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Profitability of Swedish Red and White × Holstein crossbred cows compared with purebred Holstein cows

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ABSTRACT

An economic analysis was performed using a bioeconomic simulation model based on production, reproduction and longevity indicators to compare the profitability (net income per cow) of Swedish Red and White × Holstein (S × H) cows and pure Holstein (H) cows in commercial dairy farms of the center-south of Córdoba province, Argentina. The reproductive events analyzed in the model were pregnancy, calving and abortion. The longevity events were culling, sale and death. The lactation curve for each cow was modeled with a lactation function. Estimations were made for the first, second, and third and later lactations. Incomes were from milk, culled cows and calves. Costs were from feeding, reproductive program and replacement heifers. The reproductive cost of a H cow per year was greater than that of a S × H crossbred cow (USD 6.3). The replacement costs were also higher in pure H cows than in S × H cows (USD 67.8). The revenues from the sale of calves (USD 12.1) and milk production minus the feed cost (USD 8.2) were greater for S × H cows than H cows. Hence, the S × H cows generated a greater total profit (USD 94.4) per cow per year than H cows. The present results show that, in the studied production systems, S × H crossbred cows are more profitable than H cows.
Key words: crossbreeding, simulated dairy farm, bioeconomic model, economic analysis

INTRODUCTION

Dairy farmers that use Holstein (H) cows have observed a substantial decrease in the survival (Hare et al., 2006), an increase in mortality rate (Miller et al., 2008) and a strong reduction in fertility (Lucy, 2001; Berry, 2018) for diverse production systems (Walsh et al., 2011). These changes have been attributed to selection for milk production without considering the antagonistic genetic correlation that milk production has with fertility and health traits (Miglior et al., 2017). However, over the last decade, efforts focused on genetic improvement of dairy cows have shifted from production to traits related to functions affecting the economic efficiency of production, including revenues from both calves and cull cows, feed costs, replacement cost, health treatment cost and reproductive cost (Hazel et al., 2021).

Herd reproductive performance is a critical component of the profitability of commercial dairy farms (Inchaisri et al., 2010; Li et al., 2023); failures to achieve and maintain pregnancy are the main reasons for production losses (Pinedo et al., 2020). Deficient reproductive performance has been found to be the main cause of culling in different production systems (Kerslake et al., 2018; Dallago et al., 2021).

Change in milk pricing toward the solids in milk, and global concern for the decline in fertility, health and survival of H cows has contributed to an increased interest in crossbreeding of dairy cattle (Weigel and Barlass, 2003; Buckley et al., 2014; Clasen et al., 2019). The benefits of crossbreeding using a variety of modern breeds, both in low-cost (pasture-based) and high-input (confinement) settings, had been clearly described (Buckley et al., 2014). Selection among breeds to optimize crossbreeding systems should take into account complementarity and heterosis between breeds, especially when crossing involves distantly-related breeds (Delaby et al., 2018),

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The list of standard abbreviations for JDS is available at adsa.org/jds-abbreviations-24. Nonstandard abbreviations are available in the Notes.

in addition to the gain from selection for additive genetic effects between each breed (Hazel et al., 2021). Thus, crossbreeding is a very powerful tool to improve fertility and survival of commercial dairy herds and, consequently, to enhance profitability and long-term sustainability (Lopez-Villalobos et al., 2000; Buckley et al., 2014; Clasen et al., 2020).

McAllister et al. (1994) reported annualized discounted net return of purebred Ayrshire, purebred H, and Ayrshire × H crossbred cows. The reported annualized discounted net return was calculated as the milk revenue minus costs during the lifetime of a cow, including calf values at birth and the salvage value of the cow. Statistically significant genetic solutions for reported annualized discounted net return were: $316.50 for direct additive (Holstein minus Ayrshire) and $134.30 for Ayrshire × H heterosis. A simulation study conducted in New Zealand found a higher annual net income/ha for farms with Holstein-Friesian × Jersey crossbred cows than for farms with purebred Holstein-Friesian or Jersey cows (López-Villalobos et al., 2000). In Denmark, Sørensen et al. (2008) reported +21% of heterosis for economic merit in Danish Red × H cattle.

Studies focusing on crossbreeding in dairy cattle use different methods to estimate profitability, including the analysis of individual cows or of the herd dynamics (Clasen, 2021). Some authors have used data of Dairy Herd Information system to estimate the cost of days open (Olds et al., 1979). Open days have been used in economic comparisons to identify the best management strategies (Britt and Gaska, 1998; Campos et al., 1995). Other studies used dairy farm models to calculate the reproductive cost (Schmidt, 1989; Plaizier et al., 1997) and efficiency (Groenendaal et al., 2004; Dezetter et al., 2016; Crociati et al., 2020).

Cabrera (2010) developed the Dairy Reproductive Economic Analysis, a bioeconomic model that simulates dairy farms. In this model, calculations are based on the probabilities of occurrence of different events related to the reproductive and productive efficiencies and longevity of individual cows. The indicators that feed this model are calculated for each of 9 fixed 30-d intervals for each calving to obtain a global mean of the dairy farm performance. The reproductive events involved in the model are pregnancy, calving and abortion; the longevity events are culling and sale; and production involves parameters of the lactation curve. Specifically, the Milkbot model (Ehrlich, 2011) is used for the modeling of the lactation curves of individual cows. The bioeconomic model concatenates events through a Markov chain to model transitions and changes of state in the herd (Geyer, 1992). Through recursive iterations, this distribution across states reaches a steady state, where the number of animals in the different states or conditions does not change substantially from one iteration to the other. The probabilities of transition are defined as the probabilities that a group of cows go from one state to the other. To calculate profit per cow per year the model includes milk price, heifer replacement cost, the cost of the reproductive program used, the value of a newborn calf, the value of a cull cow and feed cost. Thus, the net revenue of each cow in the herd over a specific period can be estimated as the sum of the following economic factors: incomes over feed costs, incomes from possible sales of female and male calves, costs of possible culling, costs of possible mortality, and reproduction costs.

