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Heat stress effect on fertility of two imported dairy cattle breeds from different Algerian agro-ecological areas

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Abstract

The present study investigates the susceptibility of two imported dairy cattle breeds to Algerian local climatic conditions, with a primary focus on heat stress (HS) and its repercussions on fertility traits. The dataset comprises 20,926 artificial insemination records involving 6,191 Prim'Holstein and 5,279 Montbéliarde cows. The animals originated from three distinct agro-ecological regions: littoral (L), semi-arid (SA), and arid (Ar), characterized by average annual Temperature-Humidity Index (THI) values of 75.2, 69.53, and 74.75, respectively. Logistic and linear regression models were performed to analyze the relationship between the THI on the AI day, season, and agro-ecological origin of the animals with the Conception Rate at 1st Artificial Insemination (CR 1stAI), Conception Risk (CR), Services per Conception (SPC), and reproductive period (RP). The results demonstrated a significant negative impact ($P < 0.001$) of THI > 72 compared to THI ≤ 72 on CR1st AI and CR for both cattle breeds (Prim'Holstein: -49.7% and − 17%, respectively; Montbéliarde: -20.7% and − 15%, respectively). Seasonal effects revealed a notably higher CR1stAI in winter and spring (≈ 25%) for Prim'Holstein and Montbéliarde cows compared to summer (19.41%) and autumn (19.12%), respectively. Furthermore, a reduced likelihood of conception at 1stAI and subsequent AI was observed during summer (0.839) and autumn (0.818) compared to winter for the Montbéliarde cows. Taking into account the littoral region as a reference, the likelihood of 1stAI success increased for both breeds in the SA region and decreased for the Ar region ($P < 0.001$). SPC increased for both breeds in THI > 72 categories (Prim'Holstein: 6.3%, Montbéliarde: 7.1%, $P < 0.01$), in the Ar region (Prim'Holstein: 30.9%, Montbéliarde: 26%, $P < 0.001$), and in the SA region (4%, $P < 0.05$) compared to the L region No significant seasonal effect on SPC was observed for either breed ($P > 0.05$). The RP increased in the THI > 72 category (Prim'Holstein: 4.1%, Montbéliarde: 7.4%, $P < 0.001$) and in the Ar region (Prim'Holstein: 122%, Montbéliarde: 73.4%) for both breeds. RP decreased in autumn compared to winter (Prim'Holstein: 15.3%, Montbéliarde: 8.4%). This study underscores the adverse impact of mild to severe heat stress (HS) and related factors (season, region) on fertility of Prim'Holstein and Montbéliarde cows under Algerian conditions, emphasizing the necessity for heat stress mitigation strategies, especially in adverse littoral humid and Saharan-arid environmental conditions.

Keywords Climate change · Dairy cattle · Fertility · Heat stress · Temperature humidity index

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Introduction

Extreme weather events are becoming more common and severe due to climate change over recent decades (Lee et al. 2023), with Algeria's temperature increasing by 1.5 to 2 °C, twice the global average (Yerou et al. 2021). The climate is expected to worsen, with Earth's temperature projected to rise by 0.2 °C per decade. According to the Intergovernmental Panel on Climate Change (IPCC, 2014), the global average surface temperature could increase by 1.4–5.8 °C by 2100. Future forecasts also suggest the continued expansion of desert environments (Zeroual et al. 2019).

A marked negative impact of climate change on livestock health and production is the worldwide decline in dairy cattle fertility (Mouffok et al. 2019; Vesel et al. 2020; Correa-Calderón et al. 2022). Heat stress (HS) significantly impairs cattle reproduction by disrupting ovarian follicular growth, particularly affecting preantral follicles, oocytes, and the corpus luteum (Stojanov et al. 2020; Ratsiri et al. 2021; Sammad et al. 2022; Del Río-Avilés et al. 2022; Khan et al. 2023; Kawano et al. 2024). This results from reduced synthesis of estradiol, progesterone, inhibin, and luteinizing hormone (LH), and increased follicle-stimulating hormone (FSH) (Alves et al. 2020; Nanas et al. 2020, 2021; Sammad et al. 2020; Stojanov et al. 2020; Kasimanickam and Kasimanickam 2021; Penev et al. 2021; Wachida et al. 2022; Khan et al. 2023). Temperature changes within the reproductive system further harm fertility, leading to higher embryonic mortality, especially in early pregnancy (Kasimanickam and Kasimanickam 2021; Nanas et al. 2021; Khan et al. 2023). Heat stress during gestation affects the placenta (Nanas et al. 2021), cow's metabolism during lactation (Turk et al. 2020; Chacha et al. 2022), Immunity (Joo et al. 2021; Khan et al. 2023) and the offspring's weight gain (Halli et al. 2021), Mammary (Fabris et al. 2020; Gherissi et al. 2022) and follicular development (Nanas et al. 2021; Cardone et al. 2022; Khan et al. 2023) Longevity (Laporta et al. 2020; Kipp et al. 2021) and reproductive performance (Nanas et al. 2021). In Holstein as well as other cattle breeds, HS reduces sperm motility and increases morphological abnormalities (Sabés-Alsina et al. 2019; Garcia-Oliveros et al. 2020; Netherton et al. 2022). Consequently, HS compromises conception rates, the success of first artificial insemination, and increases the number of services per conception (Djelailia et al. 2020; Nanas et al. 2021; Kaiser Parveen et al. 2022; Khan et al. 2023; Rodríguez-Godina et al. 2024). Current recovery methods still inadequate to restore normal reproduction rates particulary in improved dairy cattle breeds (Khan et al. 2023; de Jesús Mejía-Lastra et al. 2024).

Recent studies reported that the dairy sector incurs annual economic losses due to HS, ranging from over $900 million to as much as $1.5 billion (Liu et al. 2018; Gantner et al. 2019; Sesay 2023). Reduced milk production and lower milk quality directly affect the income of dairy farmers, while increased veterinary costs due to health issues add to the financial burden (Liu et al. 2018; Kim et al. 2019; Wankar et al. 2021). The reproductive challenges caused by high temperatures, such as extended calving intervals and reduced conception rates, result in additional expenses associated with artificial insemination and longer feeding periods (Kim et al. 2019; Sammad et al. 2020). To mitigate heat stress, farmers invest in cooling systems, feed supplements, and additional labor, further increasing costs (Ji et al. 2020; Purwar et al. 2019; Nanas et al. 2021). Culling unproductive cows and replacing them with more heat-tolerant animals also contributes to economic losses (Laporta et al. 2020; Nanas et al. 2021). Insurance and risk management strategies may be necessary to cope with the HS financial risks. Moreover, long-term sustainability is at risk as prolonged heat stress can lead to the degradation of pastures and feed sources (Hossain et al. 2023).

