5	1,550.3	
HCS	1,545.4	1,546.4	1,562.8	
SP	**1,543.4**	**1,543.4**	**1,545.9**	
TOEP	1,550.1	1,550.8	1,565.0	
Calving weight				
AR	2,170.5	2,170.6	2,178.0	
HAR	2,175.9	2,176.7	2,195.8	
CS	2,170.6	2,170.7	2,178.1	
HCS	2,172.9	2,173.5	2,190.3	
SP	2,168.6	2,168.6	**2,173.6**	
TOEP	2,175.8	2,176.4	2,193.3	
HTOEP	1,551.3	1,553.7	1,578.7	

[a]Smaller values indicate better adjustment. [b]For each trait, several covariance structures were tested; however, not all of them were calculable. AR=first-order autoregressive; CS=compound symmetry; SP=simple; UN=unstructured; ID=independent; TOEP=Toeplitz; HAR=heterogeneous autoregressive; HCS=heterogeneous compound symmetry; AD=ante-dependence; HTOEP=heterogeneous Toeplitz.

Table 4. Akaike's (AIC), second order (AICC), Schwarz's Bayesian (BIC) and quasi-likelihood (QIC) information criteria fit statistics for fertility traits of Brown Swiss×Zebu and Holstein×Zebu cows.

	Fit statistic[a]			
Variable/Covariance structure[b]	**AIC**	**AICC**	**BIC**	**QIC**
Days to first service after calving				
AR	2,227.1	2,227.3	2,236.1	
HAR	2,218.5	2,219.3	2,242.4	
CS	2,227.2	2,227.3	2,236.2	
HCS	2,218.1	2,218.8	2,242.0	
SP	2,225.2	2,225.3	**2,231.2**	
TOEP	2,231.7	2,232.1	2,249.6	
HTOEP	2,225.3	2,227.0	2,261.3	
Services per conception				
AR				401.62
CS				**399.15**
ID				405.82
TOEP				402.09
Conception rate at first service				
AR				351.75
CS				**351.66**
ID				352.16
OEP				351.82
Days open				
AD	2,136.3	2,138.3	2,172.3	
AR	2,145.5	2,145.7	2,154.5	
HAR	2,130.3	2,131.2	2,154.3	
CS	2,146.4	2,146.5	2,155.4	
HCS	2,130.9	2,131.8	2,154.9	
SP	2,144.4	2,144.4	**2,150.4**	
TOEP	2,151.8	2,152.5	2,172.8	
HTOEP	2,137.9	2,139.8	2,173.9	
UN	2,223.5	2,229.6	2,286.4	
Gestation length				
AR	1,505.5	1,505.6	1,514.5	
CS	1,507.7	1,507.8	1,516.7	
SP	1,505.7	1,505.7	**1,511.7**	
TOEP	1,510.6	1,511.0	1,531.5	
Calving interval				
AD	2,566.5	2,567.9	2,599.5	
AR	2,561.2	2,561.2	2,567.2	
HAR	2,564.4	2,565.0	2,585.4	
CS	2,559.8	2,559.8	2,565.7	
HCS	2,562.8	2,563.4	2,583.8	
SP	2,561.4	2,561.4	**2,564.4**	
TOEP	2,564.6	2,565.1	2,582.6	
HTOEP	2,567.5	2,568.9	2,600.5	
UN	2,583.1	2,588.2	2,646.1	
Calving weight				
AD	3,563.1	3,564.1	3,599.1	
AR	3,558.9	3,558.9	3,567.9	
HAR	3,565.3	3,565.8	3,589.3	
CS	3,559.1	3,559.2	3,568.1	
SP	**3,557.1**	**3,557.1**	**3,563.1**	
TOEP	3,560.7	3,561.0	3,578.7	

[a]Smaller values indicate better adjustment. [b]For each trait, several covariance structures were tested; however, not all of them were calculable. AR=first-order autoregressive; CS=compound symmetry; SP=simple; UN=unstructured; ID=independent; TOEP=Toeplitz; HAR=heterogeneous autoregressive; HCS=heterogeneous compound symmetry; AD=ante-dependence; HTOEP=heterogeneous Toeplitz.

Table 5. Probability values for genetic and environmental effects included in the statistical models to analyze fertility traits.

