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Assessing the economic and genetic preservation outcomes of crossbreeding indigenous dairy cattle with commercial breeds under traditional and organic herd management

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Abstract

Objective

This investigation consolidates fragmented evidence on the economic efficiency of cow crossbreeding (CCB) across regions, emphasizing both profitability and genetic preservation in traditional and organic dairy systems. It evaluates the economic and genetic outcomes of crossbreeding indigenous cattle with high-yielding commercial breeds under different herd management scenarios.

Materials and methods

The *SimHerd* stochastic simulation model was applied to replicate herd structures and evaluate breeding strategies. Three scenarios were evaluated: (1) Purebred Polled Cattle (PB-PC), (2) Purebred Red Cattle (PB-RC), and (3) a mixed herd comprising 70% PB-PC and 30% F1 Crossbred (CB) animals. Terminal crossbreeding (T-CB) strategies combined indigenous low-yielding breeds with exotic high-yielding cattle. The model incorporated genetic tools like sexed semen and genetic evaluation indices to estimate financial efficiency and genetic improvement potential.

Results

Simulations illustrated that PB-RC herds achieved the highest financial returns, exceeding PB-PC herds by €1,218 in contribution margin. The mixed PB-PC and F1 CB herd also outperformed pure PB-PC herds, generating a €181 higher margin. Terminal crossbreeding integrated with modern genetic tools improved economic efficiency for small-scale dairy farmers, with F1 crosses maintaining a favorable foreign genetic contribution (52-64.5%). These outcomes highlight the suitability of crossbreds for low-input traditional and organic production systems.

Conclusions

Crossbreeding strategies, when complemented with progressive genetic technologies, can deliver meaningful economic gains while supporting genetic diversity. Although PB-RC herds stayed the most profitable, mixed and crossbred herds supplied more stable productivity and profitability, exclusively for smallholder producers. The implementation of structured CCB programs, reinforced by breeding infrastructure and extension support, can enhance sustainability and economic resilience in expanding dairy sectors.

Keywords: crossbreeding, F1 crossbred, polled cattle, purebred, red cattle

Paper Type: Research Paper.

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Introduction

In recent decades, the global decrease in genetic diversity among indigenous cattle breeds has become a critical concern, primarily driven by the prioritization of high-yielding commercial breeds to meet rising production requests and support intensive agricultural systems. This trend has favored a restricted number of cosmopolitan breeds, leading to a contraction in the genetic base essential for maintaining resilience and adaptability. The loss of genetic variation compromises the capability of cattle populations to withstand environmental challenges, containing those posed by climate change, where adaptive traits unique to indigenous breeds could prove invaluable (Bett et al., 2013; Raguraman & Santhi, 2014). Cattle breeding stays a cornerstone of agricultural economies, providing essential products like milk, meat, hides, and manure, which underpin livelihoods, food security, and rural employment in both developing and developed nations (Javanmard et al., 2008; Ahsani et al., 2022; Gürlek & Atay, 2021; Rohallah et al., 2007; Eghtedari et al., 2024). Beyond their economic contributions, cattle serve as a source of high-quality protein that enhances human nutrition and public health, while their production levels are often applied as indicators of national expansion and welfare (Ghasemi et al., 2010; Badakhshan & Mohammadabadi, 2015; Nejad et al., 2024). Historically, securing a consistent and nutritious food supply has been a central human challenge, a challenge that endures, in spite of meaningful technological progress in agriculture (Mohammadabadi et al., 2010, 2023, 2024a, 2024b, 2024c; Sachdeva et al., 2024). The erosion of genetic diversity among indigenous cattle breeds shows a dual challenge: sustaining economic productivity in dairy systems while preserving the genetic resources vital for long-term sustainability. Intensive selection for high milk yields in commercial breeds, like Holsteins, has often resulted in reduced fertility, health issues, and improved vulnerability to environmental stressors. In contrast, indigenous breeds, often marginalized by modernization, possess unique traits like heat tolerance, disease resistance, and effective feed utilization, which are increasingly valuable under variable climatic conditions (Mehra & Iyer, 2024). The continued overlook of these breeds, coupled with unregulated or indiscriminate breeding practices, accelerates genetic erosion and undermines global biodiversity objectives like Aichi Target 13, which calls for the conservation of livestock genetic diversity (CBD, 2020). Therefore, there is a pressing requirement to identify breeding strategies that reconcile economic efficiency with the conservation of genetic resources. This investigation seeks to evaluate whether strategic crossbreeding, under traditional and organic herd management systems, can serve as a sustainable approach to enhance dairy productivity while conserving the genetic diversity of indigenous cattle. By integrating economic and genetic perspectives, it aims to supply actionable insights for farmers, policymakers, and genetic resource managers to expand breeding programs that support both productivity and biodiversity (Ebrahimi & Huy, 2018; Hlushenkova et al., 2024). Animal breeding, exclusively in dairy cattle, performs a pivotal role in ensuring food security, improving livelihoods, and fostering economic expansion globally. The sector contributes to rural economies by generating income and employment, supplying high-value food products, and supporting sustainable agricultural systems (Rohallah et al., 2007; Eghtedari et al., 2024). Furthermore, breeding programs facilitate genetic improvement via the selection of desirable traits, like increased milk yield, feed efficiency, reproductive efficiency, and disease resistance (Mohammadabadi et al., 2025), which are essential for maintaining productivity under changing environmental conditions (Javanmard et al., 2008; Ahsani et al., 2022; Gürlek & Atay, 2021). Crossbreeding (CB) has emerged as a key plan to combine the strengths of different breeds, producing hybrids that express heterosis or hybrid vigor. In dairy cattle, CB can improve fertility, health, calving ease, and longevity, thereby enhancing overall herd efficiency (Clasen et al., 2020; Hazel et al., 2021; Obetta & Obande, 2023). Strategic crossbreeding, exclusively between indigenous and commercial breeds, proposes a pathway to balance productivity with genetic conservation. By leveraging the adaptive traits of indigenous cattle, like tolerance to local diseases, heat resistance, and low-input efficiency, together with the high productivity of commercial breeds, CB can help meet both economic and ecological objectives. Animal breeding also performs a fundamental role in global biodiversity conservation, aligning with international initiatives like the Strategic Plan for Biodiversity 2011-2020, which emphasizes the requirement to conserve genetic diversity in domesticated species (CBD, 2020). Integrating traditional and modern breeding methods permits for the preservation of indigenous genetic resources while simultaneously improving production efficiency. For example, the Swedish government and other national programs have supported international action plans to conserve livestock genetic resources. However, the success of such initiatives depends on effective collaboration among farmers, breeding organizations, researchers, and policymakers (Mustefa, 2023). Strategic and scientifically guided crossbreeding programs can therefore serve as a bridge between conservation and economic advancement. When implemented within structured breeding frameworks, these programs can maintain the unique genetic traits of indigenous breeds while improving herd productivity. Such an approach supports both biodiversity conservation and sustainable dairy expansion, ensuring that future generations inherit resilient and productive cattle populations capable of adapting to evolving global challenges.

