Journal of Thermal Biology 136 (2026) 104419

Contents lists available at ScienceDirect

Journal of Thermal Biology

journal homepage: www.elsevier.com/locate/jtherbio

Climatic challenges for reproductive performances of dairy cattle herds in Algeria

Aziza Ferag [a], Djalel Eddine Gherissi [a,b,*], Tarek Khenenou [a], Ramzi Lamraoui [b,e], Amel Boughanem [c], Hafida Hadj Moussa [c], Mohammed Titaouine [g], Christian Hanzen [d], Pierre-Guy Marnet [f]

[a] *Institute of Agricultural and Veterinary Sciences, Deprtement of Veterinary Sciences, University of Souk-Ahras, 41000, Algeria*
[b] *Laboratory of Animal Production, Biotechnologies, and Health, University of Souk-Ahras, 41000, Algeria*
[c] *National Center for Artificial Insemination and Genetic Improvement (CNIAAG), Birtouta, 16045, Algeria*
[d] *Université de Liège, Faculté de médecine vétérinaire, Département de gestion vétérinaire des Ressources Animales, 4000, Liège, Belgium*
[e] *Departement of Biology of Living Organisms, faculty of Natural and Life Sciences, Universit y of Batna 2, Batna, 05110, Algeria*
[f] *Animal sciences and products department, Institut Agro Rennes-Angers, 65, rue de st Brieuc, 35000, Rennes, France*
[g] *Laboratory of Genetic, Biotechnology and Valorization of Bioressources (LGBVB), Université de Biskra, BP 68, Biskra, 07000, Algeria*

ARTICLE INFO

Keywords:
Breeds
Climatic changes
Fertility
Heat stress
Reproductive performances

ABSTRACT

Variations in climate are common throughout the Mediterranean area, particularly in Algeria. The main goal of this study is to evaluate the effects of environmental changes particularly the daily temperature-humidity index (THI), breeding region, and breed type on a variety of reproductive parameters including the conception rate at first, second, and third artificial insemination and more (CR1stAI and CR2ndAI, respectively), repeat breeding cows (RBC) overall conception rate (OCR), apparent fertility index (AFI), and reproductive period (RP). A total of 40 956 AI was performed on 24 657 cows from 2016 to 2021 sourced from CNIAAG. The results highlight the low levels of fertility in dairy cattle in Algeria, which was made worse by the COVID-19 pandemic. Furthermore, the results showed that both humid and arid regions are stressful zones (THI >72), and Algeria clearly exhibits summer heat stress. Significant correlations between THI and Algerian cattle fertility ($P < 0.000$) have been observed. When THI was less than 72, reproductive parameters were better but worsened when THI grater than72. The results of the Odds ratio (0.746 and 0.531) indicated a lowered likelihood of OCR and CR1stAI for THI >80 compared to THI <68. There were differences in reproductive parameters among regions, the arid regions had the highest levels of CR1stAI and services per conception SPC. The breeds significantly influenced the reproductive performance ($P < 0.001$), the local population exhibiting the highest performance. A significant interaction effect of multiple factors with THI was registered. This study underscores the adverse effects of climatic conditions on dairy cattle fertility, highlighting the imperative of finding strategies to alleviate these detriments. Focusing particularly on the well-being of dairy cows emerges as a key avenue for mitigating these challenges.

1. Introduction

Climate change represents a growing global concern, with profound implications for livestock production systems, animal health, and food security. North African countries like Algeria, which are particularly vulnerable to rising temperatures and increasing aridity, the impacts of climate change are becoming more pronounced. Algeria's dairy sector, already heavily reliant on imported cows and powdered milk to meet its high national milk consumption, well above the global average according to FAO (2020) and ONIL (2018), faces significant challenges. In 2020, dairy product imports reached $1.54 billion, accounting for 19.14% of Algeria's total food imports (USDA, 2020). However, imported cows often perform below their genetic potential due to environmental stressors, notably heat stress, reinforced by inadequate nutrition and reproductive issues (Ouarfli and Chehma, 2018; Yerou et al., 2021).

* Corresponding author.
E-mail address: d.gherissi@univ-soukahras.dz (D.E. Gherissi).

https://doi.org/10.1016/j.jtherbio.2026.104419
Received 3 October 2025; Received in revised form 23 January 2026; Accepted 6 February 2026
Available online 12 February 2026

Adaptive responses to heat stress include changed feeding behavior, increased respiration rate, panting, sweating, seeking shade, and increased water intake (Sammad et al., 2020; Nanas et al., 2021; Hanzen et al., 2024a). Thermal stress causes physiological and metabolic dysfunctions that affect cow productivity and reproductivity (Liu et al., 2018; Ouarfli and Chehma, 2018; Abdelnour et al., 2020; Djelailia et al., 2020; Sammad et al., 2020; Hanzen et al., 2024b, 2025). About 60% of the dairy cattle in the globe have ovarian dysfunction, increased embryo mortality, hormone imbalance, and reduced fertility due to heat stress. Additionally, it affects immunological response and raises the risk of uterine infection and mastitis (Nanas et al., 2021; Gherissi et al., 2022; Rajamanickam et al., 2022; Molinari and Bromfield, 2023). Significant economic losses are a result of this thermal stress. According to Liu et al. (2018), the dairy sector in the US suffers yearly economic losses of over $900 million as a result of heat stress. In this challenging context, "One Health" framework, which emphasizes the interconnectedness of human, animal, and environmental health, various adaptive strategies, such as improving housing design, using resilient genotypes, nutritional adjustments, and early warning climate models, are being explored to mitigate the negative effects of climate change on animal production systems (Gherissi et al., 2025).

In this context, we conducted this study to deeply analyze the relationship between the temperature-humidity index (THI) and fertility of the dairy cows from different Algerian agroecological environments located at the northern Africa. Furthermore, a particular focus on the impact of some THI-related factors such as region, and breed genotype on dairy cattle fertility were investigated.

2. Material and methods

2.1. Study area

Data was collected from seven different wilaya, Alger (36° 45′ 10.393″ N; 3° 2′ 31.373″ E), Annaba (36° 53′ 60.00″ N; 7° 46′ 0.01″ E), Chlef (36° 09′ 54.90″ N; 1° 20′ 4.27″ E), Batna (35° 33′ 21.49″ N; 6° 10′ 26.90″ E), Khenchela (35° 26′ 8.99″ N; 7° 08′ 35.99″ E), Djelfa (34° 40′ 22.04″ N; 3° 15′ 46.80″ E), and Ghardaia (32° 29′ 27.38″ N; 3° 40′ 24.49″ E) (Fig. 1).

The northern wilayas: Annaba, Alger, and Chlef, 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 departments: Batna, Khenchela, and Djelfa 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 department 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).

2.2. Study design

In this study, we aimed to understand better the changes in reproductive performance, including conception rate at the first, second, and third artificial insemination and more, overall conception rate, apparent fertility index and services per conception, and reproductive period. These parameters help to evaluate the real efficiency in the Algerian cattle reproduction. The study helps to evaluate the impact of different environmental factors and the genotype of cows on the success of the breeding, the impact of fluctuation in THI, the season changes, and the rearing region. Retrospective cohort research employing 6 years of cows' AI information was collected.

2.3. Data collection

Breeding data were obtained from individual cow registration available at the National Center for Artificial Insemination and Genetic Improvement (CNIAAG). The Database contains information on the date of the first AI, subsequent AI, pregnancy diagnosis, reproductive period, estrus type, cows' identification, cow breed, inseminator, breeders, bull name, pregnancy losses, and calving dates. The CNIAAG database underwent a structured quality control procedure prior to analysis. Records containing missing essential variables (animal ID, artificial

