

**JESSICA MARCELA VIEIRA PEREIRA**

**USE OF BEEF-SEMEN ON DAIRY COWS: BREEDING STRATEGIES, ECONOMICS  
OF USING BEEF EMBRYO ON JERSEY DAIRY COWS AND ASSOCIATION OF  
TRANSFER OF PASSIVE IMMUNITY WITH MORBIDITY AND MORTALITY IN  
DAIRY-BEEF CROSSBRED CALVES**

Thesis submitted to the Animal Science Graduate Program of the Universidade Federal de Viçosa in partial fulfillment of the requirements for the degree of *Doctor Scientiae*.

Adviser: Marcos Inácio Marcondes

Co-adviser: Fernanda Carolina Ferreira

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Marcos Inácio Marcondes  
Adviser

To God and to my dear uncle Marcelo and father Joao,

for all that I am and have achieved

**Gratitude.**

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## ABSTRACT

PEREIRA, Jéssica Marcela Vieira, D.Sc., Universidade Federal de Vicosa, March, 2022. **Use of beef-semen on dairy cows: breeding strategies, economics of using beef embryo on Jersey dairy cows and association of transfer of passive immunity with morbidity and mortality in dairy-beef crossbred calves.** Adviser: Marcos Inacio Marcondes. Co-adviser: Fernanda Carolina Ferreira.

This thesis was developed from three studies. The objectives of the first study were to describe the current management practices on the use of beef semen (BS) by dairy farms; and to determine factors associated with the price of day-old dairy-beef crossbred calves. In January 2020, we mailed a printed version of the beef semen use survey to dairy producers in California. The questionnaire consisted in: general herd information (n = 10), BS (n = 17), and sexed dairy semen (n = 6) management. Most dairies (81%) reported using BS on dairy cows, starting (58%) using BS in the past three years. Reproductive performance was an important criterion to select cows to receive BS, and 45% of the respondents reported starting breeding cows with BS from the third breeding on. The region of California, contract with a calf ranch, and the herd breed explained 76.7% of the observed variation in the day-old dairy beef crossbred calf price. Survey results demonstrated the main breeding strategies adopted by dairy farmers. The objectives of the second study were, to evaluate the economic feasibility of using beef in vitro produced embryo transfer (IVP-ET) in Jersey herds, and to evaluate the economic feasibility of retaining the ownership of Jersey-beef crossbred calves and pure-beef calves. A Markov chain model was developed to evaluate different scenarios of using BS and IVP-ET. We varied the IVP-ET cost (\$85 or \$170), the pure beef calf price (\$200 or \$300), and by marketing Jersey-beef and pure beef animals with one-day-old or raising them to 180 kg. A total of 8 scenarios were simulated. When the beef IVP-ET cost was \$170 (scenario 4), the lowest profit (\$62.1/lactating cow per year) was achieved. The highest profit was achieved for the scenario 6 raising the Jersey-beef crossbreds (\$273.6). The adoption of beef IVP-ET in a reproductive program has the potential to increase herd profitability and raising the Jersey-beef crossbred calves may be a profitable strategy. The third study aimed to describe the association of failure of transfer of passive immunity (TPI) with morbidity, mortality, and ADG in dairy-beef crossbred calves. A total of 1058 dairy-beef crossbred calves were enrolled upon arrival at a calf-raising facility in California from January to August 2021. Blood was collected at 24 h post-arrival to evaluate serum IgG concentration, serum total protein. Morbidity and mortality information were recorded until 60d of life. Calves' breeds were Holstein × Beef (49.5%), Jersey × Beef (50.6%). Prevalence of failure of TPI was 14.7% (n = 155). Overall morbidity and mortality were 84.9%

(n = 898) and 2.6% (n =27). Animals with IgG  $\geq$ 25.0 g/L had a lower percentage of morbidity. IgG levels <10.0 g/L were associated with decreased ADG by 0.12 kg/d.

Keywords: Beef on dairy, beef semen, dairy-beef crossbred calves, reproductive strategies, transfer of passive immunity.

## RESUMO

PEREIRA, Jéssica Marcela Vieira, D.Sc., Universidade Federal de Vicosa, Março, 2022. **Uso de sêmen de gado de corte em vacas leiteiras: Estratégias de uso, avaliação econômica do uso de embrião de corte em vacas Jersey e associação de transferência de imunidade passiva com morbidade e mortalidade de bezerros cruzados leite x corte.** Orientador: Marcos Inacio Marcondes. Co-orientador: Fernanda Carolina Ferreira.

Esta tese foi desenvolvida a partir de três estudos. Os objetivos do primeiro estudo foram descrever as práticas de manejo do uso de sêmen bovino por fazendas leiteiras na Califórnia, e comparar essas práticas entre as regiões do estado, rebanho e raças. Em janeiro de 2020, um questionário sobre uso de sêmen de gado de corte foi enviado produtores de leite na Califórnia. O questionário consistia de: informações do rebanho (n = 10), manejo do sêmen de gado de corte (n = 17) e manejo de sêmen leiteiro sexado (n = 6). A maioria dos laticínios (81%) relatou o uso de sêmen de gado de corte em vacas leiteiras. O sêmen Angus foi o mais utilizado (89% dos entrevistados). O desempenho reprodutivo foi um critério para selecionar as vacas para receber o sêmen de corte. A região do estado da Califórnia, contrato com recriador de bezerros, e raça do rebanho explicaram 76,7% da variação no preço do bezerro mestiço. Os resultados da pesquisa demonstraram as principais estratégias adotadas pelos produtores de leite. Os objetivos do nosso segundo estudo foram avaliar a viabilidade econômica do uso de embrião de corte em rebanhos Jersey, e a viabilidade econômica de recriar os bezerros cruzados com Jersey e bezerros puros de corte por criadores de Jersey. Um modelo Markov chain foi desenvolvido para avaliar cenários utilizando sêmen de corte e transferência de embriões produzidos in vitro (PIV-ET). Variamos o custo do IVP-ET (US\$ 85; US\$ 170), o preço do bezerro de corte puro (US\$ 200 ;US\$ 300) e a venda de animais Jersey-beef e de carne pura com um dia de idade ou com 180 kg. Oito cenários foram simulados. O custo do IVP-ET da carne bovina foi de US\$ 170 (cenário 4), o menor lucro (US\$ 62,1/vaca lactante por ano). O maior lucro foi alcançado para o cenário que recriou os Jersey x Cross até 180 kg (US\$ 273,6). A adoção de IVP-ET de corte em um programa reprodutivo tem o potencial de aumentar a rentabilidade do rebanho. Nosso terceiro estudo teve como objetivo descrever a associação de transferência de imunidade passiva (TIP) com morbidade, mortalidade e GMD em bezerros mestiços de corte até 60 dias de idade. Um total de 1055 bezerros mestiços de corte leiteiro foram inscritos na chegada a uma instalação de criação de bezerros na Califórnia de janeiro a agosto de 2021. O sangue foi coletado  $24 \pm 1$  h para avaliar a concentração sérica de IgG, e proteína total sérica (STP). As raças dos bezerros eram Holandês x Cross (49,5%), e Jersey x Cross (50,6 %). A prevalência de falha de TIP foi de 14,7% (n = 155). A morbidade foi de

84,9% (n = 898). A mortalidade foi de 2,6%. Animais com IgG  $\geq$  25,0 g/L apresentaram menor percentual de morbidade. Níveis de IgG <10,0 g/L foram associados a uma redução do GMD em 0,12 kg/d. Nossos resultados demonstraram a importância de altos níveis de IgG para reduzir a morbidade e mortalidade em mestiços de corte leiteiro.

Palavras-chave: Semen de corte em vacas de leite, semen de corte, estratégias reprodutivas, transferência de imunidade passiva.

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## GENERAL INTRODUCTION

Beef semen use on dairy cows has been used as a reproductive strategy on dairy farms, in recent years to increase farm profitability (Li and Cabrera, 2019; Geiger, 2019). The main drivers to bred beef on dairy include (1) the increase in the use of female sexed semen since 2009 (Hutchison and Bickart, 2016), (2) an excess supply of replacements in dairy herds, (3) low price of surplus heifers, (4) the high cost to raise a purebred dairy calf up to 24 months (Overton and Dhuyvetter, 2020), (5) the low market price of dairy bull calves (Farmers Livestock Market – Oakdale, CA) and (6) years of depressed milk prices (USDA - NASS). Hence, dairy-beef crossbred calves may be an option to improve profitability on commercial dairy farmers and an option to adjust heifer inventory.

The high premium paid for dairy-beef crossbred calves compared with purebred dairy calves appeared as an economic opportunity for dairies (De Vries, 2020). Li and Cabrera (2019) showed that herds can improve their income using beef semen on dairies with a good reproductive performance, because they have better opportunities to combine beef with sexed semen, and, at the genetic level, breeding sexed semen in heifers or/and in cows genetically superior and beef semen on and dairy cows genetically inferior (Ettema et al., 2017). Furthermore, controlling heifer inventory reduces the environmental footprint of dairy production, reducing methane and phosphorous emissions (Hristov et al., 2013; Vellinga and de Vries, 2018).

This new strategy is particularly relevant for California dairy producers that represent almost 18% of all cattle and 18.5% of the milk production in the United States, (CDFA, 2017). The acknowledgment of what dairies have adopted on breeding decisions it is important to understand this new strategy, and to help producers on managements decisions such as culling rate,

reproductive performance and selling of surplus animals, which might help them to find the best alternative to maximize farm profit (Li and Cabrera, 2020).

Additionally, for Jersey herds marketing Jersey-beef crossbred is an excellent opportunity to increase calf sales revenue since Jersey heifer and male calves have little or no commercial value. In addition, factors such as high costs of raising heifers and low pregnant heifer market prices justify the use of beef semen or *in vitro* produced embryo transfer (IVP-ET) as a strategy to improve Jersey herd profit. An extra alternative that may improve dairy profitability is to keep the ownership of those dairy-beef crossbred and pure-beef animals until a certain weight to market them to a feedlot or slaughter (Basham, 2020). One of the critical points to adopting the beef semen and IVP-ET is to warranty the surplus heifers necessary to your future milk herd, considering the breeding technologies adopted (Pahmeyer and Britz, 2020). Besides that, the farmer should closely follow the market price for those dairy-beef crossbred calves intended for the beef chain (Li and Cabrera et al., 2019), and produce a high quality calve to be marketed. Important factors to be considered are the first care after birth, such as colostrum feeding and navel disinfection.

Colostrum management is an important factor in reducing morbidity and mortality risk. Newborn calves received passive immunity after birth due to the absorption of IgG from colostrum. Measuring the serum IgG levels of a calf at 24 and 48 hours after birth is a practice used to know if the animal received colostrum feeding to avoid failure of transfer of passive immunity (TPI, Godden et al., 2019). Animals are categorized as having failure of TPI when their serum IgG levels are < 10.0 g/L. Male dairy calves sold to the beef supply chain often receive a lower volume of colostrum and at a later time after birth, since the management preference in a dairy farm is destined for the replacement heifers (Shivley et al., 2019; Creutzinger et al., 2021). Hence dairy-beef crossbred calves may not receive the ideal colostrum to achieve the minimum IgG concentration

to avoid FTPI, and better colostrum feeding practices are needed for non-replacement calves. However, to our knowledge, no large-scale study focusing on failure of TPI for dairy-beef crossbred calves evaluating its association with morbidity, mortality, and ADG during the preweaning phase was performed.

The objectives of this thesis were 1) to describe dairy management practices towards the use of beef semen by surveying farmers in California, the largest U.S. dairy producer; 2) to evaluate breed strategies combining dairy conventional semen, sexed semen, beef semen, and beef IVP-ET on herd dynamics and profitability by marketing those animals with one-day-old or raising them to 180 kg; and lastly 3) to evaluate the association of morbidity, mortality, and average daily gain (ADG) with TPI in dairy-beef crossbred calves raised to 60 days of life by breed and sex.

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## CHAPTER 1

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### **USE OF BEEF SEMEN ON DAIRY FARMS: A CROSS-SECTIONAL STUDY ON FARMER'S ATTITUDES TOWARDS BREEDING STRATEGIES**

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## ABSTRACT

The use of beef semen on dairy cows has been increasing steadily since 2017. We aimed to describe dairy management practices towards the use of beef semen by surveying farmers in California, the largest U.S. dairy producer. In January 2020, we mailed a printed version of the beef semen use survey to 1,017 dairy producers in California, who also had the option to answer the survey online. The questionnaire consisted of 33 questions that were categorized into three sections: general herd information (n = 10), beef semen management (n = 17), and sexed dairy semen management (n = 6). The response rate was 13.9% (n = 141). Regression models were used to evaluate the associations between the dairy-beef crossbred sale price, use of beef semen, and use of sexed dairy semen versus herd characteristics. The mean  $\pm$  standard deviation herd size was  $1,693 \pm 1,311$  milking cows. Most dairies (81%) reported using beef semen on dairy cows. Among respondents, 78% reported extra profit as the main advantage of using beef semen, followed by control of heifer inventory (69%), genetic improvement (37%), and other factors (8%). Most respondents (58%) started using beef semen in the past three years, and 34% of the respondents were breeding more than 30% of all eligible cows with beef semen. Angus semen was the most used (reported by 89% of the respondents), followed by Limousin (12%), Wagyu (10%), Charolais (7%), others (5%, Limflex, Stabilizer, and Hereford), and Simmental (4%). Reproductive performance was an important criterion to select cows to receive beef semen, and 45% of the respondents reported starting breeding cows with beef semen from the third breeding on, 18% on the fourth, and 21% on the fifth or greater breedings. The region of California (a proxy for type of production system), contract with a calf ranch, and the herd breed explained 76.7% of the observed variation in the day-old dairy beef crossbred calf price. Survey results

demonstrated the widespread use of beef semen in dairies and the main breeding strategies adopted by dairy farmers.

**Key words:** beef on dairy, beef semen, sexed dairy semen, reproductive strategy, dairy-beef crossbred calves

## INTRODUCTION

In recent years, dairy producers have increased their interest in using beef semen on dairy cows as a strategy to increase farm profitability and manage heifer inventory (Geiger, 2019; Li and Cabrera, 2019a). The sales of beef semen in the U.S. increased from 2.54 million doses in 2017 to 7.20 million doses in 2020, proportionally to the reduction of dairy semen sales from 23.2 million doses in 2017 to 18.3 million doses in 2020 (NAAB, 2021). This increase is associated with the use of beef semen on dairy cows (McWhorter et al., 2020). Even though this strategy is not new, dairy farmers are taking advantage of the advancements in technology in reproduction and genetics to maximize their incomes. For instance, drivers of this management include a positive trend in the reproductive performance of dairy herds (Berry et al., 2014), the increased use of sexed dairy semen since 2009 (Bickhart and Hutchison, 2016), excess supply of replacements in dairy herds, high costs to raise a purebred dairy heifer up to 24 months of age (Overton and Dhuyvetter, 2020), the increased value of dairy-beef crossbred offspring when compared to the traditional male calf, the low market price of surplus heifers (Farmers Livestock Market, 2021), and years of depressed milk prices (USDA, 2020).

Dairy-beef crossbred calf prices have a higher market value, with reports from \$125 to \$254/head (Reynold Livestock Market, 2021) compared to prices from \$15/head to \$150/head for Holstein bull calves (Farmers Livestock Market, 2021). The premium paid for dairy-beef crossbred calves over the market price of purebred dairy calves is an economic opportunity for dairies as it can represent a new profit center (Basham, 2020; De Vries, 2020). If sold at one day of age, dairy-beef crossbred calves increase the herd income over semen cost, especially if contracts with calf ranches are made (Li and Cabrera, 2019a). Other marketing channels include marketing 400-pound feeders and retaining ownership through harvest (Basham, 2020).

Additional positive outcomes of the use of beef semen on dairy herds are possible if calving ease and beef bull fertility are considered (Morrell et al., 2018; McWhorter et al., 2020). Dairies with favorable reproductive performance (e.g., 30% pregnancy rate versus 15% pregnancy rate for poor performance, Li and Cabrera, 2019a) have more opportunities to combine the use of sexed dairy semen, beef semen, and other strategies such as embryo transfer. For instance, farmers can breed heifers and genetically superior cows with sexed dairy semen while using beef semen in genetically inferior cows (Ettema et al., 2017). Furthermore, controlling heifer inventory is an important economic opportunity for dairy farmers (Overton and Dhuyvetter, 2020), and it presents additional benefits, such as the reduction of the environmental footprint of dairy production through the reduction of methane and phosphorus emissions (Hristov et al., 2013; Vellinga and de Vries, 2018).

Documenting current breeding decisions adopted by dairy farmers is important to evaluate the impacts of the use of technology in reproduction and genetics, as well as to understand their perceptions and attitudes towards available breeding strategies. It is also useful to identify management opportunities that would maximize the economic return of the reproductive strategy adopted. This information is important to guide research and extension activities that help farmers to maximize their dairy operations' economic returns by adjusting management decisions such as breeding strategies, heifer inventory, culling, and reproductive performance (Li and Cabrera, 2019b). Additionally, specific needs of the beef industry such as feed intake and conversion, weight gain, carcass yield, and quality are important aspects and must be considered by the dairy farmer to support a better premium price for the dairy-beef crossbred animals to guarantee the sustainability of this market (Berry, 2021; Felix, 2021).

Even though the use of beef semen by dairy herds is growing across the U.S. (Felix, 2021), it is particularly relevant for California dairy producers who represent approximately 18.5% of all cattle produced and 19% of the milk production in the U.S. (CDFA, 2020; USDA, 2021). Therefore, the objectives of this cross-sectional study were to describe the current management practices on the use of beef semen by dairy farms, using the California dairy industry as a model, and comparing these practices among regions of the state by herd size and breeds. Additionally, we aimed to determine the associations between herd characteristics and the use of beef and sexed dairy semen and the price of day-old dairy-beef crossbred calves. Our hypothesis was that herd size, region of the state, and use of sexed dairy semen are associated with the use of beef semen.

## **MATERIAL AND METHODS**

### **Study Design**

For the designed cross-sectional study, a questionnaire (Supplementary File 1) was created to obtain data on the use of beef semen by dairy herds. The state of California was chosen due to its importance for the U.S. dairy industry and the variety of production systems according to the regions of the state. The questionnaire was reviewed and approved by the University of California, Davis Institutional Review Board (IRB ID: 1510095-1). The survey was evaluated by three dairy producers for feedback on each question's content and organization. The questionnaire contained 33 questions and was categorized into three sections: general herd information, beef semen management, and sexed dairy semen management. Question format ranged from a single choice of multiple options, multiple choices of multiple options, and fill in the blank when the choice "other" was selected (a blank space was added to be filled by the respondent).