Materials and methods

Crossbreeding design: Crossbreeding (CB) is broadly distinguished as a practical approach to combine the strengths of different breeds, thereby improving the overall efficiency of the offspring. In species like pigs, poultry, and cattle, CB serves as a critical herd-level plan that enhances biological efficiency. This practice often outcomes in hybrids exhibiting greater vigor, faster growth, increased fertility, and improved adaptability to environmental and management conditions (Clasen et al., 2020; Hazel et al., 2021). In dairy cattle, crossbreeding has demonstrated clear benefits in fertility, health, calving ease, and longevity, contributing to improved herd sustainability and productivity (Obetta & Obande, 2023). In this investigation, an organic production system was simulated under three herd scenarios: (1) purebred Polled Cattle (PB-PC) only, (2) purebred Red Cattle (PB-RC) only, and (3) a two-breed terminal crossbreeding system (T-CB) between PB-PC and PB-RC. In the crossbreeding scenario, only PB-PC animals were applied as breeding candidates, while F1 CB females resulting from RC × PC matings were retained as producing animals. These F1 crossbreds were further inseminated with beef semen to generate beef × dairy crossbred offspring. The T-CB approach was implemented within the same herd structure, such that the virtual herd comprised both purebred and crossbred groups. To ensure economic comparability across the modeled herds, each scenario maintained a surplus of one to three PB calves. In purebred herds, the number of replacement heifers was pre-adjusted by mating selected PB cows with beef semen through the simulation. This adjustment reflected the proportion of PB cows capable of producing crossbred offspring within the CB system. Accounting for fertility patterns, cow longevity, and calf mortality within the simulated population, almost 30% of PB-PC females were mated with PB-RC sires after adjustment. The simulation scenarios were modeled applying an adapted version of the existing SimHerd stochastic model, referred to as SimHerd CCB, expanded to represent crossbreeding schemes at the herd level. This model tracks breed composition and inbreeding coefficients for each animal in the virtual herd across multiple generations. Each scenario was simulated for 35 years to permit the system to reach equilibrium. The announced outcomes represent the mean of 500 replicates, corresponding to the last 10 years of the simulation period (years 25-35). Although full implementation of the CB plan does not need such an extended time frame in practice, the 35-

year simulation ensured stabilization of herd structure and genetic parameters, given that transitions from PB to CB populations are not instantaneous within the SimHerd CCB framework.

