Impact of Herd Size on Milk Production in a Dairy Cattle Farm under Semi-arid Climate

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ABSTRACT

Background: This study examines the impact of herd size on milk production in semi-arid regions, where productivity and efficiency are critical. Herd size (HS) is a key determinant of both milk yield and quality.

Methods: Data from 88 farms in the Souss-Massa region, affiliated with the COPAG cooperative, were analyzed to assess total milk yield (TMY), standardized 305-day milk yield (305-dMY), standardized fat yield (MFY), fat content (FC) and lactation duration (LD) in holstein cows.

Result: The average values recorded were: 7052.19±1849.68 kg for TMY, 324.92±42.93 days for LD, 6596.66±1624.99 kg for 305-dMY, 242.18±62.36 kg for MFY and 3.70±0.53% for FC. Large herds (HS>150) showed significantly higher productivity ($p<0.001$), averaging 7360.86 kg for TMY, 6894.98 kg for 305-dMY and 242.33 kg for MFY, though with slightly lower fat content (3.65%). Smaller herds (HS≤30) yielded 6554.44 kg for TMY, 6095.92 kg for 305-dMY and 229.66 kg for MFY, but with higher FC (3.79%). Large farms benefit from modern management, automated health monitoring and optimized nutrition but face challenges such as higher stress, disease incidence and environmental concerns. These results highlight the need for balanced management strategies that enhance productivity while ensuring animal welfare and sustainability in semi-arid dairy farming.

Key words: Dairy farm management, Herd size, Holstein cattle, Milk yield, Semi-arid climate.

INTRODUCTION

The intensification of dairy farming has led to significant changes in herd management worldwide, driven by the need to enhance productivity and reduce costs. As herd sizes grow, their impact on milk production has become a key research focus, with implications for economic efficiency and animal welfare. While large herds generally yield more milk, concerns remain regarding their effects on cattle health, longevity and welfare (Bailey *et al.*, 1997; Adediran *et al.*, 2010).

This study is particularly relevant in the semi-arid Souss-Massa region, where high temperatures and low rainfall pose additional challenges to dairy production. Extreme temperature fluctuations and water scarcity strain farms, necessitating tailored management strategies (ABHSM, 2015; MEMEE, 2015). Heat stress is known to reduce milk yield and alter milk composition, particularly fat content (Mader and Davis, 2004). However, research on herd size effects in such climates remains limited. Prior studies (Grummer and Rastani, 2004; Santschi *et al.*, 2011) highlight that both environmental factors and herd size significantly influence Holstein productivity.

Beyond climate, herd size variability also relates to genetic factors and management practices. Larger herds often face increased incidences of diseases such as mastitis and lameness, which can counteract productivity gains (Grohn *et al.*, 2020; Vries *et al.*, 2014). This study examines the effects of herd size on milk production in Souss-Massa by analyzing 88 farms, aiming to determine how herd optimization can improve productivity in semi-arid conditions.

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Grounded in recent advancements in dairy science, particularly in heat stress management, nutrition and welfare, this research provides actionable insights for dairy farms in challenging climates. Aligning with global trends in herd optimization, it contributes to sustainable dairy farming by balancing productivity and animal welfare (Doyle and Kelly, 1998; Keyserlingk *et al.*, 2012; Miciñsk and Pogorzelska, 2010).

MATERIALS AND METHODS

Climate of the souss-massa region

The Souss-massa region is geographically diverse, bordered by the High Atlas to the north, the Anti-Atlas to the south and the Atlantic Ocean to the west. It includes two

main plains: Souss (4150 km^2) and Massa (1600 km^2) (ORMVA/SM, 2010). The climate ranges from semi-arid to arid, with increasing aridity from west to east and north to south. The Atlantic Ocean moderates conditions in the west, while Saharan winds affect the south and southeast. Average temperatures vary from 14°C in the High Atlas to 20°C in the Anti-Atlas, with the Souss-Massa plain averaging 19°C in winter and 27°C in summer. Summer winds, "Chergui," can reach 49°C, posing challenges for agriculture and livestock (ABHSM, 2015; MEMEE, 2015). Rainfall averages 180 mm annually in the plains, with 70-75% falling from November to March (Fig 1).