Piccardi (2014) applied the bioeconomic model developed by Cabrera (2010) to compare different simulated production systems in terms of productive and reproductive efficiency, and Masía (2021) used it to compare different production systems (pasture based, dry lot and free stall), as well as herds with and without health events. However, this model has not previously been used to evaluate the effect of dairy crossbreeding on dairy herd profitability.

The objective of the study was to use this bioeconomic model (Cabrera, 2010) to compare the profitability of Swedish Red and White × Holstein (S × H) crossbred cows with purebred H cows.

MATERIALS AND METHODS

Simulation of herds

Two herds were simulated, one with Swedish Red and White × Holstein (S × H) crossed cows, and another with purebred Holstein (H) cows. To estimate the probabilities of events of the herds, a database containing information about reproduction, production, culling and death events from crossbred and purebred cows was used. The data was collected from 2 commercial dairy farms located in Ucacha, center-south of Córdoba province, Argentina, from January 1, 2008 to December 31, 2013.

The descriptions of the herds, the cows used, and the results of the lactation curves for production of milk, fat and protein; the percentage of fat and protein; and somatic cell counts for pure H cows and S × H cows were reported by Pipino et al. (2019). There were 32,847 herd test-day records from 1,244 pure H cows and 310 S × H crossbred cows, which had the first calving from 1st January 2008 to 31st December 2013 (6 years in total). The management of the farms, the crossbreeding system and the fertility and longevity results were described in Pipino et al. (2023). Briefly, on each farm, 2 daily milkings were performed in a semi-stalled feeding system. Cows grazed alfalfa during the hot summer months and oats or barley in the winter. The diet was systematically supplemented with maize silage and regional by-products, expeller, and flours, depending on the time of year. Throughout the years of the study, the dairy producers applied the same management practices in both breed groups. They comingled heifers and cows without regard to breed group and used identical protocols within herd for artificial insemination, health treatment, and culling. Heifers and cows were grouped by age, stage of lactation, or reproductive status across breed groups. In each commercial dairy farm, H heifers and H cows were randomly assigned to be mated by artificial insemination with semen from Swedish Red and White (SRW) or H bulls. Every year, at least 20% of the purebred H females in each herd annually were mated to SRW bulls, and the remaining purebred H females in each herd were mated with H bulls. For the crossbred group, in the subsequent generation, the resulting crossbreed progeny (S × H crossbreds) were mated by artificial insemination to the H breed. All matings were with conventional, unsexed semen for both heifers and cows. The H bulls were proven artificial insemination sires and the genetics implemented came from the United States (CIALE S.A.). The H bulls were selected mainly by ranking artificial insemination bulls for the net merit index in the United States available in Argentina at the time of selection. The cryopreserved semen from the SRW bulls was imported from Sweden and commercially available in Argentina (VikingGenetics). The SRW bulls were selected mainly for functional traits, with the objective of reducing body size, improving calving ease, fertility, milk quality, udder health, and survival based on the selection indices developed for this breed (Pipino et al., 2023).

In the simulation model dry matter (DM) requirements of a cow were estimated considering the metabolic energy requirements for production and maintenance and growing of replacements following NRC (2001) formulae. The average content of metabolizable energy of the feed offered plus feed supplements was 2.64 MCal/kg DM. Weighted average live weight (±SE) of 1st, 2nd, 3rd, and ≥4th lactation cows was 651 ± 13.7 kg for pure H and 595 ± 12.8 kg for S × H cows. Data on production, reproduction, mortality and culling rates used to compare the profitability of pure Holstein cows and Swedish Red and White × Holstein crossbred cows in semi-pastured based dairy production systems in the center-south of Córdoba province, Argentina, were described in Pipino et al. (2023) and are presented in Table 1.

Estimation of probabilities used to build the model

The probabilities (expressed as percentage of eligible cows) of occurrence of the event (pregnancy, culling or abortion) necessary to run the bioeconomic model were calculated for the first, second and third and later lactations. Cows eligible to become pregnant included all

Table 1. Productive, reproductive parameters (mean ± sem), mortality and culling rates to compare the profitability of pure Holstein cows and Swedish Red and White × Holstein crossbred cows in semi-pastured based dairy production systems in the center-south of Córdoba province, Argentina

	Breed	
	Holstein	Swedish Red and White x Holstein
Productive parameters		
Milk (L/305d)	6205 ± 53	5505 ± 110
Butterfat (%)	3.55 ± 0.01	3.67 ± 0.09
Crude protein (%)	3.31 ± 0.01	3.40 ± 0.03
Butterfat (kg/305d)	226 ± 2.00	213 ± 4.00
Crude protein (kg/305)	220 ± 2.00	201 ± 2.00
Reproductive parameters		
FSCR (%)	34.4	44.9
CR (%)	32.4	40.1
SC[1]	2.6 ± 0.06	2.0 ± 0.09
DO[2]	140	105
Mortality rate[3] (%)	9.7	5.0
Culling rate[4] (%)	28.3	14.6

First service conception rate (FSCR), overall conception rate (CR), number of services per conception(SC), and days open (DO).

[1]SC expressed as mean ± SE.

[2]DO expressed as median (equal to the 50th percentile).

[3]Mortality rate = number of cows that died after the first calving to the end of this study divided by the total number of cows included in the analysis.

[4]Culling rate = number of cows that were culled after the first calving to the end of this study divided by the total number of cows included in the analysis.