A complete list of California dairy producers was obtained from the California Department of Food and Agriculture in January 2020 (n = 1,256). Duplicate addresses (n = 231) were excluded from the list. Online and paper versions of the survey were created using Qualtrics (Qualtrics Research Suite, Provo, UT). First, a postcard was sent by mail to all dairy producers on our list on January 17, 2020 (n = 1,025). The postcard contained information about the research project and survey, and instructions on accessing the online version of the questionnaire. Eight postcards were returned due to an incorrect address. One week later, we mailed all 1,017 dairy farmers a double-sided, 2-page survey and an introductory letter with the study's goals, researchers involved, the confidentiality of responses, and the method to return answers using a prepaid envelope. The first 100 respondents were rewarded with a \$10 gift card. In March, a follow-up reminder postcard was sent to dairies that did not respond. Responses were received until May 30, 2020.

Responses were categorized by herd breed as pure Holstein (HO), pure Jersey (JE), and others (OT), which included mixed breeds and/or crossbred cows, and by herd size (<500, 501 to 1,500, and >1,500 lactating dairy cows). Responses were compared across three regions as described in Love et al. (2016): northern California (NCA), northern San Joaquin Valley (NSJV), and greater Southern California (GSCA; Figure 1), to determine whether differences in the use of beef-on-dairy across the state existed as these regions host different production systems. This comparison is also important because herd size and management differences across these regions exist (Love et al., 2016). The number of respondents per question varied because the respondents were given the option to answer or skip questions. Questions without an answer or with an unclear response were not included in the data analyses. All data received were recorded in a Microsoft Excel spreadsheet (Microsoft, Redmond, WA) and later were

exported into a single file into SAS 9.4 (SAS Institute Inc., Cary, NC). The error survey rate was calculated using the Survey Random Sample Calculator (Custom Insight Inc., 2010) to obtain the accuracy of our data; an error survey rate between 4% and 8% was deemed acceptable (Pollfish, 2021).

## **Statistical Analysis**

Descriptive statistics were performed with the MEANS and FREQ procedures of SAS 9.4. The price received for the crossbred calf was a continuous variable; therefore, factors associated with it were determined using a general linear model in PROC GLM (SAS Institute Inc.). The factors considered were herd breed (HO, JE, and OT), region of the state (NCA, NSJV, and GSCA), herd size (<500, 501 to 1500, and >1500 lactating dairy cows), average milk production (kg/cow per day), whether the farmer raised the dairy-beef crossbred calves (yes, no, or both, meaning raised some and sold some), whether a contract with a calf ranch existed (yes or no), duration of time using beef semen (less than one year, between one and three years, between four and six years, and more than six years), percentage of cows bred with beef semen (less than 10%, between 11% and 20%, between 21% and 30%, and more than 30%), and the use of sexed dairy semen (yes or no). Interactions up to the third order were tested. Significance was considered at  $P < 0.05$ , and tendency at  $0.05 < P < 0.10$ .

The use of beef semen and the use of sexed dairy semen (yes or no) were analyzed by logistic regression using PROC LOGISTIC (SAS 9.4). For the use of beef semen (response variable), predictor variables were sexed dairy semen use (yes or no), region (NCA, NSJV, and GSCA), herd size (<500, 501 to 1500, and >1500 lactating dairy cows), and herd breed (HO and OT; JE herds were not included as all Jersey respondents were using beef semen). For the use

of sexed dairy semen (response variable), predictor variables were beef semen use (yes or no), region (NCA, NSJV, and GSCA), herd size (<500, 501 to 1500, and >1500 lactating dairy cows), and herd breed (HO and OT). Two-way interactions were tested but not kept in the model as they were not significant.

## RESULTS

### General Description of Respondents

A total of 141 responses (13.9%) from 21 counties in California were returned. Four respondents sold their operations; thus, the total number of surveys analyzed was 137, representing 10.3% of all California dairies in 2019 (CDFA, 2020). The number of respondents per region of California was proportional to the distribution of surveys mailed. Of the total surveys mailed, 17.9% were sent to dairies in NCA, and 15.9% of the respondents were from this region. Likewise, 40.1% and 42.0% of the surveys were mailed to NSJV and GSCA regions, and 43.6% and 40.5% of the respondents were from these regions, respectively. The sum of lactating cows from the respondents was 206,496, representing 11.9% of the total number of lactating cows in California in 2019 (CDFA, 2020). Of all respondents, 23 (16.8%) responded to the survey online. Overall, the error survey rate was 7.7%, with a 95% confidence level (Custom Insight Inc., 2010). The survey response was 65.0% by owners (n = 89), 13.1% by managers (n = 18), and 1.5% by partners (n = 2). Twenty-eight (20.4%) of respondents did not indicate their job title.

Herd characteristics according to the region of the state are summarized in Table 1. Herd size ranged from 105 to 5,500 cows, and the mean  $\pm$  SD was 1,693  $\pm$  1,311 lactating cows. Of the respondents, 18.8% had less than 500 cows (n = 23), 32.8% had between 501 and 1,500 cows

(n = 44), and 48.4% had greater than 1,500 lactating cows (n = 55). Milk production (kg/cow per day) averaged 35.2 kg and ranged from 18.1 kg to 45.3 kg. For all data regardless of region, pure Holstein was the herd breed with the greatest number of responses (72.4%, n = 89), followed by other breeds (18.7%, n = 23), and pure Jersey breed (8.9%, n = 11). Most respondents were in the NSJV, followed by GSCA, and the fewest respondents were in the NCA. The NCA had the smallest average herd size and lowest milk production per cow.

### **Beef and Sexed Dairy Semen Practices**

Eighty-one percent of respondents were using beef semen on dairy cows (n = 103). Among those herds, two were using beef embryos (1.6%), and one was breeding with male-sexed beef semen (0.8%). Extra profit (78.1%, n = 75), controlling heifer inventory (69.8%, n = 67), genetic improvement (37.5%, n = 36), and other factors such as improved conception rate and reproduction (8.3%, n = 8), were the factors reported as the main advantages of using beef semen; furthermore, 54.6% of the respondents (n = 53) reported both extra profit and control of heifer inventory as the main advantages of using beef semen on their dairy cows. Among producers who were not using beef semen (n = 25), twenty-one were Holstein herds (84%) and four were herds classified as other breeds (16%). All Jersey herds were using beef semen to breed their dairy cows. From those herds that were not using beef semen, 41.7% of Holstein herds were from NSJV (n = 10), 20.8% were from NCA (n = 5) and from GSCA (n = 5), and 8.3% of the other herds were from NCA (n = 2) and GSCA (n = 2).

Overall, 14% of respondents have been using beef semen for less than one year (n = 14), a higher percentage of 58% were using from 1 to 3 years (n = 58), 20% were using from 4 to 6 years (n = 20), and a small percentage were using it for more than six years (8.0% n = 8). Approximately twenty-six percent (n = 26) of the respondents were using beef semen in less

than 10% of their herd (nulliparous and multiparous cows), 21% (n = 21) were breeding between 11% and 20% of, 19% (n = 19) were using beef semen in 21% to 30%, and 34% (n = 34) were using beef semen in more than 30% of all cows. The percentage of dairies raising their own dairy-beef crossbred calves was 19.4% (n = 19), and among those, 57.9% (n = 11) were both selling one- day-old and raising dairy-beef crossbred calves. The majority of the respondents (82.7%, n = 81) reported a cost of less than \$10 per straw of beef semen, and 17.3% had a cost between \$10 to \$15.

A summary of beef semen practices of all respondents by California region are presented in Table 2. Most respondents breeding more than 30% of their cows with beef semen were from GSCA, followed by NSJV then NCA. Figure 2 shows the most common beef breeds used by dairy farmers in California in 2020 for inseminating their cows. More than 90% of pure Holstein herds were breeding with Angus semen, followed by Wagyu and Charolais at less than 10%. Pure Jersey herds mostly used Angus and Limousin semen. Other California dairy herds also were breeding mostly with Angus and a smaller percentage of Limousin semen. Overall Angus semen was the most common single breed of beef semen used, followed by Limousin, Wagyu, Charolais, others (Limflex, Stabilizer, and Hereford), and Simmental. The proportion of respondents using more than one beef breed for inseminating their cows was the greatest for Jersey herds (80%, n = 8). Pure Holstein (81.7%, n = 58) and other herds (66.7%, n = 10) predominantly used one beef breed. Eighty-six percent of the respondents using beef semen also reported the use of sexed dairy semen (n = 84).

The logistic regression model results for the associations between herd characteristics and beef and sexed dairy semen use are summarized in Table 3. Region of the state tended (P = 0.061) to be associated with the use of beef semen where compared with the NSJV, herds in the

NCA had lesser odds of using beef semen (odds ratio [OR]: 0.139, CI: 0.025-0.776). No difference was observed between GSCA and NSJV (OR: 1.077, CI: 0.289-4.016). A tendency (P = 0.067) was also observed for the association between herd size and the use of beef semen, where herds with a number of lactating cows between 501-1,500 had lower odds of using beef semen when compared to herds with < 500 lactating cows (OR: 0.166, CI: 0.027-1.002). Herd breed was not associated with the use of beef (P = 0.446) or sexed dairy semen (P = 0.857). Farmers who use beef semen had greater odds of using sexed dairy semen (OR: 6.912, CI: 2.054-23.262), and herds with 501-1,500 lactating cows and more than 1,500 lactating cows had 5.233 and 8.597 greater odds of using sexed dairy semen than dairies with < 500 lactating cows (OR: 5.233, CI: 1.181-23.177 and OR: 8.597, CI: 1.734-42.612), respectively.

### **Cow Selection Criteria**

Criteria for selecting cows for breeding with sexed semen and beef semen are summarized in Figures 3a and 3b, respectively. Overall, lactation number (n = 46), reproductive performance (n = 37), genomic testing (n = 34), and milk production (n = 31) were the main factors producers used to select cows to breed with sexed dairy semen (Figure 3a). Sexed dairy semen was mostly being used in heifers (94.1%, n = 79) and first lactation cows (69.1%, n = 58). Based on reproductive performance, 26.4% (n = 19) of producers were breeding sexed dairy semen on their cows on first breeding, 62.5% (n = 45) on first and second breedings, 6.9% (n = 5) on first, second, and third breedings, 2.8% (n = 2) from the first to fourth breedings, and 1.39% (n = 1) were using sexed dairy semen from first to fifth breedings or more.

Sixty percent of the producers (n = 60) combined more than one criterion for selecting cows to be eligible to receive beef semen. Reproductive performance (n = 74), lactation number (n = 54), and milk production (n = 42) were the most common criteria farmers reported for

selecting cows to breed with beef semen (Figure 3b). Most farmers started using beef semen for breeding cows in their third and greater lactations (51.4%, n = 36), followed by second (37.1%, n = 26) and first (22.9%, n = 16) lactations; and 25.7% (n = 18) of respondents reported starting using beef semen on their heifers. The greatest percentage of farmers (45.0%) reported starting breeding with beef semen on the cow's third breeding, 18.0% on the fourth breeding, and 21.0% from the fifth breeding onward. Overall, preference of the calf ranch (42.3%, n = 41), cost of the beef semen (42.3%, n = 41), and calving ease (21.6%, n = 21) were the main factors driving the selection of the beef semen used, but 24.7% of the respondents (n = 24) were combining more than one factor for beef semen selection. Among respondents, 9.4 % (n = 9) reported issues using beef semen. Fertility (55.6%, n = 5), calf size (22.2%, n = 2), and calving difficulty (22.2%, n = 2) were the main issues described.

### **Dairy-beef Crossbred Calf Price**

The prices received by the respondents for their day-old dairy-beef crossbred calves are shown in Figure 4. Regardless of the herd breed, Angus-dairy crossbred calves had the greatest day-old price variation, from less than \$50/calf to more than \$250/calf. Within Holstein herds, the range of day-old crossbred calf prices was between less than \$50/calf to more than \$250/calf, but the highest prices were obtained when Wagyu and Charolais semen were used (more than \$250). For Jersey herds, the day-old crossbred calf prices were between less than \$50/calf to \$201- \$250/calf. Within Jersey herds, using Charolais semen earned the best market value for the crossbred calf (\$201-\$250).

Region of the state (P = 0.017; 11.8%), contract with a calf ranch (P <0.0001, 31.1%), and the herd breed (P <0.0001, 33.8%) were associated with the price received for the dairy-beef crossbred calf, explaining 76.7% of the observed variation of the day-old crossbred calf price.

The least-square mean prices (SE) for GSCA, NCA, and NSJV, respectively, were \$180.30 (\$8.60), \$136.20 (\$14.50), and \$157.50 (\$7.90). For herd breed, the least-square means (SE) were \$184.40 (\$7.20, pure Holstein herds), \$113.00 (\$13.30, pure Jersey herds), and \$176.60 (\$10.70, other herds). The percentage of dairies that reported contracting with a calf ranch was 41.2% (n = 40). When producers were asked the question “How do you feel the crossbred market will be in the next few years?”, 57.3% of the respondents reported that the dairy-beef crossbred calf price would decrease (n = 55), few believed that the price would increase (5.2%, n = 5), and 27.1% reported that the market would remain the same (n = 26).

## **DISCUSSION**

This cross-sectional study summarizes the practices regarding the use of beef semen on dairy herds adopted by dairy producers and demonstrates factors associated with the day-old dairy-beef crossbred price. The use of beef semen on dairy herds brings flexibility and economic opportunities to dairy farmers through their reproductive management program. This strategy is not new, but has gained momentum due to current market conditions. In California, most producers have started using beef on dairy in the last four years, regardless of herd size or breed, in accordance with the increase in the sales of beef semen in the U.S. (NAAB, 2021). Like California, dairies in other states across the U.S. are using beef semen as well. As reported by AgSource Dairy (2019) using data from 3,200 dairy farms from the eastern U.S., 16% of all cow breedings in 2019 were with beef semen. A survey conducted in Wisconsin, Michigan, and Iowa reported that almost 80% of the respondents used beef genetics on their dairy cows (Halfman and Sterry, 2019), similar to what we reported in this study. Even though our survey was conducted only among California dairy farmers, California holds almost 20% of all dairy cattle

in the U.S. (USDA, 2021). The California dairy industry contributes 19% - 22% to the U.S. beef production (Boetel, 2016), hence the importance of documenting the beef on dairy management practices in the state.

The data presented here are representative of the variety of farms that comprise the California dairy industry. Dairies in the NCA region are characterized by small herds, certified organic producers, and pasture-based herds (Love et al., 2016; CDFA, 2018; Martins et al., 2019), whereas the NSJV concentrates most of the commercial, freestall, and dry lot herds. Herds in the NCA region had lower odds of using beef and sexed dairy semen when compared to herds in the NSJV, regardless of size. Furthermore, the reported day-old dairy-beef crossbred prices received by producers in the NCA were lower than prices received by producers in the NSJV and GSCA. Differences in reproductive performance, milk price, heifer raising, and market conditions for the herds in these regions may explain these differences. Herds using beef semen had greater odds of using sexed dairy semen. This result agrees with the literature as the availability and use of sexed dairy semen allows farmers to obtain the number of heifers needed from a reduced number of breedings (De Vries et al., 2019), giving the producers a greater opportunity to manage their reproductive programs.

In our study, producers reported extra profit as the main perceived advantage for using beef semen on dairy cows. Overall, economic opportunities of using beef on dairy have been highlighted by other studies (Li and Cabrera, 2019a; Ettema et al., 2017). The second most important perceived advantage of using beef on dairy was the control of heifer inventory. Sexed dairy semen use, improvements in reproductive performance, and better heifer management have resulted in an excess number of replacement heifers (Bickhart and Hutchison, 2016; De Vries, 2020). The current cost of raising heifers is estimated to be \$2,016 (Overton and

Dhuyvetter, 2020), but the average market price for California, for instance, for females due to calve is \$1,350 (Farmers Livestock Market – Oakdale, CA, April 2021). Therefore, raising excess replacement heifers under current market conditions may lead to economic losses (Overton and Dhuyvetter, 2020; De Vries, 2020), and increasing culling rates to accommodate excess heifers is not an optimal economic decision (De Vries, 2017). Genetic improvement of the herd was also perceived as an additional advantage of using beef on dairy, and in our study, producers reported the use of genomic selection to select cows to receive sexed dairy and beef semen. This strategy increases the genetic gain, reducing the genetic lag of the herd due to the use of dairy semen on the genetically superior heifers and cows (Ettema et al., 2017; De Vries et al., 2019). However, the use of genomic information may be a less valuable strategy when beef semen is used and the prices of the day-old dairy-beef crossbred calves are high (De Vries, 2019).

The economic advantage of using beef on dairy would depend on herd reproductive performance, the lifespan of cows, costs of the sexed dairy and beef semen (Pahmeyer and Britz, 2020), and market conditions such as heifer and the day-old crossbred calf price (Li and Cabrera, 2019b). For instance, in an economic simulation from Li and Cabrera (2019a), considering an adequate supply of replacement heifers and a premium of \$225/head paid on day-old dairy-beef crossbred calves, income from calves over semen costs would be maximized when sexed dairy semen is used in the first and second breeding of heifers, in the first breeding of first and second lactation cows, and all other breedings are done with beef semen. The reproductive practices reported by producers in our study are aligned with this strategy, as they have mostly used sexed dairy semen in heifers and first breeding of cows, with parity and breeding number being the main criteria used to select which cows would receive each type of semen.

We observed a large variation in the beef semen chosen and, consequently, in the price of the day-old dairy-beef crossbred calf. The herd breed, having a contract with a calf ranch, and the region of California where the farm is located (a proxy for the type of farm) were factors associated with the price received when dairy-beef crossbred calves were sold. The greatest variation observed for Angus crosses may be explained by the widespread use of Angus semen, which is the semen with the highest domestic sales in the U.S. (NAAB, 2021). A greater number of Angus breedings generates data that may lead to the improvement of Angus bulls focused on dairy-beef crossbred performance (McWhorter et al., 2020), reinforcing its widespread use.