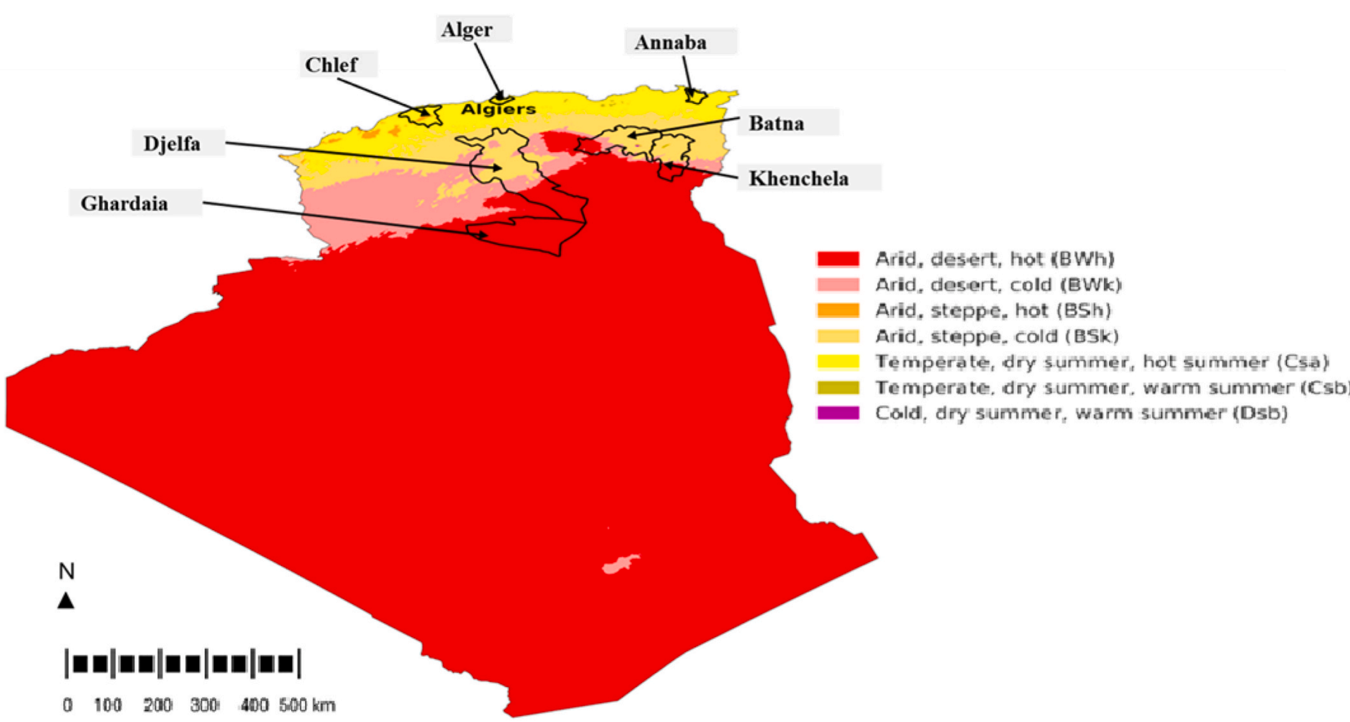

Fig. 1. Map of Algeria showing the geographic origins of the studied animals across different Algerian agroecological zones (Beck et al., 2018).

insemination date, insemination outcome …) or implausible values were excluded. Duplicate entries were identified and removed. Values falling outside physiological ranges were corrected when recorded by the same inseminator or excluded from the dataset.

During the study period (2016-2021) a total number of 40956 AI were performed on 24658 cows. They are distributed as follows: 24769; 13091; and 3096 AI were performed on 15032; 8203; and 1423 dairy cows in littoral (humid), semi-arid, and arid regions, respectively. A total of 13789, 4091, 7809, and 15267 AI were performed on 8502, 2548, 4632, and 8976 dairy cows during the period with THI <68; 69-71; 72-79; and THI>80, respectively. The study involved a diverse range of improved (foreign) breeds, namely indigenous cattle, Prim 'Holsteins, Montbéliarde, crossbred dairy cattle, Brown Swiss, Fleckvieh, Normande. These cows underwent artificial insemination (AI) with the following respective numbers: 263, 18657, 16511, 2186, 277, 2629, and 433. The total numbers of cows for each breed were respectively 176, 11211, 9904, 1444, 166, 1541, and 216.

2.4. Meteorological data

The monthly average of daily data of maximum ambient temperature and maximum relative humidity were electronically provided by "Weather Underground", https://www.wunderground.com/history between 2016 and 2021 (Weather Underground, 2016-2021). These data were used to calculate the Temperature-Humidity Index (THI) values for each AI day. The THI was calculated using the following formula (Eq (1): NRC, 1971):

$$THI\ \max = (1.8 \times Max\ T + 32) - (0.55 - 0.0055 \times H) \times (1.8 \times Max\ T - 26) \tag{1}$$

T max = maximum ambient temperature in °Celsius; H = relative humidity in %

THI was combined with breeding parameters by assigning insemination days. To make it easier to see the impact of heat stress and conduct statistical research, THI is separated into four classes. Comfortable THI< 68, mild heat stress (HS) for THI ranges from 69 to 71, moderate HS 72 to 79, and severe heat stress for THI>80 (Collier and Collier, 2012; Bod'o et al., 2022; Hanzen et al., 2024a)

2.5. Dairy cattle fertility indicators

The Conception at First and Second Artificial Insemination (CR1stIA and CR2ndAI): calculated as the ratio multiplied by 100 between the number of pregnancies obtained after the first and second insemination and the total number of animals inseminated at least once for which confirmation or non-confirmation of pregnancy has been determined. Overall Conception Rate (OCR) as recommended by Souames et al. (2015). The Repeat Breeding Cows (RBC) represents the number of cows inseminated more than twice divided by the total number of inseminated cows. The Apparent Fertility Index (AFI), also known as the total number of Services Per Conception (SPC): calculated as the ratio of the total number of inseminations carried out on animals confirmed pregnant by the number of pregnant animals. The Reproductive Period (RP): represented by the interval between first-last artificial insemination. (Hanzen, 1994; Badinand et al., 2000).

2.6. Statistical analysis

Data were collected using Excel and organized into columns containing the following information: date of insemination, daily THI, THI classes, number of inseminations per cow, and region as independent variables. The results of each insemination were considered as the dependent variable. On the other hand, reproductive performance metrics, including the reproductive period, overall conception rate, conception rate at the first and second artificial insemination, repeat breeding cows, fertility index and services per conception, were calculated for each dairy cow and treated as the second group of continuous or categorical independent variables. The data were then transferred to the SPSS analytical software for multiple analyses.

Using the Chi-square Test, we examined the comparison of insemination results, conception risk, the results of the first and second artificial insemination, and repeat breeding cows with respect to THI classes, regions, and breeds. The Kruskal-Wallis analysis of variance (KW ANOVA) test was conducted to compare the means of THI scores based on months, seasons, and regions, after evaluating the normality of distribution using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Subsequently, we used the Kruskal-Wallis test to determine the statistical differences in the averages of the reproductive period and apparent fertility index according to THI classes, regions, and breeds. Homoscedasticity was also evaluated through residual diagnostics.

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: $\text{Logit}(Y) = \alpha + \beta 1 \times X1 + \beta 2 \times X2 + \ldots + \beta nXn$, where Y represents the CR1stAI, CR2ndAI, RBC, and OCR α denotes the intercept parameter, and β signifies the logistic regression coefficients for the explanatory effects (X, the THI, Breeds, and Region) incorporated in the statistical model. To account for potential bias due to small sample sizes in certain breeds (e.g., Normande and Brown Swiss), analyses were repeated using appropriate weighting procedures, which did not materially affect the results. Furthermore, the generalized linear Model was carried out for SPC and RP: $Y1 = B0 + B1Xi + B2 \times X2 + \ldots + BnXn$, 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 THI, Breeds, and Region). Statistical significance was determined at a threshold of $P < 0.05$.

3. Results

3.1. Climatological conditions in relation with dairy cattle heat tolerance

Our results (Table 1) showed that the THI is significantly different between regions ($p < 0.05$), with the Littoral (75.09 ± 11.43) and Arid (74.80 ± 9.9) regions, belonging to the same group and considered stressful regions and semi-arid (69.91 ± 13.68) region is characterized by mild heat stress. Furthermore, THI fluctuates significantly with the passing of each season. Animals were exposed to mild, moderate, and severe HS during spring, autumn, and summer in humid regions. On the other hand, in arid regions, this condition of moderate HS persists in the spring. Evidently, in semi-arid zones, animals experience heat stress during lesser periods, mostly during summer, and mild HS during autumn.

The overall monthly THI scores in this study are shown in Fig. 2. The animals are generally raised in heat stress during the period between May to October, where the THI values exceed 72. The greatest THI was recorded in August (87.87 ± 5.43). On the other hand, the THI values do not exceed the critical threshold of 72 during the period between November to April, and animals can rise in thermal comfort (Minimal in January 58.31, Max in April 70.22).

Fig. 2 showed the monthly evolution of THI levels in the three regions of the study. In both humid (littoral) and arid regions, the pattern of changes in the monthly THI curves is nearly superimposed. Critical THI values persist for approximately 7 months (from April to October), with higher values ranging from 72 to over 85 during this time interval. In the semi-arid region, THI values > 72 are recorded for 5 months between months 5 and 9, with values considerably lower than the other two regions.

Table 1
Average temperature-humidity index (THI) according to the regions and seasons in Algeria.