First service conception rate (FSCR), overall conception rate (CR), number of services per conception(SC), and days open (DO).

open cows present on farm that were eligible for services during the period in question. Cows eligible to abort included pregnant cows but excluded deliveries at term. Cows eligible for culling were all cows present on farm. Lactations were divided into 30-d periods, with the probability for each period calculated as the number of cows that displayed the event, divided by the number of cows eligible to display the event. Calculations were made using a survival analysis with actuarial life tables, since the observation of the events was made at fixed intervals (30 d). In this method, survival times are divided into intervals that allowed us to derive a hazard function. With this function, it is possible to estimate at each time the probability that the event will occur at that moment, given that it has not occurred before.

The hazard function captures the dynamics of the studied process because its values provide a suitable approach to the incidence rate of the event of interest, which allows us to determine the moment of greatest risk for the individual to get pregnant, be culled, or have an abortion. To estimate the hazard functions for the 2 breeds studied, we used PROC LIFETEST in SAS 9.4 (SAS Institute Inc., 2011) for each number of lactation (see Tables A1 to A5 in the Appendix).

The hazard function is:

$$h\left(t\right)=\frac{P(t\leq T<t+\dfrac{\Delta t}{T}\geq t)}{\Delta t},$$

where h is the probability, per unit of time t, that the event will occur in the next interval (Δt), given that it has not occurred earlier.

To build the bioeconomic model, we used the probabilities of abortion for a pasture-based system described by Masía (2021), who made estimations from a total of 137,509 lactations from 90,609 cows. To avoid bias in the analysis, the variable probability of abortion was kept constant in the scenarios analyzed, both for S × H crossbred and purebred H cows.

Estimation of production indicators

The parameters of the milk production curves for each of the production systems were obtained by fitting lactation curves with the MilkBot model (Ehrlich, 2011) using PROC NLMIXED in SAS (SAS Institute Inc., 2011). Estimations were made for the first, second and third and later lactations.

The MilkBot function of is nonlinear and is represented as follow:

$$Y\left(t\right)=a\left(\frac{exp\,\dfrac{c-t}{b}}{2}\right)exp^{-dt},$$

where Y(t) is milk production on day t of lactation. This function has 4 parameters; parameter a, scale, is a multiplier that determines the overall magnitude of milk production and is expressed as L/day. Parameter b, ramp, controls the rate of rise in milk production in early lactation and is expressed in days. Parameter c, offset, describes the offset in time between calving and the maximal growth rate of milk productive capacity; it is expressed in days. Finally, parameter d, decay, controls the loss of productive capacity and is expressed as days^{-1}.

Determination of economic values

The economic values used to implement the model were market reference values converted to US dollars (USD, dollar commercial sales exchange rate, Banco de la Nación Argentina) calculated on November 8, 2022, which was 165 $AR/1 USD (Table 2). One of the costs and profits that are considered in the model are the price of milk (USD/liter), which was obtained from the Dirección Nacional de Lechería, Sistema Integrado de Gestión de la Lechería Argentina (SIGLeA, Tablero de comando sectorial, https://www.magyp.gob.ar/sitio/areas/ss_lecheria/estadisticas/). The price of milk was defined considering milk quality and the milk solids produced (butterfat + crude protein).

The cost of the reproductive program used (USD/cow/month) was obtained by considering the cost of veterinary treatment, which accounts for 1.5% of the gross incomes of the dairy farm; the cost of labor required for estrous detection (ED) and artificial insemination (AI), which accounts for 2% of the gross incomes of the dairy farm; and the cost of semen, i.e., the number of doses of cryopreserved semen necessary for each breed analyzed (Pipino et al., 2023). The cost of hormones, solutions and/or reagents used for timed artificial insemination, the dose of prostaglandin F2α (PgF2α, analogs of different trademarks) and the cost of paint applied at the base of the tail as and aid to ED (Ce-Lamark®, Productos Veterinarios) were also included.

The income from a newborn was defined by the economic value of a newborn male or female. The model also considered the cost of a replacement heifer (USD/animal), the market value of a newborn calf of 45 kg (USD/animal), and the same values were assumed for both breeds. The cull value is the estimated revenue obtained the market value from the sale of a cull cow (carcass value USD/animal), considering the price and the average kg of live weight of each breed, since pure H cows have greater live weight than S × H cows, but the latter have a higher sale price per kg of live weight. The cost of culling is calculated as: carcass value – replacement heifer. Hence, replacement heifer is embedded in the cost of culling and the model used for its analysis does not report these values independently. Finally, the feed cost was deducted from the revenue from milk production were reported by Pipino et al. (2019). Feed cost is the cost of one kg of dry matter (kg DM) of feed offered to the milking cows, expressed in USD/Kg DM, and includes all the purchase costs or feed production of feeding on a farm (including opportunity cost of land). The milk income over feed cost was calculated as the milk value less the feed cost. Market values used to compare profitability for both breeds is presented in Table 2.

Fit of the model

Once all the information required to build the bioeconomic model was available, it was run for each breed group using the version available online (Cabrera, 2010) https://dairymgt.info/markov/reader.php.

RESULTS

Probability of pregnancy

The probability of pregnancy (expressed as percentage) of the first, second and third or more lactations for the 2 simulated breed groups studied are shown in Figure 1. In all the lactations, approximately on d 60 after calving, the likelihood of pregnancy started to increase, reaching a peak between d 90 and 120 of lactation. This peak was more extreme in crossbred cows. The probability of pregnancy was greater in S × H cows than in H in all the lactations analyzed. On d 90 of lactation, the probability of pregnancy was greater for S × H cows, by +16%, +7% and +10% for the first, second and third or more lactations, respectively. The greater probability of pregnancy for S × H cows persisted up to 150 d of lactation.

Table A1 and A2 (Appendix) show the probabilities of pregnancy for the 2 simulated breed groups used to build the bioeconomic model.