For dairy herds, conception rate and calving ease are important features that must be considered when selecting the beef bull to be used, especially due to the use of beef semen on repeated breeders (Cauffman et al., 2019; Halfman and Sterry, 2019). In our study, low conception rates, calf size, and difficult calving were common issues reported by dairy farmers when using beef semen. Besides, the sustainability of the dairy-beef crossbred market also depends on the ability of dairy farmers to provide a high-quality product that would fulfill the beef industry's needs for feed efficiency in the feedlot and carcass characteristics. In our study, most dairy farmers reported choosing beef semen on the basis of the preferences of the calf rancher purchasing the day-old dairy-beef crossbred calf. However, semen cost is a criterion used by only 18% of the dairy producers. Semen cost was reported as the most important aspect for beef semen choice by dairy producers in Iowa, Michigan, and Wisconsin (Halfman and Sterry, 2019). Even though semen cost may influence the income from calves over semen cost (Li and Cabrera, 2019a), it is possible to obtain good reproductive performance on the dairy side and greater results on feed intake and carcass weight and quality on the beef side (Twomey et al., 2020).

In our study, only 19% of respondents were raising their dairy-beef crossbred calves. Knowledge about the beef market and its needs is an opportunity for dairy farmers to increase the premium received for their dairy-beef crossbred calves, especially for Jersey herds that historically have received very low prices for their male calves (Bechtel, 2018). Dairy farmers could capture additional economic opportunities if the ownership of dairy-beef crossbred calves were kept until 180 kg or slaughtered. Basham (2020) reported that retaining ownership of dairy-beef crossbred calves up to 180 kg would be the most profitable strategy for dairy farmers, although higher risk incurs. Therefore, it is important to consider market conditions and plan the need for replacement heifers to obtain a maximum economic return from the use of beef semen on dairy cows, and economic studies evaluating the most profitable management alternative for dairy farmers are warranted.

Lastly, our study may contain biases as dairy producers who do not use beef semen may have been less likely to respond to the survey. Furthermore, important aspects that may determine the opportunity to use beef semen by dairy herds such as reproductive performance of the herd, breeding program, intention to expand the herd, heifer raising system and performance indexes, and type of production system were not captured by our survey. Another important consideration is that some answers were received right at the beginning of the COVID-19 pandemic in the US, affecting dairy and beef markets greatly, and possibly affecting some of the responses obtained. Nonetheless, the information presented here demonstrates the multiplicity of beef on dairy strategies adopted by farmers and highlights the need for further studies on the topic.

The results of our study demonstrated the widespread use of beef semen in dairy herds. Parity and breeding number were the main criteria dairy farmers used to choose which cows to

receive sexed dairy and beef semen. There was high variability in the price received for the day-old, dairy-beef crossbred calf, and having a contract with a calf ranch, Angus crosses, and breed of the dairy herd were associated with the calf price. The beef strategies on dairy practices reported here may not differ from other dairy herds across the US, but herd reproductive performance and market conditions may influence the adopted reproductive strategy.

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**Table 1.** Dairy herd characteristics of all respondents by region of the California beef semen survey.

Item	N <sup>1</sup>	Region		
		NCA <sup>2</sup>	NSJV <sup>3</sup>	GSCA <sup>4</sup>
	126	15.9	43.6	40.5
Average herd size (lactating cows)	119	537	1,498	2,301
Herd size (1st - 3rd quartile)		300-650	675-2,000	1,150-3,500
Average milk production per cow (kg/day $\pm$ SD)	101	26.8 $\pm$ 5.8	37.6 $\pm$ 4.6	36.1 $\pm$ 3.9
Herd breed	120			
Pure Holstein (%)	87	9.2	47.1	43.7
Pure Jersey (%)	10	20	40	40
Others <sup>5</sup> (%)	23	30.4	39.1	30.4

<sup>1</sup>Number of respondents (varied according to the survey question).

<sup>2</sup>Northen California

<sup>3</sup>Northern San Joaquin Valley

<sup>4</sup>Greater Southern California

<sup>5</sup>Indicates herds with crossbred, Jersey, and Holstein cows

**Table 2.** Dairy herd characteristics of all respondents using beef semen by California region.

Item	N1	Percentage by Region		
		NCA <sup>2</sup>	NSJV <sup>3</sup>	GSCA <sup>4</sup>
Number of respondents using beef semen	100	12	44	44
Duration of beef semen use	98			
Less than 1 year	14	7.1	36.0	57.1
1 to 3 years	56	12.5	46.4	41.1
4 to 6 years	20	10.0	50.0	40.0
More than 6 years	8	12.5	25.0	62.5
Percentage of cows in herd bred with beef semen	98			
0 to 10%	25	20.0	40.0	40.0
11 to 20%	21	14.3	42.9	42.9
21 to 30%	18	0.0	55.6	44.4
More than 30%	34	8.8	41.2	50.0
Average price per straw	96			
Less than \$10	80	10.0	40.0	50.0
\$10 to \$15	16	18.8	56.2	25.0
More than \$15	0	0.0	0.0	0.0
Breed of beef semen used	100			
Angus	88	11.1	36.4	41.4
Charolais	7	0.0	42.9	57.1
Limousin	12	33.3	41.7	25.0
Others <sup>5</sup>	5	20.0	80.0	0.0
Simmental	4	0.0	50.0	50.0
Wagyu	10	0.0	40.0	60.0
Multiple <sup>6</sup>	25	16.0	48.0	36.0

<sup>1</sup>Number of respondents

<sup>2</sup>Northern California

<sup>3</sup>Northern San Joaquin Valley

<sup>4</sup>Greater Southern California

<sup>5</sup>Others: Hereford (2), Limflex (2), Stabilizer (1)

<sup>6</sup>Herds that are using more than one beef semen breed

**Table 3.** Estimates and effect measure from a logistic regression model for the association between herd characteristics and the use of beef and sexed dairy semen by California dairies in 2020.

Predictor	Reference category	Estimate	SE	P-value	Odds ratio	95% CI	
						Lower	Upper
<b>Beef semen use</b>							
Sexed dairy semen use				0.001			
Yes	No	1.962	0.63		7.118	2.067	24.513
Region				0.061			
NCA <sup>1</sup>	NSJV <sup>2</sup>	-1.974	0.873		0.139	0.025	0.776
GSCA <sup>3</sup>		0.073	0.657		1.077	0.289	4.016
Herd size				0.067			
501-1500	<= 500	-1.797	0.916		0.166	0.027	1.002
>1500		-0.692	1.02		0.5	0.067	3.719
Herd breed				0.446			
Pure Holstein	Others <sup>4</sup>	-0.554	0.725		0.574	0.138	2.396
<b>Sexed dairy semen use</b>							
Beef semen use				0.001			
Yes	No	1.933	0.61		6.912	2.054	23.262
Region				0.874			
NCA <sup>1</sup>	NSJV <sup>2</sup>	0.12	0.831		1.128	0.221	5.753
GSCA <sup>3</sup>		-0.284	0.655		0.752	0.206	2.749
Herd size				0.022			
501-1500	<= 500	1.655	0.751		5.233	1.181	23.177
>1500		2.151	0.81		8.597	1.734	42.612
Herd breed				0.857			
Holstein	Others <sup>4</sup>	-0.126	0.707		0.881	0.221	3.512

<sup>1</sup>Northern California

<sup>2</sup> Northern San Joaquin Valley

<sup>3</sup>Greater Southern California

<sup>4</sup>Indicates herds with crossbred, Jersey, and Holstein cows

Figure 1. Map of California regions included in the beef semen survey: Northern California (NCA), northern San Joaquin Valley. (NSJV), and greater Southern California (GSCA) (adapted from Love et al., 2016).

Figure 2. Most common beef semen breeds used according to dairy herd breed in California in 2020. An = Angus, Wa = Wagyu, Ch = Charolais, Si= Simmental, Li = Limousin, Ot = Limflex, Stabilizer, and Hereford semen, Others = Indicates herds with crossbred, Jersey, and Holstein cows.

Figure 3. Distribution of dairy herds according to the main factors considered for breeding cows with (A) sexed dairy semen or (B) beef semen in 2020. Respondents had the option to select more than one strategy; thus, percentages do not total to 100%.

Figure 4. Distribution of the day-old dairy-beef crossbred calf sale price according to breeds of dairy cows and beef semen used in California in 2020. An = Angus, Wa = Wagyu, Ch = Charolais, Si= Simmental, Li = Limousin, Ot = Limflex, Stabilizer, and Hereford semen, Others = Indicates herds with crossbred, Jersey, and Holstein cows.

Figure 1.JPEG



Figure 2.TIFF

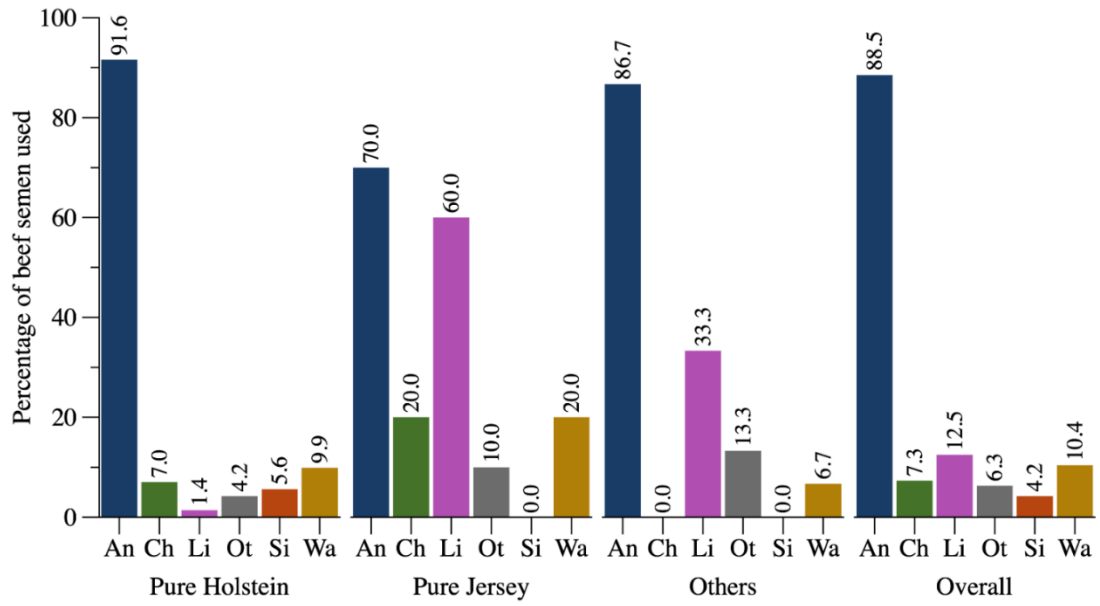


Figure 3.TIFF

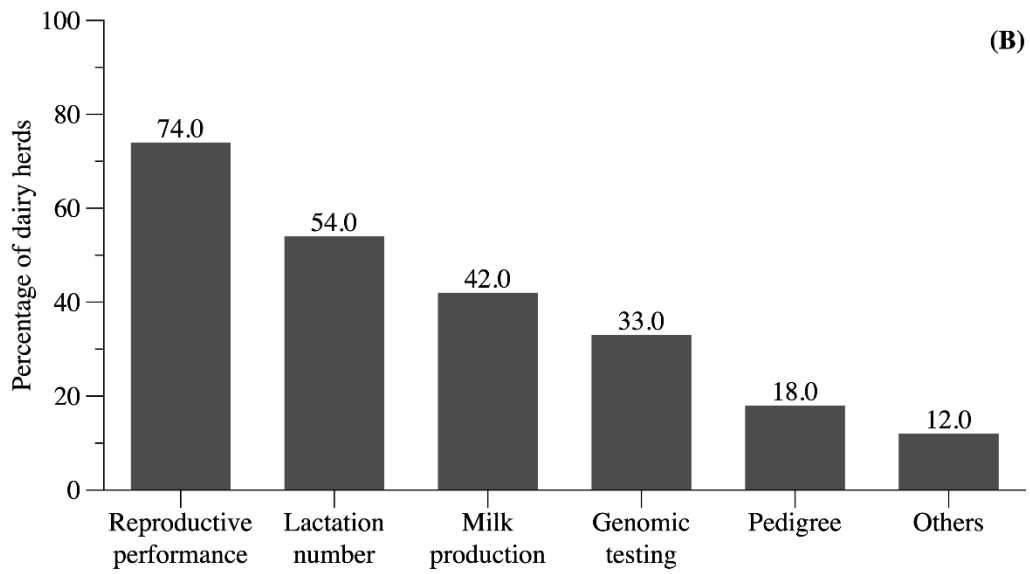
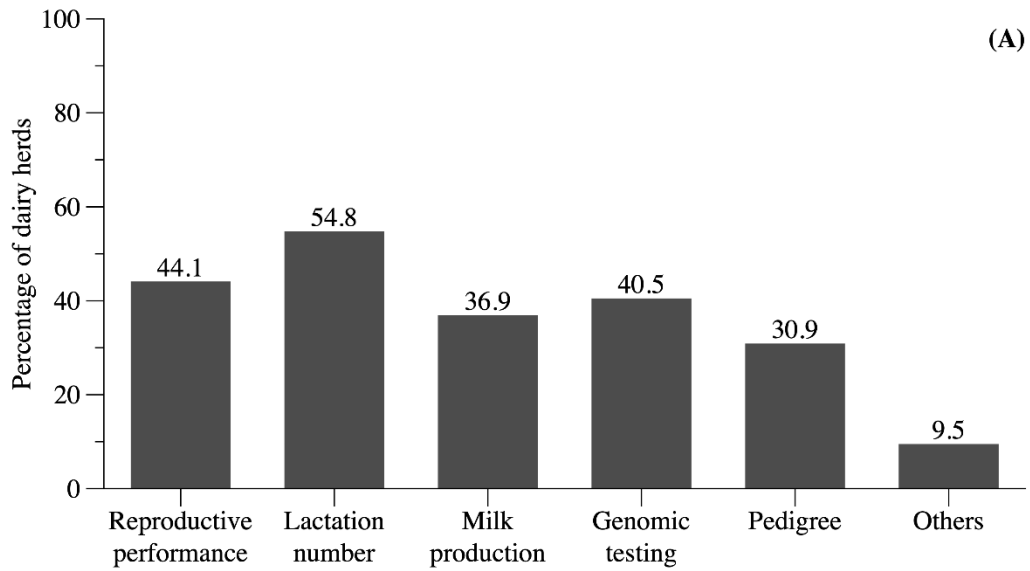
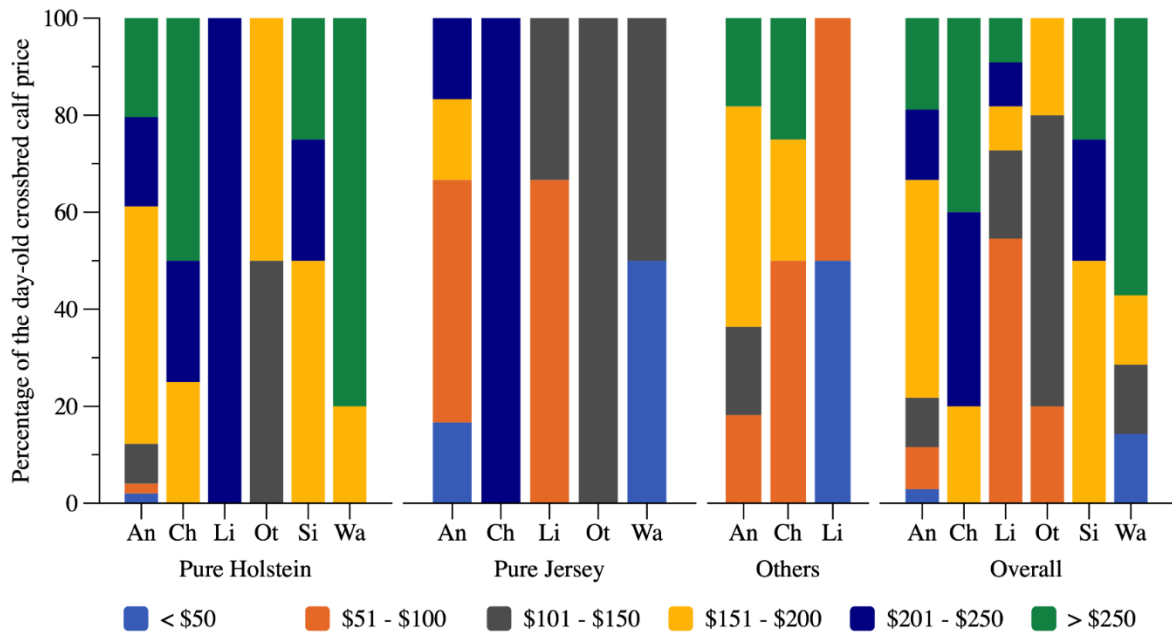


Figure 4.TIFF



## CHAPTER 2

### **ECONOMICS OF USING BEEF SEMEN AND BEEF *IN VITRO* PRODUCED EMBRYO TRANSFER IN JERSEY HERDS**

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## ABSTRACT

The use of sexed semen (SS) and beef semen (BS) has been adopted by dairy herds to control heifer inventory and increase calf sales revenue. Beef *in vitro*-produced embryo transfer (beef IVP-ET) may be an alternative to increase calf sales revenue. Besides, raising those Jersey beef crossbred and/or pure beef animals in a dairy system may be a new source of revenue. We aimed to evaluate breed strategies combining dairy conventional semen (CS), SS, BS, and beef IVP-ET on herd dynamics and profitability by marketing those animals with one-day-old or raising them to 180 kg. A Markov chain model was developed to maximize herd profitability of a Jersey herd by changing the number of dairy heifers sold at birth and the culling rate of the 3<sup>rd</sup> and greater parity cows. The model presents inputs of the reproductive and productive performance over time for heifers and cows. The last year's data (year 10 – steady state) was used to calculate accrual operational cost and revenue per cow per year. We varied the breeding strategy by breeding order and parities, the embryo transfer cost (\$85 or \$170), the pure beef calf market price (\$200 or \$300), and by marketing Jersey-beef and pure beef animals with one-day-old or raising them to 180 kg. A total of 8 scenarios + default scenario were simulated. Overall, the proportion of SS use was  $47.3 \pm 0.6\%$ . For the scenarios replacing all CS breedings with BS breedings,  $52.3 \pm 0.6$  was the proportion of CS and BS used. When beef IVP-ET was used, the percentage of BS and beef IVP-ET used was  $22.4 \pm 0.1\%$  and  $31.0 \pm 0.1\%$ , respectively. We observed that SS:BS scenario compared with the default scenario reduced in 83.5% the production of purebred Jersey male calves and increased profit/milking cow per year from \$133 to \$238.8. When a beef IVP-ET of \$85 per transfer was used (scenario 2 and 3), profit/lactating cow per year was \$170.8 and \$206.8 for a pure-beef calf price of \$200 and \$300, respectively. When the beef IVP-ET cost was \$170 (scenario 4), the lowest profit (\$62.1/lactating cow per year) marketing one-day-old pure-beef calf of \$200. The highest profit was achieved for scenario raising the Jersey-beef crossbred animals to 180 kg (\$273.6, scenario 6), followed by the scenario 7 (\$261.6, SS:BS:IVP-ET) with a embryo transfer cost of \$85. Under the current market conditions, combining SS and BS in the reproductive program was a feasible economic opportunity for Jersey herds. The adoption of beef IVP-ET in a reproductive program has the potential to increase profit/milking cow per year, but its profitability will depend on the beef IVP-ET pregnancy cost, the pure-beef market price, and the herd reproductive performance. Lastly, raising the Jersey-beef crossbred calves may be a profitable

strategy, and dairy producers need to evaluate the best option to invest since it will take an extra risk to produce high-quality animals to market.