Dairy herd management for holstein cattle

Between 2008 and 2012, the regional dairy herd comprised 85000 cattle, including 56000 Holstein dairy cows (95%). Most (74.67%) were in the Souss plain, with the remainder in Massa. The cows originated from local heifers and imports from the U.S.A, France, Germany and the Netherlands. They were housed in open, ventilated paddocks with synthetic windbreaks and misting systems to reduce summer heat stress, improving welfare and productivity (Fig 2). Nutrition was optimized with forage (alfalfa, maize silage, wheat straw) and concentrated feeds (soybean meal, canola meal, corn, molasses, minerals). The region allocated 21844 hectares to forage crops, supporting dairy farming (MAPM/DSS, 2015).

Artificial Insemination (AI) was widely used in cooperative farms with semen from leading dairy countries. After three failed AI attempts, natural mating was used. Imported heifers were inseminated abroad and transferred pregnant to Morocco, maximizing genetic gains and enhancing milk production efficiency.

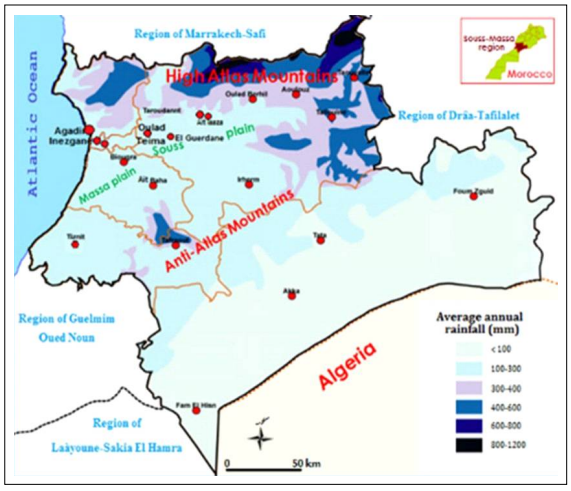


Fig 1: Rainfall map of the Souss-massa Region (MI/DGCL, 2015).

Data source and statistical analysis

This study analyzed data from COPAG, a cooperative in Taroudant, Souss-massa, using official milk control records. Monthly records were collected by trained technicians using the ICAR A4 protocol (ICAR, 2012). The dataset included 8833 lactations from 4797 Holstein cows across 88 farms, recording milk yield, fat content and fat percentage, with total and 305-day standardized yields calculated. Farms were classified by herd size into six categories and ANOVA (SAS 9.2) was used to assess the impact of herd size on milk yield, fat content, lactation length and fat percentage. The chosen methods were designed to evaluate productivity variations in a semi-arid climate. The ICAR A4 protocol ensured consistent data quality through monthly lactation control (ICAR, 2012), aligning with research like Miciñsk and Pogorzelska (2010), which linked herd size with milk composition. The Fleischmann interpolation method, validated by ICAR, bridged data gaps between monthly controls (Idele, 2012). However, it may overlook daily milk yield fluctuations due to short-term environmental changes, as seen in thermal stress studies (Mader and Davis, 2004).

Unlike longitudinal studies tracking individual cows, this cross-sectional design focused on herd-level trends, offering useful management insights but limiting the



Fig 2: An open paddock free-stall housing system for intensive cattle farming.

ability to assess individual cow health over time. Grohn *et al.* (2020) highlighted that intensive herd sizes may harm welfare, especially in hot climates. Future studies could incorporate real-time monitoring for a more dynamic understanding of productivity under climate stress. ANOVA and GLM, consistent with similar studies (Doyle and Kelly, 1998; Smith *et al.*, 1997), helped examine the relationship between herd size and production. However, ANOVA may overlook farm-level management practices, which significantly impact productivity (Adediran *et al.*, 2010).