Heterosis: Reproduction within extracted populations leads to inbreeding (IB), which reduces genetic diversity and improves the likelihood of expressing deleterious recessive alleles. This process outcomes in inbreeding depression (IBD), a reduction in overall herd fitness created by decreased genomic heterozygosity. The decrease in fertility observed among Holstein cows exemplifies the adverse effects of inbreeding and intense selection for specific production traits, which inadvertently compromise other momentous characteristics like health and longevity (Royal et al., 2000). Inbreeding depression can only be alleviated via outbreeding or crossbreeding with genetically unrelated populations. When unrelated breeds or lines are crossed, the homozygosity of deleterious alleles is disrupted, resulting in offspring that often exhibit superior efficiency compared to the mean of the parental breeds. This phenomenon, known as heterosis or hybrid vigor, is quantified by comparing the relative efficiency of crossbred progeny to the parental average (Upadhyay et al., 2019). The improved efficiency is primarily due to improved heterozygosity, which modifies gene interactions within loci (dominance effects) and among loci (epistatic effects). However, crossbreeding separate pure breeds may also disrupt favorable gene combinations exist in the parental populations, a phenomenon termed recombination loss. Heterosis is effectively the opposite of inbreeding depression, though its magnitude depends on the degree of genetic divergence between the breeds involved. The initial cross (F1 generation) between unrelated lines typically exhibits the highest heterosis (100%). The greater the genetic distance between the parent breeds, the higher the expected heterosis. In contrast, backcrossing a crossbred animal to one of its parent breeds reduces heterosis by almost 50% with each successive generation (Figure 1). Over successive backcrosses, heterosis approaches zero by the eighth generation. In rotational systems, however, heterosis stabilizes over time: two-breed rotational crosses maintain almost 60% of the maximum heterosis, while three-breed rotational crosses preserve about 85%, making the latter the most effective approach for maintaining hybrid vigor across generations. The heterosis effect tends to be more pronounced for traits with low heritability than for those with high heritability (Oakley et al., 2019). In dairy cattle, the greatest heterosis effects are typically observed for reproductive efficiency, health, and survival traits, whereas the smallest effects are found for production traits like milk yield. While F1 crossbreds may exhibit slight disadvantages in certain production characteristics due to recombination loss, their improvements in fertility and health traits generally result in superior overall herd efficiency and longevity.

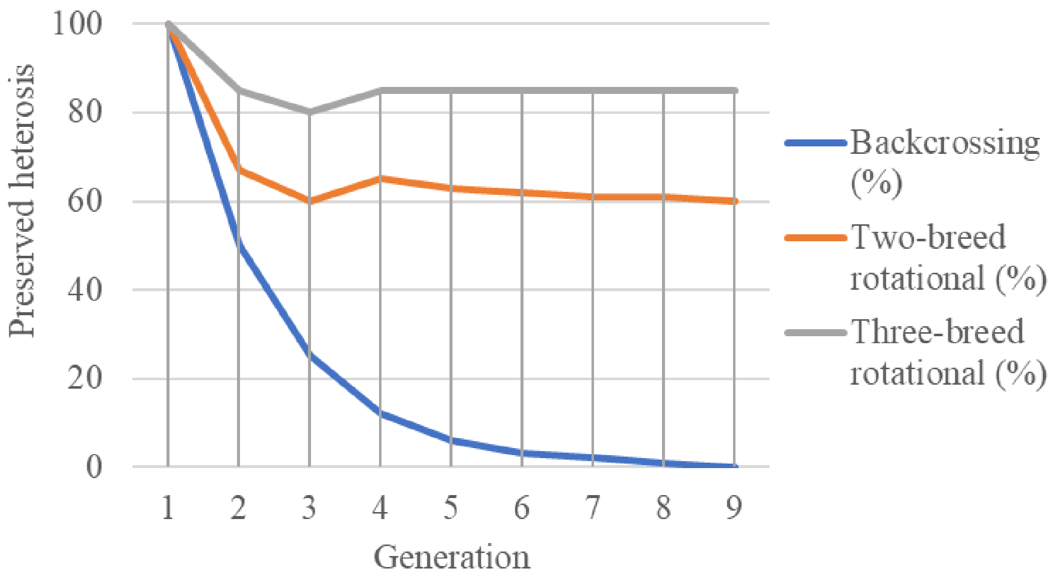


Figure 1. Preserved heterosis across generations in crossbreeding systems

Systematic crossbreeding methods in animal husbandry: The term systematic crossbreeding refers to structured breeding methodologies that follow a defined sequence or rotation of mating between specific breeds within a herd or population. In contrast, unstructured crossbreeding lacks a planned framework and often arises from random or opportunistic matings. In commercial pig and poultry industries, the predominant system is terminal crossbreeding (T-CB). In this approach, crossbred females are not applied for further breeding with the original pure breeds, permitting the retention of maximum heterosis within the F1 generation. The crossbred offspring may be further mated with a third breed or other crossbreds, or the F1 generation may represent the final product of the breeding cycle (Figure 2a). Within large-scale herd or flock-level CB programs, both purebred and crossbred groups can coexist, typically managed as separate but complementary subpopulations. In cattle and sheep husbandry, rotational crossbreeding (Figure 2b) is commonly employed. This system involves mating crossbred females with sires from the breed that is least represented in their ancestry. Two-breed rotational crosses typically stabilize at about 60% retained heterosis after an initial decrease, while three-breed rotations maintain almost 85% heterosis, thereby proposing the most effective mechanism for sustaining hybrid vigor across multiple generations.