Keywords: beef-on-dairy, jersey herds, reproductive strategy, beef in vitro produced embryo transfer, sexed semen, beef semen

## INTRODUCTION

Dairy bull calves' sales represent, on average, between 6 to 8% of Holstein dairy herds' revenue (USDA - ERS, 2021); however, Jersey bull calves have reduced or no commercial value (Bechtel, 2018). As a strategy to produce Jersey bull calves with higher market values, farmers have adopted the use of beef-on-dairy to increase their income due to the better dairy-beef crossbred calves' market price (Li and Cabrera, 2019; Pereira et al., 2022). A survey conducted in California reported that most of the Jersey producers reported the use of beef genetics on their cows (Pereira et al., 2022). Moreover, using beef semen (BS) on multiparous and genetically inferior cows and sexed semen (SS) on the younger animals allows farmers to control for the surplus heifers produced and increase the selection intensity, reducing the genetic gap between generations of the future milking herd (De Vries et al., 2022).

Several studies have reported the economic outcomes of using beef semen on dairy cows (Ettema et al., 2017; Clasen et al., 2021; Li and Cabrera et al., 2019). Cabrera (2021) reported an income over semen cost using SS and BS on medium and higher reproductive performance herds (e.g., between 20% and 30 % of pregnancy rate) of \$2,001 and \$6,215, respectively. Also, De Vries et al. (2022) emphasized the increase in profit/milking cow per year (between \$149 - \$159/milking cow per year) when dairies used beef-on-dairy compared with the use of conventional dairy semen only, with a higher profit for herds with better reproductive performance. For most of those studies, one of the critical points is to warranty the replacement heifers necessary to your future milk herd, considering the breeding technologies adopted (Pahmeyer and Britz, 2020). Besides that, the farmer should closely follow the market price for those dairy-beef crossbred calves intended for the beef chain (Li and Cabrera et al., 2019; Pereira et al., 2021).

Additionally, dairy farmers may adopt the use of beef *in vitro* produced embryos to market a purebred beef calf instead of a dairy-beef crossbred calf. The main reason for this strategy is the greater market value of purebred beef calves, representing increased profit for the dairy farmer (Ferreira et al., 2021). This strategy may be more valuable, especially for Jersey herds, which receive a lower price for their crossbred calves than Holstein herds (Pereira et al., 2021). However, factors such as embryo quality, health status, parity order, and breeding number of the receptors, along with the total cost of the embryo and the transferring process, should be taken into consideration when a beef *in vitro*-produced embryo transfer (beef IVP-ET) program is

implemented (Coyne, 2020; Metzger, 2021). Also, a higher pregnancy loss when frozen embryos are used has been reported (Stewart et al., 2011; Ferreira et al., 2021). Dairy farmers may also improve dairy profitability if the ownership of the dairy-beef crossbred and pure beef calves is retained until a certain weight is kept. These calves could be marketed directly to a feedlot or slaughter in this scenario. Basham (2020) compared which market option was the most profitable considering mainly the feed cost to market those animals; however, a detailed economic analysis considering the total reproductive cost from the dairy side is warranted.

Given what has been reported in the literature, studies evaluating the economic feasibility of using beef IVP-ET in Jersey herds are lacking. Furthermore, an economic analysis of retaining the ownership of dairy-beef crossbred and pure beef calves by Jersey herds has not been reported in the literature. Therefore, our objectives were to 1) evaluate the economic feasibility of using beef IVP-ET in Jersey herds, and 2) evaluate the economic feasibility of retaining the ownership of Jersey-beef crossbred calves and pure-beef calves by Jersey farmers.

## **MATERIALS AND METHODS**

### **Model of the study**

We adapted the discrete Markov chain model to evaluate the impact of different reproductive scenarios on a Jersey herd dynamic and profitability. Briefly, the Markov-chain model was defined by the cow state, and transition probabilities (Giordano et al., 2012), where cow state is defined according to the cow category (e.g., heifer, lactating or non-lactating), and the transition probability. The transition probability is the probability used to change an animal by category for each period of 22-d. The period of 22-d was adopted to correspond to a cow's reproduction cycle and was used to simulate the probabilistic performance of Jersey heifers and cows by cycle. The 22-d period sequence, according to the probabilities, is called flows, and in this study flows depend on the cow state in the 22-d before. Our model was adapted from Ferreira et al. (2021) and had 2,788 states for non-pregnant animals which consisted of 17 periods of 22-d per year multiplied by 41 periods of 22-d per parity (which consisted of periods from heifer category to the pregnant category) multiplied by four parities, and 884 states for pregnant animals which consisted of 17 periods of 22-d per year multiplied by 13 periods of 22-d per pregnancy multiplied by four parities.

The transition probabilities and performances for cows from parity one to three were modeled in the same way, according with the probability of the period sequence. The performance in parities 3 and greater was similar. The model started with 1,000 milking cows, and the transition probabilities were changed following the 22-d period through consecutive parities until cows were culled. Thus, by each period of 22-d, the transition probability of being bred, pregnant, giving birth, lactating, culled, being sick; and also the number of animals born, kept, and sold, milk sales, total operational costs, accrual operational costs, and the net revenue were tabulated.

The model's objective function was used to maximize the annual herd profit by changing two different variables: (1) the percentage of culling for lactating cows on parity 3 and greater, and (2) the number of heifers calves sold at one day old entering the milking herd each 22-d period. The model was subjected to constraints of a maximum of 1,000 milking cows to simulate an established herd with a parlor constraint. We used the nonlinear program solver (GRG nonlinear) to find the optimal annual herd profit under constraints. We assumed no possibility of purchasing or selling heifers at calving; thus, all pregnant heifers entered the cowherd, and all open heifers were automatically sold for beef. Finally, we allowed the model to simulate for 10 years, and the last year's data (sum or average depending on the variable) was computed to compare the scenarios (steady state condition at year 10).

The model was adapted to estimate the requirements for growth and milk production for different categories of a dairy herd according to NRC (2001). The calf's nutritional model was based on an average milk intake of 4 L/day for pre-weaning calves. The starter intake was added as 0.7% of calves' BW to balance energy and protein requirements. After weaning at 66 days of life (3 periods of 22-d), concentrate intake was fixed as 0.5% of the body weight, and the corn silage intake was calculated from the difference between dry matter intake requirements and concentrate intake. Knowing the energy and protein supplied by the forage source, the deficit of energy and protein was met by the proportion of the protein source and energy source of the concentrate composition (only corn meal and soybean meal were used). The mineral was fixed at 5% of the concentrate DM.

For lactating cows, the model followed the same strategy used with growing heifers. The DMI was estimated, concentrate intake was calculated, and the forage intake was based on the difference between DMI value and concentrate intake. For lactating cows, concentrate intake was

not fixed; thus, the authors fitted an equation using literature data and their expertise to estimate concentrate intake using milk yield as the independent variable:

$$\text{Concentrate intake} = 0.88 \times \text{milk yield} / (-0.999 \times (\text{Log}(\text{milk yield}) + 6.2476)).$$

Forage was fed as 60% corn silage and 40% alfalfa silage. The concentrate was composed of corn meal and soybean meal (changeable by the model to fit energy and protein requirements of each category) plus a mix containing 10% citrus pulp, 10% soybean hulls, 20% cottonseed meal, 6% mineral, and 0.5% buffer (% total DMI intake).

The output data of the scenarios were used to calculate the accrual operational cost and the revenue per cow per year. The accrual operational cost was obtained from the total operational cost (feed, medicine, reproduction, breeding detection, and hired labor cost), depreciation and owner withdrawals. The revenue was calculated with the income of milk sales, culling animals, and animals sales.

### **Model description (Inputs, prices, and assumptions)**

The inputs were adopted to simulate a Jersey herd in the state of California. Prices inputs for the diet composition, veterinary costs, hired labor, family labor, and depreciation were based on five years of the United States Department of Agriculture, Economic Research Service (USDA – ERS, 2021) data, from 2016 to 2020.

The milk production model was performed as described in Ferreira et al. (2021). The default peak yields were 27.0, 35.0, and 41.0 kg/milking cow per day, days in milk at peak yield were 110, 80, and 80 days, the monthly decline was 6.0%, 10.0%, and 12.0%, the 305 days of milk yield were 6,494, 8,230 and 9,214 kg/cow, for first, second and third and greater lactating cows respectively. Milk price was calculated using the class III formula based on milk composition (5% of fat, 3.8% of protein, and 14.7% of total solids) for a Jersey cow, and the price used was \$0.44/kg of milk. Dry matter intake for cows and heifers was based on the requirements according to with NRC (2001).

Reproductive rates were estimated for Jersey herds based on the author's expertise, literature, and market rates. Service and conception rates varied according to parity, breeding number, and whether SS, conventional dairy semen (CS), BS, and beef IVP-ET were used. Lastly,

we used the same conception rate model (as a function of temperature-humidity indexes, THI) described by Ferreira et al. (2021), but considering a conception rate 10% higher for Jersey than Holstein (CDCB 2019) and heat electronic detectors improving heat detection rate by 30% (Holman et al., 201; Mayo et al., 2019). We used THI values for California, obtained from the National Oceanic and Atmospheric Administration (NOAA, 2015) data from 2007 to 2013. Heifers were eligible to be bred from 13 to 23 mo of age and cows from 66 days after calving up to 273 days in milk. The percentage of female calves from CS and BS were 48% and for SS were 90% (Stewart et al., 2011; Holden and Butler, 2018).

The cost for artificial insemination for CS and BS was fixed at \$15.0 per breeding (labor and semen straw). For sexed semen, the cost per breeding was \$35.0 (Li and Cabrera, 2019). Calf prices were set at \$10.0/Jersey bull calf, \$20.0/Jersey female calf (reference), and \$110.0/ Jersey-beef crossbred calf (Pereira et al., 2022). The beef IVP-ET proceeding cost and the market price for the pure-beef calf varied between scenarios and explained in the sensitivity analysis topic.

The culling risks for calves and heifers were 3% up to 66 days old and 0.5% per 22-d period from weaning until calving. First, second, and third, and greater parity non-pregnant cows had a culling risk of 1.5, 3.5, and 5.0%, respectively. First, second, third, and greater parity pregnant cows had a culling risk of 0.4, 0.9, and 1.3%, respectively. Cow culled price was set at \$1.1/kg of live weight (Overland Livestock Market, 2021).

### **Sensitivity analysis and scenarios**

Figure 1 describes the strategies evaluated in our economic model. Overall, three main strategies were evaluated: first a default strategy using dairy CS and SS only, the second strategy we used BS and dairy SS, and the third strategy was a combination of BS, dairy SS and Beef IVP-ET use. The description of semen and/or embryo transfer used by parity and breeding order is described in Table 1. The breeding order used was according to Jersey producers' reproductive management reported in a beef semen survey carried out in CA (Pereira et al., 2022).

To evaluate the effect of IVP-ET cost on revenue and profitability, we evaluated two different costs: \$85 or \$170 per IVP-ET. The cost of \$85/IVP-ET was estimated based on the use

of ovaries from slaughterhouse as a source of low-cost oocytes (Ribeiro et al., 2012; Metzger J., 2021). The \$170 cost per IVP-ET was based on a realistic range of cost per breeding for lactating cows (Ribeiro et al., 2012; Ferreira et al., 2021). The market price of the pure-beef calf produced was also varied to evaluate the return of a high value calf compared with the Jersey-beef crossbred calf. In addition to evaluate the economic return on retaining the Jersey-beef crossbred calf and/or the pure beef calf at the farm we included three scenarios marketing these animals with 180 kg. Thus, a total of eight scenarios plus the default scenario were evaluated in our sensitivity analysis (Table 2).

For the scenarios raising the calves up to 180 kg, an ADG 0.8 kg/d and 1.0 kg/d were established for the jersey-beef crossbred calves, and pure-beef animals, respectively; thus, the animals were sold with 190 days or 150 days of life respectively to achieve 180 kg. The market price for the Jersey-beef crossbred and the pure-beef feeder was set at \$620/head and \$784/head, respectively (Overland Livestock Market, 2021; USDA – Livestock Market, 2022). For all scenarios the price for male or female animals from the BS or beef IVP-ET was not varied.

## RESULTS

### **The effect of reproductive strategies on Jersey herd dynamics**

*Marketing one-day-old Jersey-beef calves and pure-beef calves.* Table 3 shows the dairy herd dynamics by reproductive strategy, marketing Jersey-beef and pure-beef calves with one-day-old. Comparing the default scenario with SS:BS (scenario 1) and the SS:BS:IVP-ET (scenarios 2 to 5) the average number of cows (milking + dry cows) had a slight reduction by 0.6% (7 cows) and 0.8% (9 cows) respectively. The proportion of milking on parity 1, 2, and 3 was 37.6%, 29.2%, and 33.2% respectively, and did not change between scenarios. In our scenario 1 (SS:BS) the SS breeding was representing 47.8% of all breedings, and BS breeding 52.3%. Scenarios 2, 3, 4 and 5, (SS:BS:IVP-ET), SS breeding was representing 46.7% , BS breeding 22.4% and IVP-ET 31.0% of all inseminations. Comparing the default scenario with scenario 1 (SS:BS), the number of heifers born and sold was reduced by 33.3% and 70.2% respectively. In addition, we observed a reduction of 83.5% (333 calves) in bull calves' sales for SS:BS scenario marketing the calves with one-day-

old. Thus, the strategy of using BS (scenario 1 SS:BS) reduced by 77.0% the market of non-replacement calves (surplus heifers and dairy bull calves). Moreover, the number of heifers kept, had a reduction of 6.7% (35 replacement heifers) using BS (scenario 1 SS:BS) compared with the default scenario. Overall, the distribution of heifers born, kept, sold and dairy bull calves sold changed in small proportions when the IVP-ET strategy was used (scenario 2 to 5) compared with SS:BS (scenario 1).

*Marketing Jersey-beef calves and pure-beef calves with 180 kg.* Table 4 shows the dairy herd dynamics by scenario, marketing Jersey-beef and pure-beef calves with 180 kg (scenarios 6 to 8). Overall, the herd dynamics between marketing the Jersey-beef and pure-beef with 180 kg compared with the one-day-old market had approximately identical results for the number of milking and dry cows, number of breeding, and calves born, kept, sold per year. A total of  $631 \pm 5$  beef animals (Jersey-beef and pure beef animals) will be raised monthly. This number represents an increase of 1.3 times more animals raised compared with the strategy of marketing one-day-old Jersey-beef and pure-beef calves (scenarios 1 to 5, Table 3).

The culling rate was similar among scenarios (28.8%), and, on average, the DMI cost per day was \$0.19/kg for lactating cows and \$0.13/kg for heifers and dry cows by scenario.

### **The effect of reproductive strategies on Jersey herd economics**

*Marketing one-day-old Jersey-beef calves and pure-beef calves.* Table 5 shows herd economics outputs by scenarios marketing calves with one-day-old. The total operational and the accrual operational cost reduced by \$17.9 and \$27.7/cow per year comparing the default scenario with the SS:BS scenario. Using IFV-ET (scenario 2 to 5) compared with scenario 1 (SS:BS), an increase of 2.5% (\$75.3/cow/year) and 5.6% (\$137.5/cow/year) for the total operational cost was observed when the embryo transfer cost was \$85 and \$170 respectively.

For the BS breeding cost, a reduction from \$25.5 to \$10.5/cow per year was observed comparing scenarios 3, 4, and 5 (SS:BS:IVP-ET), with scenario 1 (SS:BS). Pregnancy costs did not vary between scenarios for SS and BS breeding. The breeding and pregnancy cost/cow per year increased by 50% due to the high price per IVP-ET.

The revenue from culling heifers and cows slightly changed between the default and scenarios 2 - 5; the main difference was the decrease in the heifer and bull dairy calf sales revenue in 70.5 and 83.8%, respectively. Sales of culling heifers and cows and sales of one-day-old bull calves and dairy heifers were kept the same between the SS:BS scenario and IVP -ET scenarios. Jersey-beef calves sales revenue reduced from \$64.5 to \$29.5/cow per year from scenario 1 (BS:SS) to scenario 3 (SS:BS: IVP -ET). When the pure-beef calf was marked with a price of \$200 (scenario 2 and 4) and \$300 (scenario 3 and 5) an increase in the revenue of \$62.2 and \$93.3/cow per year for pure-beef calf sales was observed, respectively. Milk sales revenue between scenarios kept, on average, the same value (~\$3,916.2).

The profit/lactating cow per year for SS:BS scenario resulted in an increase of \$105.8/cow per year compared to the default strategy. The SS:BS scenario had the highest profit/lactating cow per year (\$238.8). Comparing only scenarios using IVP-ET, scenario 3 (\$85/IVP-ET, \$300/pure-beef calf) had the highest profit/lactating cow per year of \$206.8, followed by scenario 2 (\$85/IVP-ET, \$200/pure-beef calf). The lowest profit/milking cow per year was achieved with a cost of \$170/IVP-ET and \$200/head for the pure-beef calve market with one-day-old of \$62.1. Were used a total of 3.6 IVP-ET (scenarios 2 to 5) by pregnancy, and conventional and sexed semen were used 2.9 and 3.0 semen by pregnancy, respectively.