The study was conducted by the laboratory of plant biotechnology in department of biology, faculty of sciences, Ibnou Zohr university. The research project was initiated in 2021.

RESULTS AND DISCUSSION

The analysis of 88 Holstein herds showed significant variation in dairy productivity, highlighting the influence of herd size and management. Table 1 presents key parameters: TMY, standardized 305-day 305-dMY, MFY, FC and LD. High variation coefficients for 305-dMY (24.63%), TMY (26.23%) and MFY (25.75%) indicate notable disparities in milk quantity and composition. The standardized 305-day milk yield averaged 6596.66±1624.99 kg, with an MFY of 242.18±62.36 kg and FC of 3.70±0.53%. The TMY was 7052.19±1849.68 kg over 324.92±42.93 days, aligning with dairy studies in varied environments (Adediran *et al.*, 2010; Pishchan *et al.*, 2021).

Herd size and production

ANOVA results (Table 2) reveal a highly significant effect of herd size (HS) on all production parameters ($p<0.001$), except for lactation duration (LD), which remains significant ($p<0.01$). Larger herds consistently showed higher yields, with those exceeding 150 cows achieving the highest total milk yield (TMY) at 7360.86 kg. Herds with 90-150 cows followed closely, averaging 7134.66-7186.51 kg. In contrast, the smallest herds (HS≤30 cows) had the lowest TMY at 6554.44 kg, highlighting a strong positive correlation between herd size and productivity. Milk yield variation was substantial across herds. Over a standardized 305-day lactation, production ranged from 3909.23 kg to 8460.52 kg. The standardized 305-day milk yield (305-dMY) also varied significantly ($p<0.001$) across herd size classes, increasing from 6095.92 kg in small herds to 6894.98 kg in large herds (HS>150 cows). However, an exception was noted in the 120-150 cows category, where the average 305-dMY slightly declined to 6698.28 kg. These findings confirm that herd size is a key factor in production efficiency, with larger herds benefiting from economies of scale but potentially facing diminishing returns at certain thresholds.

A detailed analysis of fat yield and lactation length further confirms the impact of herd size on production parameters. Larger herds recorded higher standardized 305-day fat yields (305-d MFY), though they exhibited slightly lower fat percentages and shorter lactation durations. Herds with more than 150 cows achieved an average 305-d MFY of 242.33±1.39 kg but had a lower fat content (FC) of 3.65%. In contrast, smaller herds (HS≤30 cows) produced the lowest fat yield (229.66 kg) but with a higher FC of 3.79%, despite their lower standardized milk yield (6095.92 kg). The moderate decline in fat content as herd size increases suggests that larger herds may prioritize milk volume over composition, influencing overall fat percentages. These findings highlight a trade-off between quantity and composition, emphasizing the need for balanced herd management strategies to optimize both production and milk quality.

Variability within herds and comparative analysis of herd size

Significant variability within herd categories highlights the impact of genetics, microclimatic conditions and farm-specific management. Fig 3 illustrates the influence of herd size on production across the 88 analyzed herds. While larger herds generally achieve higher productivity, production values vary, suggesting that optimizing feeding, housing and health management could further enhance yields. Despite fluctuations, overall productivity remains high, indicating that smaller farms could benefit from adopting efficient practices from larger operations. Milk production among Holstein cows shows substantial variability, with highly significant differences between herds ($p<0.001$). Herd size is the primary factor driving these variations, influenced by genetic potential, environmental conditions and farm management strategies. Management decisions-such as feeding, reproduction and health systems-play a crucial role in determining milk yield. Large-scale farms (>150 cows) consistently outperform smaller

Table 1: Productive performance of holstein cows from 88 herds (n=8833).