Probabilities of abortion

Abortion rates for each breed were not available in our database, therefore, identical values they were assumed for each breed. These were obtained from Masía (2021), who analyzed a database containing information from 72 commercial dairy farms in the Argentine provinces of Córdoba, Buenos Aires, Santa Fe and Entre Ríos for the years 2016, 2017 and 2018 and consisting of 164,334 lactations from 109,066 cows. In all the lactations and production systems analyzed by Masía (2021), 2 peaks of maximum probability of abortion were observed: one at about 90 d of gestation and the second, between 210 and 240 d of gestation. The cumulative probability of abortions reported by Masía (2021) for pastoral systems was 11.7% and 10.5% for first- and third-lactation animals, respectively. Table A3 (Appendix) indicates the probabilities of abortion (expressed as percentage) for all the lactations in the pasture-based production system described by Masía (2021).

Culling risk

Figure 2 shows the culling risk (expressed as percentage) of the first, second, and third or more lactations for the 2 simulated breed groups. During the first 60 d after calving, H cows had 1.6% and 1.7% risk of being culled in the first and second lactations, respectively, whereas for the crossbred cows, this risk for that period was zero. For both breed groups, the risk of culling remained low for around 1 year and then increased rapidly. The culling risk increased with greater number of days of lactation; this was observed in pure H cows from around d 390 after

Table 2. Market values[1] of November 2022 for Argentina used to compare profitability of pure Holstein cows and Swedish Red and White × Holstein crossbred cows, in semi-pasture based milk production systems in central-south of Córdoba province, Argentina

Variable	Breed: Holstein	Breed: Swedish Red and White × Holstein
Milk price (USD/L milk)	0.37	0.40
Feed cost (USD/kg DM)	0.11	0.11
Feed cost per day (USD/Cow/d)	2.16	1.97
Value of replacement heifer (USD/animal)	1866	1866
Value of cull cow (USD/animal)	829	865
Value of calf of 45 kg (USD/animal)	82	82
Cost of reproductive program (USD/animal/month)	9.89	9.49

[1]Values in US dollar (USD).

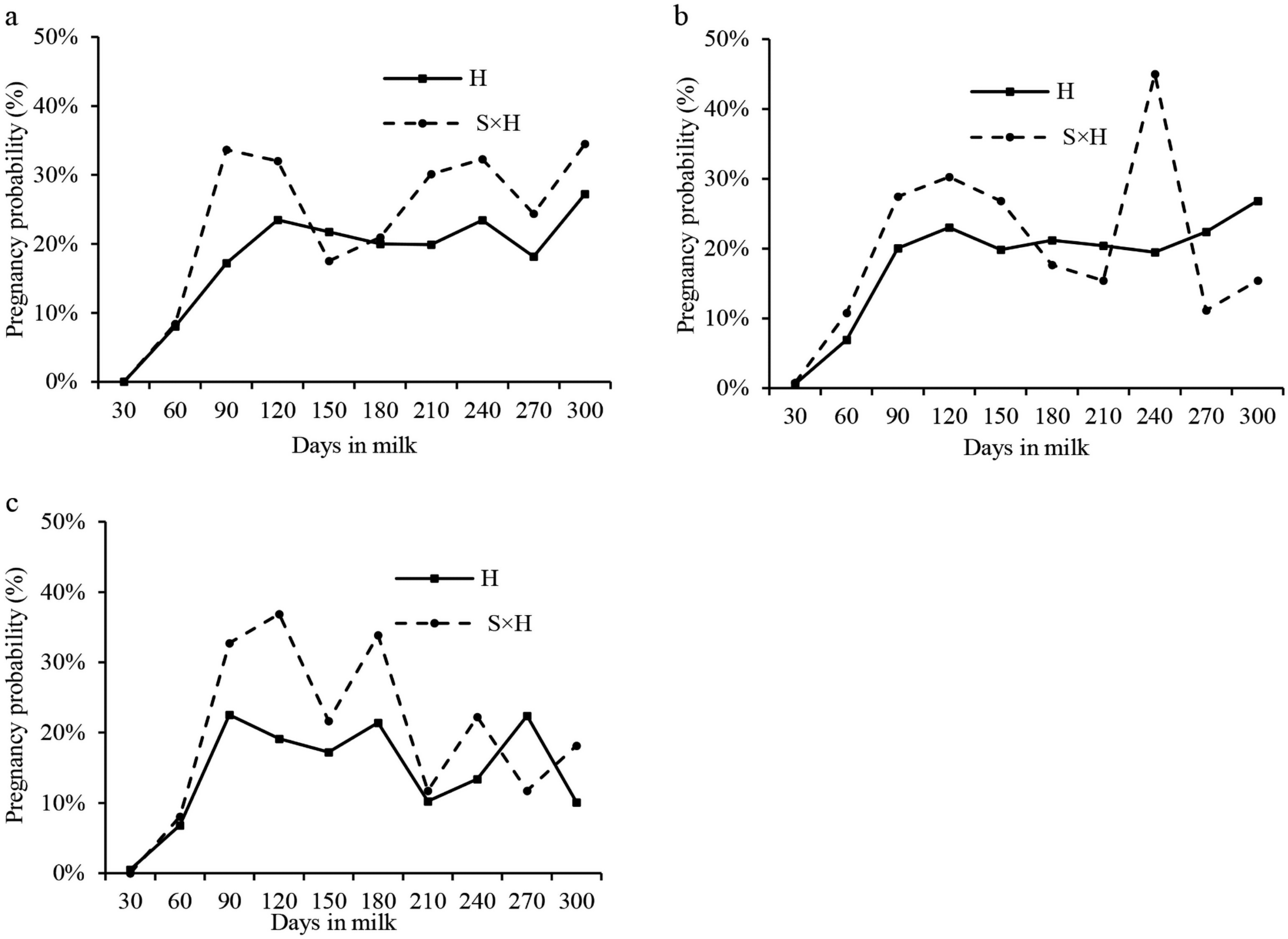

Figure 1. Probability of pregnancy (%) for the first (a), second (b) and third and later lactations (c) for Holstein (H) cows and Swedish Red and White × Holstein (S × H) crossbred cows, in semi-pasture based milk production systems in central-south of Córdoba province, Argentina.

calving, both in the first and second lactations, whereas in the third or more locations, it occurred as of d 330 after calving. The analysis of overall lactations showed a cumulative risk of culling of 11% for H cows and of 4% for S × H crossbred cows.