*Marketing Jersey-beef calves and pure-beef calves with 180 kg.* Table 6 shows the dairy herd dynamics by scenario, marketing Jersey-beef and pure-beef calves with 180 kg (Scenarios 6 to 8). Marketing the Jersey-beef and the pure-beef animals up to 180 kg, with an age of 225 and 180 days respectively, increased the total operational cost of heifers overall by \$126/cow per year compared with the heifer total operational cost selling them with one-day-old. Profit/cow per year for scenarios 6 and 7 achieved the highest value compared with scenario 8 and all scenarios marketing the Jersey-beef and the pure-beef animals with one-day-old.

Figure 2 shows the net return of the cost to produce a Jersey-beef crossbred and the pure-beef calf by calf market price of selling with one-day-old or raising at 180 kg by scenarios of using SS:BS and SS:BS:IVP-ET. The economic return considering solely the cost to produce Jersey-beef crossbred calves were positive between scenarios (marketing with one-day-old or raising at to 180 kg). When marketing the Jersey-beef calves and pure-beef calf with one-day-old, the maximum net return was \$67.4/animal (Jersey-beef crossbred marketed). The lowest revenue was achieved

marketing the pure-beef animals with on-day-old (\$170 / transfer; \$200/pure beef calf). Animals marketed with 180 had the highest net return, varying from \$120.0 to \$219.3.

## **DISCUSSION**

Our objectives were to evaluate the economic feasibility of using beef IVP-ET in Jersey herds and retaining the ownership of 180 kg of Jersey-beef crossbred and pure-beef calves. We evaluated the annual herd profit of a Jersey herd by different scenarios using SS, BS, and or IVP-ET. In accordance with other publications in the literature, the most profitable scenarios were observed when a combination of SS and BS was used (Ettema et al., 2017; De Vries et al., 2022). This increase is due to current market conditions in which a premium is being paid for dairy-beef crossbred day-old calves (Pereira et al. 2022), reflecting the actual scenarios of Jersey dairy herds in the USA, with a lower value of Jersey heifer and bull calves.

This study also reported the economics of the use of embryo transfer on dairy cows to produce non-replacement calves. A negative effect of using high embryo transfer costs under the profitability of a Jersey herd was achieved. A positive impact of using IVP-ET (with an embryo transfer cost of \$85/transfer) was achieved when the pure-beef calf was raised and sold with 180 kg. Raising those pure-beef calves increased profit/lactating cows per year by \$90.8 compared with the strategy of selling those animals at one day old for \$200/head (\$85/IVF-ET). In addition, an increase of \$34.8/lactating cow per year of the Jersey-beef crossbred calves marketed with 180 kg profit was achieved.

### **Effects of beef semen use**

The economic impact of using beef semen on dairy cows, as reported by Cabrera (2021) and De Vries (2022), depends on the herd reproductive performance. Therefore, our model was created based on a Jersey herd with good reproductive performance (average pregnancy rate of 31%), capable of achieving positive profit and guaranteeing the number of necessary replacement heifers.

Beef-on-dairy use positively impacted profit/milking cow per year with the constraints and assumptions used in our strategies. Two reasons explained this increase in profitability. First, Jersey male and female calves have a lower market price (Bechtel, 2018); second, the actual better market price for dairy-beef crossbred calves, compared with the pure-dairy breed, allows farmers to minimize market loss of Jersey dairy calves since the beef chain for Jersey males is not consolidated as for Holstein males due to the slower growth rates (Lehmkuhler and Ramos, 2008; Schaefer et al., 2017).

An effect on the herd structure of using BS instead of CS is the control of the excess surplus heifers. In addition to a better overall reproductive performance, Jersey herds use a higher proportion of SS in both cows and heifers (Pereira et al., 2020); thus, a high number of surplus heifers is usually produced. Moreover, raising excess heifers under the actual market is not the optimal decision due to the lower price of replacement heifers compared to the higher raising costs (Overton et al., 2020). However, when we compared the number of heifers sold, a considerable number still remained to be sold (surplus heifers, average of 112 heifers sold by BS and IVP-ET scenarios), suggesting that the number of animals bred with BS could be increased. Our strategies for BS use were based on the results of a beef-on-dairy survey in California (Pereira et al., 2022), thus based on what most farmers are currently doing. The Jersey producers respondents answered that one of the main reasons to use beef-on-dairy cows was to control the number of surplus heifers (Pereira et al., 2022). Additionally, De Vries (2022) reported a positive net return in an economic analysis selling 100% of surplus heifers; thus, optimizing the sales of surplus heifers might be the best strategy. However, this strategy can also be risky, and guaranteeing a certain number of surplus heifers is warrantable to avoid any necessity of buying replacement heifers in case of an increase in the culling rate. The revenue for the SS:CS differed from SS:BS mainly because of the income from the Jersey-beef crossbred calves.

### **Effects of beef embryo use**

The use of reproductive technologies, such as artificial insemination, sex-sorted semen, superovulation, embryo production, genomic testing, and others (Crowe et al., 2021), has the purpose of accelerating genetic gain and also to improve economic return for dairy herds (Ettema

et al., 2017; Clasen et al., 2021). All strategies, including the SS, BS, and IVP-ET (\$85/transfer), improved the farm economic return. In the current market, the use of BS is warranted (De Vries et al., 2022). A low cost of IVP-ET is also warranted (\$85); however, even though lower IVP-ET can be found in the market (\$50), the total cost of transferring may be much higher (Ferreira et al., 2021). In addition, problems associated with embryo transfer such as recipients not synchronizing, and increased pregnancy loss, were not accounted for in this study.

Producers that already implemented the embryo transfer technology as part of the breeding program to generate superior replacement heifers had an excellent opportunity to adopt the IVP-ET as a part of the breeding program. For instance, in farms where embryo transfer is already adopted for dairy animals, adopting IVP-ET may reduce cost/pregnancy for both dairy and beef embryos due to the high number of embryos transferred. Consequently, a reduced embryo transfer cost/breeding can be achieved (Viana et al., 2012; Sanches et al., 2019; Crowe et al., 2021).

The IVP-ET scenarios (scenarios 2-5, 7 and 8) compared with SS:CS scenarios (Scenarios 1 and 6) had lower profit/lactating cow per year, with a reduction varying between 4.4% and 73.9%; the same negative results were observed by other studies that evaluated the pregnancy cost of using embryo transfer (Ribeiro et al., 2012; Ferreira et al., 2021). A difference of \$206.3 and \$510.5 between SS pregnancy cost and IVP-ET pregnancy cost difference was observed with a IVP-ET cost of \$85 and \$170; Ribeiro et al. (2012) found a similar cost difference (\$329) comparing the sexed semen pregnancy cost and the in vitro produced embryo transfer cost.

Despite the IVP-ET pregnancy cost, one of our IVP-ET scenarios (SS:CS:IVP-ET, \$85/transfer) improved profit/lactating cow per year by 10%, compared with the default strategy (using only SS and CS). Producing a higher quality animal can be a source for higher economic returns when dairy herds use IVP-ET. Nonetheless, we should highlight that this offspring should achieve a similar performance of the beef animal from beef dams (e.g., average daily gain, feed conversion) and also similar carcass traits (e.g., carcass weight, conformation). Twomey et al. (2020) reported the management of male calves as a by-product of the dairy industry to the beef chain (dairy-beef or pure dairy animals), and it influences the carcass merit in later life. Additionally, challenges in early life such as the lower colostrum feeding, long distance of transportation, housing system and nutrition (Renaud D., 2021; Lombard et al., 2020) may be stressors that can negatively impact the sustainability of beef-on-dairy animals. Likewise, it is important to keep consistent (monthly) availability of high-quality beef animals (dairy-beef

crossbred or pure-beef) to establish a steady market between the dairy and beef chain. Therefore, despite the growth in beef-on-dairy marketed animals in the past years, the market is still adapting to these new opportunities and these changes should be followed closely.

### **Effects of marketing the Jersey-beef crossbred calf and the pure-beef calf up to 180 kg**

Raising the Jersey-beef crossbred and the pure-beef calves (SS:CS and SS:CS:IVP-ET - \$85/transfer) had a higher positive impact on farm profitability since the cost to produce those animals were lowest than the sales price established, which indicate that these strategies are market price dependent. When the IVP-ET cost of \$170 was used, the net return per calf sold (\$200/pure-beef) reached the lowest value (-\$412.0). This shows that the premium price offered for those dairy-beef crossbred and pure-beef calves needs to be higher than the pregnancy cost to produce one animal, and also the dairy herd needs to have a good reproductive performance to reduce the pregnancy per breeding used.

Regardless of the final profit raising these animals in a dairy system as we evaluated in our model, it is important to highlight that the decision to keep the ownership of those animals up to 180 kg or more needs to be based on the labor and facilities available. Besides that, some dairy producers have raised these animals (also dairy bull, surplus and/or replacement heifers) in a calf ranch and, after a certain age, returned to the dairy farm or sold to a feeder system. This strategy is highly adopted by large dairy farmers with more than 500 milking cows in the West regions of the USA (Schaefer et al., 2017; Machado and Ballou, 2022), thus this might be an alternative for the lack of labor and facilities.

## **CONCLUSIONS**

Considering our constraints and inputs for the actual market prices, Jersey herds can improve profit/milking cow per year using combining SS use to produce the replacement heifers needed, and BS or IVP-ET, to take advantage of the current dairy-beef crossbred calves and pure-beef price. Keeping the ownership up to 180 kg for our assumption showed to be the most profitable

scenario, for the SS:BS and the SS:BS:IVP-ET scenario (\$85/IVP-ET). The profit achieved the lowest values using IVP-ET with a cost of \$170.0/embryo transfer. Results from our economic model evaluating different reproductive strategies suggest that the benefit of IVP-ET depends on the total cost per transfer when used in a herd with a good reproductive performance. Hence, factors such as the herd's reproductive performance, culling rate, semen cost, embryo transfer cost, and the premium paid for those dairy-beef crossbred and pure-beef calf will drive the best strategy adopted by dairy producers.

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Table 1. Summary of the strategies used on a simulated 1,000 Jersey milking cows herd size by parity and breeding number.

Breeding	Animals			
	Heifers	Parity 1	Parity 2	Parity 3+
<i>Default scenario<sup>1</sup></i>				
1st	Sexed	Sexed	Sexed	Conventional
2nd	Sexed	Sexed	Sexed	Conventional
3rd	Sexed	Conventional	Conventional	Conventional
4th	Sexed	Conventional	Conventional	Conventional
5th	Conventional	Conventional	Conventional	Conventional
6th +	Conventional	Conventional	Conventional	Conventional
<i>SS<sup>2</sup>.B<sup>32</sup> strategy</i>				
1st	Sexed	Sexed	Sexed	<b>Beef</b>
2nd	Sexed	Sexed	Sexed	<b>Beef</b>
3rd	Sexed	<b>Beef</b>	<b>Beef</b>	<b>Beef</b>
4th	Sexed	<b>Beef</b>	<b>Beef</b>	<b>Beef</b>
5th	<b>Beef</b>	<b>Beef</b>	<b>Beef</b>	<b>Beef</b>
6th +	<b>Beef</b>	<b>Beef</b>	<b>Beef</b>	<b>Beef</b>
<i>Beef IVP-ET<sup>4</sup> strategy</i>				
1st	Sexed	Sexed	Sexed	<b>Embryo</b>
2nd	Sexed	Sexed	Sexed	<b>Embryo</b>
3rd	Sexed	<b>Embryo</b>	<b>Embryo</b>	Beef
4th	Sexed	<b>Embryo</b>	<b>Embryo</b>	Beef
5th	Beef	Beef	Beef	Beef
6th +	Beef	Beef	Beef	Beef

<sup>1</sup>Default: strategy using conventional dairy and sexed semen for all breedings. <sup>2</sup>SS: Sexed semen; <sup>3</sup>BS: beef semen; <sup>4</sup>IVP-ET: in vitro produced embryo transfer

Table 2. Description of the sensitivity analysis on a 1,000 Jersey lactating cows herd size.

Scenarios	Sexed semen use	Conv. Dairy semen use	Conv. Beef semen use	Beef IVP-ET use	IVP-ET cost	Pure beef one-day-old calf price
Default <sup>1</sup>	yes	yes	no	no	.	.
<i>Marketing with one-day-old<sup>2</sup></i>						
Scenario 1 (SS <sup>3</sup> :BS <sup>4</sup> )	yes	no	yes	no	.	.
Scenario 2 (SS:BS:IVP-ET)	yes	no	yes	yes	\$85	\$200
Scenario 3 (SS:BS: IVP -ET)	yes	no	yes	yes	\$85	\$300
Scenario 4 (SS:BS: IVP -ET)	yes	no	yes	yes	\$170	\$200
Scenario 5 (SS:BS: IVP -ET)	yes	no	yes	yes	\$170	\$300
<i>Marketing with 180 kg</i>						
Scenario 6 (SS:BS)	yes	no	yes	no	.	.
Scenario 7 (SS:BS: IVP-ET)	yes	no	yes	yes	\$85	.
Scenario 8 (SS:BS:IVP-ET)	yes	no	yes	yes	\$170	.

<sup>1</sup>Default: strategy using conventional dairy and sexed semen for all breedings. <sup>2</sup>Jersey-beef crossbred one-day old price was set as \$110/head <sup>3</sup>SS: Sexed semen; <sup>4</sup>BS: beef semen; <sup>5</sup>IVP-ET: *in vitro* produced embryo transfer

Table 3. Summary of the dynamic outputs of Jersey herds by scenarios marketing the Jersey-beef crossbred calf and the pure-beef with one-day-old

Output	Scenarios - Marketing with one-day-old					
	Default Scenario <sup>1</sup>	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
		SS <sup>2</sup> :BS <sup>3</sup>	SS:BS:IVP-ET <sup>4</sup>	SS:BS:IVP-ET	SS:BS:IVP-ET	SS:BS:IVP-ET
IVP-ET cost, \$/transfer	-	-	85	85	170	170
Pure beef one-day old calf price	-	-	200	300	200	300
Average number of cows (lactating + dry), n	1,094	1,087	1,084	1,084	1,084	1,084
Number of lactating cows, n (%)						
Parity 1	346	345	348	348	348	348
Parity 2	264	269	270	270	270	270
Parity 3+	325	312	305	307	307	307
Number of breedings per year						
Conventional dairy semen						
Heifer	98	0	0	0	0	0
Cows	1,900	0	0	0	0	0
Sexed dairy semen						
Heifer	809	789	793	793	793	793
Cows	1,023	1,019	1,022	1,022	1,022	1,022
Conventional beef semen						
Heifer	0	90	90	90	90	90
Cows	0	1,892	779	779	779	779
IVF-ET						
Heifer	0	0	0	0	0	0
Cows	0	0	1,204	1,204	1,204	1,204
Number of animals per year						
Heifers calved	404	396	398	398	398	398
Cows calved	893	906	898	898	898	898
Heifer calves born	897	598	601	601	601	601
Heifer calves kept	521	486	489	489	489	489

Heifer calves sold	376	112	112	112	112	112
Dairy bull calves sold	399	66	67	67	67	67
Dairy -beef crossbred calves sold	0	637	291	291	291	291
Pure-beef calves sold	0	0	337	337	337	337

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<sup>1</sup>Default: strategie using conventional dairy and sexed semen for all breedings. <sup>2</sup>SS: Sexed semen; <sup>3</sup>BS: beef semen; <sup>4</sup>IVP-ET: *in vitro* produced embryo transfer

Table 4. Summary of the dynamic outputs of Jersey herds by scenarios marketing the Jersey-beef crossbred calf and the pure-beef calf at 180 kg.

Output	Scenarios - Marketing at 180 kg		
	Scenario 6	Scenario 7	Scenario 8
	SS <sup>1</sup> :BS <sup>2</sup>	SS:BS:IVP-ET <sup>3</sup>	SS:BS:IVP-ET
IVP-ET cost, \$/transfer	-	85.0	170.0
ADG for the Jersey-beef animal (kg /d )	0.8	0.8	0.8
ADG for the Pure-beef animal (kg /d )	0.0	1.0	1.0
Average number of cows (lactating + dry), n	1,087	1,084	1,086
Number of lactating cows			
Parity 1	346	348	347
Parity 2	269	270	269
Parity 3+	311	306	310
Number of breedings per year			
Conventional dairy semen			
Heifer	0	0	0
Cows	0	0	0
Sexed dairy semen			
Heifer	791	794	789
Cows	1,021	1,023	1019
Conventional beef semen			
Heifer	90	90	90
Cows	1890	778	786
IVP-ET			
Heifer	0	0	0
Cows	0	1,204	1208
Number of animals per year			
Heifers calved	397	399	397
Cows calved	906	897	899
Heifer calves born	600	602	599
Heifer calves kept	487	490	486
Heifer calves sold	112	112	113
Dairy bull calves sold	67	67	67
Dairy -beef crossbred calves sold	636	290	292
Pure-beef calves sold	0	337	338

<sup>1</sup>SS: Sexed semen; <sup>2</sup>BS: beef semen; <sup>3</sup>IVP-ET: *in vitro* produced embryo transfer

Table 5. Summary of the profitability outputs of Jersey herds by scenarios marketing the Jersey-beef crossbred and the pure-beef with one-day-old.