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The present study aims to perform an extensive analysis of the relationship between fertility traits and Temperature-Humidity Index (THI) levels, while also considering various heat stress-related factors including regions and seasons. This analysis is conducted within the framework of the predominant dairy cattle breeds imported into Algeria (Prim'Holstein and Montbéliarde).

Materials and methods

Data collection

Breeding data for the years 2016 to 2019 were obtained from individual cow registration available at the National Center for Artificial Insemination and Genetic Improvement (CNIAAG). This dataset comprised information on 6,191 Prim'Holstein cows and 5,279 Montbéliarde cows, totaling 20,926 insemination records. Specifically, 11,430 inseminations were performed on Prim'Holstein cows, while 9,496 were conducted on Montbéliarde cows. All cows included in the study were considered healthy in the absence of any particular clinical signs during the pre-insemination clinical examination. The inseminations were exclusively practiced by professional inseminators under the supervision of CNIAAG and spanned four-years period (covering three distinct agroecological regions (Fig. 1): The littoral areas: Annaba (36° 53' 60.00" N; 7° 46' 0.01" E), Alger (36° 45' 9.00" N; 3° 02' 31.09" E), and Chlef (36° 09' 54.90" N; 1° 20' 4.27" E), are situated in the east, center, and west and are characterized by the Mediterranean climate (classification of Köppen Csa). The average annual rainfall ranges between 300 and 1000 mm, and the average annual temperature is 18°C. The highland and steppe locations: Batna (35° 33' 21.49" N; 6° 10' 26.90" E), Khenchela (35° 26' 8.99" N; 7° 08' 35.99" E), and Djelfa (34° 40' 22.04" N; 3° 15' 46.80" E) are dominated by a semi-arid climate (classification of Köppen BSk). The annual average temperature is 15.7°C, and the annual rainfall is about 400 mm. Finally, Ghardaia location (32° 29' 27.38" N; 3° 40' 24.49" E) is considered in this study as a desert climate (classification of Köppen BWh). The average annual temperature is about 22.61 °C, and the average rainfall is in the order of 81.1 mm (Zeroual et al. 2017; Cherier et al. 2018; Amirouche et al. 2021). The database included details on the date of the first artificial insemination, subsequent inseminations, pregnancy diagnoses, reproductive periods, estrus type, cow identification, cow breed, breeders, bull data, pregnancy losses, and calving dates.

Meteorological data

The weather underground® website was used to electronically extract the monthly mean values for daily maximum ambient temperature and maximum relative humidity data for insemination day specifically to each study region (Weather Underground, 2016–2019) (McLaughlin et al. 2020; Newcomer et al. 2020). The values for each day's Temperature-Humidity Index (THI) were determined using this data using the following formula (Eq. 1):

$$THI\ max = (1{,}8 * \ Max\,T + 32) - (0{,}55 - 0{,}0055 * H) * \ (1{,}8 * Max\,T - 26)$$

T max = maximum ambient temperature in °Celsius; H = relative humidity in % (National Research Council 1971).

Subsequently, these THI levels were correlated with specific insemination days. The THI readings were categorized into two distinct groups: "Comfortable" when THI ≤ 72 and "Mild - Severe" when THI > 72 (Djelailia et al. 2020; Foris

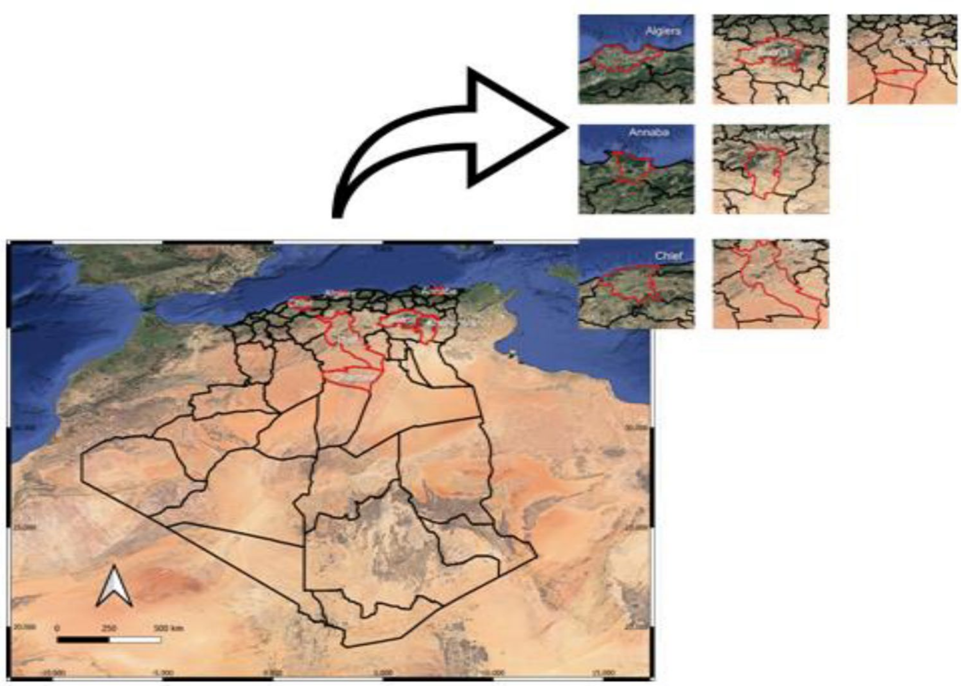

Fig. 1 Map of Algeria displaying the geographic positions where the examined dairy cattle are raised, generated with Qgis

et al. 2023). This dichotomous categorization was undertaken to facilitate robust statistical analysis, enhance the clarity of the study, and gain a deeper understanding of how heat stress impacts the fertility traits of both Prim'Holstein and Montbéliarde cattle breeds. This analysis was conducted while considering variations in THI, season, and agro-ecological regions.