Parameters	Mean	SD	Min	Max	CV (%)
Lactation duration (days)	324.92	42.93	240.00	412.00	13.21
Total milk yield (kg)	7052.19	1849.68	1968.70	15612.00	26.23
305-days milk yield (kg)	6596.66	1624.99	1968.70	12855.10	24.63
305-days milk fat yield (kg)	242.18	62.36	59.41	525.20	25.75
305-days fat content (%)	3.70	0.53	1.18	8.45	14.32
Calving age (months)	44.36	17.10	18.67	108.60	38.55

CV: Coefficient of variation; Max: Maximum; Min: Minimum; N: Number of lactations; SD: Standard deviation.

Table 2: Effect of herd size on production parameters of holstein cows from 88 herds.

Classes	n	NH	CA	TMY	LD	305-dMY	MFY	FC
			Mean±SE	Mean±SE	Mean±SE	Mean±SE	Mean±SE	Mean±SE
				***	**	***	***	***
HS≤30 cows	454	16	45.34±0.12	6554.44±72.71^{e}	326.75±2.06^{ab}	6095.92±64.65^{d}	229.66±2.59^{d}	3.79±0.022^{a}
30<HS≤60	2031	36	46.53±0.05	6839.91±41.25^{d}	326.56±0.95^{ab}	6365.99±35.29^{c}	230.54±1.38^{d}	3.65±0.012^{c}
60<HS≤90	1657	15	42.83±0.06	6908.25±43.18^{c}	322.05±1.05^{b}	6493.99±38.15^{cd}	244.98±1.52^{bc}	3.81±0.014^{a}
90<HS≤120	1488	10	42.64±0.06	7186.51±53.38^{b}	326.88±1.13^{a}	6707.65±47.88^{b}	247.15±1.80^{b}	3.72±0.013^{b}
120<HS≤150	1295	6	47.87±0.07	7134.66±45.72^{b}	324.51±1.16^{ab}	6698.28±39.76^{b}	255.33±1.55^{a}	3.84±0.013^{a}
HS>150 cows	1908	5	42.09±0.06	7360.86±42.96^{a}	324.00±0.98^{ab}	6894.98±37.66^{a}	242.33±1.39^{c}	3.65±0.012^{d}

SE: Standard error; HS: Herd size; N: Number of lactations; NH: Number of herds per class. CA: Calving age (months); LD: Lactation duration (days); FC: Standardized fat content (%); MFY: 305 days Milk fat yield (Kg); 305-dMY: 305-days Milk yield (Kg); TMY: Total milk yield (Kg).a,b,c,d,e: Means within columns with different superscripts are significantly different (p<0.05).

herds (≤90), underscoring the importance of modern dairy farming techniques. These farms use intensive rearing systems, housing cows in well-ventilated free-stall barns with high-structure paddocks, shielding them from drafts and extreme heat. Additionally, misting systems help regulate temperature, mitigating heat stress and improving overall productivity.

HS significantly influenced Lactation Duration (LD) (p<0.01), with values ranging from 309.30 to 348.73 days. Smaller herds (HS≤30 and 30<HS≤60 cows) had longer lactations (326.75 and 326.56 days), while larger herds (HS≥120 cows) had shorter durations (»324 days). Small farms extend lactation, though total milk yield depends more on lactation peak than persistence. Feeding management also plays a key role, as cows in well-managed large farms achieve higher yields than those in smaller, subsistence-oriented farms. TMY varied significantly (p<0.001), with herd size playing a major role (p<0.001). TMY ranged from 4233.76 kg to 9012.57 kg, consistently increasing with herd size. Smaller herds (HS≤30 and 30<HS≤60 cows) recorded lower TMY (6554.44 kg and 6839.91 kg), while medium and large herds (HS≥90) produced significantly more (7134.66-7360.86 kg). These results highlight the impact of herd size on production efficiency, reinforcing the benefits of well-equipped, intensive management systems in larger farms. Despite longer lactation durations in smaller herds, production differences stem from management practices. Cows in small herds (HS≤30 and 30<HS≤60 cows) had higher average calving ages of 45.34 and 46.53 months, compared to 42.09 months in large herds (HS≥150). This suggests that large farms optimize productivity by continuously renewing their herds with younger, high-yielding heifers. Older cows negatively impact herd productivity and economic efficiency, reinforcing the advantage of herd renewal strategies in larger, well-managed dairy operations.