Output	Default Scenario	Scenario1 SS <sup>1</sup> :BS <sup>2</sup>	Scenario2 SS:BS:IVP-ET <sup>3</sup>	Scenario3 SS:BS:IVP-ET	Scenario4 SS:BS:IVP-ET	Scenario5 SS:BS:IVP-ET
IVP-ET cost, \$/transfer	-	-	85.0	85.0	170.0	170.0
Pure beef one-day old calf price	-	-	200.0	300.0	200.0	300.0
Total operational cost, \$/cow per year						
Heifer and dry cows	481.1	466.6	469.3	469.4	469.4	469.4
Lactating cows	2,553.5	2,550.1	2,622.8	2,622.7	2,714.8	2,714.9
Accrual operational cost, \$/cow per year						
Heifer and dry cows	733.6	711.7	715.5	715.7	715.7	715.7
Lactating cows	3,304.6	3,298.9	3,372.3	3,372.2	3,464.4	3,464.4
Conventional dairy breeding cost, \$/cow per year						
Heifer	1.3	0.0	0.0	0.0	0.0	0.0
Cows	26.1	0.0	0.0	0.0	0.0	0.0
Sexed dairy breeding cost, \$/cow per year						
Heifer	25.9	25.4	25.6	25.6	25.6	25.6
Cows	32.8	32.8	32.9	33.0	33.0	33.0
Conventional beef breeding cost, \$/cow per year						
Heifer	0.0	1.2	1.2	1.2	1.2	1.2
Cows	0.0	25.5	10.5	10.5	10.5	10.5
IVP-ET cost, \$/cow per year						
Heifer	0.0	0.0	0.0	0.0	0.0	0.0
Cows	0.0	0.0	92.2	92.2	184.3	184.3
Pregnancy cost, \$/cow per year						
Sexed semen	-	97.6	97.5	97.5	97.4	97.4
Conventional beef semen	0.0	46.7	44.8	44.8	44.8	44.8
IVP-ET	0.0	0.0	303.7	303.7	607.4	607.4
Revenue, \$/cow per year						
Heifer cull sales	50.7	48.3	48.7	48.7	48.7	48.7
Cow cull sales	174.3	172.2	172.8	172.8	172.8	172.8

Heifer dairy calf sales	6.9	2.1	2.1	2.1	2.1	2.1
Bull Dairy calf sales	3.7	0.6	0.6	0.6	0.6	0.6
Jersey-beef crossbred calf sales	0.0	64.5	29.5	29.5	29.5	29.5
Pure-beef calf sales	0.0	0.0	62.2	93.3	62.2	93.3
Milk sales	3,916.2	3,916.1	3,917.5	3,917.2	3,917.2	3,917.3
Profit \$/cow per year	113.5	203.3	145.5	176.2	52.9	84.2
Profit \$/lactating cow per year	133.0	238.8	170.8	206.8	62.1	98.8

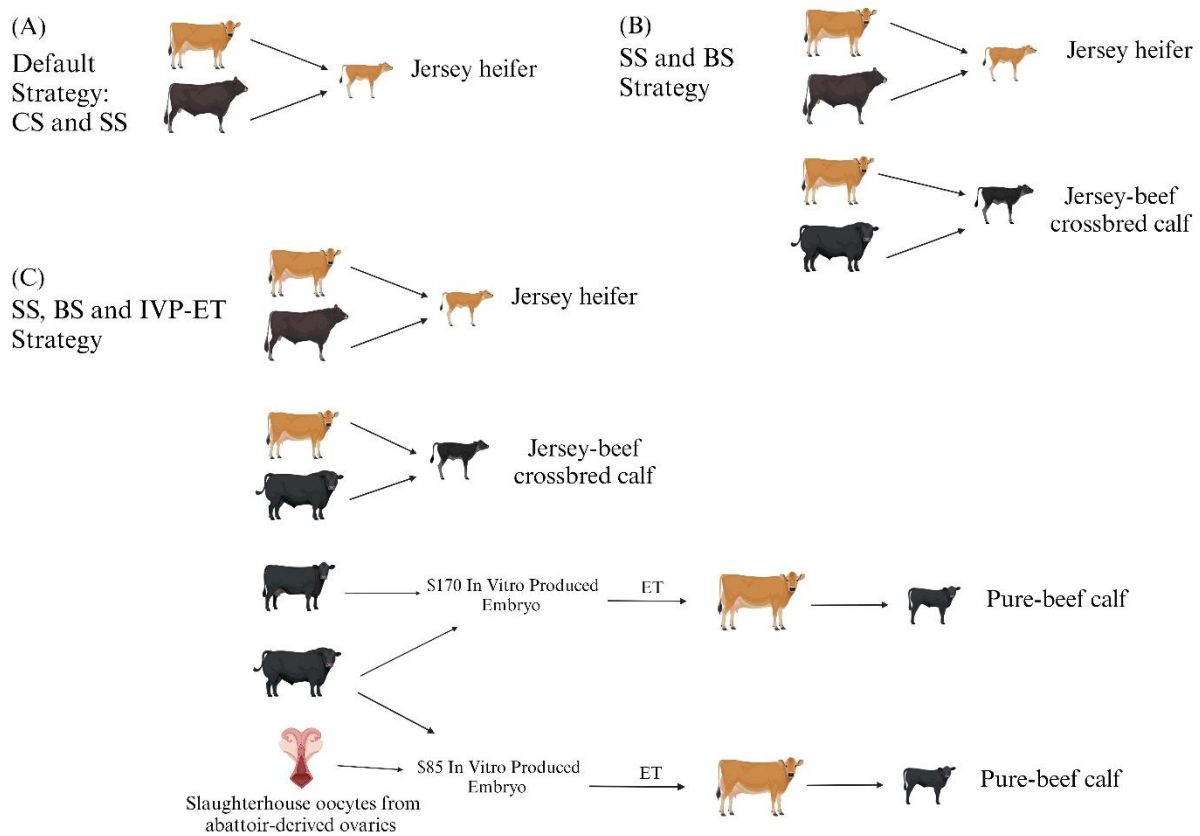
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<sup>1</sup>SS: Sexed semen; <sup>2</sup>BS: beef semen; <sup>3</sup>IVP-ET: *in vitro* produced embryo transfer

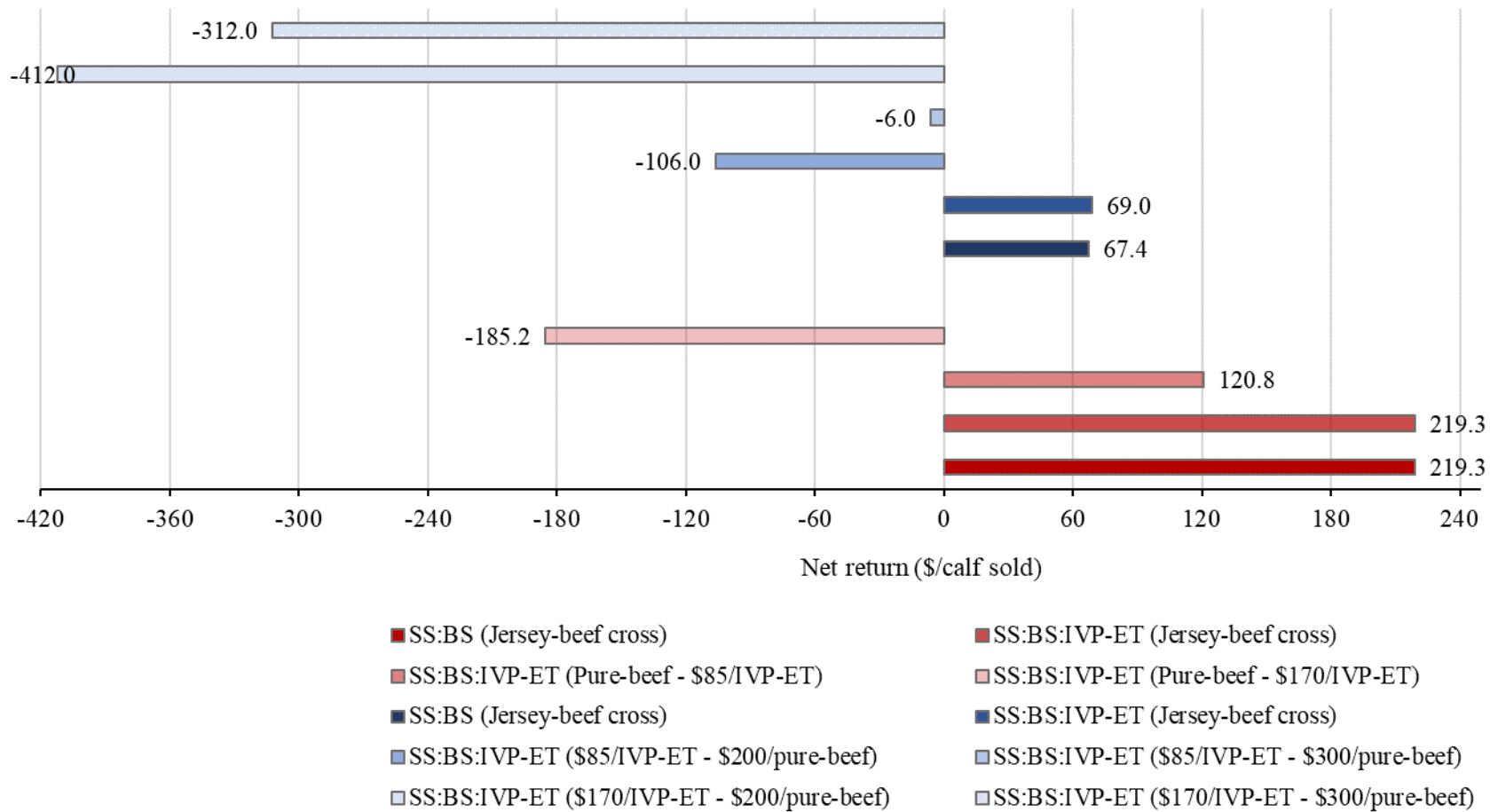
Table 6. Summary of the profitability outputs of Jersey herds by scenarios marketing the Jersey-beef crossbred calf and the pure-beef calf at 180 kg.

Outcome	Scenario 6	Scenario 7	Scenario 8
	SS <sup>1</sup> :BS <sup>2</sup>	SS:BS:IVP-ET <sup>3</sup>	SS:BS:IVP-ET
IVP-ET cost, \$/transfer		85.0	170.0
ADG for the Jersey-beef animal (kg /d )	0.8	0.8	0.8
ADG for the Pure-beef animal (kg /d )	0.0	1.0	1.0
Total operational cost, \$/cow per year			
Heifer and dry cows	601.7	586.2	583.6
Lactating cows	2,549.6	2,619.2	2,716.1
Accrual operational cost, \$/cow per year			
Heifer and dry cows	938.2	913.2	909.4
Lactating cows	3,298.4	3,368.7	3,465.7
Conventional dairy breeding cost, \$/cow per year			
Heifer	0.0	0.0	0.0
Cows	0.0	0.0	0.0
Sexed dairy breeding cost, \$/cow per year			
Heifer	25.5	25.6	25.5
Cows	32.9	33.0	32.8
Conventional beef breeding cost, \$/cow per year			
Heifer	1.2	1.2	1.2
Cows	25.5	10.5	10.6
IVP-ET cost, \$/cow per year			
Heifer	0.0	0.0	0.0
Cows	0.0	92.1	184.6
Pregnancy cost, \$/cow per year			
Sexed semen	97.6	97.4	97.5
Conventional beef semen	46.7	44.8	45.0
IVP-ET	0.0	303.7	608.0
Revenue, \$/cow per year			
Heifer cull sales	48.4	48.7	49.4
Cow cull sales	172.1	172.7	173.2
Heifer dairy calf sales	2.1	2.1	2.1
Bull Dairy calf sales	0.6	0.6	0.6
Jersey-beef crossbred calf sales	321.9	147.5	148.1
Pure-beef calf sales	0.0	218.4	218.5
Milk sales	3,924.4	3,914.8	3,917.5
Profit \$/cow per year	232.9	222.9	1.33.3
Profit \$/lactating cow per year	273.6	261.6	156.4

<sup>1</sup>SS: Sexed semen; <sup>2</sup>BS: beef semen; <sup>3</sup>IVP-ET: *in vitro* produced embryo transfer



**Figure 1.** Main strategies used to produce Jersey-beef crossbred calves and pure-beef calves. (A) Default strategy: Jersey dams inseminated with a conventional Jersey semen (CS) or sexed Jersey semen (SS). (B) SS and beef semen (BS) strategy: Jersey dams were inseminated with SS and/or BS, producing a Jersey heifer and/or Jersey-beef crossbred calf. (C) SS, BS and IVP-ET strategy: Jersey dams were inseminated with SS, and/or BS, or in-vitro beef embryo was transferred, producing Jersey heifer, Jersey-beef crossbred calf and pure-beef calf. For strategy using IVP-ET the cost per breeding used was \$170 or \$85 per breeding.



**Figure 2.** . Net return by calf sold (cost to produce calf – calf market price) by scenarios. Blue colors represent one-day-old marketed animals, and the red colors represent animals marketed at 180 kg. For calves sold, the cost considered was the cost per pregnancy; for calves sold with 180 kg, the cost used was the cost per pregnancy and the cost of raising the calves (Jersey-beef crossbred and the pure-beef calf). SS: Sexed semen use; BS: beef semen use; IVP-ET: in vitro produced embryos..

## CHAPTER 3

### **ASSOCIATION OF MORBIDITY, MORTALITY, AND PERFORMANCE WITH TRANSFER OF PASSIVE IMMUNITY IN DAIRY-BEEF CROSSBRED CALVES UP TO 60 D OF LIFE**

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## ABSTRACT

An adequate transfer of passive immunity (TPI) is a cornerstone for a proper health status of calves. In the literature, there is limited information on the prevalence of failure of TPI in dairy-beef crossbred calves and its impact on morbidity, mortality, and performance during the preweaning period. Therefore, the objective of this study was to evaluate the association between TPI with morbidity, mortality, and average daily gain (ADG) in preweaned dairy-beef crossbred calves. A total of 1,055 dairy-beef crossbred calves were enrolled upon arrival at a calf-raising facility in California from January to August 2021. Farm of origin, genetic group, sex, and body weight were recorded upon arrival. Blood was collected at  $24 \pm 1$  h post-arrival to evaluate serum IgG concentration, serum total protein (TP), and packed cell volume. Morbidity (diarrhea and respiratory treatments records) and mortality were recorded daily until 60 d of life. Calves were grouped into 2 genetic groups - Holstein x Beef (Ho x Be, 49.6%) and Jersey x Beef crossbred calves (Je x Be, 50.4%). Descriptive statistics and Cox proportional hazard models were created to evaluate the association of TPI categories for serum IgG (TPI-IgG: poor:  $< 10.0$  g/L, 184 fair:  $10.0 - 17.9$  g/L, good:  $18.0 - 24.9$  g/L, and excellent:  $\geq 25.0$  g/L) and TP (TPI-TP: 185 poor:  $< 5.1$  g/dL, fair:  $5.1 - 5.7$  g/dL, good:  $5.8 - 6.1$  g/dL, and excellent:  $\geq 6.2$  g/dL), sex, and genetic group, with morbidity and mortality. Additionally, a mixed linear regression was performed to evaluate the association of sex, genetic group, and TPI categories with ADG. Overall morbidity and mortality were 84.8% ( $n = 895$ ) and 2.5% ( $n = 26$ ). Calves classified as TPI-IgG excellent were associated with the lowest (43.2% less) hazard of being treated compared with TPI-IgG poor calves. For mortality, a dairy-beef crossbred calf TPI-IgG excellent was associated with a reduction of 82.0% in the hazard of dying compared with TPI-IgG poor. The TPI-IgG poor and TPI-IgG fair calves were associated with a decreased ADG of 101.0 and 98.8 g/d, respectively in comparison with calves TPI-IgG good calves. Performance of TPI-IgG good and TPI-IgG excellent calves were not different. In our study, dairy-beef crossbred calves enrolled in this study may have endured challenging conditions that increased morbidity. This reinforces the importance of high IgG levels to decrease morbidity and mortality and maximize performance in dairy-beef crossbred calves raising systems. Further research should evaluate the effects the TPI categories in a long-term of dairy-beef crossbred calves.

**Keywords:** dairy-beef crossbred calves, transfer of passive immunity, morbidity, mortality, average daily gain.

## INTRODUCTION

The first care of a newborn calf is a critical moment and can impact the future performance of the animal (Godden et al., 2019). Colostrum management is one of the first steps to guarantee the absorption of immunoglobulins (Ig) and to protect the calves from diseases. The IgG represents  $\pm 85\%$  of the Ig in the maternal colostrum. To assess the calf's immune status, serum IgG concentration can be measured between 24 h to 7 d of life. However IgG analysis is laborious and costly. Thus, serum total protein (TP) has been used to achieve the health status of newborns, as its analysis is easily to perform and TP values are highly correlated with serum IgG concentration (McBeath et al., 1971). In the literature, the cutoff point of 10 g/L of serum IgG is adopted to classify calves as having failure of transfer of passive immunity (TPI). This level of IgG is likely due to its association with greater rates of mortality (Godden et al., 2019). Although this threshold has been widely used in the literature and in the field to classify calves as having a failure of TPI, recent studies have shown that to achieve reduction in morbidity and mortality new standards of serum IgG levels should be adopted (Urie et al., 2018; Lombard et al., 2020).

There is a wealth of literature evaluating failure of TPI, morbidity, and mortality in replacement heifers in the North America (USDA-NAHMS, 2014a; Renaud et al., 2018; Lombard et al., 2020; Abdallah et al., 2022). This is primarily due to the economic importance of replacement heifers to the dairy industry and the impact of disease incidence on early life in their future milk production and reproductive performance (Stanton et al., 2012). Moreover, non-replacement calves (surplus heifers, male dairy calves, and dairy-beef crossbred calves) are subjected to numerous challenges in their early life, such as reduced volume of colostrum feeding, long period between birth and first colostrum feeding (Shivley et al., 2019; Renaud et al., 2020), and long distance of transportation to auction markets, or to a raising facility at their

first weeks of life (USDA-NAHMS, 2014b; Renaud et al., 2018). All those practices are likely linked to an increased risk of morbidity and mortality in non-replacement calves.

Since 2008, the US has seen a sudden increase in the use of beef semen by dairy herds motivated by the high use of sexed semen, high costs of raising heifers, decreased heifer prices, and increased prices of the day-old dairy-beef calf (Pereira et al., 2022). Day-olds crossbred calves are raised in systems similar to replacement heifers up to 140 d, when they go to feedlots to enter the beef supply chain. Previous studies evaluating morbidity, colostrum management, and adequate TPI in purebred Holstein veal calves have reported that non-replacement calves have greater high risk for diseases in early life due to receiving low quality and quantity of colostrum and at a later time than replacement heifers (Pempek et al., 2017; Renaud et al., 2017; Shivley et al., 2019). As part of the dairy industry fails to properly manage newborn male dairy calves (Shivley et al., 2019), it is likely that dairy-beef crossbred calves might be managed similarly, despite their greater market value. Machado and Ballou, (2022) reported that calf-raising facilities might pay a premium price for calves classified as having adequate TPI, implying that the calf-rearing industry is concerned about the crossbred calf health status and its impact on the economics of their business. For instance, increased morbidity and mortality, negatively impact performance, inflating veterinary and labor costs (Raboisson et al., 2016; Schinwald et al., 2022). Additionally, Marcato et al. (2022) reported an almost 30 kg reduction in veal calves treated with antibiotics, reflecting how disease events can impact growth performance in pre-weaned calves.