The percentages of mortality found for the 2 simulated breed groups was +1.5% higher in pure H cows (5.0%) than in S × H crossbred cows (3.5%) for all lactations. Appendix Tables A4 and A5 show the probabilities of culling for the 2 simulated breed groups used to construct the bioeconomic model.

Productive indicators

The fitted curves showed a similar behavior for the first, second and third and later lactations between simulated breed groups. Parameters of MilkBot lactation curves for the 2 simulated breed groups studied are shown in Table 3.

Bioeconomic model

The results of the bioeconomic simulation model for each breed are detailed in Table 4. The reproductive cost of a H cow (USD 40.0) per year is higher than that of a S × H cow (USD 33.7). Likewise, the culling costs (carcass value - replacement heifer)) were higher for H cows (USD 118.4) than for S × H cows (USD 50.6). Moreover, the revenue obtained from the selling of newborn calves (+12.1) and milk income over feed cost, income over feed cost (deducting the feed cost of +8.2) was higher for S × H cows. The S × H cows generated a higher total final net income per cow per year (USD 94.4) than pure H cows. The S × H cows generated greater profitability per cow per year.

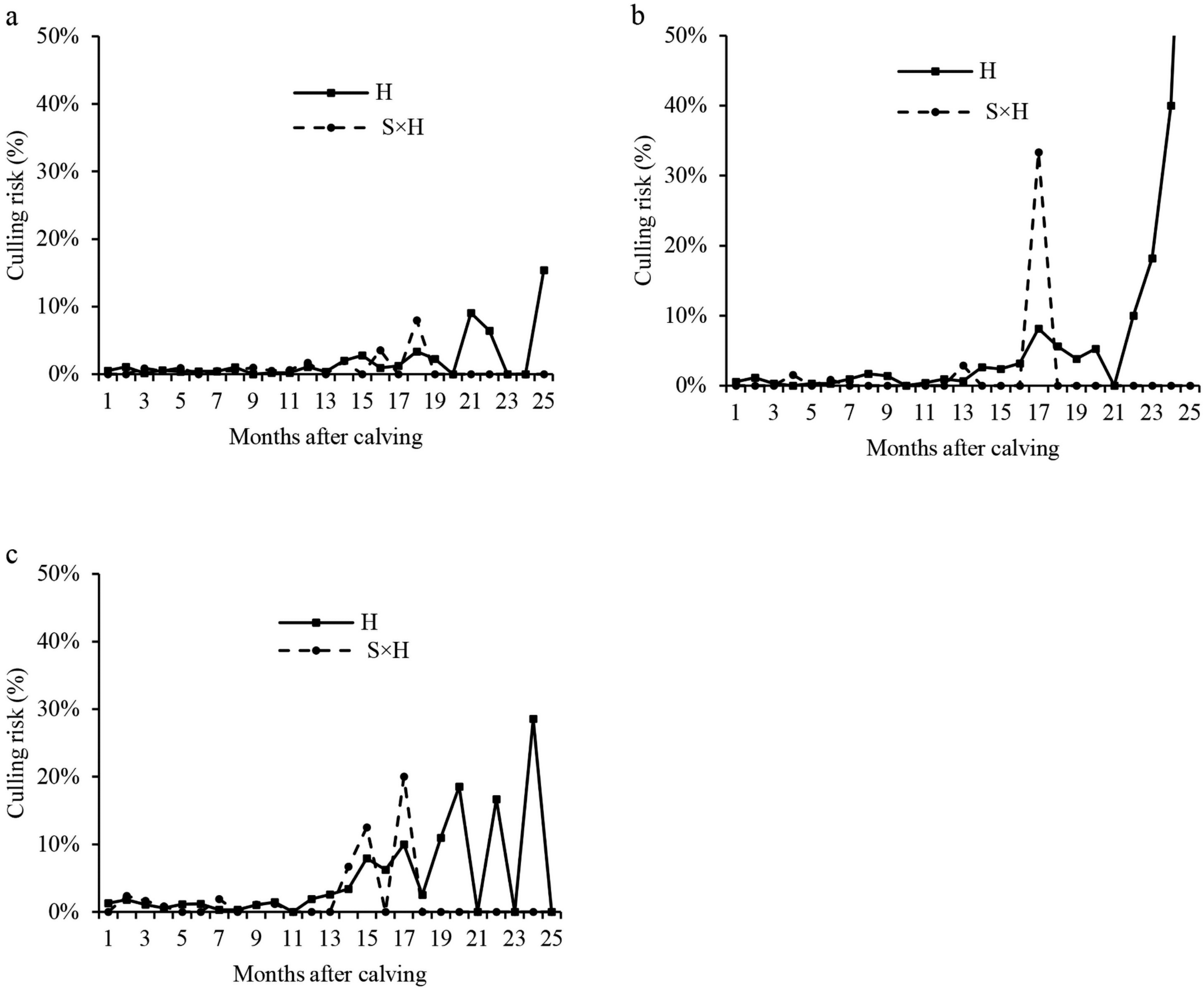

Figure 2. Culling risk (%) for the first (a), second (b) and third and later lactations (c) for Holstein (H) cows Swedish Red and White × Holstein (S × H) crossbred cows, in semi-pasture based milk production systems in the center-south of Córdoba province, Argentina.