Herd size (HS) significantly influenced standard milk yield (305-dMY) (p<0.001), with values ranging from 3724.77 to 8946 kg per 305-day lactation. Small herds (HS≤30) were the least productive (6279.56 kg), while large herds (HS≥150) peaked at 7075.12 kg. However, 305-dMY declined in the 120-150 cows category (6818.78 kg) compared to the 90-120 class (6886.92 kg), likely due to higher calving ages (47.87 vs. 42.64 months). Fat yield (MFY) also varied significantly (p<0.001), increasing with herd size and peaking at 255.30 kg in medium-sized herds (120≤HS<150 cows).

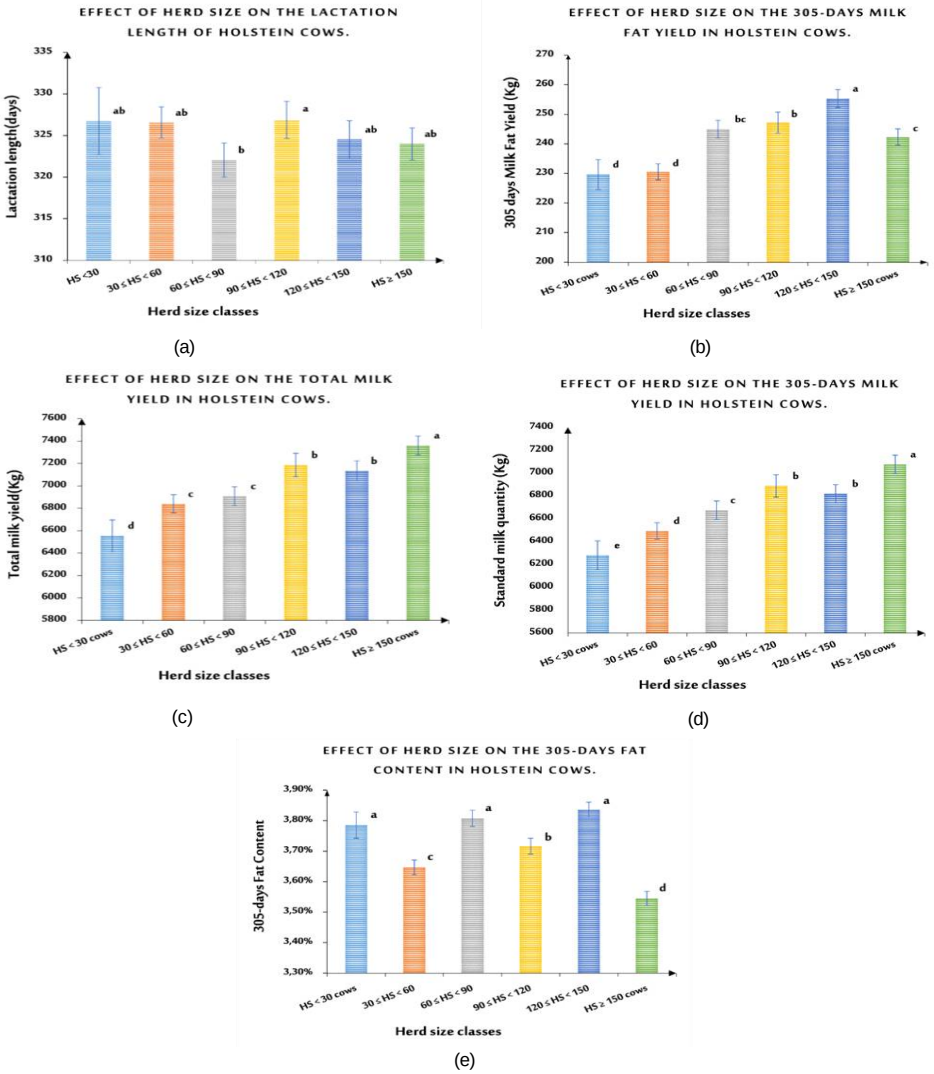
After peaking, fat yield declined in large herds (HS≥150) to 242.33 kg. Smaller herds produced less fat but had higher fat content (3.79%) than large herds (3.54%). This difference stems from lower milk production (305-dMY: 6279.56 kg vs. 7075.12 kg). High FC with low milk yield suggests energy deficiencies, metabolic disorders, or imbalanced feed. Nutrition plays a key role in milk composition (Delaby *et al*., 2003; Cobanoglu *et al*., 2017). Milk fat percentage depends on concentrate type, feed