To our knowledge, no study has yet been performed on the TPI in dairy-beef crossbred calves and its association with morbidity, mortality, and average daily gain (ADG) during the preweaning period. We hypothesized that high serum IgG concentration would reduce morbidity and mortality and increase ADG in dairy-beef crossbred dairy calves raised in calf-raising facilities up to 60 d of life. Therefore, the objective of this prospective cohort study was

to describe the association between TPI with morbidity, mortality, and ADG of dairy-beef crossbred calves.

## **MATERIALS AND METHODS**

This study was approved by the University of California, Davis Institutional Animal Care and Use Committee (Animal use and care protocol # 22089).

### ***Facilities, and management***

This prospective cohort study was performed on a single calf-raising facility in the Central Valley, California, from January to August 2021. Cattle enrollment criteria included being a dairy-beef crossbred calf arriving at the facility with available information regarding calf identification number, breed, sex, and dairy of origin. Enrolled calves came from 6 source dairies in the California Central Valley with herd sizes ranging from 1,050 to 4,800 and located 4.0 to 39.0 miles away from the raising operation. Calves enrolled were either born on the enrollment day or were one day old. Calves arrive at the raising facility daily, where they were housed in individual wood calf hutches and weaned at  $61 \pm 6$  d after arrival. After weaning, calves were kept in the hutches until d 85 when they were moved to group pens or another facility. Upon arrival at the calf raising facility, all calves received nasal vaccine for bovine respiratory disease (Nasalgen 3 – Merck Animal Health, Madison, NJ); the navel was disinfected using 7% of tincture of iodine, and male calves were castrated using the rubber ring method (following the procedure described in Booker et al., 2009).

Calves were fed 2 L of milk replacer twice a day (22% CP, 20% fat, containing 22.5 mg/kg of decoquinatone) until  $d 55 \pm 5$ ; then, reduced to one feeding per day until weaning. Calf starter was offered at libitum after on  $d 3 \pm 1$  and contained alfalfa hay (4.9%), protein-pellet ration (44.1%), steam-flaked corn (49.4%), and oil (1.6%).

### ***Data Collection and Animal Records***

*Average daily gain.* All crossbred calves were weighed on arrival using a Tru-Test digital weight scale (Model EW7i, Mineral Wells, TX) at the arrival day. A random subset of calves (n = 337) were weighed at  $60 \pm 5$  d after arrival. Calves ADG was calculated by subtracting the initial body weight from the final body weight divided by the number of days between weightings.

*Blood collection.* Blood samples were collected  $24 \pm 1$  h after arrival at the calf raising facility from the jugular vein into a 10 mL tube without anticoagulant by a single trained farm personnel and one researcher. This sample was used for measuring serum IgG and TP concentration. At the same time, a second blood sample was collected using anticoagulant (EDTA) tubes to analyze packed cell volume (PCV). For IgG and TP analysis, the blood was centrifuged (1,500 g, 15 min) to separate the serum from the clot. The TP was determined using a digital refractometer (Model DD-2, Misco, Solon, OH). One sample of serum was stored at  $-20^{\circ}\text{C}$  for IgG analysis. Serum IgG concentration was measured using the single radial immunodiffusion test kit, following the manufacturer's protocol (Triple J Farms, Bellingham, WA). For the PCV analysis, the blood was centrifuged (12,000 g, 5 min) using a microhematocrit centrifuge in a microhematocrit tube. The PCV was obtained by measuring the height of the red cell column using a microhematocrit reader (C-MH30, Unico, Dayton, NJ).

*Disease treatment records.* Calf health evaluations and disease treatments were performed daily at 5 am by two trained farm personnel. The disease treatment protocols were designed by the farm veterinarian to identify and treat diarrhea and pneumonia diseases. Clinical symptoms of diarrhea checked were fecal consistency (score 1 = normal consistency to feces, score 2 = semi-formed or pasty feces, score 3 = runny, spreads easily, score 4 = liquid; Renaud et al., 2019), decreased milk intake, and depression. Briefly calves presenting a fecal score of 3 or 4, that were not presenting other signs received 2 L/d of oral electrolytes. If fecal

score persisted, on the second day calves were treated with antibiotics between 2 to 7 d (Penicillin, 1 mL/45 kg of BW). For calves that presented depression, and reduced milk intake, in addition of the antibiotic treatment, calves received 2 L of intravenous fluid for 1 to 2 d. No additional treatment was administered if diarrhea signs persisted. For respiratory disease calves were treated if presenting signs of ocular and nasal discharge, cough, abnormal respiration, dropped ear and head tilt. Calves with less than 15 d of age were treated with enrofloxacin (Baytril, 1.1-2.3 mL/45 kg of BW), calves with 15 d until weaning, were treated with tulathromycin (Draxxin, 1.1 mL/45 kg of BW) and a dose of ceftiofur (Excede, 1.5 mL/45 kg). Diarrhea and respiratory number of cases were defined if the calf received at least one dose of antibiotic. For both diarrhea and respiratory treatments, the farm personnel recorded the disease, day of diagnostic, and number of days treated, on the individual calf health cards placed in each hutch. During the study period, researchers collected information on antimicrobial treatments (morbidity) daily, immediately after the calf health evaluation. The treatments recording system described, was a similar approach used by (Menta et al., 2022).

*Mortality records.* Mortality data (calf number and death date) were collected every 15 days from the calf-raising facility management software.

### **Sample size calculation**

We used the software OpenEpi to calculate the sample size for our study. Based on previous work by Lombard et al. (2020), assuming an IgG threshold of 18 g/L, it was estimated that animals with IgG below 18.0 g/L would have a mortality risk of 5.6%, whereas calves with an IgG concentration above 18.0 g/L would have a mortality risk of 2.0%. Thus, assuming a 1.6 ratio of unexposed (animals classified as having IgG < 18.0 g/L): exposed (animals classified as having IgG > 18.0g/L) animals, 95% of confidence and 80% of power, the sample size required was 1,004 calves. The IgG concentration of 18.0 g/L was established due to the

higher reduction in mortality risk according to Lombard et al. (2020), compared with the commonly used IgG threshold concentration of less than 10.0 g/L (Godden et al., 2019).

### **Statistical analysis**

For all statistical analysis, crossbred calves were classified into two genetic groups: Jersey × beef (Je × Be; crosses of Jersey x Charolais and Jersey x Angus) and Holstein × beef (Ho × Be; crosses of Holstein x Angus) calves. The TPI categories were classified according with Lombard et al., (2020) based on IgG concentrations (TPI-IgG: poor: < 10.0 g/L, fair: 10.0 – 17.9 g/L, good: 18.0 – 24.9 g/L, and excellent: ≥ 25.0 g/L) and serum TP values (TPI-TP: poor: <5.1 g/dL, fair: 5.1 – 5.7 g/dL, good: 5.8 – 6.1 g/dL, and excellent: ≥ 6.2 g/dL).

Descriptive statistics were performed with the MEANS and FREQ procedures of SAS 9.3. The correlation between continuous variables (IgG, and TP) was generated from PROC CORR. To identify the optimal threshold concentration of serum IgG and TP for morbidity and mortality, the OUTROC option of the PROC LOGISTIC of SAS was used. From the OUTROC output, we used the sensitivity and specificity values to calculate the Younden's index (J) criterion (Younden, 1950), where  $J = (\text{sensitivity} + \text{specificity} - 1)$ . The maximum J was used to identify the optimal serum IgG and TP threshold for morbidity and mortality.

Factors associated with ADG were determined using the PROC MIXED of SAS. Two models were evaluated, to determine the effect of the TPI categories for IgG concentration (TPI-IgG: poor: < 10.0 g/L, fair: 10.0 – 17.9 g/L, good: 18.0 – 24.9 g/L, and excellent: ≥ 25.0 g/L) and serum TP values (TPI-TP: poor: <5.1 g/dL, fair: 5.1 – 5.7 g/dL, good: 5.8 – 6.1 g/dL, and excellent: ≥ 6.2 g/dL). In addition both models considered factors of genetic group (Ho × Be, and Je × Be), and sex (male, female). Farm of origin was added to both models as a random effect. Backward elimination was used, and variables were deleted one by one if the significant

condition was not satisfied ( $P < 0.05$ ). Interactions up to the third order were also included in the model and eliminated using the same procedure if non-significant.

Cox proportional hazard models (PROC PHREG, SAS 9.3) were created to evaluate the association between our predictor variables with morbidity and mortality. The variables analyzed were sex (male and female), genetic group (Ho × Be, Je × Be), and TPI categories for IgG (TPI-IgG: poor: < 10.0 g/L, fair: 10.0 – 17.9 g/L, good: 18.0 – 24.9 g/L, and excellent:  $\geq$  25.0 g/L), and TP (TPI-TP: poor: <5.1 g/dL, fair: 5.1 – 5.7 g/dL, good: 5.8 – 6.1 g/dL, and excellent:  $\geq$  6.2 g/dL). Farm was added as a random effect, and all two-way interactions were tested. The non-significant variables were removed using a backward approach, and only the significant variables were presented in the final models. For all analyses,  $P < 0.05$  was declared significant.

## RESULTS

A total of 1,072 dairy-beef crossbred calves were enrolled in our study. Due to missing morbidity and mortality information, 17 animals were excluded from our analysis. Descriptive statistics of the number of calves, farm, blood parameters, ADG, and disease incidence by genetic group are summarized in Table 1. The final data set included 523 Ho × Be (49.6 %), and 532 Je × Be (50.4 %) calves. Body weight at arrival was obtained from 893 calves and a subsample of 337 of those calves were also weighted at weaning for ADG calculation.

### Morbidity

Overall, the median time after arrival for the first disease treatment was 9 d (25<sup>th</sup> percentile: 5 d; 75<sup>th</sup> percentile 12 d). Disease incidence and day at first disease are summarized by TPI-IgG and TPI-TP categories in Table 2 and 3 respectively.

There was an association between TPI-IgG categories and morbidity ( $P < 0.001$ , Table 4). No association were founded for sex, and genetic group with morbidity. Calves categorized

as TPI-IgG-excellent was associated with a greater reduction of 43.2% ( $P < 0.001$ ) in the hazard of being ill compared with a calf in the TPI-IgG-poor category (reference category). Calves in the TPI-IgG-fair and good categories were associated with a 25.0% ( $P = 0.039$ ) and 35.0% ( $P = 0.002$ ) reduction in the hazard of being ill compared with the TPI-IgG-poor category (reference category), respectively.

Morbidity was associated with TPI-TP categories ( $P = 0.002$ , Table 5). Sex, and genetic group were not associated with morbidity. The TPI-TP-excellent calves was associated with a reduction of 31.7% ( $P < 0.001$ ) in the hazard of being ill compared with a calf in the TPI-TP-poor category (reference category), while TPI-TP-fair and good were associated with a 20.0% ( $P = 0.011$ ) and 23.9% ( $P = 0.014$ ) reduction in the hazard of being ill compared with the TPI-TP-poor category.

Kaplan-Meier survival curve of non-disease probability for dairy-beef crossbred calves up to 60 d of life, by TPI-IgG, and TPI-TP categories, are shown in Figure 1A and 1B. Overall, the survival curves showed that 66.9% of all disease treatments occurred in the first 12 d of life. After this period, the number of cases slowly increased until the 60 d of age.

Based on the predicted probabilities obtained from Youden's index criterion (Youden, 1950), the optimal serum IgG concentration and serum TP threshold to predict disease treatment was 21.2 g/L (area under the curve = 0.56; sensitivity = 0.40; specificity = 0.72) and 5.3 g/dL (area under the curve = 0.58; sensitivity = 0.43; specificity = 0.70), respectively.

## **Mortality**

Overall mortality risk was 2.5% ( $n = 26$ ). The mortality percentage by TPI-IgG and TPI-TP categories is shown in Table 2 and 3.

The final hazard ratio TPI-IgG models result for mortality are shown in Table 4. Sex and genetic group were not associated with mortality. The TPI-IgG categories was associated

with mortality ( $P < 0.011$ ). The TPI-IgG-excellent calves was associated with the greater reduction (82.0%,  $P = 0.004$ ) in the hazard of dying compared with a calf in the TPI-IgG-poor (reference category). The TPI-IgG-good calves were associated with 76.6% ( $P = 0.016$ ) of reduction in the hazard of dying compared with the reference category (TPI-IgG-poor), respectively. The final hazard ratio TPI-TP models result for mortality are shown in Table 5. The TPI-TP, sex and genetic group were not associated with mortality.

Kaplan-Meier survival curve for mortality curve for dairy-beef crossbred calves up to 60 d of life, by TPI-IgG and TPI-TP categories, is shown in Figure 2A and 2B.

Based on the predicted probabilities obtained from Youden's index criterion (Youden, 1950) the optimal serum IgG concentration and serum TP threshold to predict mortality was 18.6 g/L (area under the curve = 0.68; sensitivity = 0.81; specificity = 0.61) and 5.1 g/dL (area under the curve = 0.56; sensitivity = 0.31; specificity = 0.74), respectively.

### **The effect of TPI on average daily gain**

Results of the regression reported an effect of TPI-IgG categories ( $P < 0.002$ ) and TPI-TP ( $P = 0.004$ ) for ADG in the first 60 d of life (Figure 3A and 3B, respectively); where TPI-IgG-excellent and good calves had greater ADG when compared to TPI-IgG-fair, and poor calves. The TPI-TP-poor calves had reduced ADG compared with TPI-IgG-fair, good and excellent calves. The categorical variables sex, genetic group were not associated with ADG for both TPI classification.

## **DISCUSSION**

This study described the association of TPI for IgG concentration and serum TP with morbidity, mortality, and ADG in dairy-beef crossbred calves. Overall, our results demonstrated that the TPI-IgG categories were associated with morbidity and mortality in

dairy-beef crossbred calves until 60 d of life. In addition, regardless of TPI classification evaluated (TPI-IgG or TPI-TP), all calves categorized as having failure of TPI (TPI-IgG-poor < 10.0 g/L or TPI-TP-poor < 5.1 g/dL) showed reduced performance compared with fair, good and excellent TPI calves.

In our study, using the cut-off value of IgG <10.0 g/L, 14.5% of calves failed to achieve TPI. This percentage is within the range previously reported for Holstein calves (range 12.1 - 36.2% of failure of TPI; Beam et al., 2009; Shivley et al., 2018; Abuelo et al., 2019). However, in the aforementioned studies, IgG was measured between 2 to 7 d after birth, and likely IgG had declined by the time they were measured (Correa et al., 2022). Accordingly, Shivley et al. (2019) reported that male dairy calves tended to receive low volumes of low-quality colostrum, which may lead to a higher proportion of animals with TPI failure. However, this was not the case with our study, which indicates that calves raising facilities are implementing strategies to incentivize dairy producers to take better care of their surplus newborn animals such as premiums based on serum TP or TPI; the distribution of our calves by TPI-IgG categories (lower:14.5%, poor: 23.5%, fair: 26.9% and excellent: 35.1%) confirmed that, as the TPI-IgG distribution was similar with what was reported by NAHMS (2014, lower:12.0%, poor: 26.8%, fair: 25.7% and excellent: 35.5%), but in contrast our TPI-IgG distribution was lower compared with the consensus recommendation by Lombard et al., (2020; lower: < 10%, poor: 23.5%, fair: 26.9% and excellent: 35.1%), which brings the idea of TPI standards being farm specific, but it's important to evaluate farm specific results to compare with for example the consensus indicated by Lombard et al., (2020). However for the TPI-TP distribution (lower: 32.1%, poor: 34.1%, fair: 14.1% and excellent: 19.6%) our data was not between of the recommendations by Lombard et al., (2020). Based on this results it's important to consider that factors such as dehydration and colostrum source fed can impact the serum TP values (Lopez et al., 2020). In our data, no cases of dehydration were found, but data of colostrum management - colostrum

feeding time, volume, and quality, were not recorded for this study, which is a limitation to better understanding factors that affected the TPI-TP categories and then its influence on morbidity and mortality percentages.

We observed a high percentage of morbidity in our study, where diarrhea events had the highest percentage between genetic groups, followed by respiratory diseases. Previous studies have shown data on Holstein heifer calves' morbidity ranging from 33.8 to 50.0% (Furman-Fratczak et al., 2011; Urie et al., 2018; Lora et al., 2019) therefore, the percentage of calves treated in our study (84.8%) was higher than the literature reports. Our morbidity was based on-farm treatment records of antimicrobial use. This was an unexpected results, as our TPI was similar to the ones observed in the literature. For that reason, we speculate that this higher morbidity is likely due to management instead of the failure of TPI, and the farm could benefit from new staff training. The high percentage of calves' morbidity observed in our study, and that of Scott et al. (2019) reported may reflect the challenges faced by non-replacement calves in the dairies (e.g., low volume of colostrum feeding, early age at the transport, transportation distance, feed and water availability for long-distance), and at calf raising facilities (e.g., housing system, and nutrition plan; Creutzinger et al., 2021). These risks are challenges that non-replacement calves face in their early lives and may negatively impact their health status and growth (Goetz et al., 2021; Marcato et al., 2022) in a long-term.

Although our morbidity rates were high, our mortality rates (2.5%) were less than previously reported in the literature (3.2% to 8.9% from birth until slaughter; (Lombard et al., 2020; Schinwald et al., 2022). Based on the greater morbidity recorded, we expected a greater mortality rate; however, we can attribute this small mortality due to intense calf care effort for calves that were more depressed, and due to the time we kept the mortality records of our data (until 60 d of age).

For decades, the IgG threshold to define TPI was 10.0 g/L, based on an early study reporting higher mortality rate of heifer Holstein calves (Wells et al., 1996). However, other authors have suggested different optimal serum IgG thresholds that ranged from 20.0 to 25.0 g/L to reduce mortality (Chigerwe et al., 2015), 16.7 g/L to reduce mortality (Renaud et al., 2018), and 15 g/L to reduce morbidity and mortality (Urie et al., 2018), and  $\geq 25.0$  g/L for morbidity and mortality (Lombard et al., 2020). These results were similar with our identified optimal threshold points for serum IgG of 21.2 and 18.6 g/L for morbidity and mortality respectively. This is interesting considering the differences in breed, time of sampling, gender between studies.