Fertility parameters

The study calculated key fertility parameters. The conception rate following the first artificial insemination (CR1st AI) represents the number of cows that become pregnant after the first artificial insemination. The conception risk (CR) represents the percentage of inseminated cows that become pregnant at each service. The number of insemination services required per successful conception (SPC) represents the number of services necessary for a successful conception. The apparent fertility Index (AFI) was calculated as the ratio of the total number of inseminations carried out on animals confirmed pregnant by the number of pregnant animals, and the reproductive period (RP) represented by the interval between first-last artificial insemination. These parameters were calculated to estimate how is frequently used the AI to obtain pregnancy and how is longer the time after the calving for confirmed conception (Hanzen 1994; Fathoni et al. 2022). In this study, we calculated the apparent fertility index instead of the total fertility index, as it was not possible to measure the latter due to a lack of information on the outcomes (culling or not) of inseminated cows that did not conceive.

Statistical analysis

Data were collected and organized using Excel, with columns containing information such as the date of insemination, THI on the day of insemination, THI classes, number of inseminations per cow, season, and region as independent variables. The results of each insemination were considered as dependent variables. Additionally, reproductive performance metrics, including the CR1stAI, CR, SPC, and RP were calculated for each dairy cow and treated as a second set of categorical variables or continuous variables for the reproductive period. Subsequently, the data were transferred to the SPSS analytical software (IBM SPSS version 26) for statistical analyses. The Chi-square Test was used to compare the insemination results, and outcomes of the first artificial insemination (the CR1stAI and CR) of the two studied dairy cattle breeds across THI, seasons, and regions classes. The statistical significances of the THI-related, seasonal, and regional averages of the RP and SPC were identified for each cattle breed using Kruskal-Wallis test after normality distribution of these continuous variables using Shapiro-Wilk and Kolmogorov-Smirnov tests. To identify the variables influencing dairy cattle fertility performances, logistic regression analyses were carried out. It served to assess the impact of various independent variables on the likelihood of achieving a successful insemination. The general equation for this model was expressed as follows: Logit (Y) = $\alpha + \beta 1 \times 1 + \beta 2 \times 2 + \ldots + \beta nXn$, where Y represents the CR and CR1stAI, α denotes the intercept parameter, and β signifies the logistic regression coefficients for the explanatory effects (X, the daily THI, Season, and Region) incorporated in the statistical model. Furthermore, the generalized linear Model was carried out for SPC and RP: $Y1 = B0 + B1Xi + B2 \times 2 + \ldots\ldots + BnXn$, where Y1 represents the vector SPC and RP, B0 represents the intercept. B1, B2, and Bn are the regression coefficients for X1, X2, and Xn (the daily THI, Season, and Agroecological region). Statistical significance was determined at a threshold of $P < 0.05$.

Results

Critical analysis of the THI changes

Animals reared in different agroecological regions are living under heat stress conditions from May to October in L, from May to September in SA, and from April to October in Ar regions, with THI readings often exceeding the critical level of 72, according to monthly THI statistics (Supplementary Fig. 1a, b, c). THI readings consistently fall within the range of 74 to 90 during this period. In contrast, animals enjoy thermal comfort from November to April in L region, October to May in SA, and November to March in L as THI levels typically range between 53 and 71, remaining below the critical level. The month with the lowest THI value is January, while July registers the highest THI value.

According to the supplementary Table 1. Showing the annual averages of THI in the studied regions, the SA aera is seen to be more comfortable (69.53 ± 13,82), whereas the littoral (75.02 ± 11.66) and arid (74.75 ± 10.06) regions are considered as stressful environments. Furthermore, the Supplementary Fig. 1(d) shows that there are substantial difference between seasonal THI level in the three study regions (L, SA and Ar: $p < 0.001$). Animals in Ar are subjected to stressful conditions for three seasons (spring to autumn), while this condition are seen only for summer and autumn in littoral region. Animals in semi-arid regions are exposed to stressful THI levels for shorter periods, particularly in the summer (85.16 ± 5.72). THI readings rise over the threshold of 72 during stressful times, with summer and autumn

Table 1 Overall and compared fertility traits for Prim'Holstein and Montbéliarde dairy cattle

	Prim'Holstein	Montbéliarde	Overall	Objective	Threshold	*P*-value	Odds ratio
CR1st AI (%)	(1380/6191) 22.29	(1165/5279) 22.07	(2545/11470) 22.19	> 60	< 40	0.031	0.876
CR (%)	(3628/11430) 31.70	(2981/9496) 31.39	(6609/20926) 31.58	> 50	< 40	0.589	
IFA	1.82 ± 0.828	1.79 ± 0.796	1.81 ± 0.814	< 1.5	2	0.214	0.984
RP (days)	49.75 ± 62.088	47.40 ± 58.392	48.68 ± 60.44	< 30	> 30	0.101	

CR1st AI conception rate at the first artificial insemination. IFA: fertility index. CR: Conception Risk. RP: reproductive period

Table 2 Comparison of the fertility parameters between the different modalities of independent factors (THI, season, and region) in the studied dairy cattle population

Factors		CR1st AI		CR		RP		AFI	
		%	Sig	%	Sig	Mean (days)	Sig	Mean	Sig
THI	≤ 72	25.52 (1380/5408)	0.000	33.91 (3270/9644)	0.000	47.96 ± 62.64	0.000	1.76 ± 0.81	0.000
	> 72	19.22 (1165/6062)		29.60 (3339/11282)		49.35 ± 58.34		1.86 ± 0.80	
Season	Winter	25.29 (732/2894)	0.000	33.64 (1701/5056)	0.000	48.70 ± 65.99	0.000	1.75 ± 0.816	0.000
	Spring	23.29 (731/3139)		32.61 (1826/5600)		51.36 ± 63.99		1.78 ± 0.80	
	Summer	19.74 (538/2725)		30.04 (1518/5054)		51.07 ± 59.26		1.84 ± 0.804	
	Autumn	22.19 (544/2712)		29.98 (1564/5216)		43.01 ± 49.59		1.87 ± 0.814	
Region	Littoral	22.26 (1636/7351)	0.000	30.78 (4014/13041)	0.000	46.12 ± 60.76	0.000	1.77 ± 0.78	0.029
	Semi-arid	23.70 (836/3527)		35.91 (2332/6495)		46.45 ± 50.66		1.83 ± 0.78	
	Arid	12.33 (73/592)		18.92 (263/1390)		93.95 ± 88.62		2.33 ± 1.22	

CR1stAI rate conception at first artificial insemination, CR: conception risk, RP: reproductive period, AFI: Apparent fertility index

showing THI levels of 88.05 ± 6.35 and 77.45 ± 8.85, respectively.