preparation and distribution. Specific feedstuffs like corn silage and sugar beets enhance FC (Hoden and Coulon, 1991). Small farms should optimize feed management to improve milk quality.

Implications for dairy farm management

A detailed analysis of herd size categories revealed significant differences ($p<0.001$) in most production parameters, except lactation length ($p<0.01$). Herds with 90-120 and 120-150 cows achieved yields similar to larger herds (HS>150 cows), indicating that intermediate-sized herds can perform at levels comparable to large herds. Large herds benefit from optimized management practices, such as free-stall housing and thermal regulation, which mitigate environmental stress. Smaller herds often lack these due to financial or logistical limitations. These findings align with previous studies (Miciñsk and Pogorzelska, 2010; Adediran *et al.*, 2010; Satashia and Pundir, 2021), showing larger herds tend to have higher yields, especially in regions with proper infrastructure and herd management. However, productivity gains in large herds must be balanced with animal welfare, as intensive systems often face health challenges. Farms in semi-arid regions like Souss-Massa should implement advanced cooling systems to reduce heat stress for herds exceeding 150 cows. Additionally, targeted management practices like selective breeding and tailored nutrition can enhance productivity while ensuring animal well-being.

This study highlights the significant role of herd size in determining milk productivity, aligning with broader research that links larger herds to higher yield and efficiency. The positive correlation between herd size and milk yield is consistent with studies by Adediran *et al.* (2010) and Doyle and Kelly (1998), which show that larger herds often



(a). Effect of HS on the lactation length; (b). Effect of HS on the 305-dMY; (c). Effect of HS on the TMY; (d). Impact of HS on MFY; (e). Effect of HS on FC.

Fig 3: The influence of herd size on the production parameters of the 88 herds.

support greater output due to economies of scale and better management (Chanda *at al.*, 2022). Larger herds benefit from specialized infrastructure like free-stall housing and ventilation, which is particularly advantageous in semi-arid regions like Souss-Massa, where thermal stress limits productivity (Mader and Davis, 2004; Talbi and EL Madidi, 2015). Significant variations ($p<0.001$) were observed in milk yield, fat yield and lactation length across herd sizes, indicating the productivity advantages of larger herds. As Grohn *et al.* (2020) and Santschi *et al.* (2011) found, larger herds benefit from advanced management and nutrition, leading to higher yields. However, while herds over 150 cows achieved higher total yield, a slight decline in milk fat percentage was observed, likely due to a focus on milk volume (Krystallis *et al.*, 2009). Smaller herds maintained more consistent fat content (Hill *et al.*, 2009).