	Winter	Spring	Summer	Autumn	(Mean region)	Std. Deviation
Littoral	63.40	71.85	87.86	77.06	75.09[a]	11.43
Semi-arid	55.58	67.94	85.32	70.55	69.91[b]	13.68
Arid	63.18	74.21	85.58	76.05	74.80[a]	9.91
Mean (seasons)	60.02[c]	70.51[d]	86.45[e]	74.13[f]		
Std. Deviation	7.39	8.96	5.79	10.09		

Note: The values marked with the different letters differ significantly (p < 0.01).

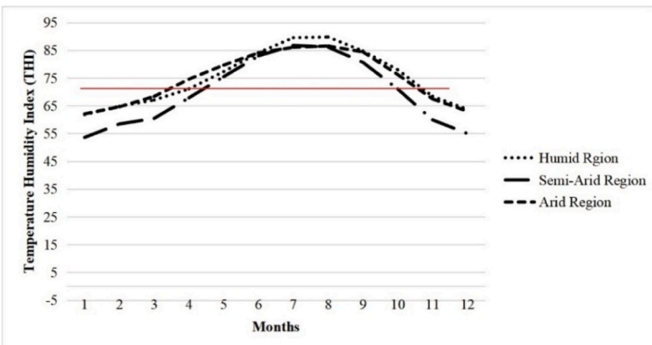

Fig. 2. Overall monthly THI levels in the study region.
THI value is used to assess heat stress levels in dairy cattle by combining the effects of temperature and humidity, THI≥72 is indicative of heat stress affecting animals.

3.2. Overall reproduction traits of dairy cows

Table 2 presented the reproductive performance of 24657 dairy cattle between 2016 and 2021. Mean reproductive parameters were as follows: OCR, 25.03%; CR1stIA, 20.45%; CR2ndIA, 21.12%; RBC, 9.48%; AFI, 1.71 ± 0.835; and RP, 49.90 ± 7.68 days. Reproductive traits reached their lowest values in 2020 and 2021. Fertility parameters varied significantly across the study period (P < 0.001), with the most pronounced declines occurring in 2020 and 2021.

3.3. The THI relationship with dairy cattle fertility

The total number of artificial inseminations recorded for the four THI classes; THI <68, 68-71, 72-79, and THI>80 were 13 789, 4 091, 7 809, and 15 267, respectively. The reproductive parameters were significantly ($P<0.001$) affected by THI classes (Table 3).

The best levels of OCR and $CR2^{nd}AI$ (29.12% and 24.35%, respectively) were recorded in the comfortable zone of THI (THI<68). Both OCR and $CR2^{nd}AI$ were decreased significantly during mild (THI between 68 and 71), moderate (THI ranges between 72 and 79), and severe heat stress (THI>80). The $CR1^{st}IA$ and RBC showed non-significant differences in comfortable and mild heat stress zones. However, a decrease from 24.50% to 11.55% when THI< 68 to 18.18% and 8.26% and to 16.60% and 7.91% is registered for $CR1^{st}IA$ and RBC when THI ranges between 72 and 79 and when THI passes 80, respectively.

Similar trends were observed in each year for the period going from 2016 to 2021. The lowest OCR (11.83%), $CR1^{st}IA$ (11.44%), $CR2^{nd}AI$ (2.59%), and RBC (0.67%) were recorded in 2021 when THI exceeded 80. Inversely, the highest OCR (36.61%), $CR1^{st}IA$ (35.94%), $CR2^{nd}$ AI (40.79%), and RBC (21.90%) were obtained in 2016, 2018, and 2017 respectively, when THI is less than 72.

The AFI increased significantly with THI ($P<0.001$) from 1.64 when THI< 72 to 1.79 when THI ≥72. The years 2017, 2018, and 2019 registered no significant changes in THI impact on the AFI. The minimum and the maximum AFI (1.31 and 1.97) for THI ranges between 68 and 72 in 2021 and 2019, respectively.

Furthermore, the RP increased from 48 days to 50, 53, and 49 days for the following THI classes: <68, 68-72, 72-79, and >80 with non-significant changes in the RP between the comfortable zone and mild heat stress and between moderate and severe heat stress classes. In addition, there were no significant changes in RP with the changes in the THI during the years 2018 and 2019. The minimum and the maximum RP (34 days and 66 days) for THI, ranging between 68 and 72, were recorded in 2016 and 2019, respectively.

The logistic regression analyses indicated a significant effect of THI on the predicted probability of obtaining successful insemination, successful insemination from the first and second AI, and repeat breeding ($P<0.001$), as shown in Table 4. The logistic regression findings show accuracies ranging from 54 to 74, suggesting a non-significant variation between the comfortable THI zone and mild heat stress, but a significant notable difference between comfortable conditions and moderate to severe heat stress ($P<0.001$).

The OCR decreases by 1.2, 22.6 and 25.4% for mild, moderate, and severe heat stress on the day of the AI, respectively compared to comfortable THI zones. In the same line, the $CR1^{st}AI$ decreases by factors 0.599 and 0.531 during moderate and severe heat stress compared to comfortable zones, inversely, the $CR1^{st}AI$ in cows experiencing mild heat stress increased by a factor of 1.04. Furthermore, a decreased likelihood of the $CR2^{nd}AI$ of 12.1, 21.6 and 30.4% are registered in cows experiencing mild, moderate, and severe heat stress compared to cows in comfortable zones. The odds ratio results for THI classes (0.8, 0.705, and 0.751 for THI ranges between 68 and 71, 72-79, and THI>80, respectively). showed that heat stress has a high potential effect on the decrease of the RBC.

The results of the linear regression analysis indicated that the SPC is dependent on the THI (Table 5). Specifically, for severe heat stress

Table 2
Reproductive traits for Algerian dairy cattle for the period between 2016 and 2021.

Reproductive traits	Years ***						Mean Values
	2016	2017	2018	2019	2020	2021	
CR1stAI %	30.16 1452/4814	21.06670/3181	20.63 648/3141	19.05 577/3029	17.64 866/4908	14.84 829/5585	20.45 5042/24658
CR2ndAI%	29.00 975/3362	37.87 951/2511	36.74 916/2493	32.38 794/2452	7.60 307/4042	4.21 200/4755	21.12 4143/19615
RBC%	14.83 354/2387	21.47 335/1560	18.14 286/1577	14.36 238/1658	4.02 150/3735	2.26 103/4555	9.48 1466/15472
OCR %	33.82 2604/7700	32.78 1978/6035	31.06 1813/5837	29.69 1702/5732	18.44 1342/7276	14.60 1223/8376	25.03 10662/40956
AFI	1.58 ± 0.764 [a]	1.90 ± 0.849 [b]	1.79 ± 0.792 [c]	1.87 ± 0.826 [b, c]	1.53 ± 0.842 [e]	1.50 ± 0.883 [e]	1.71 ± 0.835
RP (days)	43.67 ± 63.63 [a]	48.04 ± 58.34 [b]	51.51 ± 65.89 [b, c]	59.40 ± 78.93 [d]	55.15 ± 80.49 [e]	43.87 ± 53.57 [e]	49.90 ± 7.68

Means followed by the same letter are not significantly different (p > 0.05); Statistical significance: P < 0.001 (***); $CR1^{st}AI$, $CR2^{nd}AI$: Conception rate at first and second AI; RBC: Repeat breeding cows; OCR: Overall conception rate; AFI: Apparent fertility index; RP: Reproductive period.

Table 3
Reproductive traits in Algerian dairy cattle according to the THI during the study period (2016-2021).