Overall dairy cattle fertility level

The reproductive traits of Prim'Holstein and Montbéliarde dairy cattle are illustrated in Table 1. The overall CR1st AI, CR, AFI, and RP were 22.19%, 31.58%, 1.81 ± 0.814, and 48.68 ± 60.44, respectively. It is observed a significantly higher CR1st AI in Prim'Holstein compared to Montbéliarde ($P = 0.031$), while the fertility index, the conception risk, and the reproductive period are not significantly different between the breeds ($P > 0.05$).

Comparison of fertility level according to the THI, season, and region

Table 2 illustrates the impact of THI and THI-related factors (season and region) on dairy cattle fertility parameters. The THI level demonstrates a notable effect on fertility parameters. The CR1stAI and CR decreased significantly ($P < 0.001$) when THI > 72 (19.22% and 29.60%, respectively) compared to the THI ≤ 72 class, during the hot season (19.74% and 30%, respectively) compared to the winter and autumn (spring) and in arid region (12.33% and 18.92%, respectively) compared to the littoral and semi-arid regions. While the RP and AFI increased significantly ($P < 0.001$) when THI > 72 (49.35 days and 1.86, respectively), during the summer (51 days and 1.87, respectively) and in arid region (93.95 days and 2.33, respectively).

Multivariate analysis of reproductive traits

Conception risk (CR %)

The multivariate model in Table 3 demonstrates that the THI and related factors exert a significant negative influence on the CR, resulting in a reduction of 50% and 52% for Prim'Holstein and Montbéliarde, respectively. The THI > 72 was associated with a significant ($P < 0.01$) decrease by about 17% and 15% of the odds of CR in Prim'Holstein and Montbéliarde breeds, respectively. There is no significant ($P > 0.05$) impact of spring (increase of 0 to 2%), autumn (decrease of 8 to 12%), and summer (decrease of

Table 3 Multiple logistic regression of the conception risk CR (%) with THI and THI-related factors (season and region) in Prim'Holstein and Montbéliarde dairy cattle

		Prim'Holstein								Montbéliarde							
		%	**B**	**S.E.**	**Wald**	**Sig.**	**Exp (B)**	**95%CI EXP (B)**	**p (χ2)**	**%**	**B**	**S.E.**	**Wald**	**Sig.**	**Exp (B)**	**95%CI EXP (B)**	**p (χ2)**
Constant			-0,677	0,04	230,27	0.000	0,50				-0,714	0,04	239,42	0.000	0,48		
THI	THI ≤ 72	34.23 (1782/5206)	Reference						0.000	33.6 (1490/4440)	Reference						0.000
	THI > 72	29.66 (1846/6224)	-0,176	0,05	9,76	0,002	0,83	0,75 – 0,93		29.5 (1493/5058)	-0,162	0,06	6,90	0,009	0,85	0,75 – 0,96	
Season	Winter	33.91 (914/2701)			2,35	0,503			0.000	33.4 (787/2357)			5,54	0,136			0.000
	Spring	32.54 (979/3009)	0,002	0,06	0,001	0,972	1,00	0,88 – 1,13		32.7 (847/2591)	0,02	0,06	0,12	0,72	1,02	0,9 – 1,16	
	Summer	29.91 (844/2822)	-0,012	0,08	0,02	0,879	0,98	0,84 – 1,15		30.2 (674/2232)	-0,013	0,08	0,02	0,878	0,98	0,83 – 1,17	
	Autumn	30.68 (889/2898)	-0,076	0,06	1,27	0,26	0,92	0,81 – 1,05		29.1 (675/2318)	-0,118	0,07	2,50	0,113	0,88	0,76 – 1,02	
Region	Littoral	31.10 (2048/6585)			138,59	0.000			0.000	30.5 (1967/6457)			29,27	0.000			0.000
	Semi-arid	36.4 (1452/3992)	0,229	0,04	28,62	0.000	1,25	1,15 – 1,36		35.2 (881/2504)	0,213	0,05	17,95	0.000	1,23	1,121-1,366	
	Arid	15 (128/853)	-0,941	0,1	89,18	0.000	0,39	0,32 – 0,47		31.4 (2983/9498)	-0,281	0,10	7,41	0,006	0,75	0,616-0,924	

B Coefficients, S.E: Standard Error, Sig: Significance, Exp(B): The odds ratio, 95% CI EXP(B): Confidence Interval

2%) seasons on CR compared to winter season (reference season) for both dairy cattle breeds. When comparing the semi-arid and arid regions with the littoral region (reference region), a significant decrease in the odds of CR was observed in the arid region for both Prim'Holstein (-61%; $p < 0.001$) and Montbéliarde (-25%; $p < 0.01$) breeds. Conversely, there was a significant increase in the odds of CR for both breeds when AI was practiced in dairy cattle originating from the semi-arid region (Prim'Holstein: 25% and Montbéliarde: 23%; $p < 0.001$).

Conception rate at first artificial insemination (CR1stAI %)

Table 4 presents the outcomes of the multivariate model of CR1stAI according to THI and THI-related factors. There is a significant negative effect of THI > 72 ($p < 0.01$) on CR1stAI, with Prim'Holstein showing a decrease of approximately 49.7% and Montbéliarde of about 20.7%. The odds of CR1stAI in Prim'Holstein increased by approximately 44% during the spring ($p < 0.01$) compared to winter. However, there were no significant odds changes for the summer and autumn seasons ($p \geq 0.05$). This parameter did not show any significant relationship with the seasons of AI practice in the Montbéliarde breed. As for CR1stAI parameter, animals living in semi-arid regions compared to those in the littoral region had the best CR1stAI scores, with significantly positive odds ratios for both breeds (Prim'Holstein: 37.8%, $p < 0.01$; Montbéliarde: 56.1%, $p < 0.001$). Under arid region, Montbéliarde dairy cattle, unlike Prim'Holstein, exhibited a significant negative impact on CR1stAI compared to those living in the littoral region (52%, $P = 0.001$; 32%, $P > 0.05$; respectively).