Serum TP values is commonly used for dairy producers to estimate serum IgG concentration and evaluate the TPI of their calves. Levels of serum TP of 5.2 g/dL have been associated with mortality of calves with less than 5 weeks of age, where serum TP levels between 5.7 to 6.3 g/dL was associated with reduction of disease in calves (McGuirk and Collins, 2004; Todd et al., 2018). In our study we found an optimal threshold points for serum TP of 5.3 and 5.1 g/dL for morbidity and mortality respectively. The variation between serum TP levels to predict morbidity and mortality may be associated with the colostrum source fed to the calves. In fact, Lopez et al. (2020) evaluated TPI of dairy calves fed a whey-based colostrum replacer, and reported that a serum TP threshold point of 4.2 g/dL as a predictor of serum IgG concentration of 10.0 g/L. Thus, due to the use for dairy producers of serum TP as an alternative to evaluate TPI, is important to know the management of the colostrum feeding to better assess TPI of their calves.

In our study it's interesting to highlight that besides the high disease percentage, we observed a decreased risk of morbidity and mortality for the TPI-IgG-good and TPI-IgG-excellent calves. Data reporting the impact of the failure of TPI on calf's morbidity and mortality is essential to guide calf producers for best management practices and to avoid

treatment costs (Raboisson et al., 2016). As previously mentioned, it is important to highlight, the lower morbidity for animals with greater IgG concentration ( $\text{IgG} \geq 18.0 \text{ g/L}$ ; Urie et al., 2018) and understand the implications of the association between performance and disease events in dairy-beef crossbreds. Our results also reported a reduction in ADG for TPI-IgG-poor animals. This may be due to the greater percentage of animals with a disease event categorized as having failure of TPI, which may be associated with more days in treatment, and the number of treatments per disease event (e.g., treatment for the respiratory disease) has been associated with carcass loss weight of veal calves (Pardon et al., 2013; Marcato et al., 2020). A study evaluating veal calves health (Marcato et al., 2022) reported a 27.5 kg carcass weight reduction for calves treated with more than 4 antibiotic treatments in veal calves (24 weeks of age). This information supports the relevance of colostrum management by the dairy side and the management at the calf-raising facility to identify high-risk calves for morbidity and mortality. In addition, due to the increased number of dairy-beef crossbred calves going into the beef market (Basiel and Felix, 2022), data reporting the effect of TPI on morbidity, mortality, and performance are necessary to understand how these animals would perform in calf-raising facilities based on their level of TPI.

A few studies evaluated the association between sex, with TPI, morbidity, and mortality (Renaud et al., 2020; Marcato et al., 2022), and no studies were founded evaluating genetic group with TPI, morbidity or mortality. In our study, sex was not associated with a greater risk of morbidity and mortality. In addition, Marcato et al. (2022) reported a greater prevalence of navel inflammation in male calves compared with female calves. Our study did not record navel inflammation but based on field observations by the researchers, navels were cared for equally, regardless of sex. As previously mentioned studies evaluating TPI do not commonly evaluate breed (Walker et al., 2012; Pempek et al., 2017; Scott et al., 2019). However, due to the increased number of dairy-beef crossbred calves going into the beef market (Basiel and Felix,

2022), data reporting the effect of genetic group on morbidity, mortality, and performance are necessary to understand how these animals would perform in calf-raising facilities and their level of TPI.

As Urie et al. (2018) reported, the risk of reduction of morbidity and mortality depends on the serum IgG concentration. Besides the high percentage of illnesses, high IgG levels showed to be effective in reducing the risk of diseases and mortality. Therefore, calf-raisers must select animals with higher levels of serum IgG concentration in calf sales to reduce the risk of disease and mortality in their operations. Additionally, adequate management by dairy farmers at early life, mainly for the colostrum feeding practice in volume, quality, and time (Godden et al., 2009), would reduce the risk of selling non-health calves and may assure higher performance during the preweaning period. However, some important points should be considered when interpreting our results. First, the recorded diseases incidence may not reflect all sick calves because we collected data from farm personnel and overtreatment or undertreatment could have happened. However, it is noteworthy to remark that the farm personnel had years of experience in disease identification and treatment with weekly supervision from the calf raising operation veterinarian. Also, our data was from a single calf-raising facility; thus, the morbidity and mortality risks must be evaluated carefully, as the challenges may change from facility to facility. Nonetheless, although our data were from a single commercial facility, this represents part of the calf industry, and we did not have variation in the calf-raising management. Studies evaluating dairy-beef crossbred calves of different calf-raising facilities from 1<sup>st</sup> week of life through the slaughter phase are needed to evaluate the TPI categories effects on performance and health.

## **CONCLUSIONS**

Transfer of passive immunity was a predictor of morbidity and mortality in dairy-beef crossbred calves using serum IgG concentration. Sex and genetic group were not a predictor for morbidity and mortality and were not associated with ADG. Animals categorized as fair, good and excellent for TPI-IgG had greater ADG gain compared with poor TPI-IgG animals. The best predict point of serum IgG for morbidity and mortality was 21.2 and 18.6 g/L, and for serum TP was 5.3 and 5.1 g/dL respectively. Our study confirms the association of TPI-IgG with morbidity and mortality, and TPI-TP with morbidity; and to further reduce morbidity and mortality, high levels of IgG are needed due to the challenges in the rearing phase. Future research should evaluate the long-term effects of TPI categories on performance, health and carcass characteristics of dairy-beef crossbred animals.

#### **CONFLICT OF INTEREST STATEMENT**

The authors have not stated any conflicts of interest.

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Table 1. Descriptive statistics of dairy-beef crossbred calves measured upon arrival at a calf-raising facility in California

Item	Overall	Ho × Be <sup>1</sup>	Je × Be <sup>2</sup>
No. of calves			
Female	499	254	245
Male	556	269	287
No. of source dairies	6	3	6
Arrival BW, kg <sup>4</sup>	38.0 ± 5.9	40.9 ± 5.5	34.8 ± 4.4
Serum IgG, g/L	21.3 ± 10.2	24.8 ± 8.5	17.9 ± 10.6
Serum total protein, g/dL	5.5 ± 0.8	5.6 ± 0.7	5.3 ± 0.8
Packed red blood cells (%)	27.5 ± 5.6	27.9 ± 5.6	27.1 ± 5.5
ADG, g/day <sup>5</sup>	555.9 ± 144.1	599.0 ± 148.0	497.1 ± 115.2
Incidence of disease (%)			
Diarrhea	65.4	58.9	71.8
Respiratory disease	55.5	57.4	53.6

<sup>1</sup>Ho × Be: Holstein × beef crossbred calves; <sup>2</sup>Je × Be: Jersey × beef crossbred calves; <sup>3</sup>number of female and male calves

**Table 2.** Number of calves, disease incidence, age at first disease, and mortality by transfer of passive immunity categories for serum IgG (TPI-IgG) of dairy-beef crossbred calves up to 60 days after arrival at calf raising facility in California

Item	TPI-IgG (g/dL) categories <sup>1</sup>			
	Poor (<10.0)	Fair (10.0 – 17.9)	Good (18.0 – 24.9)	Excellent (≥ 25.0)
Number of calves, n (%)	153 (14.5)	248 (23.5)	284 (26.9)	370 (35.1)
Disease incidence (%)				
Overall	90.2	87.9	83.1	81.9
Diarrhea	72.6	71.0	64.1	59.7
Respiratory disease	74.0	58.1	52.8	48.1
Day at first disease (d)				
Overall	9	11	12	14
Diarrhea	7	8	8	9
Respiratory disease	10	13	14	17
Mortality (%)	5.9	3.6	1.4	1.1

<sup>1</sup>TPI: Transfer of passive immunity categories of serum IgG concentration (g/dL)

**Table 3.** Number of calves, disease incidence, age at first disease, and mortality by transfer of passive immunity categories for serum total protein (TPI-TP) of dairy-beef crossbred calves up to 60 days after arrival at calf raising facility in California

Item	TPI-TP (g/dL) categories			
	Poor ( $< 5.1$ )	Fair ( $5.1 - 5.7$ )	Good ( $5.8 - 6.1$ )	Excellent ( $\geq 6.2$ )
Number of calves, n (%)	339 (32.1)	360 (34.1)	149 (14.1)	207 (19.6)
Incidence of disease (%)				
Overall	89.7	83.3	85.2	79.2
Diarrhea	71.7	65.3	61.7	58
Respiratory disease	66.4	51.7	55.7	44
Day at fist disease (days)				
Overall	11	12	13	13
Diarrhea	7	8	9	8
Respiratory disease	12	14	15	16
Mortality (%)	3.8	1.9	1.3	1.9

<sup>1</sup>TPI-TP: Transfer of passive immunity categories of serum total protein concentration (g/L)

**Table 4.** Cox proportional hazards models results of transfer of passive immunity categories of serum IgG concentration (TPI-IgG, g/L), and its association with morbidity and mortality for dairy-beef crossbred calves up to 60 days after arrival at calf raising facility in California

Item	Hazard ratio	P-value	95% CI	
			Lower	Upper
<b>Morbidity – TPI-IgG (g/L)<sup>1</sup></b>				
Poor (<10.0)	Reference			
Fair (10.0-17.9)	0.75	0.039	0.570	0.986
Good (18.0-24.9)	0.65	0.002	0.492	0.858
Excellent (≥ 25.0)	0.57	<0.001	0.432	0.748
<b>Mortality – TPI-IgG</b>				
Poor (<10.0)	Reference			
Fair (10.0-17.9)	0.61	0.293	0.242	1.535
Good (18.0-24.9)	0.23	0.016	0.072	0.761
Excellent (≥ 25.0)	0.18	0.004	0.055	0.584

<sup>1</sup>TPI: Transfer of passive immunity categories of serum IgG concentration in g/L.

**Table 5.** Cox proportional hazards models results of transfer of passive immunity categories of serum total protein concentration (TPI-TP, g/dL), and its association with morbidity and mortality for dairy-beef crossbred calves up to 60 days after arrival at calf raising facility in California

Item	Hazard ratio	<i>P</i> -value	95% CI	
			Lower	Upper
<b>Morbidity – TPI-TP (g/dL)</b>				
Poor (< 5.1)	Reference			
Fair (5.1 - 5.7)	0.80	0.011	0.67	0.95
Good (5.8 - 6.1)	0.76	0.015	0.61	0.95
Excellent ( $\geq$ 6.2)	0.68	<0.001	0.56	0.84
<b>Mortality – TPI-TP (g/dL)</b>				
Poor (< 5.1)	Reference			
Fair (5.1 - 5.7)	0.57	0.236	0.22	1.45
Good (5.8 - 6.1)	0.41	0.243	0.09	1.84
Excellent ( $\geq$ 6.2)	0.56	0.32	0.18	1.75

<sup>1</sup>TPI: Transfer of passive immunity categories of serum total protein concentration in g/dL.

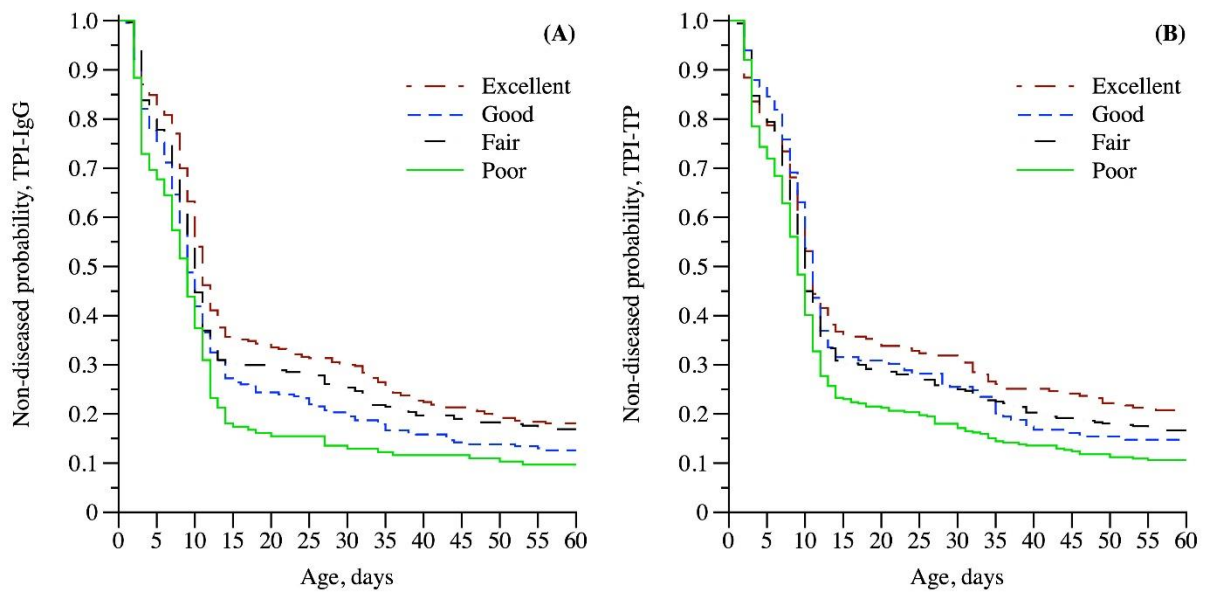


Figure 1. Non-disease survival probability of transfer of passive immunity categories by (A) IgG concentration (TPI-IgG; poor: <math><10.0\text{ g/L}</math>, fair:

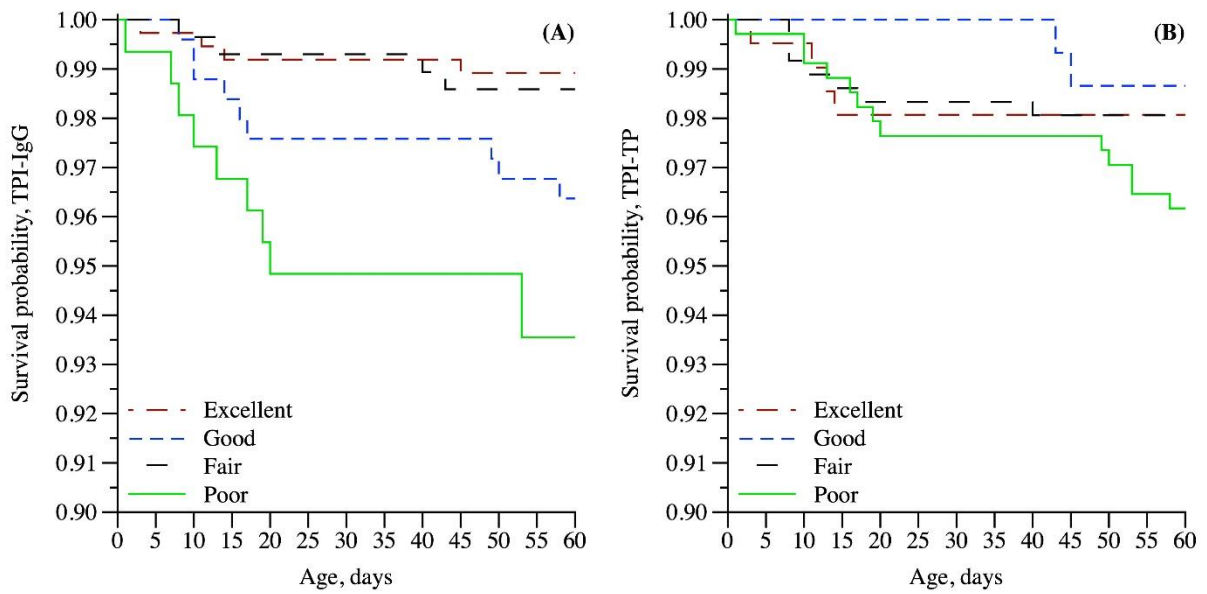


Figure 2. Survival probability of transfer of passive immunity categories by (A) IgG concentration (TPI-IgG; poor: <math><10.0\text{ g/L}</math>, fair:

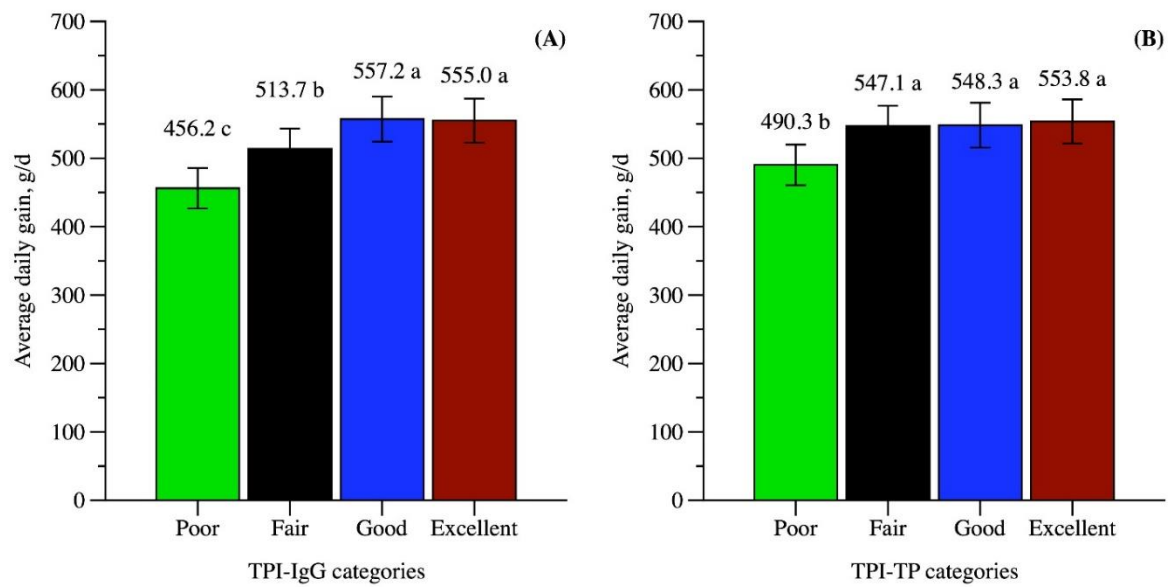


Figure 3. Average daily gain by transfer of passive immunity (TPI) categories for (A) serum IgG concentration (TPI-IgG: poor (n = 33; < 10.0 g/L), fair (n = 89; 10.0 – 17.9 g/L), good (n = 93; 18.0 – 24.9 g/L); excellent (n = 122; ≥ 25.0 g/L)) and (B) serum total protein (TPI-TP: poor (n = 108; < 5.1 g/dL), fair (n = 122; 5.1 – 5.7 g/dL), good (n = 53; 5.8 – 6.1 g/dL); excellent (n = 54; ≥ 6.2 g/dL)) of dairy-beef crossbred calves from a calf raising facility in California.