		THI***			
		<68	68-71	72-79	>80
CR1stAI (%)	2016	32.99	35.94	30.63	25.13
	2017	25.54	22.39	17.34	18.35
	2018	23.75	23.10	18.55	17.38
	2019	22.24	20.61	16.19	16.59
	2020	24.24	20.03	14.07	13.07
	2021	17.89	19.81	12.67	11.44
	Total	24.50	24.57	18.18	16.60
$CR2^{nd}AI$ (%)	2016	31.81	31.39	26.74	26.94
	2017	38.97	34.13	36.83	38.15
	2018	40.79	36.63	34.16	33.69
	2019	31.90	34.13	35.68	30.84
	2020	12.46	10.32	7.65	3.41
	2021	5.06	7.72	4.13	2.59
	Total	24.35	22.16	19.79	18.76
RBC (%)	2016	15.73	13.77	15.33	14.11
	2017	21.81	21.90	20.46	21.53
	2018	20.36	13.29	18.87	16.76
	2019	17.45	18.25	6.71	13.89
	2020	6.00	9.86	4.20	1.24
	2021	3.51	6.21	1.40	0.67
	Total	11.55	11.56	8.26	7.91
OCR (%)	2016	35.38	36.61	34.77	31.30
	2017	35.52	30.75	29.48	32.17
	2018	33.35	34.09	27.80	29.29
	2019	32.17	34.46	29.96	27.07
	2020	23.68	23.26	16.34	14.13
	2021	16.63	18.59	14.67	11.83
	Total	29.12	26.87	24.13	23.46
AFI	2016	1.44 ± 0.682 ^{a}	1.44 ± 0.715 ^{a}	1.6 ± 0.758 ^{b}	1.73 ± 0.823 ^{c}
	2017	1.83 ± 0.819 ^{a}	1.85 ± 0.906 $^{a, b}$	1.96 ± 0.848 $^{b, d}$	1.96 ± 0.86 $^{c, d}$
	2018	1.79 ± 0.803 ^{a}	1.89 ± 0.84 ^{a}	1.83 ± 0.797 ^{a}	1.86 ± 0.755 ^{a}
	2019	1.86 ± 0.832 ^{a}	1.97 ± 0.972 ^{a}	1.89 ± 0.83 ^{a}	1.85 ± 0.76 ^{a}
	2020	1.42 ± 0.753 ^{a}	1.51 ± 0.836 $^{a, b}$	1.64 ± 0.898 ^{b}	1.6 ± 0.901 ^{b}
	2021	1.32 ± 0.658 ^{a}	1.31 ± 0.643 ^{a}	1.77 ± 1.041 ^{b}	1.63 ± 1.015 ^{c}
	Total	1.64 ± 0.795 ^{a}	1.64 ± 0.851 ^{a}	1.76 ± 0.859 ^{b}	1.79 ± 0.852 ^{b}
RP (days)	2016	40.75 ± 61.415 $^{a, b}$	34.66 ± 48.972 ^{a}	48.59 ± 75.969 ^{b}	47.06 ± 62.494 ^{c}
	2017	47.31 ± 60.95 ^{a}	56.54 ± 68.131 ^{a}	46.64 ± 46.585 ^{a}	47.38 ± 57.618 ^{a}
	2018	48.44 ± 64.46 ^{a}	50.56 ± 62.648 ^{a}	57.52 ± 76.277 ^{a}	52.19 ± 61.9 ^{a}
	2019	60.68 ± 84.391 ^{a}	66.14 ± 105.325 ^{a}	56.28 ± 83.404 ^{a}	57.77 ± 60.649 ^{a}
	2020	52.46 ± 85.208 ^{a}	60.57 ± 84.446 ^{b}	59.89 ± 78.321 ^{b}	52.55 ± 74.214 ^{b}
	2021	40.31 ± 60.462 ^{a}	43.21 ± 53.889 $^{a, b}$	50.85 58.475 ^{b}	43.39 ± 43.957 ^{b}
	Total	48.27 ± 70.288 ^{a}	50.15 ± 71.572 ^{a}	53.17 ± 72.198 ^{b}	49.79 ± 60.878 ^{b}

Means followed by the same letter are not significantly different ($p > 0.05$). Statistical significance: $P < 0.001$ (***); $CR1^{st}AI$, $CR2^{nd}AI$: Conception rate at first and second AI; RBC: Repeat breeding cows; OCR: Overall Conception Rate; AFI: Apparent Fertility Index; RP: Reproductive Period.

conditions with THI>80, there was an observed significant increase of 0.042 in the SPC. The analysis revealed a significant slope for RP, with an increase of 4.896 for 72< THI <79 compared to THI<68.

3.4. Heat stress-related factors impact on fertility

The multiple logistic regression analysis (Table 6) has an accuracy of 53.6%, indicating significant (*P < 0.001*) effects of the interaction of THI classes, regions, and breeds on the success of the first artificial insemination. In comparison to the local population (reference class), the Prim'Holstein, Montbéliarde Improved dairy cattle, Brown Swiss, Fleckveih, and Normande exhibited all a significant decrease (*P < 0.001*) in the probability of having successful insemination from the first AI by factors of 0.121, 0.11, 0.141, 0.163, 0.134, and 0.13, respectively. Additionally, the THI significantly decreased the likelihood by factors of 0.551 and 0.688 for THI levels causing moderate or severe heat stress, respectively. Furthermore, a significant regional effect is registered, where the likelihood is increased by 80.8% in arid areas and decreases by 22.9% in semi-arid areas compared to littoral areas.

The regression analysis (Table 7) indicates a positive slope with a significant (*P < 0.001*) increase in SPC with THI and related factors (breeds and region). The results revealed that the SPC is a function of THI, breeds, and agroecological regions. Specifically, the results suggest that different breeds, THI and regions correspond to an increase in the SCP. An increase of 0.268, 0.288, 0.166, 0.36, and 0.553 in SPC for the Prim'Holstein, Montbéliarde, Brown Swiss, Fleckvieh, and Normande, respectively, compared to local breeds. An increase of 0.06 and 0.076 in moderate and severe heat stress conditions. Moreover, there was an increase of 0.005 and 0.349 in the semi-arid and arid regions.

4. Discussion

This study was started because of widespread acknowledgment of the low reproductive performance in Algerian cattle. The main objective of this study was to thoroughly evaluate the several factors that caused this problem. The study focused precisely on the environmental circumstances, including the Temperature-Humidity Index (THI), the agro-ecological region, and the breeds. The research aims to suggest more information on the issues affecting Algerian cow reproductive performance.

The surface temperature of the earth is expected to increase by 1.5 °C between 2030 and 2052, according to the Intergovernmental Panel on Climate Change (IPCC, 2021), and severe heat waves and droughts are suspected (Rajamanickam et al., 2022). Algeria's temperature ascended by 1.5 to 2 °C, twice more than the global average. Future predictions indicate continued desert expansion across Algeria (Zeroual et al., 2019; Yerou et al., 2021), accompanied by progressive and substantial warming throughout the 21st century. Abed (2021) demonstrated that minimum temperatures will increase by 2.4 °C in the near future (2011–2040), 2.4–4.0 °C by mid-century (2041–2070), and 3.6–5 °C by late century (2071–2100). Maximum temperature increases will be more pronounced, ranging from 3.6 to 5.0 °C by the 2050s and escalating to 5–8 °C by the 2080s, representing a 2–3-fold intensification relative to earlier periods. These projections indicate that Algeria will experience unprecedented super- and ultra-extreme heatwave conditions, with temperatures potentially exceeding 56 °C and events persisting for several weeks (Zittis et al., 2021).

The results showed a level of 20.45%, 21.12%, and 25.03% for CR1stAI, CR2ndAI, and OCR, respectively. These values were less than the recommended objectives by Hanzen (2009). CR1stAI was lower than those obtained in previous studies conducted in semi-arid and northern Algeria by Ferag et al. (2024a, 2025) on imported dairy cattle (Prim'-Holstein and Montbéliarde) and local cattle, by Mouffok et al. (2019) on Holstein and Montbéliarde, Souames and Berrama, 2020 on improved dairy cattle, and Haou et al. (2021) in northeast Algeria. CR was lower than the observation by Ferag et al. (2024a). These changes could be related to the number of studied animals, to the distribution of the animals in different agro-ecological regions, to the studied breeds, and further to the period of the conducted study. Where in the current study, we are studying a higher number of animals breeds during longer periods. The changes in the reproductive performances between animal breeds are generally due to their productive performance.

The analysis showed a significant effect of THI levels on the reproductive performances, including $CR1^{st}$ AI, $CR2^{nd}$ AI, and OCR. A decrease was registered when THI arrives at the moderate levels of HS or

Table 4
Simple logistic Regression of Overall Conception Risk OCR (%) and Conception Rate at First CR1stAI (%) Second (CR2ndAI) artificial insemination, and Repeat Breeding Cows (RBC) with the THI.

	THI	χ^2	Prediction %	B	S.E.	Sig.	OR	95% CI
CR1stAI %	<68	0.000	60.9			0.000		
	68-71			0.039	0.063	0.533	1.04	0.919 - 1.177
	72-79			−0.512	0.052	0.000	0.599	0.541 - 0.664
	>80			−0.633	0.043	0.000	0.531	0.488 - 0.578
	Constant			−0.128	0.03	0.000	0.88	
CR2ndAI %	<68	0.000	53.9			0.000		
	68-71			−0.13	0.078	0.095	0.879	0.754 - 1.023
	72-79			−0.243	0.062	0.000	0.784	0.694 - 0.886
	>80			−0.363	0.051	0.000	0.696	0.629 - 0.769
	Constant			0.12	0.037	0.001	1.128	
RBC %	<68	0.000	54.5			0.001		
	68-71			−0.223	0.119	0.061	0.8	0.633 - 1.01
	72-79			−0.35	0.103	0.001	0.705	0.577 - 0.862
	>80			−0.287	0.086	0.001	0.751	0.635 - 0.888
	Constant			0.034	0.06	0.567	1.035	
OCR %	<68	0.000	74			0.000		
	68-71			−0.012	0.039	0.758	0.988	0.915 - 1.067
	72-79			−0.256	0.032	0.000	0.774	0.726 - 0.825
	>80			−0.293	0.027	0.000	0.746	0.708 - 0.786
	Constant			−0.89	0.019	0.000	0.411	

χ^2: Chi-square statistic, Prediction %: Percentage of correctly predicted cases by the model, B: Regression coefficient (log-odds), S.E.: Standard Error of the coefficient, Sig: p-value of the coefficient, OR: Odds Ratio (Exp(B)) – effect size of the predictor on the odds, 95% CI: 95% Confidence Interval of the Odds Ratio.