Services per conception (SPC)

Table 5 presents the impact of THI classes, seasons, and regions on SPC for the Prim'Holstein and Montbéliarde breeds. The models significantly explained the pattern of change in SPC according to the indicated risk factors in both dairy cattle breeds ($P < 0.001$). The regression analysis indicates that animals inseminated when THI > 72 showed positive slope with a significant ($P < 0.01$) increase in SPC of 6.3% and 7.1% compared to those inseminated at THI ≤ 72 for Prim'Holstein and Montbéliarde breeds, respectively. Compared to the winter season (reference season), there were no prominent seasonal changes in SPC. A non-significant decrease of approximately 4.4% was observed during autumn for Prim'Holstein cattle, while Montbéliarde breed showed a slight decrease of 3.4% during the summer season ($P > 0.05$). The spring season also did not show any significant impact on SPC compared to winter. Moreover, comparing to L areas, Ar areas results in a significant ($P < 0.001$) increase of 30.9% and 26%, and SA causes an SPC increases ($P < 0.05$) of 4% for the same cattle breeds.

Reproductive period (RP)

Table 6 illustrates the relationship between THI classes, seasons, and regions in relation to the reproductive period (RP) of Prim'Holstein and Montbéliarde dairy cattle. The generalized linear model significantly explained the variation in RP according to THI and THI-related factors for the two breeds ($P < 0.001$). The animals inseminated at THI > 72 showed a significant higher RP of 4.1% ($P < 0.001$) and 7.4% ($P < 0.001$) for Prim'Holstein and Montbéliarde, respectively. In other hand, we recorded a lower RP of 15.3% for Prim'Holstein ($P < 0.001$) and of 8.4% for Montbéliarde ($P < 0.001$) cows inseminated in autumn season compared to winter and non-significant difference for those inseminated during the summer season ($P > 0.05$). Animals living in arid areas exhibit significantly higher odds of having increased RP (Prim'Holstein: 2.229, $P < 0.001$; Montbéliarde: 1.734, $P < 0.001$). These areas are characterized by high THI levels and harsh living conditions for dairy cattle, as previously reported in subchapter 1. Moreover, compared to the L region, Prim'Holstein cows exhibit a modest increase in RP averaging about 4%, while Montbéliarde cows show a slight decrease of about 3% in SA regions.

Discussion

The Prim'Holstein and Montbéliarde cattle breeds, renowned for their high milk production potential, are integral to Algeria's dairy industry. However, the prolonged impact of environmental factors on their fertility raises significant concerns regarding the sustainability and productivity of dairy farming. Our study aims to comprehensively assess the influence of heat stress on the fertility levels of these two prominent dairy cattle breeds imported into Algeria. This is particularly crucial as Algeria, like other North African regions, faces the looming threat of worsening heat stress challenges, exacerbated by alarming reports of further desertification (Zeroual et al. 2019; Yerou et al. 2021). Indeed, we tend to provide valuable insights by unraveling the complex interplay between environmental stressors, breed characteristics, and reproductive outcomes.

The overall fertility of the studied dairy cattle, as shown by the CR1stAI of 22.19% and the overall conception rate CR of 31.58%, was lower than the recommended objectives. Prim'Holstein dairy cows exhibited a slightly higher CR1stAI compared to Montbéliarde breeds (22.29% vs. 22.07%, $p = 0.031$), while the CR was comparable for

Table 4 Multiple logistic regression of the Conception Rate at First Artificial Insemination CR1stAI (%) with THI and related factors (season and region) in Prim'Holstein and Montbéliarde dairy cattle

		Prim'Holstein								Montbéliarde							
		%	B	S.E.	Wald	Sig.	Exp (B)	95%CI EXP (B)	p ($\chi 2$)	%	B	S.E.	Wald	Sig.	Exp (B)	95%CI EXP (B)	p ($\chi 2$)
Constant			0,339	0,088	14,868	0.000	1,404			-	0,424	0,09	22,315	0	1,528		
THI	THI ≤ 72	25.46 (730/2867)	Reference						0.000	25.58 (650/2541)	Reference						0.000
	THI > 72	19.55 (650/3324)	-0,679	0,129	27,82	0.000	0,507	0,394–0,653		18.81 (515/2738)	-0,232	0,122	3,642	0,056	0,793	0,62 – 1,00	
Season	Winter	25.12 (380/1513)			11,222	0,011			0.000	25.49 (351/1381)			9,826	0,02			0.000
	Spring	23.58 (400/1696)	0,366	0,135	7,343	0,007	1,442	1,107–1,879		22.94 (331/1443)	0,171	0,128	1,786	0,181	1,187	0,92 – 1,52	
	Summer	19.41 (292/1504)	0,35	0,177	3,934	0,05	1,42	1,004 – 2,007		20.15 (246/1221)	-0,176	0,168	1,091	0,296	0,839	0,60 – 1,16	
	Autumn	20.84 (308/1478)	0,058	0,152	0,145	0,704	1,06	0,787–1,427		19.12 (236/1234)	-0,2	0,146	1,895	0,169	0,818	0,61 – 1,08	
Region	Littoral	22.41 (827/3690)			12,796	0,002			0.000	22.10 (809/3661)			37,613	0.000			0.000
	Semi-arid	24.01 (518/2157)	0,321	0,108	8,807	0,003	1,378	1,115–1,703		23.21 (318/1370)	0,445	0,094	22,502	0.000	1,561	1,29 – 1,87	
	Arid	10.17 (35/344)	-0,383	0,23	2,773	0,096	0,682	0,434–1,07		15.32 (38/248)	-0,734	0,225	10,617	0,001	0,48	0,30 – 0,74	

B Coefficients, S.E: Standard Error, Sig: Significance, Exp(B): The odds ratio, 95% CI EXP(B): Confidence Interval

both breeds. The CR1stAI is lower than that previously reported by Mouffok et al. (2019) on Holstein and Montbéliarde breeds in eastern Algeria, by Souames and Berrama (2020) in north Algeria, and by Haou et al. (2021) in northeast Algeria. Comparable levels of CR were observed by (Koch et al. 2022). A similar observation was made by Haou et al. (2021) indicating a higher level of CR1stAI for Prim'Holstein than for Montbéliarde breeds. These results were contradictory to previous studies that claimed lower reproductive performance for Holstein breeds due to their high milk production. However, this may not be applicable to the reported studies as the production level is often below the actual genetic potential of this breed due to environmental factors (heat stress, feed availability, etc.) and management practices (welfare, heat stress management, health, etc.).