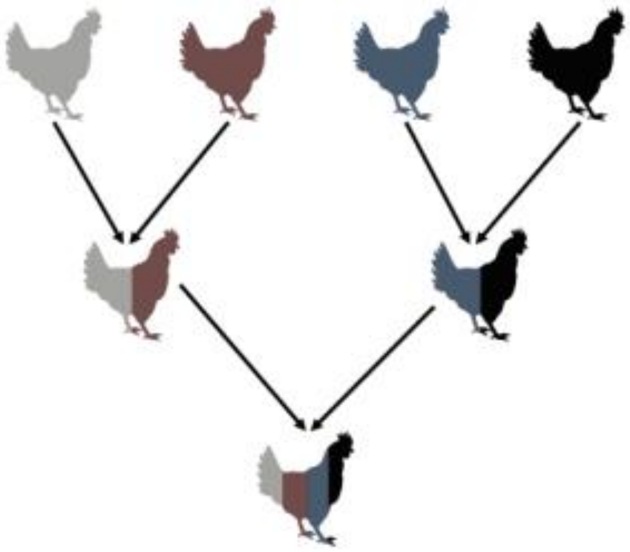


Figure 2a. Terminal crossbreeding (T-CB) process in poultry farming: illustration of hybrid offspring production across generations

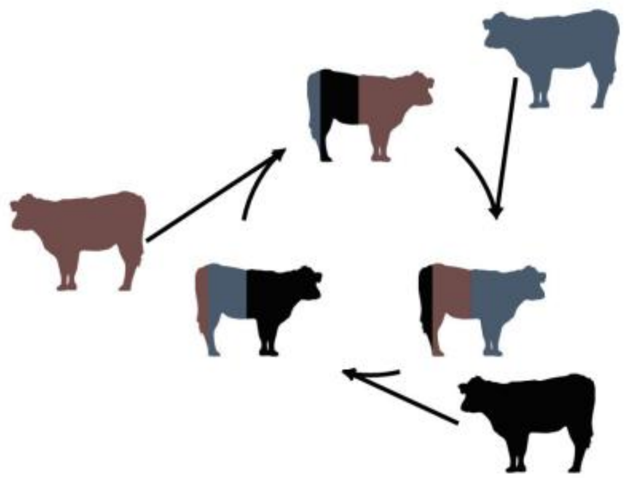


Figure 2b. Rotational crossbreeding (CB) cycle in cattle and sheep husbandry: illustration of multi-generational breeding for sustained heterosis

Crossbreeding in dairy cattle: In spite of the demonstrated advantages of crossbreeding, its application in modern dairy systems has historically been restricted. With the global emphasis on maximizing milk yield, the productivity of dairy cows improved substantially, yet this progress was often accompanied by declining fertility, health, and overall robustness, exclusively evident in seasonal calving systems (Clasen et al., 2021). The reasons for the restricted adoption of CB in dairy cattle across many regions stay complex and multifactorial. Adjustments in breeding goals within purebred populations, along with evolving management strategies, may have temporarily masked or delayed recognition of CB's benefits. Furthermore, the long-standing perception of crossbreeding as a "last resort" for poorly managed herds has contributed to its underutilization. However, recent empirical investigations have challenged this misconception, demonstrating that CB supplies measurable advantages across diverse management systems. As global request grows for resilient and regionally adapted dairy production systems, interest in crossbreeding has been steadily revived among researchers and commercial producers. Experimental programs and commercial herds have successfully implemented rotational CB strategies, exclusively between PB-PC and PB-RC breeds (Nyamushamba et al., 2017). This structured program, now marketed as ProCross2, has gained increasing popularity in numerous regions due to its capacity to enhance herd health, fertility, and adaptability while maintaining economically viable milk production.