Table 5
Simple linear regression of Reproduction Period RP (days) and Services per Conception (SPC) with the THI.

			B	S.E.	Beta	T	Sig.	R^2	95% CI
RP	Constant		48.275	0.880		54.879	0.000	0.000	46.551 - 49.999
	THI	<68	Reference						
		68-71	1.875	1.837	0.009	1.021	0.307		−1.726 - 5.476
		72-79	4.896	1.520	0.028	3.221	0.001		1.917 - 7.875
		>80	1.520	1.255	0.011	1.211	0.226		−0.940 - 3.979
SPC	(Constant)		1.694	0.013		131.688	0.000	0.001	1.669 - 1.720
	THI	<68	Reference						
		68-71	−0.022	0.027	−0.008	−0.800	0.424		−0.075 - 0.0031
		72-79	0.041	0.023	0.019	1.754	0.079		−0.005 - 0.087
		>80	0.042	0.019	0.023	2.181	0.029		0.004 - 0.080

B: Regression coefficient, S.E.: Standard error, Beta: standardized regression coefficient, t: t-statistic. Sig: Significance (p-value), R^2: Coefficient of determination, CI95%: 95% Confidence Interval, RP: reproductive period; SPC: services per conception; THI: Temperature Humidity Index.

Table 6
Logistic regressions of CR1stAI (%) with THI and related-THI factors (region, breed) in Algerian dairy cattle during the study period (2016-2021).

		Prediction	B	S.E.	OR	95%CI	Sig.
Constant			2.069	0.267	7.92		0.000
Breeds	Local	53.6%	Reference				0.000
	Prim'Holstein		−2.111	0.268	0.121	0.072 -0.205	0.000
	Montbéliarde		−2.203	0.268	0.111	0.065 -0.187	0.000
	Improved dairy cattle		−1.959	0.276	0.141	0.083 - 0.239	0.000
	Brown Swiss		−1.812	0.357	0.163	0.093 - 0.28728	0.000
	Fleckvieh		−2.007	0.277	0.134	0.079 -0.227	0.000
	Normande		−2.041	0.347	0.13	0.13 - 0.225	0.000
THI	<68		Reference				0.000
	68-71		0.061	0.038	1.063	1.063 - 0.986	0.11
	72-79		−0.551	0.031	0.577	0.577 - 0.542	0.000
	>80		−0.688	0.026	0.503	0.503 - 0.478	0.000
Region	Littoral		Reference				0.000
	Semi-Arid		−0.26	0.025	0.771	0.735 - 0.809	0.000
	Arid		0.592	0.055	1.808	1.624 - 2.012	0.000

B: Regression coefficient (log-odds), S.E.: Standard Error of the coefficient, Sig: p-value of the coefficient, OR: Odds Ratio (Exp(B)) – effect size of the predictor on the odds, 95% CI: 95% Confidence Interval of the Odds Ratio.
B: Bias, S.E.: Standard error, Sig: significance, Odds Ratio: Likelihood.

severe levels. For CR1stAI decreased by 40.1% and 46.9% for moderate and severe HS, respectively. A similar incidence of heat stress was reported in Algerian cattle by Ferag et al. (2024a, 2025), and in a Tunisian dairy herd by Djelailia et al. (2020) with a decrease in CR1stAI of 1.39% for each point increase in the THI value above 67. a decrease of 1.2% in CR1stAI for each point increase in THI values between 56 and 78 (Ben

Table 7
Linear regressions of SPC with THI and related-THI factors (region, breed) in Algerian dairy cattle during the study period (2016-2021).

		B	S.E.	Beta	T	Sig.	R^2	95%CI
Constant		1.385	0.07		19.719	0.000	0.022	1.248 - 1.523
Breeds	Local	Reference						
	Prim'Holstein	0.268	0.07	0.149	3.81	0.000		0.13 - 0.406
	Montbéliarde	0.288	0.07	0.169	4.095	0.000		0.15 - 0.425
	Improved dairy cattle	0.085	0.072	0.027	1.187	0.235		−0.056 - 0.226
	Brown Swiss	0.166	0.083	0.021	2.008	0.045		0.004 - 0.328
	Fleckvieh	0.36	0.071	0.15	5.074	0.000		0.221 - 0.5
	Normande	0.553	0.076	0.104	7.284	0.000		0.404 - 0.702
THI	<68	Reference						
	68-71	−0.037	0.016	−0.014	−2.294	0.022		−0.069 - 0.005
	72-79	0.06	0.014	0.027	4.351	0.000		0.033 - 0.087
	>80	0.075	0.011	0.042	6.528	0.000		0.052 - 0.097
Region	Littoral	Reference						
	Semi-Arid	0.005	0.011	0.003	0.492	0.623		−0.016 - 0.027
	Arid	0.349	0.02	0.103	17.54	0.000		0.31 - 0.388

B: Regression coefficient, S.E.: Standard error, Beta: standardized regression coefficient, t: t-statistic. Sig: Significance (p-value), R^2: Coefficient of determination, CI95%: 95% Confidence.

Salem and Bouraoui, 2009). Furthermore, the hot season declined CR1stAI three times more than the cold season (Kananub et al., 2018; Souames and Berrama, 2020; Fathoni et al., 2022). Low CR1stAI might result in longer days open, more inseminations, reproductive assistance, culling, replacement heifers, feeding, and more financial loss, which can reach 622.40$ (Kim and Jeong, 2019).

The OCR decreased by 22.4% and 24.5% for moderate and severe HS, respectively. This aligns with previous research that noted a decrease in CR with increasing THI levels, with declines ranging from 1.2% (Ooi et al., 2023), 1.74% (Rolando et al., 2022), or 15% (Shi et al., 2021), and even more important reductions of 50% in Sahiwal cows (Parveen et al., 2022) and 50.12% - 61% in Holstein (Rhoads, 2020) with increasing THI values. A significant decrease in CR when the THI >72 (Ferag et al., 2024a). The CR2ndAI decreased by 21.6% and 30.4%. Copley et al. (2022) claimed that an increased chronic heat load in the period surrounding conception will reduce the proportion of females that are pregnant. Heat stress's impact on CR is attributed to compromised ovarian activity postpartum, quiet ovulation, and anestrus (Damarany, 2020). As it is found, cows exposed to higher THI are less likely to conceive, 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; 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 (Parveen et al., 2022).

Furthermore, CR1stAI was affected by the interacting effect of heat stress (HS) and HS-related factors, including the agro-ecological region and the breed. The imported and improved dairy cattle were compared to local dairy cattle (OR< 0.2), showing that the local population showed superior and noticeably greater reproductive performance rates compared to other breeds. This result aligns with the findings by our recent study showing the differences in the CR1stAI between breeds (Ferag et al., 2024b). Furthermore, CR1stAI decreased in semi-arid areas (OR = 0.771). Although the semi-arid areas offer a more comfortable and less stressful environment to the animals, the humid and arid areas experienced extended periods of exposure to HS compared to the semi-arid areas. Contradictory results were obtained in a previous study that showed that animals (Prim'Holstein and Montbéliarde, local) reared in semi-arid areas had higher CR1stAI levels (Ferag et al., 2024a, 2025). Anyways, 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, 2018; Ferag et al., 2024a, 2025) and highlights the link between reproductive performance and environmental factors across different agroecological regions (Khan et al., 2023; Mouffok et al., 2019; Haou et al., 2021; Eulmi et al., 2023; Ferag et al., 2024a, 2025). 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; 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 et al., 2019; Assan, 2022; Singh et al., 2021), 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 particularly high prevalence and parasitic intensity observed in littoral region (Meguini et al., 2021) further compromising fertility.