These findings suggest that while larger herd sizes boost milk volume, they require specific management adjustments to maintain milk quality, particularly fat content, which is crucial in dairy markets. The data support theoretical models that position herd size as a key productivity factor, as noted by Allore *et al.* (1997). Larger herds benefit from economies of scale, improving feeding, veterinary care and environmental control. Selective breeding in larger herds enhances traits like heat stress resilience, critical in semi-arid areas like Souss-Massa (Vries *et al.*, 2014) and supports improved herd health and sustainability (Neethirajan, 2024). However, larger herds present challenges for animal welfare, with higher disease rates, lameness and mastitis due to crowded housing and limited movement (Garber *et al.*, 1994; Keyserlingk *et al.*, 2012). These issues can be mitigated through welfare-focused management, such as rotational grazing and enriched environments.

For dairy farms in semi-arid regions, cooling systems and shade structures are vital to reduce thermal stress, which impacts both productivity and welfare. Miciñsk and Pogorzelska (2010) recommend misting and shading systems to preserve milk yield and fat content during peak summer months. In regions like Souss-Massa, where high temperatures challenge dairy operations, these cooling systems are essential. Additionally, tailored nutritional regimes for high-yield cows are crucial. Structured feeding approaches that optimize milk output without compromising quality or health are necessary. Balanced nutrition programs, emphasizing forage quality and high-protein concentrates (Smith *et al.*, 1997), can enhance both milk composition and overall yield. These adjustments support sustainable dairy farming, improving productivity while managing environmental constraints.

Intensive farming with large herds boosts productivity but raises concerns about long-term sustainability and animal welfare. Studies show a strong link between large herd sizes and increased disease incidence, particularly mastitis and lameness, which affect milk yield and quality (Barkema *et al.*, 2009). Lievaart *et al.* (2007) found that close physical proximity and poor ventilation in large herds exacerbate disease spread, especially in hot climates. Balancing productivity and animal welfare is essential, as seen in welfare-oriented dairy farming practices in the U.S.A and Netherlands. Garber *et al.* (1994) and Trotz-Williams *et al.* (2008) advocate for regular health monitoring, sufficient space and reduced density to address welfare challenges. Integrating welfare into herd management helps sustain long-term productivity and animal health, which is critical, as poor welfare leads to higher culling rates and decreased reproductive efficiency (De Vries *et al.*, 2020).

The study suggests that dairy farms in semi-arid climates can increase productivity by optimizing herd size and implementing targeted management strategies. However, this must be balanced with animal welfare to ensure sustainability. Future research could explore the effectiveness of welfare interventions like cooling and nutritional adjustments in enhancing productivity without compromising health. Longitudinal studies could also provide insights into the long-term effects of intensive management on herd longevity, offering comprehensive models that consider productivity, welfare and economic viability over time (Dinsmore, 2021). The relationship between herd size, productivity and welfare is complex, requiring careful management. As dairy farms in semi-arid regions expand, balancing these factors will be crucial for developing resilient, sustainable dairy production systems.

CONCLUSION

This study examined the impact of herd size on milk production in semi-arid conditions, focusing on key productivity indicators such as milk yield, fat content and lactation duration in Holstein cattle. The results confirm that larger herds achieve significantly higher milk yields, reinforcing herd size as a key productivity factor. However, managing large herds presents challenges, particularly regarding milk composition and animal welfare. These findings highlight the need for optimized herd management strategies to maximize productivity while maintaining milk quality and animal health. Future research should explore targeted interventions, such as improved housing and cooling systems, to mitigate disease risks and thermal stress in large herds. Longitudinal studies on the long-term effects of intensive farming on herd health and lifespan are crucial for sustainable dairy production.

Advancing herd monitoring through real-time health tracking could provide dynamic insights into climate and density effects on individual cows. Expanding research to other dairy breeds and climates would enhance comparative understanding and support region-specific management strategies. Overall, this study provides a foundation for optimizing herd management in semi-arid regions, balancing productivity and sustainability.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care.

Conflict of interest

All authors declared that there is no conglict of interest.

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