Results and discussion

Dairy producers worldwide are increasingly facing rising request for dairy products, growing public concerns regarding animal welfare, and the escalating impacts of climate change (Lukić & Đurić, 2023). These challenges compel farmers to adopt innovative approaches in dairy cattle breeding and management to maintain competitiveness and sustainability (Hempel et al., 2019; Gustavsen & Rickertsen, 2018). The Holstein breed stays the predominant dairy breed globally, primarily due to its exceptional milk production capacity (Khyade et al., 2017). However, prolonged selection centralized exclusively on milk yield has had detrimental effects on the breed's reproductive efficiency and overall health (Miglior et al., 2017). Consequently, minor populations of regionally adapted breeds have demonstrated comparative advantages in fertility, longevity, and resilience. Crossbreeding (CB) such local breeds with high-yielding Holsteins has emerged as an effective plan to generate robust and productive dairy cows capable of delivering both high milk output and improved adaptability (Mackay et al., 2021). Global investigations illustrate that CB proposes a hopeful alternative for achieving a balance between productivity and sustainability in dairy systems. Figure 3 shows the proportion of crossbred cattle across different countries. New Zealand exhibits the highest proportion of CB animals, accounting for 50.5% of its total dairy herd—substantially surpassing other nations. Denmark (12.6%), Sweden (9.5%), France (6.6%), and the United States (5.4%) follow at considerably lower levels. These figures propose that New Zealand's dairy sector demonstrates a strong commitment to crossbreeding, likely enhancing herd efficiency, versatility, and disease resistance (DairyNZ, 2021; Mohamadinejad et al., 2024). Conversely, the relatively restricted adoption of CB in countries like the United States and France may stem from cultural preferences for purebred cattle or breeding objectives better aligned with intensive production systems and specific climatic conditions.

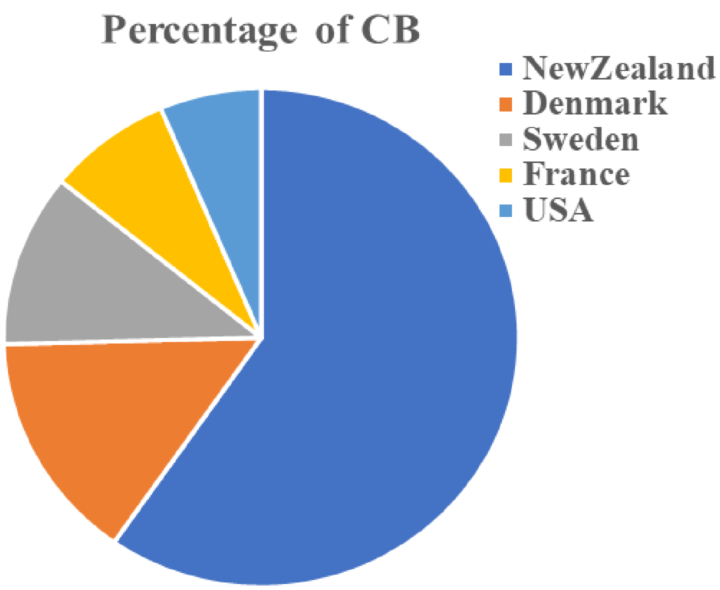


Figure 3. Percentage of crossbred (CB) cattle across different countries: global distribution in dairy farming practices

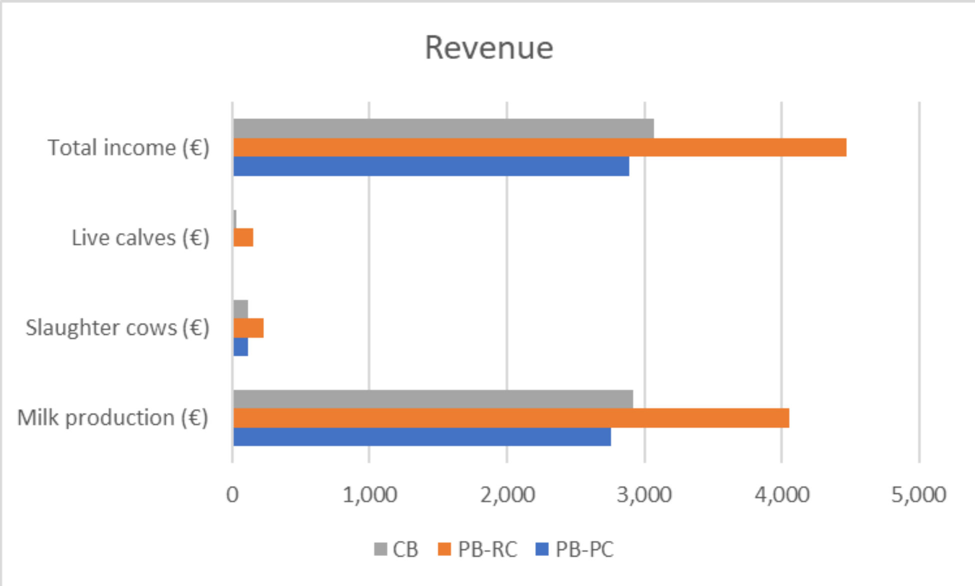
Impact of crossbreeding on purebred populations: The introduction of crossbreeding between high-yielding commercial breeds and indigenous or traditional cattle populations began primarily as an attempt to enhance milk production through the late twentieth century (Widi et al., 2020). However, unregulated "upgrading" of regional breeds has often resulted in the genetic dilution or loss of traditional breeds (TB). For instance, the incorporation of American Holstein sires into the Swedish Red Cattle population, now referred to as the Swedish Holstein, has led to less than 6% of the original Swedish Red genetic composition staying in the population. Similar examples are observed globally, where American Holsteins have been applied to improve numerous native black-and-white breeds, often at the expense of local genetic distinctiveness.