The overall RBC was 9.48%. This was within the range of 10% to 24% mentioned by Hanzen (2009). Our results were higher than the previous findings by Mouffok et al. (2019) of 6.9% in a semi-arid area. A significant decrease in RBC rate with THI was registered. Further, the average AFI was 1.71 ± 0.835, which is lower than the higher limit threshold (Hanzen, 2009). The AFI was found to be affected by THI, an increase from 1.64 to 1.79 for THI< 68 to THI> 80. With SPC increased by 0.042 points with THI increasing from 68 to >80. Previous studies showed increased insemination frequency coupled with decreased fertility as THI reaches stressful levels (Djelailia et al., 2020; Ouarfli and Chehma, 2018; Ferag et al., 2024a, 2025). Pregnancy per service was lower with lower levels of THI (Djelailia et al., 2020), and the number of services per conception increased from 2.44 to 3.02 with an increase in THI from 58 to 80 (Gaafar et al., 2011). The SPC increased by 0.007 points for each point increased in THI over 68 (Ferag et al., 2025).

The HS and HS-related factors negatively affected SPC, with an increase in the SPC with higher THI recorded, but also, imported and improved dairy cattle registered higher SPC than the local breeds. Research by Toledo-Alvarado et al. (2017) and Allouche et al. (2018) showed a variation in the fertility and the number of AI among breeds. The production of milk may be the cause of these striking modifications in reproductive function, where the high milk production causes delayed ovulation and reduced fertility (Halakoo et al., 2023), and low milk production cows are having less metabolic disorder and improved reproductive health (Chacha et al., 2022). Additionally, areas with higher THI with extended periods of high THI negatively impacted SPC. Where there is an increase of 0.349 points in SPC in arid areas compared to littoral areas. A recent study showed the long-term consequences of prolonged thermal stress on bovine fertility (El-Bakly et al., 2023). 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).

A period of 50 days was registered as the RP for the studied animals, similar to a previous study by Ferag et al. (2024a), exceeding findings from previous studies in Algeria (Akkou et al., 2022; Haou et al., 2021), but shorter than reported by Miroud et al. (2014). The RP was found to change and be affected by THI levels. An increase of 4.896 days increased THI to 72-79. 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).

Heat stress affects cows' fertility; the heat stress alters estrus detection, endometrial welfare, and uterine secretory activity. Heat stress had an impact on ovarian follicular dynamics, suppressing the dominance of large follicles and smaller follicular size and altering oviductal function. Furthermore, it affected embryo development and implantation, embryonic survival, and oocyte quality. Heat stress led to hormonal imbalances, a drop in serum estradiol concentration, decreased plasma concentration of LH, and alterations in progesterone secretion (Baruselli et al., 2020; El-Sheikh Ali et al., 2020; Abdelnour et al., 2020; Sammad et al., 2020; Rahmoun et al., 2020; Singh et al., 2021; Kawano et al., 2022; Hanzen et al., 2025). Furthermore, heat stress causes uterine disease, including retained placenta and post-partum metritis, that negatively affects the cow's fertility (Nguyen-Kien et al., 2017; Molinari et al., 2023).

Heat stress affects ovarian function and reproduction not only through direct physiological pathways, but also indirectly via energy deficit and metabolic disturbances (Ishida et al., 2024; Hanzen et al., 2024b). These metabolic challenges arise from decreased appetite and reduce dry matter intake (DMI) in response to elevated temperatures (Chen et al., 2024). High-producing European breeds are particularly vulnerable to such energy deficits, especially during early lactation when demands for milk production and reproduction compete for limited metabolic resources (Chacha et al., 2022; Halakoo et al., 2023). Furthermore, heat-induced fertility decline extends beyond female-specific factors. Male reproductive performance is also compromised, manifesting as reduced libido in natural breeding systems and diminished sperm quality. Notably, impaired sperm cryotolerance represents a particularly problematic consequence, as deteriorated semen quality suitable for freezing and preservation can extend fertility problems beyond periods of elevated THI, thereby prolonging the reproductive impact of heat stress events (Llamas-Luceño et al., 2020; Capela et al., 2022; Khan et al., 2023).

The reproductive performances were the lowest during the period from 2019 to 2021, as evidenced by the highest levels of CR1st and OCR that were registered in 2016 and in 2017 for CR2ndAI, and the lowest levels were registered between 2019 and 2021, especially in 2021, which coincides with the COVID period. This could be related to the limited activity of inseminators and breeders during this period.

Earlier research mentioned that the activity during the COVID period was limited, with a lack of data collection during this period due to sanitary reasons advocating for the farmer to receive no visits on his farm (David, 2021). Therefore, documentation registered a continuous decline in reproductive performance over time (Sammad et al., 2020).

5. Conclusion

The present study, conducted in North Africa, a region seriously threatened by climate change and experiencing significant climatological variations in recent years, has demonstrated the high negative impact of heat stress and related factors on the fertility of dairy cows in Algeria. Reproductive parameters were notably altered when the temperature-humidity index (THI) exceeded 72. Agroecological differences also influenced fertility, with the indigenous cattle breed “Atlas brown” showing superior reproductive performance. The findings underscore the need to strengthen adaptation and mitigation strategies, promote smart reproductive practices, and ensure quality nutrition and housing during heat stress periods, especially for sensitive breeds. Genetic improvement is essential to boost heat stress resilience. The study emphasizes the critical importance of integrating climate change considerations into dairy cattle breeding policies and development plans.

CRediT authorship contribution statement

Aziza Ferag: Writing – original draft, Investigation, Formal analysis, Data curation. **Djalel Eddine Gherissi:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Conceptualization. **Tarek Khenenou:** Writing – review & editing, Supervision, Conceptualization. **Ramzi Lamraoui:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Amel Boughanem:** Writing – review & editing, Resources, Formal analysis, Data curation. **Hafida Hadj Moussa:** Writing – review & editing, Resources, Formal analysis, Data curation. **Mohammed Titaouine:** Writing – review & editing, Writing – original draft, Resources, Investigation, Data curation. **Christian Hanzen:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Pierre-Guy Marnet:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

Data availability statement

The data that support the findings of this study were provided by the Centre National d’Insémination Artificielle et d’Amélioration Génétique (CNIAAG) for exclusive use within the framework of the doctoral research project. As this dataset remains the exclusive property of CNIAAG, the data cannot be shared publicly.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to express their gratitude to the CNIAAG personnel, as well as the breeders and veterinarians of the study area, for their willingness to participate and provide crucial information for this study.

Abbreviations

AFI	Apparent fertility index
CR1stAI	Conception rate at first artificial insemination
CR2ndAI	Conception rate at second artificial insemination
OCR	Overall conception rate
HS	Heat stress
SPC	Services per conception
RBC	repeat breeding cows
RP	reproductive period
THI	Temperature humidity index

Data availability

The authors do not have permission to share data.

References

Abdelnour, S.A., Swelum, A.A., Abd El-Hack, M.E., Khafaga, A.F., Taha, A.E., Abdo, M., 2020. Cellular and functional adaptation to thermal stress in ovarian granulosa cells in mammals. J. Therm. Biol. 92, 102688. https://doi.org/10.1016/j.jtherbio.2020.102688.

Abed, S.S., 2021. Future climate projections in Algeria using statistical downscaling model. https://doi.org/10.21203/rs.3.rs-627355/v1.

Akkou, M., Mohamed, B., Fatiha, S., 2022. Effects of milk yield and quality at post-calving period on Algerian cows' reproductive performances. J. Hellenic. Vet. Med. Soc. 73 (1), 3757–3764. https://doi.org/10.12681/jhvms.25681.

Allouche, L., Madani, T., Mechmeche, M., Bouchemal, A., 2018. Reproductive performance of montbeliard cows reared under subtropical environment: effects of heat stress and acclimatization duration. Livest. Res. Rural Dev. 30 (7), 128. http://www.lrrd.org/lrrd30/7/lyall30128.html.

Amirouche, M., Smadhi, D., Zella, L., Bachir, H., 2021. Rainfall trends in semi-arid cereal regions of Algeria. Al-Qadisiyah J. Agric. Sci. 11 (1), 36–44. https://www.iasj.net/iasj/download/c57b357ff52e37c5.

Assan, N., 2022. Climate change impact on small-scale animal agriculture: Livestock water & food security in Africa. Univers. J. Food. Secur. 1 (1), 13–39. https://doi.org/10.31586/ujfs.2022.541.

Badinand, F., Bedouet, J., Cosson, J.L., Hanzen, C., Vallet, A., 2000. Lexique des termes de physiologie et de pathologie et performances de reproduction chez les bovins. Ann. Med. Vet. 144, 289–301. ULg-Université de Liège, Liège, Belgium. https://orbi.uliege.be/bitstream/2268/12795/1/BadinantF_AnnMedVet_2000.pdf.