Logistic regression analysis revealed that a THI > 72 significantly and negatively impacts CR1stAI, with a higher impact on Prim'Holstein (odds ratio of 50%) compared to Montbéliarde (odds ratio of 20%). This suggests that Prim'Holstein cows are more susceptible to heat stress, likely due to their higher metabolic heat production (Correa-Calderón et al. 2022) and higher cortisol secretion (Nedić et al. 2017; Vesel et al. 2020) as a physiological adaptation associated with the onset of lactation and production peak in the postpartum period. This breed-dependent susceptibility was confirmed by the seasonal analysis of CR1stAI levels. Similarly, a significant decrease in CR when the THI > 72, with a more pronounced decline observed in Prim'Holstein compared to Montbéliarde breeds (17% vs. 15%). This aligns with previous research by Rhoads (2020), Shi et al. (2021), Kaiser Parveen et al. (2022), Rolando et al. (2022), and Ooi et al. (2023), which noted a decrease in CR with increasing THI levels. Studies reported declines ranging from 1.74% (Rolando et al. 2022), 15% (Shi et al. 2021), or 1.2% (Ooi et al. 2023) for every unit increase in THI, and even more substantial reductions of 50% in Sahiwal cows (Kaiser Parveen et al. 2022), and 50.12–61% in Holstein (Rhoads 2020) with rising THI values. Dairy cows exposed to high THI levels were 63–80% less likely to conceive (Schüller et al. 2016), attributed to elevated body temperature reducing uterine blood flow, nutrient availability, and hormone levels, thereby altering the follicular microenvironment and impeding sperm fertilization and embryo development (El-Sherief et al. 2022; Kaiser Parveen et al. 2022). Moreover, heat stress affects dry matter intake and may exacerbate negative energy balance, impacting oocyte development, uterine synchronization, conception, fertilization, and embryo development, leading to adverse outcomes such as abortion, anestrus, and repeat breeding (Kaiser Parveen et al. 2022).

Table 5 Multiple linear regression of the services per conception (SPC) with THI and related factors (season and region) in Prim'Holstein and Montbéliarde dairy cattle

	Prim'Holstein							Montbéliarde						
	mean	B	S. E	95% Wald CI	Sig.	Exp(B)	95% Wald CI Exp(B)	Mean	B	S. E	95% Wald CI	Sig.	Exp(B)	95% Wald CI Exp(B)
Intercept		0.566	0.0162	0.54–0.60	0.000	1.762	1.71–1.82		0.532	0.0166	0.5–0.57	0.000	1.703	1.65–1.76
THI ≤ 72	1,79 ± 0.85	0[a]	Reference			1		1,75 ± 0.80	0[a]	Reference			1	
[THI > 72	1,85 ± 0.81	0.061	0.0211	0.02–0.10	0.004	1.063	1.02–1.11	1,84 ± 0.79	0.069	0.0223	0.025–0.11	0.002	1.071	1.03–1.12
Winter	1,82 ± 0.88	0[a]	. Reference			1	.	1,75 ± 0.84	0[a]	Reference.			1	
Spring	1,82 ± 0.82	-0.015	0.0219	-0.06–0.03	0.501	0.985	0.94–1.03	1,79 ± 0.78	-0.001	0.0232	-0.05–0.044	0.954	0.999	0.95–1.05
Summer	1,85 ± 0.81	-0.041	0.0296	-0.10–0.02	0.162	0.959	0.91–1.02	1,81 ± 0.79	-0.035	0.0318	-0.10–0.03	0.278	0.966	0.91–1.03
Autumn	1,80 ± 0.79	-0.045	0.0258	-0.1–0.01	0.079	0.956	0.91–1.01	1,83 ± 0.76	0.007	0.0271	-0.05–0.06	0.789	1.007	0.96–1.06
L	1,78 ± 0.81	0[a]	Reference			1	.	1,75 ± 0.77	0[a]	Reference			1	
SA	1,84 ± 0.79	0.04	0.0156	0.01–0.07	0.01	1.041	1.01–1.07	1,82 ± 0.76	0.041	0.0181	0.01–0.08	0.024	1.042	1.01–1.08
A	2,32 ± 1.27	0.269	0.0364	0.20–0.34	0.000	1.309	1.22–1.41	2,19 ± 1.17	0.231	0.0375	0.16–0.31	0.000	1.26	1.17–1.36

B Coefficients, S.E: Standard Error, CI (95%): Confidence Interval, Sig: Significance

According to the seasonal impact, the Prim' Holstein cows showed significant seasonal variation in CR1stAI, with a decrease in summer and an increase in spring, while Montbéliarde cows did not exhibit significant seasonal changes. However, our findings reveal a discrepancy between THI and seasonal influences on CR. Earlier studies indicated a higher likelihood of CR1stAI during winter, followed by spring (Ouarfli and Chehma 2018b; Mouffok et al. 2019), and a decline in CR1stAI with increased temperature (Borş et al. 2019), while the CR is higher in spring and early summer compared to late summer, autumn, and winter (Koch et al. 2022). Significant differences in the seasonal impact on CR1stAI rates between breeds were observed, with Montbéliarde cows being more susceptible during the autumn (Mouffok et al. 2019) and Prim' Holstein cows during the summer (Hagiya et al. 2017; Nguyen-Kien et al. 2017). Seasonal variations in cattle conception reveal a complex pattern influenced by geographical and bioclimatic conditions. Koch et al. (2022) reported higher CR in spring and early summer, while Correa-Calderón et al. (2020), Nanas et al. (2021), and Guinn et al. (2019) observed increased CR during winter. Specifically, Nanas et al. (2021) noted a 10–15% higher conception likelihood in winter for Holstein cattle. These seasonal effects on CR sometimes show a disjunctional relationship with stressful temperature-humidity index (THI) levels, suggesting that multiple factors are at play. The seasonal compromise of cattle fertility in North Africa can be attributed to a combination of elements, including daylight length (Koch et al. 2022), management practices, feed quality (Mouffok et al. 2019), disrupted postpartum biochemical statuses, negative energetic balance (Chacha et al. 2018, 2022), decreased welfare levels (Kechroud et al. 2023), increased incidence of udder health constraints (Gherissi et al. 2022). This multifaceted interplay underscores the complexity of reproductive performance in cattle across different seasons and environments.