Another example is the Flemish Red breed, which underwent crossbreeding with Danish Red cattle to sustain population numbers. However, this process eventually became unregulated, resulting in a scarcity of pure Flemish Red calves lacking Danish Red genetic impression. Likewise, Danish Red cattle themselves have lost part of their distinctiveness due to uncontrolled introgression from other red breeds in attempts to mitigate inbreeding depression. These examples highlight the potential risks of unregulated crossbreeding, which can lead to genetic homogenization and the erosion of valuable local genetic traits. In contrast, methodical or structured crossbreeding can serve as a powerful tool for conserving native dairy cattle populations while maintaining their economic viability. Different international initiatives have been launched to preserve indigenous cattle breeds, and guidelines for integrating crossbreeding within traditional breed conservation programs have been expanded. Successful conservation efforts in some countries are closely linked to the creation of Protected Designation of Origin (PDO) products derived from traditional breeds, which help secure niche markets and sustain breed populations. However, in regions where consumer request for such specialized products is restricted, indigenous populations continue to decrease in spite of government incentives. Thus, applying crossbreeding as a conservation plan for indigenous dairy cattle warrants further scientific and economic evaluation.

Economic performance of herd systems: Figure 4 shows the projected annual economic outcomes (€/cow) for each scenario in terms of revenue and cost. Among the evaluated systems, purebred Red Cattle (PB-RC) achieved the highest total revenue (€4,469), primarily driven by greater milk income (€4,055) and calf sales (€157). The crossbred herd (CB) achieved a moderate revenue of €3,073, while purebred Polled Cattle (PB-PC) documented the lowest income at €2,887. The cost structure shows only minor variation among systems. PB-RC herds incurred the highest feed costs (€1,369), followed by CB (€992) and PB-PC (€943). Total expenditures for PB-RC reached €1,918; however, this was offset by its meaningfully higher revenues, resulting in the largest contribution margin of €2,552 per cow. Comparative analysis illustrates that PB-RC herds yield the highest economic returns, with a contribution margin exceeding PB-PC by €1,218. Meanwhile, the crossbred system outperformed PB-PC by €181. These results demonstrate that crossbreeding supplies a clear financial advantage over purebred PB-PC systems, although PB-RC stays the most profitable overall. The outcomes emphasize the economic superiority of PB-RC in organic systems and propose that farmers can enhance profitability by incorporating crossbreeding with PB-RC genetics or by transitioning from PB-PC to RC-based herds.

Effect of milk price improves on system profitability: Figure 5 shows the impact of rising milk prices on the economic outcomes of herds containing at least some PB-PC animals (PB-PC and CB scenarios), compared with PB-RC herds. The PB-RC herd maintained a constant income of €2,750 per cow per year, assuming no alter in milk prices. In contrast, both PB-PC and CB herds exhibited positive correlations between income and increasing milk prices. PB-PC herds started with a base income of almost €1,750, while CB herds began at a higher level of €2,500.

As milk prices improved, the CB system showed the greatest financial responsiveness, reaching a revenue of about €3,200 per cow at a 50% price improve, whereas PB-PC achieved €2,500 under the same conditions. These outcomes illustrate that CB systems benefit most from rising milk prices, rendering them the most profitable option under scenarios of increasing market value. Although PB-RC herds generated the highest baseline income, their efficiency did not improve with rising milk prices, proposing that their revenue potential is less elastic than that of other systems. This implies that crossbred herds propose a strategic advantage in market environments where milk prices are expected to rise, exclusively within organic and traditional production frameworks. As milk production levels improve due to genetic progress in PB-RC but stay static in PB-PC, the efficiency gap between PB-PC and the CB herds widens. Consequently, the overall contribution margin per cow-year is notably higher in the CB system, further reinforcing its economic potential.