Baruselli, P.S., Ferreira, R.M., Vieira, L.M., Souza, A.H., Bó, G.A., Rodrigues, C.A., 2020. Use of embryo transfer to alleviate infertility caused by heat stress. Theriogenology 155, 1–11. https://doi.org/10.1016/j.theriogenology.2020.04.028.

Beck, H.E., Zimmermann, N.E., McVicar, T.R., Vergopolan, N., Berg, A., Wood, E.F., 2018. Present and future köppen–geiger climate classification maps at 1-km resolution. Sci. Data 5, 180214. https://doi.org/10.1038/sdata.2018.214.

Ben Salem, M.B., Bouraoui, R., 2009. Heat stress in Tunisia: effects on dairy cows and potential means of alleviating it. S. Afr. J. Anim. Sci. 39 (Suppl. 1), 256–259.

Boďo, Š., Lüttmerding, G., Gálik, R., Kunc, P., Knížková, I., Gürdil, G.A.K., 2022. Analysis of selected data from robotic milking regarding to heat stress of dairy cows. Acta Technol. Agric. 25 (2), 92–96. https://doi.org/10.2478/ata-2022-0015.

Broucek, J., Uhrincat, M., Sistkova, M., Soch, M., Hanus, A., 2019. Effect of supplemental water source on performance of calves during milk feeding and their cross-sucking after weaning. Anim. Sci. Pap. Rep. 37, 19–28.

Capela, L., Leites, I., Romão, R., Lopes-da-Costa, L., Pereira, R.M.L.N., 2022. Impact of heat stress on bovine sperm quality and competence. Animals 12 (8), 975. https://doi.org/10.3390/ani12080975.

Chacha, F., Gherissi, D.E., Lamraoui, R., Bouzebda-Afri, F., Bouzebda, Z., 2022. Evaluation of body condition, daily milk production and some biochemical parameters during the postpartum period according to the calving season in montbeliard dairy cows reared in the semi-arid region. Algeria. Vet. Stanica. 53 (6). https://doi.org/10.46419/vs.53.6.3.

Chen, L., Thorup, V.M., Kudahl, A.B., Østergaard, S., 2024. Effects of heat stress on feed intake, milk yield, milk composition, and feed efficiency in dairy cows: a meta-analysis. J. Dairy Sci. 107 (5), 3207–3218. https://doi.org/10.3168/jds.2023-24059.

Cherier, M.K., Benouaz, T., Bekkouche, S.M.A., Hamdani, M., 2018. Some solar passive concepts in habitat through natural ventilation case study: dry climate in Algeria Ghardaia. Case Stud. Therm. Eng. 12, 1–7. https://doi.org/10.1016/j.csite.2018.02.002.

Collier, R.J., Collier, J.L. (Eds.), 2012. Environmental Physiology of Livestock, first ed. Wiley. https://doi.org/10.1002/9781119949091. 9781119949091.

Cooke, A.S., Machekano, H., Gwiriri, L.C., Tinsley, J.H., Silva, G., Nyamukondiwa, C., Safalaoh, A., Morgan, E.R., Lee, M.R., 2023. The Nutritional Feed Gap: a Review of Seasonal Variation in Ruminant Forage Availability and Quality in Southern Africa. https://doi.org/10.2139/ssrn.4673336.

Copley, J.P., Engle, B.N., Ross, E.M., Speight, S., Fordyce, G., Wood, B.J., Voss-Fels, K.P., Hayes, B.J., 2022. Environmental variation effects fertility in tropical beef cattle. Transl Anim Sci 6 (2). https://doi.org/10.1093/tas/txac035 txac035.

Damarany, A., 2020. Influence of temperature-humidity index level on ovarian activity and conception rate in egyptain baladi cows under climatic conditions of aswan governorate. Egypt. J. Anim. Prod. 57 (1), 13–24. https://doi.org/10.21608/ejap.2020.92767.

David, X., 2021. Covid-19 pandemic and its impact on the breeding world. Anim. Front. 11 (1), 51–53. https://doi.org/10.1093/af/vfaa055.

Djelailia, H., Bouraoui, R., Jemmali, B., Najar, T., 2020. Effects of heat stress on reproductive efficiency in holstein dairy cattle in the North African arid region. Reprod. Domest. Anim. 55 (9), 1250–1257. https://doi.org/10.1111/rda.13772.

El-Bakly, M.K., Mostafa, I.A., Mahboub, H.D., 2023. Evaluation of reproductive performance and disorders in holstein-friesian and its crossbreds with montbeliarde under Egyptian conditions. Alex. J. Vet. Sci. 77 (1). https://doi.org/10.5455/ajvs.93260.

El-Sheikh Ali, H., Tamura, Y., Sameshima, H., Kitahara, G., 2020. Impact of summer heat stress on the thermal environment of bovine female genital tract. Trop. Anim. Health Prod. 52, 3449–3455. https://doi.org/10.1007/s11250-020-02378-4.

El-Sherief, A.A., El-Komy, S.M., Rashad, A., El-Hedainy, D.K., 2022. Reproductive performance of lactating holstein cows as influenced by season of calving and parity under subtropical conditions. J. Adv. Vet. Res. 12 (1), 11–17. https://advetresearch.com/index.php/AVR/article/view/822.

Eulmi, H., Deghnouche, K., Gherissi, D.E., 2023. Dairy cattle breeding practices, production and constraints in arid and semi-arid Algerian bioclimatic environments. Int. J. Environ. Res. 1–18. https://doi.org/10.1080/00207233.2023.2228616.

FAO Stat, 2020. Statistical Database. Food and Agriculture Organization (FAO), Rome.

Fathoni, A., Boonkum, W., Chankitisakul, V., Duangjinda, M., 2022. An appropriate genetic approach for improving reproductive traits in crossbred Thai–holstein cattle under heat stress conditions. Vet. Sci. 9, 163. https://doi.org/10.3390/vetsci9040163.

Ferag, A., Gherissi, D.E., Khenenou, T., Boughanem, A., Moussa, H.H., Maamour, A., Hanzen, C., 2025. Fertility of indigenous "Atlas Brown" Algerian cattle under different heat stress levels. Int. J. Environ. Sci. 1–21. https://doi.org/10.1080/00207233.2025.2507444.

Ferag, A., Gherissi, D.E., Khenenou, T., Boughanem, A., Moussa, H.H., Kechroud, A.A., Fares, M.A., 2024a. Heat stress effect on fertility of two imported dairy cattle breeds from different Algerian agro-ecological areas. Int. J. Biometeorol. 68, 2515–2529. https://doi.org/10.1007/s00484-024-02761-y.

Ferag, A., Gherissi, D.E., Khenenou, T., Boughanem, A., Moussa, H.H., Maamour, A., 2024b. Reproduction efficiency of native and imported algerian cattle under challenging climatic conditions. Biol. Life Sci. Forum. 36, 13. https://doi.org/10.3390/blsf2024036013.

Gaafar, H.M.A., Ma, A.E.H., El-Gendy, M.E., Bassiouni, M.I., Halawa, A.A., ShM, S., 2011. Eefect of heat stress on perfprmance of dairy Friesian cows 2-Reproductive performance. http://www.sciencepub.net.

Gherissi, D.E., Chacha, F., Lamraoui, R., Messaadia, F., Nouadri, S.E., Bouzebda, Afri F., Bouzebda, Z., 2022. Bulk tank milk somatic cell count in relation to the season and milking practice in the dairy cattle farms at the northeast Algeria. Pakistan J. Agric. Sci. 59 (4), 531–542. https://doi.org/10.21162/PAKJAS/22.94.

Gherissi, D.E., Cabaraux, J.F., Hornick, J.L., Hanzen, C., 2025. Le stress thermique environnemental dans l'espèce bovine : 4. Moyens de lutte. Rev. Elev. Med. Vet. Pays Trop. 78, 37495. https://doi.org/10.19182/remvt.374951.

Guinn, J.M., Nolan, D.T., Krawczel, P.D., Petersson-Wolfe, C.S., Pighetti, G.M., Stone, A. E., Ward, S.H., Bewley, J.M., Costa, J.H.C., 2019. Comparing dairy farm milk yield and components, somatic cell score, and reproductive performance among United States regions using summer to winter ratios. J. Dairy Sci. 102 (12), 11777–11785. https://doi.org/10.3168/jds.2018-16170.

Halakoo, G., Kavian, A., Kamali, R., Nobari, K., 2023. Economic evaluation of productive and reproductive traits of holstein and mont billiard cattle and their hybrids in subtropical conditions. J. Ruminant Res. 11 (3), 19–32. https://doi.org/10.22069/EJRR.2023.20572.1862.