Regional differences in reproductive performances were also registered. Animals from the SA region expressed higher CR1stAI (23.70%) and a significant positive likelihood of CR1stAI for both breeds. In contrast, dairy cows from the Ar region experienced a significant decrease in CR1stAI, with Montbéliarde cows showing a decline and Prim'Holstein cows facing an even more pronounced drop of CR. The L and Ar areas experience extended periods of exposure to HS compared to SA region (from May to September). The SA region provides a more comfortable and less stressful environment for animals, reflected in a lower THI level (69.53) and higher CR. This fertility pattern aligns with previous findings in Holstein cattle in both northern (Littoral) and arid regions of Algeria (Merdaci and Chemmam 2016; Ouarfli and Chehma 2018b) and highlights the link between reproductive performance and environmental

Table 6 Multiple linear regression of the Reproductive Period (days) with THI and related factors (season and region) in Prim'Holstein and Montbéliarde dairy cattle

	Pri'Holstein							Montbéliarde						
	Mean	B	S.E.	95% Wald CI	Sig.	Exp(B)	95% Wald CI Exp(B)	Mean	B	S.E.	95% Wald CI	Sig.	Exp(B)	95% Wald CI Exp(B)
Intercept		3,838	0,0043	3,83 – 3,85	0.000	46,448	46,06–46,84		3,788	0,0046	3,78 – 3,80	0.000	44,167	43,77 – 44,57
THI ≤ 72	49,42 ± 64.37	0a	Reference			1		46,30 ± 60.57	0	Reference			1	
THI > 72	50,04 ± 60.01	0,04	0,0056	0,03 – 0,05	0.000	1,041	1,03 – 1,05	48,47 ± 56.19	0,071	0,0061	0,06 – 0,08	0.000	1,074	1,06 – 1,09
Winter	51,25 ± 68.78	0	Reference			1		45,79 ± 62.59	0	Reference			1	
Spring	51,27 ± 63.00	0,016	0,0058	0,01 – 0,03	0,005	1,016	1,01–1,03	51,47 ± 65.19	0,096	0,0064	0,08 – 0,11	0.000	1,101	1,09 – 1,12
Summer	52,89 ± 62.90	-0,012	0,0077	-0,03 – 0,003	0,104	0,988	0,97 – 1,003	48,78 ± 54.32	-0,006	0,0087	-0,03	0,481	0,994	0,98 – 1,01
Autumn	43,18 ± 51.54	-0,166	0,0069	-0,18 – 0,15	0.000	0,847	0,84 – 0,86	42,80 ± 47.09	-0,088	0,0077	-0,03	0.000	0,916	0,90 – 0,93
L	46,08 ± 62.28	0	Reference			1		46,15 ± 59.16	0	Reference			1	
SA	47,50 ± 51.15	0,047	0,0043	0,04 – 0,06	0.000	1,048	1,04 – 1,06	44,76 ± 49.84	-0,03	0,0052	-0,02	0.000	0,971	0,96 – 0,98
A	103,22 ± 93.50	0,802	0,0064	0,79 – 0,81	0.000	2,229	2,20 – 2,26	80,81 ± 79.59	0,55	0,0083	0,53 – 0,57	0.000	1,734	1,71 – 1,76

B Coefficients, S.E: Standard Error, CI (95%): Confidence Interval, Sig: Significance

factors across different agroecological regions (Khan et al. 2023; Mouffok et al. 2019; Haou et al. 2021; Eulmi et al. 2023). High temperatures and humidity disrupt estrous cycles, lower conception rates, and affect embryo development and uterine conditions (Djelailia et al. 2020; Kasimanickam and Kasimanickam 2021; Nanas et al. 2021; Kaiser Parveen et al. 2022; Khan et al. 2023; Rodríguez-Godina et al. 2024). Additionally, climate conditions affect forage quality (Hart et al. 2022; Cooke et al. 2023; Tamboli et al. 2023) and availability (Cooke et al. 2023; Tamboli et al. 2023) directly influence nutrition and body condition score, impacting reproductive health (Tamboli et al. 2023). Water scarcity compounds these challenges (Broucek 2019; Assan 2022; Singh et al. 2022), affecting hydration critical for metabolic processes and thermoregulation (Assan 2022). Disease and parasite pressures vary geographically (Haymanot and Kaba 2022; Eulmi et al. 2023), with particular high prevalence and parasitic intensity are observed in littoral region (Meguini et al. 2021) further compromising fertility. It is mandatory to point out that in addition to climate changes, differences in reproductive practices may also contribute to these regional variations. For instance, the majority of registered inseminations in our study were performed in the littoral region, while 74% of breeders in the southern region preferred natural mating to AI (Bensaha and Arbouche 2014; Eulmi et al. 2023). Previous research on Holstein cattle by Guinn et al. (2019) also highlighted variations in CR among regions with low and high THI levels, with lower CR observed in areas with higher THI. Heat stress's impact on CR is attributed to compromised ovarian activity postpartum, quiet ovulation, and anestrus (Damarany 2020).