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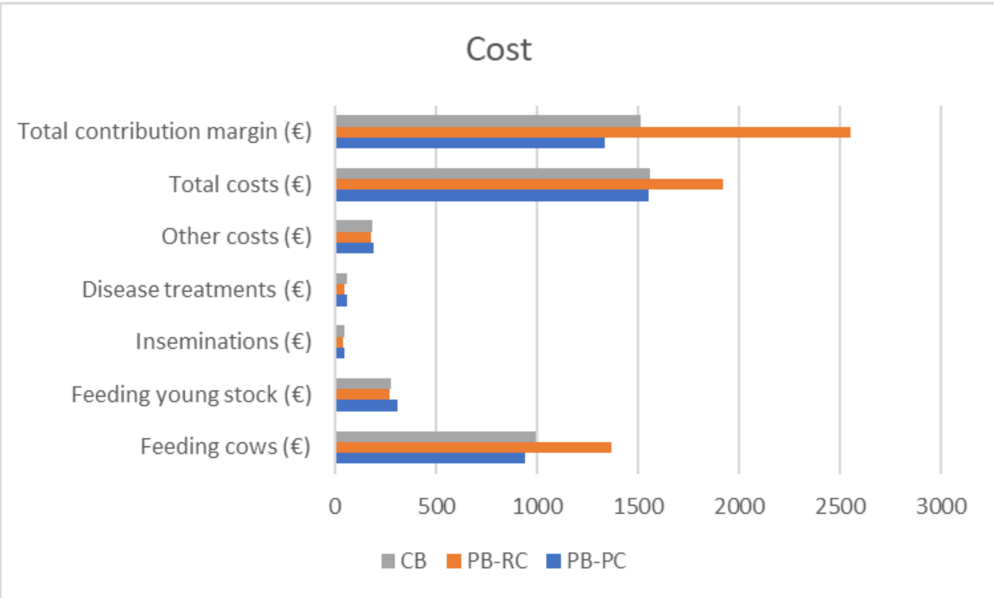

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Figure 4. Economic performance analysis of traditional and organic dairy herds (€/cow). a: Revenue contributions (€/cow) from milk production, slaughter cows, and live calves. b: Cost expenditures (€/cow), containing feeding and total expenses

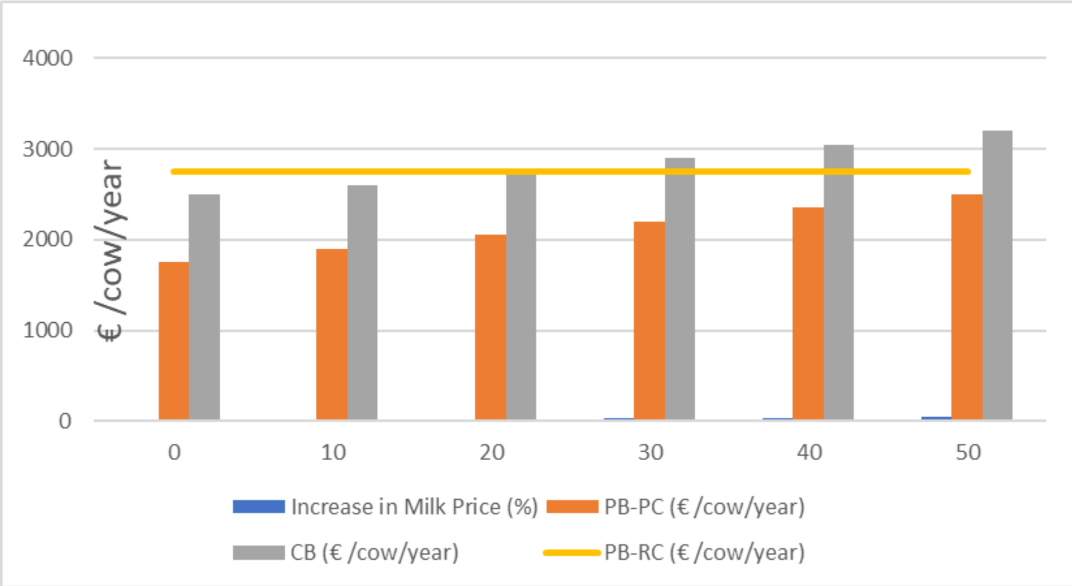

Figure 5. Impact of rising milk prices on economic outcomes for traditional and organic dairy herds across management systems

Conclusion: This investigation analyzed the economic and conservation outcomes of crossbreeding indigenous dairy cattle with commercial breeds under traditional and organic herd management. The simulation scenarios implemented via the SimHerd CCB model included: (1) a herd of purebred Polled Cattle (PB-PC), (2) a herd of purebred Red Cattle (PB-RC), and (3) a mixed herd comprising 70% PB-PC and 30% F1 crossbreds (CB). The integration of terminal crossbreeding (T-CB) strategies, combined with the genetic advantages of selective semen use and efficiency-based genetic evaluation, proved economically beneficial. Crossbreeding between low-yielding traditional breeds and high-yielding commercial breeds meaningfully improved financial efficiency. PB-RC herds achieved the highest total revenue (€4,469), primarily due to superior milk production (€4,055) and calf sales (€157), followed by CB (€3,073) and PB-PC (€2,887). Furthermore, outcomes demonstrated that CB systems exhibit the greatest responsiveness to increasing milk prices, making them the most financially dynamic under variable market conditions. Although PB-RC herds maintained the highest absolute income, their revenue was less flexible in response to market fluctuations. Therefore, crossbreeding represents a strategic option for enhancing profitability, resilience, and long-term sustainability in traditional and organic dairy production systems.