DISCUSSION

Probability of pregnancy

The maximum values of probability of pregnancy reached in the first, second and third or more lactations were 39% for S × H crossbred cows and 26% for H cows. These higher maximum values of probability of pregnancy gradually decreased with increasing number of lactations. The same behavior was observed in previous works (Melendez and Pinedo, 2007; Santos et al., 2009). The values of probability of pregnancy reached by H cows are similar to results reported by Piccardi (2014) and Masía (2021). On the other hand, the values of probability of pregnancy reached by S × H cows indicate a better reproductive performance than that of H cows. Different works have reported greater fertility in S × H cows than in H cows (Malchiodi et al., 2014; Piccardi et al., 2014; Pipino et al., 2023).

Probability of culling

The observed probability of culling for H cows agrees with several previous works (Godden et al., 2003; Dechow and Goodling, 2008; De Vries et al., 2010). The probability of involuntary culling follows a typical pattern, with a slightly greater risk of culling at the beginning of lactation, followed by a decrease to a plateau

Table 3. Estimation of the parameters of the lactation curves fitted with a mixed model with a random effect associated with the parameter a, using the equation of the Milkbot model[(1)], for pure Holstein cows and Swedish Red and White × Holstein crossbred cows, for the first, second and third and later lactations, in semi-pasture-based milk production systems of the center-south of Córdoba province, Argentina

		Lactation number		
Breed	Parameter	1	2	3 and later
Holstein	*a*	26.306	34.782	37.887
	b	18.724	14.919	17.278
	c	2.492	2.709	3.936
	d	0.001	0.002	0.002
Swedish Red and White × Holstein	*a*	23.834	30.829	35.444
	b	11.600	9.234	15.522
	c	4.921	3.996	4.348
	d	0.001	0.002	0.002

[(1)] $Y\left(t\right) = a\left[\left(\frac{\frac{\exp\exp\left(c-t\right)}{b}}{2}\right)\right]exp^{-dt}.$

after the transition period, a slight increase between the middle and the end of lactation, and finally a drastic increase later in lactation (Cabrera, 2014). Therefore, clearly, the longer the cow remains open in lactation, the higher the risk of being culled (Cabrera, 2014). The main causes of an increase in the probability of culling were found to be death during early lactation and poor reproductive performance during late lactation (De Vries and Marcondes, 2020). Cows that leave the herd early, after only 1 or 2 lactations reduce the profitability of the dairy herd (Lehenbauer and Oltjen, 1998; De Vries, 2020). Improved fertility of S × H cows contributed to their lower probability of culling.

Improved health, conformation and fertility reduce involuntary culling and contribute to decision making about culling of functionally healthy cows (De Vries and Marcondes, 2020). In summary, in the present study, S × H cows had lower culling and mortality rates than pure H cows. Cow mortality represents a significant loss of revenues for dairy farmers because salvage value and future production are lost, and heifer replacement costs may not be offset (Heins et al., 2012; Pritchard et al., 2013).

Bioeconomic model

Profitability of dairy farms depends on the productive and reproductive performance, and survival of the cows; however, this is a complex relationship.

In Argentina, US and other country of the world, fat and protein production have become more commonplace as gauges for economic productivity of cows (Hazel et al., 2021, SIGLeA, Tablero de comando sectorial, https://www.magyp.gob.ar/sitio/areas/ss_lecheria/estadisticas/). Therefore, most dairy producers in Argentina should compare productivity of breed groups of cows based on solids (kg) production instead of on fluid volume of milk. The S × H crossbred cows in this study had greater fat (3.67%) and protein (3.40%) percentage ($P < 0.01$) compared with the 3.55% and 3.31% of the H cows respectively (Pipino et al., 2019). Our results agree with the values of fat (3.56%) and protein (3.30%) percentages reported in Argentina by Gastaldi et al. (2018) in Holstein cows. Therefore, the price of milk defined by the milk solids produced (fat and crude protein) was greater (USD 0.03/L) for the milk from the S × H cows than for the milk from the purebred H cows (Table 2).

Dairy farmers and consultants can evaluate the reproductive performance by comparing the pregnancy rate or other reproductive metrics, but they find it difficult to measure the economic impact (e.g., profitability) of

Table 4. Values of costs (negative values) and revenues (positive values) per cow per year (USD/cow/year) for pure Holstein cows and Swedish Red and White × Holstein crossbred cows, in semi-pasture-based milk production systems in the center-south of Córdoba province, Argentina

	Total costs and revenues				
Breed	IOFC[1]	Culling	Reproduction	Calves	Net Return
Holstein	2053.9	−118.4	−40.0	48.5	1943.9
Swedish Red and White × Holstein	2062.1	−50.6	−33.7	60.6	2038.4

[1]Income over feed cost.

the changes on reproductive results, on the alternative reproductive management programs or on reproductive management decisions affecting individual cows (Cabrera and Giordano, 2019). The marginal net revenue obtained from the introduction of reproductive innovations and changes in management might be evaluated by simulating the reproductive performance along with its costs and benefits (Giordano et al., 2011; 2012; 2013; Kalantari and Cabrera, 2012) and calculating the expected net productivity (De Vries et al., 2010; Fricke et al., 2010; Cabrera, 2011). The capacity to compare the future profitability of the current reproductive program of a dairy farm with an alternative reproductive program is essential for reproductive management decision making (Cabrera and Giordano, 2019). The bioeconomic model developed by Cabrera (2010) has still not been used to simulate the effect of crossbreeding on profitability of dairy herds in Argentina or other countries worldwide, which highlights the importance of the results of the present study.

Our results agree with those reported by Heins et al. (2012) by commercial dairies herds in California, who found that S × H cows had a lower replacement cost per day, survived for a longer period and gave birth more frequently than H cows, thereby achieving an additional profit (USD 55 per cow and per year) with respect to H cows. Moreover, S × H cows involved in this study, as reported by Pipino et al. (2023), had a significantly longer productive life than pure H cows.