	Trait[a]							
Data set/Effect	**AFC**	**DFS**	**SPC**	**CR[b]**	**DO**	**GL**	**CI**	**CW**
Brown Swiss×Zebu (BZ)								
Cow	NS[c]	0.0055			0.0010	NS	0.0364	0.0012
Percentage of genes	0.7075	0.6344	0.2554		0.6698	0.9158	0.8873	0.3837
Calving year	0.0047	0.0009	0.2325		0.0004	0.5784	0.0023	<0.0001
Calving season	0.8724	0.8887	0.6390		0.3225	0.3603	0.5667	0.4767
Cow age		NS	NS		NS	NS	NS	<0.0001
Holstein×Zebu (HZ)								
Cow	NS	NS			0.0047	0.0314	NS	<0.0001
Percentage of genes	0.0089	0.3570	0.2509	0.4556	0.0423	0.1898	0.0295	0.5956
Calving year	<0.0001	0.0010	0.0881	0.3493	0.0014	0.8197	0.0025	<0.0001
Calving season	0.2678	0.0911	0.9558	0.0240	<0.0001	0.0131	0.0022	0.3229
Cow age		NS	NS	0.0107	NS	NS	NS	<0.0001
Stage of lactation				0.5252				
BZ and HZ								
Cow	NS	0.0003			0.0314	0.0044	NS	<0.0001
Cow genotype	0.8436	0.2387	0.0661	0.9083	0.8674	<0.0001	0.7935	0.0066
Calving year	<0.0001	<0.0001	0.0020	0.1555	0.0007	0.8215	<0.0001	<0.0001
Calving season	0.1704	0.2632	0.0173	0.0299	0.0034	0.0098	0.0249	0.2646
Cow age		NS	0.0002	0.0012	NS	NS	0.0216	<0.0001
Stage of lactation				0.2137				

[a]AFC=age at first calving; DFS=days to first service after calving; SPC=services per conception; CR=first service conception rate; DO=days open; GL=gestation length; CI=calving interval; CW=calving weight. [b]Conception rate at first service was not calculable for Brown Swiss×Zebu cows. [c]NS= not significant effect (p>0.05) in preliminary analysis.

Table 6. Least squares means and standard errors for age at first calving (AFC; years), days to first service after calving (DFS), services per conception (SPC), first service conception rate (CR, %), days open (DO), gestation length (GL; days), calving interval (CI; days), and calving weight (CW; kg).

	Trait							
Genotype	**AFC**	**DFS**	**SPC**	**CR[z]**	**DO**	**GL**	**CI**	**CW**
BS×ZE								
≥75%	3.4±0.13[a]	149.4±21.0[a]	1.9±0.2[a]		164.2±22.6[a]	286.0±1.2[a]	486.3±22.7[a]	484.9±8.5[a]
<75%	3.4±0.11[a]	162.4±21.0[a]	1.6±0.2[a]		176.4±22.6[a]	286.3±1.1[a]	482.6±22.0[a]	474.8±8.3[a]
HO×ZE								
≥75%	3.5±0.09[a]	148.6±13.2[a]	2.3±0.3[a]	45±0.07[a]	248.8±23.8[a]	281.8±0.9[a]	530.4±20.7[a]	502.3±8.4[a]
<75%	3.2±0.10[b]	136.8±14.2[a]	1.9±0.2[a]	53±0.08[a]	209.0±25.4[b]	280.4±1.0[a]	485.6±22.5[b]	508.6±9.6[a]
BS×ZE	3.3±0.08[a]	165.4±13.6[a]	1.4±0.1[a]	45±0.07[a]	201.1±19.5[a]	286.2±0.8[a]	501.8±16.2[a]	481.9±6.7[a]
HO×ZE	3.4±0.07[a]	147.4±11.4[a]	1.7±0.1[a]	45±0.06[a]	198.0±17.4[a]	281.2±0.7[b]	497.7±14.8[a]	504.7±5.7[b]

[a,b]Means with different superscript letters within columns indicate significant difference (p<0.05). BS×ZE= Brown Swiss×Zebu; HO×ZE= Holstein×Zebu; ≥75%= cows with 75% or more of *Bos taurus* genes; <75%= cows with less than 75% of *Bos taurus* genes. [z]Conception rate at first service was not calculable for Brown Swiss×Zebu cows.

Brown Swiss×Zebu and Holstein×Zebu cows did not differ in age at first calving, days to first service after calving, conception rate at first service, days open and calving interval; however, Holstein×Zebu cows had five fewer days pregnant ($p<0.05$) and were 22.8 kg heavier at calving ($p<0.05$) than Brown Swiss×Zebu cows.

Discussion

Brown Swiss×Zebu crosses with less than 75% B genes, and Brown Swiss×Zebu crosses with 75% B inheritance or more had similar reproductive performance in the current study. In accordance with this result, a meta-analysis of crossbreeding experiments involving European×indigenous breeds in the tropics of Africa, Asia, and Latin America, published between 1966 and 1996, revealed that 1/4, 3/8, 1/2, 5/8 and 3/4 Brown Swiss cows did not differ in age at first calving and calving interval (Rege, 1998). Likewise, in a more recent study, other authors (Zárate-Martínez *et al.*, 2010) reported that 80 to 99, 60 to 79, and 50% Brown Swiss heifers had similar age at first conception. On the contrary, two studies carried out in Veracruz, Mexico, showed that F1 Brown Swiss×Zebu cows were younger at first calving, and had fewer days open and shorter calving intervals than ¾ Brown Swiss×¼ Zebu cows (Vite-Cristóbal *et al.*, 2007; López-Ordaz *et al.*, 2009), in disagreement with the present findings, suggesting that differences among crosses could depend on the environment.