In our study, the recorded fertility index was 1.81 ± 0.814, with no significant differences observed between the two dairy cow breeds (1.82 ± 0.828 for Prim'Holstein and 1.79 ± 0.796 for Montbéliarde breeds). Similar results were reported in previous studies in Algeria by Souames and Berrama (2020) and Haou et al. (2021), while Mouffok et al. (2019) showed lower fertility. Mouffok et al. (2019) and Haou et al. (2021) demonstrated significant differences in fertility between breeds, likely influenced by milk production performances affecting cow fertility. Generalized Linear models analysis of the SPC parameter revealed that THI > 72 was associated with an increase in SPC, with a greater effect observed in Montbéliarde compared to Prim'Holstein breeds. Previous studies showed increased insemination frequency coupled with decreased fertility as THI reaches stressful levels (Djelailia et al. 2020; Ouarfli and Chehma 2018b). Recent study, showed the long-term consequences of prolonged thermal stress on bovine fertility (El-Bakly et al. 2023). In arid areas, where high temperatures are more prevalent, SPC increased for both studied breeds, with region L exhibiting the highest AFI. Previous studies performed in Algerian dairy cattle have demonstrated superior fertility indices in semi-arid regions, but also variability in fertility between breeds based on their rearing locations and ability to cope with local thermal conditions (Chacha et al. 2018; Mouffok et al. 2019; Eulmi et al. 2023; Lamari and Saber 2021). The detrimental effects of high THI levels and heat stress-related factors on SPC are primarily attributed to reduced intrauterine blood circulation resulting from increased uterine temperature (Siatka et al. 2017). This physiological response to elevated body temperature underscores the intricate interplay between seasonal thermal variations, regional climatic influences, and the body's thermoregulatory responses, all of which significantly affect dairy cattle reproductive outcomes. The heat stress and seasonal effects on SPC show a disparate relationship of THI levels on the day of AI and the season, indicating that multiple factors are involved. Heat-dissipation capabilities are one of the most important breed-related factors of reliance to HS. Factors such as coat characteristics, including color and hair diameter (Lamari et al. 2018), play a crucial role in an animal's ability to regulate body temperature under hot conditions. Additionally, variations in milk production levels (Siatka et al. 2017) contribute to differing heat stress responses among breeds. Particularly, high milk-producing animals often exhibit lower fertility when subjected to heat stress, indicating a physiological trade-off between milk production and reproductive efficiency in thermally challenging environments (Purohit et al. 2020; Sesay 2023). This competitive relationship underscores the complex interplay between elevated temperatures, heat stress, and the biological functions of dairy cattle.

Our data analysis revealed an average RP of 48.68 ± 60.44 days, exceeding findings from previous studies in Algeria (Akkou et al. 2022; Haou et al. 2021) and Italy (Toledo-Alvarado et al. 2017), but shorter than reported by Miroud et al. (2014). Crucially, RP increased at mild to severe THI levels, highlighting the direct impact of elevated temperatures on reproductive physiology. Seasonal temperature variations significantly affect RP, with a decrease observed from winter to autumn. This seasonal effect is more pronounced in Prim'Holstein (12.6% decrease) compared to Montbéliarde breeds. Under Algerian breeding conditions, Haou et al. (2021) observed breed-specific differences in RP, with Prim'Holstein breeds showing higher RP compared to Montbéliarde breeds. This prolonged RP is related to an increased number of services per conception and extended inter-service periods (Sammad et al. 2020; Shi et al. 2021; Fathoni et al. 2022; Tadesse et al. 2022), particularly due to reduced estrus detection efficiency and impaired follicular development (Guinn et al. 2019; Shi et al. 2021; Tadesse et al. 2022).

The reproductive efficiency differences between Montbéliarde and Prim'Holstein dairy cows stem from physiological, genetic, and management factors, with heat stress playing a crucial role. Prim'Holstein dairy cattle experience more severe negative energy balance post-calving (Pires et al. 2015; Merdaci et al. 2024), due to higher milk production, leading to delayed ovulation and reduced fertility (Pires et al. 2015; Halakoo et al. 2023). This is exacerbated by heat stress, to which Prim'Holstein are more susceptible (Ouarfli and Chehma 2018a; Ferrari et al. 2023; Halakoo et al. 2023). According to Ghassemi et al. (2017), Lamari et al. (2018), Isola et al. (2020), and Purohit et al. (2020); coat color, hair texture, length, and diameter all affect resistance to thermal stress. Cows with shorter, smoother hair exhibit better adaptation to heat stress (Sesay 2023). However, despite higher solar radiation absorption by darker-colored coats, fertility traits didn't show significant changes based on coat color (Anzures-Olvera et al. 2019). Genetically, Montbéliarde cows have been selected for balanced traits, including fertility and heat tolerance, while Prim'Holstein have been bred primarily for milk yield (Ferrari et al. 2023), resulting in reduced heat adaptation and fertility. Purohit et al. (2020) confirmed that cows with higher milk production may be more vulnerable to heat stress due to genetic competition between milk productivity and heat tolerance regulation. Management-wise, Montbéliarde cows often thrive in less intensive systems, maintaining better body condition and fertility even under heat stress (Ouarfli and Chehma 2018a; Chacha et al. 2022). The lower milk production in Montbéliarde reduces metabolic disorders and improves reproductive health, particularly during hot periods (Chacha et al. 2022). These factors, combined with the Montbéliarde superior heat tolerance, contribute to their better reproductive performance compared to heat-sensitive Prim'Holstein cows (Balandraud et al. 2018; Halakoo et al. 2023). The complex relationship between environmental heat load and bovine fertility emphasizes the need for targeted strategies to mitigate the impacts of rising temperatures on bovine reproduction and productivity.

Conclusion

Our study has concluded that the fertility levels of dairy cows are consistently above the objective average for dairy farms. Heat stress on the day of artificial insemination significantly impacts the fertility efficiency of dairy cattle in Algeria. Both Holstein and Montbéliarde dairy cows are less likely to achieve pregnancy at the first artificial insemination (CR1stAI), exhibit lower pregnancy likelihood per AI (CR), and experience an increased number of services per conception (SPC), resulting in a prolonged reproductive period (RP). The occurrence of stressful THI levels (> 72) days is significantly higher during the hot and autumn seasons compared to winter and spring, as well as in littoral and arid regions compared to semi-arid regions, leading to higher negative odds ratios of CR1stAI and CR, while showing higher positive odds ratios of SPC and RP. In most heat-stress scenarios, Prim'Holstein cattle tend to be more susceptible to heat stress than Montbéliarde cattle. This emphasizes the importance of implementing breed-specific measures to mitigate heat stress in cattle farming for the sustainability of the Algerian dairy cattle industry.

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Declarations

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