Author Contributions

Manisha Chandna conceptualized the investigation and prepared the original draft of the manuscript. Abhishek Singla contributed to the expansion of the methodology, software implementation, and validation of the investigation. Thiru Chitrambalam carried out formal data analysis and curated the datasets. Bavanilatha M. managed the investigation, coordinated resources, and oversaw experimental execution. Gangandhar Nayak assisted with data visualization and contributed meaningfully to manuscript review, writing, and editing. Arunkumar D. T. supplied overall supervision and project administration. Ramakant contributed via funding acquisition, oversight of study progress, and guidance on scientific direction. All authors reviewed, critically revised, and approved the final version of the manuscript.

Data availability statement

The data supporting the results of this investigation are not publicly available as the manuscript is currently under review. However, the data can be made available from the corresponding author upon reasonable request, subject to institutional and confidentiality guidelines.

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Ethical considerations

This investigation did not involve human participants, experimental animals, or sensitive personal data. Therefore, formal ethical approval was not needed. All procedures and methods were managed in compliance with applicable institutional, national, and international guidelines for study integrity and scientific conduct. The authors affirm that no ethical conflicts arose through the course of this work.

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Conflicts of interest

The authors declare that they have no conflicts of interest, financial or otherwise, related to this investigation. All authors affirm that the content presented in this manuscript is original, and no part of the work has been submitted elsewhere.

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چکیده

هدف: این پژوهش شواهد پراکنده در مورد کارایی اقتصادی تلاقی نژادی گاوهای شیری (CCB) را در مناطق مختلف گردآوری کرده و بر سودآوری و همچنین حفظ ژنتیکی در سامانه‌های شیری سنتی و ارگانیک تمرکز دارد. این مطالعه به ارزیابی پیامدهای اقتصادی و ژنتیکی تلاقی نژادهای بومی با نژادهای تجاری پُربازده در چارچوب‌های متفاوت مدیریت گله می‌پردازد.

مواد و روش‌ها: از مدل شبیه‌سازی تصادفی SimHerd برای بازآفرینی ساختار گله‌ها و ارزیابی راهبردهای اصلاح نژاد استفاده شد. سه سناریو گاوهای خالص اصیل (PB-PC)، گاوهای خالص قرمز (PB-RC)، و گله ترکیبی شامل ۷۰ درصد PB-PC و ۳۰ درصد گاو دورگه نسل اول (F1 CB) بررسی شد. راهبردهای تلاقی نهایی (T-CB) شامل آمیزش نژادهای بومی کم‌بازده با نژادهای خارجی پُربازده بودند. مدل از ابزارهای ژنتیکی مانند اسپرم تعیین جنسیت‌شده و شاخص‌های ارزیابی ژنتیکی برای برآورد کارایی مالی و پتانسیل بهبود ژنتیکی بهره گرفت.

نتایج: شبیه‌سازی‌ها نشان دادند که گله‌های PB-RC بیشترین بازده مالی را داشتند و حاشیه مشارکت آن‌ها ۱۲۱۸ یورو بیش از گله‌های PB-PC بود. گله ترکیبی PB-PC و F1 CB نیز عملکرد بهتری از گله‌های PB-PC خالص داشت و ۱۸۱ یورو حاشیه سود بالاتری ایجاد کرد. تلاقی نهایی همراه با ابزارهای ژنتیکی مدرن، کارایی اقتصادی دامداران کوچک‌مقیاس را افزایش داد؛ درحالی‌که گاوهای دورگه نسل اول سهم مطلوبی از ژن خارجی (۵۲ تا ۶۴/۵) را حفظ کردند. این نتایج نشان‌دهنده تناسب گاوهای دورگه برای سامانه‌های تولید سنتی و ارگانیک کم‌نهاده است.

نتیجه‌گیری: راهبردهای تلاقی نژادی، هنگامی‌که با فناوری‌های نوین ژنتیکی همراه شوند، می‌توانند سود اقتصادی معناداری فراهم آورند و در عین حال از تنوع ژنتیکی پشتیبانی کنند. هرچند گله‌های PB-RC همچنان سودآورترین بودند، اما گله‌های ترکیبی و دورگه پایداری بیشتر در تولید و سودآوری، به‌ویژه برای دامداران خُرد نشان دادند. اجرای برنامه‌های ساختارمند CCB با پشتیبانی زیرساخت اصلاح نژاد و خدمات ترویجی، می‌تواند پایداری و تاب‌آوری اقتصادی را در بخش‌های در حال رشد لبنی ارتقا دهد.

کلمات کلیدی: تلاقی نژادی، گاو اصیل، گاو دورگه نسل اول، گاو قرمز، نژاد خالص

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