The profit from S × H cows was +94.40 USD/cow/year greater than that from pure H cows in the present study. Considering that farm 1 and farm 2 have 180 and 350 milking cows, respectively (Pipino et al., 2023), the additional annual profit compared with a H herd if the farms had only S × H cows would be USD 16,992 USD and USD 33,040 for each farm, respectively. The results of this research demonstrate that dairy herd profitability depends on fertility and survival as well as milk yield. In this study, the cows with improved fitness were more profitable than the cows with greater productivity.

Using the bioeconomic model tool with only H breed, Cabrera and Giordano (2019) estimated a net profit of 13.2 USD/cow/year with the increase of percentage of inseminated cows from 40 to 70% through the use of estrus detection devices in 50% of lactating cows. In addition, the authors reported that the introduction of estrus detection (50% of the cows) after the first timed artificial insemination provides a profit of 12.3 USD/cow/year to the general reproductive program of the farm. They also observed an increase of up to 59 USD/cows/year in the present net value when the intervals between services were shortened. Giordano et al. (2011) reported an increase of up to 69 USD/cow/year in the net present value for timed artificial insemination programs compared with the basic reproductive program. As it can be observed, there is an additional positive impact of S × H crossed cow as it increases the profit beyond of what has been observed previously only due to improved reproduction performance (even under extreme circumstances). This study therefore quantifies the multifactor impact of crossbreeding on profitability, which could justify the decision of modifying the production system.

The costs of health treatments were not available for the present study, and their inclusion might have affected the results for profits. Indeed, for all the livestock species, heterosis tends to be expressed most notably in fitness-related traits (Sørensen et al., 2008; Heins et al., 2012; Hazel et al., 2021). The results of our study were similar to findings of VanRaden and Sanders (2003) and Heins et al. (2012), who reported that profits from crossbred cows were higher than those of pure H cows, even when not including health costs. Nevertheless, the lower rate of culling of S × H cows indicates that they were unlikely to experience greater health costs and if health treatments had been included, the difference in favor of S × H vs. H would had been even greater.

Our results agree with findings of Hazel et al. (2021), who reported that Viking Red × H cows had +18% lifetime revenue from production than H cows. Furthermore, crossbred cows generated more revenue from cull cow sales, not only because their carcasses had a higher price than those of H cows, but also because fewer crossbred cows were culled during the first lactation and fewer crossbred cows (12.4%) died during the herd life compared with the H herd mates (16.3%) (Hazel et al., 2021). The dairy herd is a complex interrelated system that is dynamically affected by changes in reproductive performance (Cabrera, 2014). Economic profits obtained from improving the reproductive performance are derived from an increased productivity, increased milk sales and potentially higher milk revenues over feed cost; increased sale of calves, reduced replacement costs and mortality; and reduced reproductive costs. These would be the most important factors determining economic reproductive efficiency (Giordano et al., 2012; Galvao et al., 2013).

Heterosis in farm animal species is largest for traits related to fertility, mortality and birth, health and longevity (Sørensen et al., 2008; Hazel et al., 2021). The advantages for these traits explain the difference in the daily profit observed for S × H cows compared with pure H cows (Oltenacu and Broom, 2010, Hazel et al., 2021; Pipino et al., 2023). The longer productive life of the crossbred cow herd than that of H herd mates was the main factor contributing to a lower daily cost of replacement of S × H cows (Hazel et al., 2021; Pipino et al., 2023).

CONCLUSION

Using a bioeconomic simulation model, we quantified the effects of introducing crossbreeding with Swedish Red and White bulls on Holstein cow dairy farms, providing insights into this long-term decision. In this study, crossbreeding improved the fertility and survival of the cows which led to improved profitability. The simulated model showed that crossbreeding between Holstein cows and Swedish Red and White generated greater total net return of +94.40 USD per cow per year. Hence, adoption of this breeding strategy is expected to lead to improved cow welfare and enhanced economic efficiency in the dairy industry.

Notes

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APPENDIX: LIFE TABLES

The tables associated with estimation of conditional probabilities, expressed in percentages, of pregnancy, culling and abortion events, per number of lactation and period (30-d intervals) are presented for each breed.

Table A1. Estimation of the conditional probability of pregnancy (in percentage) for each interval (30 d) for Holstein cows, relative to the number of lactations, in semi-pasture-based milk production systems in the center-south of Córdoba province, Argentina

	Number of lactations								
30 d interval	1	2	3	4	5	6	7	8	9
1	0.00	0.57	0.52	0.52	0.52	0.52	0.52	0.52	0.52
2	8.06	6.90	6.81	6.81	6.81	6.81	6.81	6.81	6.81
3	17.21	20.03	22.53	22.53	22.53	22.53	22.53	22.53	22.53
4	23.47	23.03	19.13	19.13	19.13	19.13	19.13	19.13	19.13
5	21.72	19.83	17.22	17.22	17.22	17.22	17.22	17.22	17.22
6	20.00	21.17	21.40	21.40	21.40	21.40	21.40	21.40	21.40
7	19.88	20.39	10.26	10.26	10.26	10.26	10.26	10.26	10.26
8	23.44	19.48	13.41	13.41	13.41	13.41	13.41	13.41	13.41
9	18.18	22.41	22.39	22.39	22.39	22.39	22.39	22.39	22.39
10	27.21	26.83	10.10	10.10	10.10	10.10	10.10	10.10	10.10
11	25.74	25.45	20.51	20.51	20.51	20.51	20.51	20.51	20.51
12	28.57	21.05	18.87	18.87	18.87	18.87	18.87	18.87	18.87
13	16.67	29.63	25.00	25.00	25.00	25.00	25.00	25.00	25.00
14	21.05	13.33	29.63	29.63	29.63	29.63	29.63	29.63	29.63
15	14.81	40.00	12.50	12.50	12.50	12.50	12.50	12.50	12.50
16	10.00	66.67	18.18	18.18	18.18	18.18	18.18	18.18	18.18