In the present study, Holstein×Zebu cows with less than 75% H inheritance were younger at first calving and had fewer days open than Holstein×Zebu cows with 75% H inheritance or more. In addition, the calving interval of Holstein×Zebu cows with less than 75% H genes was shorter than that of Holstein×Zebu cows with 75% H genes or more. These results are similar to those from Cuba, where Siboney cows (5/8 Holstein×3/8 Zebu) had fewer days open and shorter calving intervals than Mambí cows (¾ Holstein×¼ Zebu) (Simón *et al.*, 2010), and Ethiopia, where ½ Friesian×½ Barca (Zebu) cows had shorter calving interval than ¾ Friesian×¼ Barca and 7/8 Friesian×1/8 Barca cows (Tadesse and Dessie, 2003). In contrast, a study conducted in Sudan (Ahmed *et al.*, 2007) revealed that ¼ Holstein×¾ Zebu, 3/8 Holstein×5/8 Zebu, ½ Holstein×½ Zebu, 5/8 Holstein×3/8 Zebu and ¾ Holstein×¼ Zebu cows had similar age at first calving and calving interval. In Yucatán, Mexico, F1 Holstein×Zebu and ¾ Holstein×¼ Zebu cows had similar calving interval (Teyer *et al.*, 2003), result that is also in discrepancy with the present study.

Fertility difference between Holstein×Zebu crosses with less than 75% and those with 75% H inheritance or more could be caused by higher milk yield in cows with 75% H inheritance or more. It has been reported that poor reproductive performance is strongly correlated with high milk yield (Zink *et al.*, 2012). Pryce *et al.* (2001) argued that cows with high genetic potential for milk yield are likely to undergo marked body tissue mobilization with increasing risk of impairment of reproductive performance. In addition, cows that produce more milk undergo more stress, which affects their reproductive performance; this association can be magnified under tropical conditions where the environmental stress is higher.

In the present study, Brown Swiss×Zebu and Holstein×Zebu cows did not differ in age at first calving, days to first service after calving, conception rate at first service, days open, and calving interval. This result is similar to those found in Hueytamalco, Puebla, Mexico, where Brown Swiss×Zebu and Holstein×Zebu cows had similar age at puberty (Rosete *et al.*, 1991), and Sucilá, Yucatán, Mexico, where the same genotypes had similar calving interval (Hernández-Reyes *et al.*, 2001), in agreement with the present findings. However, in the present study, Holstein×Zebu cows had five fewer days pregnant and were heavier at calving than Brown Swiss×Zebu cows. In accordance with this result, a study conducted under subtropical conditions of Mexico showed that pure Holstein cows had heavier body weight at calving (21 kg difference) compared with pure Brown Swiss cows (Ríos-Utrera *et al.*, 2013).

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In the present study, conception rate at first service was not affected by stage of lactation; result that is similar to that reported by Ríos-Utrera *et al.* (2020). On the contrary, Pursley *et al.* (1997) detected that cows that were >76 d postpartum and treated with exogenous hormones for synchronization of ovulation had greater pregnancy rate per artificial insemination compared with cows that were 60 to 75 d postpartum (43.4 vs 26.0%). Likewise, in a study conducted in Mexico (Calderón-Robles *et al.*, 2017), cows in Stage 4 of lactation (≥151 d postpartum) had higher pregnancy rate at first service than cows in Stages 1 (from 1 to 50 d postpartum), and 2 (from 51 to 100 d postpartum) of lactation (63 versus 44, and 50%, respectively). The inconsistency between studies was probably due to the influence of presence and suckling activity of calves on their dams in dual-purpose production systems, practice that is different to that in dairy systems where suckling stimulus of the calf is not needed before milking. It is well known that the presence and suckling of the calf alter the interaction among hypothalamus, pituitary and ovaries inhibiting the release of GnRH, which results in insufficient LH pulses, preventing the ovulation (Williams *et al.*, 1996).

In conclusion, the relationship between fertility of cows and percentage of *Bos taurus* genes differ among the breeds used. The percentage of *Bos taurus* genes did not affect fertility traits of Brown Swiss×Zebu cows. In contrast, Holstein×Zebu cows with less than 75% H genes were younger at first calving and had fewer days open and shorter calving intervals than Holstein×Zebu cows with 75% H genes or more. Therefore, to avoid declining fertility, cows with 75% H inheritance or more should not be used. Overall, Brown Swiss×Zebu and Holstein×Zebu cows had similar reproductive performance; however, the difference in body weight in favor of Brown Swiss×Zebu cows could reduce the potential milk yield advantage of the Holstein breed in the dual-purpose production system since heavier cows require more dietary energy for growth and maintenance.

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

Ángel Ríos Utrera supervised the genetic management of the herd, collected and analyzed data, and wrote and edited the manuscript; Juan Prisciliano Zárate Martínez designed the study, performed the reproductive management of cattle and collected data; Vicente Eliezer Vega Murillo supervised the genetic management of the herd; Javier Francisco Enríquez Quiroz supervised feeding of animals and status of pastures; Maribel Montero Lagunes did laboratory analyses of concentrate supplements and grasses; Francisco Tobías Barradas Piña supervised health status of animals; Martha Eugenia Valdovinos Terán coordinated and supervised the study.

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