Table A2. Conditional probabilities of pregnancy (in percentage) for each interval (30 d) for Swedish Red and White × Holstein crossbred cows, relative to the number of lactations in semi-pasture-based milk production systems in the center-south of Córdoba province, Argentina

	Number of lactations								
30 d interval	1	2	3	4	5	6	7	8	9
1	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	8.39	10.77	8.06	8.06	8.06	8.06	8.06	8.06	8.06
3	33.67	27.43	32.73	32.73	32.73	32.73	32.73	32.73	32.73
4	32.00	30.26	36.88	36.88	36.88	36.88	36.88	36.88	36.88
5	17.50	26.80	21.69	21.69	21.69	21.69	21.69	21.69	21.69
6	20.97	17.65	33.90	33.90	33.90	33.90	33.90	33.90	33.90
7	30.11	15.38	11.76	11.76	11.76	11.76	11.76	11.76	11.76
8	32.26	45.00	22.22	22.22	22.22	22.22	22.22	22.22	22.22
9	24.39	11.11	11.76	11.76	11.76	11.76	11.76	11.76	11.76
10	34.48	15.38	18.18	18.18	18.1	18.18	18.18	18.18	18.18
11	33.33	40.00	57.14	57.14	57.14	57.14	57.14	57.14	57.14
12	18.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	75.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A3. Estimation of the conditional probability of abortion (in percentage) for each time interval (months of gestation) relative to the number of lactations, in pasture-based milk production systems in the provinces of Córdoba, Buenos Aires and Santa Fe, Argentina, for the 2016 - 2018 period (Masía, 2021)

	Number of lactations								
Gestation month	1	2	3	4	5	6	7	8	9
1	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1.87	1.44	1.83	1.83	1.83	1.83	1.83	1.83	1.83
3	0.92	2.31	2.66	2.66	2.66	2.66	2.66	2.66	2.66
4	1.07	1.93	1.96	1.96	1.96	1.96	1.96	1.96	1.96
5	1.44	1.60	1.24	1.24	1.24	1.24	1.24	1.24	1.24
6	1.74	2.04	1.85	1.85	1.85	1.85	1.85	1.85	1.85
7	1.29	1.33	1.15	1.15	1.15	1.15	1.15	1.15	1.15
8	3.34	2.47	2.27	2.27	2.27	2.27	2.27	2.27	2.27
9	4.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A4. Estimation of the conditional probability of culling (in percentage) for each interval (30 d) for Holstein cows, for all the lactations, in semi-pasture-based milk production systems in the center-south of Córdoba province, Argentina

	Number of lactations								
30 d interval	1	2	3	4	5	6	7	8	9
1	0.52	0.55	1.26	1.26	1.26	1.26	1.26	1.26	1.26
2	1.08	1.14	1.82	1.82	1.82	1.82	1.82	1.82	1.82
3	0.19	0.29	1.08	1.08	1.08	1.08	1.08	1.08	1.08
4	0.57	0.00	0.55	0.55	0.55	0.55	0.55	0.55	0.55
5	0.39	0.30	1.13	1.13	1.13	1.13	1.13	1.13	1.13
6	0.40	0.31	1.17	1.17	1.17	1.17	1.17	1.17	1.17
7	0.41	0.96	0.31	0.31	0.31	0.31	0.31	0.31	0.31
8	1.05	1.67	0.33	0.33	0.33	0.33	0.33	0.33	0.33
9	0.00	1.40	1.02	1.02	1.02	1.02	1.02	1.02	1.02
10	0.22	0.00	1.42	1.42	1.42	1.42	1.42	1.42	1.42
11	0.24	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	1.11	0.97	1.91	1.91	1.91	1.91	1.91	1.91	1.91
13	0.36	0.66	2.59	2.59	2.59	2.59	2.59	2.59	2.59
14	1.99	2.63	3.42	3.42	3.42	3.42	3.42	3.42	3.42
15	2.78	2.41	7.95	7.95	7.95	7.95	7.95	7.95	7.95
16	0.91	3.20	6.25	6.25	6.25	6.25	6.25	6.25	6.25
17	1.23	8.16	10.00	10.00	10.00	10.00	10.00	10.00	10.00
18	3.36	5.63	2.50	2.50	2.50	2.50	2.50	2.50	2.50
19	2.25	3.85	10.96	10.96	10.96	10.96	10.96	10.96	10.96
20	0.00	5.26	18.52	18.52	18.52	18.52	18.52	18.52	18.52
21	9.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	6.45	10.00	16.67	16.67	16.67	16.67	16.67	16.67	16.67
23	0.00	18.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	40.00	28.57	28.57	28.57	28.57	28.57	28.57	28.57
25	15.38	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A5. Estimation of the conditional probability of culling (in percentage) for each interval (30 d) for Swedish Red and White × Holstein crossbred cows (S × H), for all lactations, in semi-pasture-based milk production systems in the center-south of Córdoba province, Argentina

	Number of lactations								
30 d interval	1	2	3	4	5	6	7	8	9
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	2.35	2.35	2.35	2.35	2.35	2.35	2.35
3	0.88	0.00	1.63	1.63	1.63	1.63	1.63	1.63	1.63
4	0.46	1.56	0.84	0.84	0.84	0.84	0.84	0.84	0.84
5	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.49	0.00	1.88	1.88	1.88	1.88	1.88	1.88	1.88
8	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	1.01	0.00	1.06	1.06	1.06	1.06	1.06	1.06	1.06
10	0.53	0.00	1.16	1.16	1.16	1.16	1.16	1.16	1.16
11	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	1.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	2.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	1.96	0.00	6.67	6.67	6.67	6.67	6.67	6.67	6.67
15	0.00	0.00	12.50	12.50	12.50	12.50	12.50	12.50	12.50
16	3.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	33.33	20.00	20.00	20.00	20.00	20.00	20.00	20.00
18	8.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00