Hanzen, C., Delhez, P., Knapp, E., Hornick, J.L., Gherissi, D.E., 2024a. Le stress thermique environnemental dans l'espèce bovine : 1. Caractéristiques générales et méthodes d'évaluation. Rev. Elev. Med. Vet. Pays Trop. 77, 37379. https://doi.org/10.19182/remvt.37379.

Hanzen, C., 1994. Etude des facteurs de risque de l'infertilité et des pathologies puerpérales et du postpartum chez la vache laitière et chez la vache viandeuse. https://hdl.handle.net/2268/142129.

Hanzen, C., 2009. Approche épidémiologique de la reproduction bovine. Université de Liège, Faculté de Médecine Vétérinaire, Service de Thériogénologie des Animaux de Production, Liège, Belgique, p1-8. (Consulted online: 2024).

Hanzen, C., Delhez, P., Hornick, J., Lessire, F., Gherissi, D.E., 2024b. Le stress thermique environnemental dans l'espèce bovine : 2. Effets physiologiques, pathologiques, comportementaux, alimentaires, immunitaires et sur la production laitière. Rev. Elev. Med. Vet. Pays Trop. 77, 37380. https://doi.org/10.19182/remvt.37380.

Hanzen, C., Delhez, P., Lessire, F., Hornick, J.L., Gherissi, D.E., 2025. Le stress thermique environnemental dans l'espèce bovine : 3. Effets sur la reproduction. Rev. Elev. Med. Vet. Pays Trop. 78, 1–15. https://doi.org/10.19182/remvt.37381.

Haou, A., Miroud, K., Gherissi, D.E., 2021. Impact des caractéristiques du troupeau et des pratiques d'élevage sur les performances de reproduction des vaches laitières dans le Nord-Est algérien. Rev. Elev. Med. Vet. Pays Trop. 74 (4), 183–191. https://doi.org/10.19182/remvt.36798.

Hart, E.H., Christofides, S.R., Davies, T.E., Rees Stevens, P., Creevey, C.J., Müller, C.T., Rogers, H.J., Kingston-Smith, A.H., 2022. Forage grass growth under future climate change scenarios affects fermentation and ruminant efficiency. Sci. Rep. 12 (1), 4454. https://doi.org/10.1038/s41598-022-08309-7.

Haymanot, F., Kaba, T., 2022. Prevalence and associated factors of gastrointestinal helminthiasis of lactating cow and effect of strategic deworming on milk quantity, fat, and protein in Kucha, Ethiopia. BMC Vet. Res. 18 (1), 150. https://doi.org/10.1186/s12917-022-03251-2.

Ipcc, 2021. In: Masson Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., et al. (Eds.), Climate Change: the Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021. IPCC.

Ishida, S., Nishiura, A., Yamazaki, T., Abe, H., Nakagawa, S., Nakahori, Y., Hagiya, K., 2024. Effects of heat stress on predicted energy balance, fat-to-protein ratio, and milk β-hydroxybutyrate in first-lactation holstein cattle in Hokkaido, Japan. Anim. Sci. J. 95 (1), e70013. https://doi.org/10.1111/asj.70013.

Kananub, S., VanLeeuwen, J.A., Arunvipas, P., 2018. Association between milk urea nitrogen and first service conception in smallholder dairy farms under heat and humidity stress. Vet. World 11 (11), 1604–1608. https://doi.org/10.14202/vetworld.2018.1604-1608.

Kasimanickam, R., Kasimanickam, V., 2021. Impact of heat stress on embryonic development during first 16 days of gestation in dairy cows. Sci. Rep. 11 (1), 14839. https://doi.org/10.1038/s41598-021-93665-3.

Kawano, K., Yanagawa, Y., Nagano, M., Katagiri, S., 2022. Effects of heat stress on the endometrial epidermal growth factor profile and fertility in dairy cows. Reprod. Fertil. Dev. 68 (2), 144–151. https://doi.org/10.1262/jrd.2021-120.

Khan, I., Mesalam, A., Heo, Y.S., Lee, S.-H., Nabi, G., Kong, I.-K., 2023. Heat stress as a barrier to successful reproduction and potential alleviation strategies in cattle. Animals 13 (14), 2359. https://doi.org/10.3390/ani13142359.

Kim, I.H., Jeong, J.K., 2019. Risk factors limiting first service conception rate in dairy cows and their economic impact. Asian-australas. J. Anim. Sci. 32 (4), 519–526. https://doi.org/10.5713/ajas.18.0296.

Liu, W.B., Peh, H.C., Wang, C.K., Mangwe, M.C., Chen, C.F., Chiang, H.I., 2018. Effect of seasonal changes on fertility parameters of holstein dairy cows in subtropical climate of Taiwan. Asian-australas. J. Anim. Sci. 31 (6), 820. https://doi.org/10.5713/ajas.17.0301.

Llamas-Luceño, N., Hostens, M., Mullaart, E., Broekhuijse, M., Lonergan, P., Van Soom, A., 2020. High temperature-humidity index compromises sperm quality and fertility of holstein bulls in temperate climates. J. Dairy Sci. 103 (10), 9502–9514. https://doi.org/10.3168/jds.2019-18089.

Meguini, M.N., Righi, S., Boucheikhchoukh, M., Sedraoui, S., Benakhla, A., 2021. Investigation of flukes (Fasciola hepatica and Paramphistomum sp.) parasites of cattle in north-eastern Algeria. Ann. Parasitol. 67 (3). https://doi.org/10.17420/ap6703.358.

Merdaci, L., Chemmam, M., 2016. Evolution comparée des performances de vaches laitières Prim'Holsteins et Montbéliardes au Nord-Est algérien. Livest. Res. Rural Dev. 28. http://www.lrrd.org/lrrd28/2/merd28023.html.

Miroud, K., Hadef, A., Khelef, D., Ismail, S., Kaidi, R., 2014. Bilan de reproduction de la vache laitière dans le nord-est de l'Algérie. Livest. Res. Rural. Dev. 26 (6). http://www.lrrd.org/lrrd26/6/miro26107.htm.

Molinari, P.C., Bromfield, J.J., 2023. Inflammatory responses of bovine endometrial epithelial cells are increased under in vitro heat stress conditions. J. Therm. Biol. 114, 103564. https://doi.org/10.1016/j.jtherbio.2023.103564.

Molinari, P.C., Davidson, B.D., Laporta, J., Dahl, G.E., Sheldon, I.M., Bromfield, J.J., 2023. Prepartum heat stress in dairy cows increases postpartum inflammatory responses in blood of lactating dairy cows. J. Dairy Sci. 106 (2), 1464–1474. https://doi.org/10.3168/jds.2022-22405.

Mouffok, C., Allouni, A., Semara, L., Belkasmi, F., 2019. Factors affecting the conception rate of artificial insemination in small cattle dairy farms in an Algerian semi-arid area. Livest. Res. Rural Dev. 31 (4), 1–9. http://www.lrrd.org/lrrd31/4/mouff31049.html.

Nanas, I., Chouzouris, T.M., Dovolou, E., Dadouli, K., Stamperna, K., Kateri, I., Barbagianni, M., Amiridis, G.S., 2021. Early embryo losses, progesterone and pregnancy associated glycoproteins levels during summer heat stress in dairy cows. J. Therm. Biol. 98, 102951. https://doi.org/10.1016/j.jtherbio.2021.102951.

Nguyen-Kien, C., Van Khanh, N., Hanzen, C., 2017. Study on reproductive performance of holstein x lai sind crossbred dairy heifers and cows at smallholdings in Ho Chi Minh City, Vietnam. Trop. Anim. Health Prod. 49 (3), 483–489. https://doi.org/10.1007/s11250-016-1217-0.

NRC, 1971. National Research Council, 1971.

ONIL, 2018. National interprofessional office for milk and dairy products. https://onil.dz/.

Ooi, E., Stevenson, M.A., Goddard, M.E., Beggs, D.S., Mansell, P.D., Pryce, J.E., Pyman, M.F., 2023. Validating the female fertility estimated breeding value in Australian commercial dairy herds. J. Dairy Sci. 106 (5), 3376–3396. https://doi.org/10.3168/jds.2022-21955.

Ouarfli, L., Chehma, A., 2018. Temperature-humidity index and success of artificial insemination of holstein and montbéliarde cows in the Saharan region. Livest. Res. Rural Dev. 30 (10). http://www.lrrd.org/.../ouarf30180.html.

Parveen, K., Gupta, A.K., Mumtaz, S., Khan, A.H., Rathore, A., 2022. Impact of heat stress on reproductive performance of sahiwal cows. Indian J. Dairy Sci. 75 (2), 167–172. https://mjl.clarivate.com/search-resultsorhttps://epubs.icar.org.in/index.php/IJDS/article/view/102310.

Rahmoun, D.E., Fares, M.A., Gherissi, D.E., Lieshchova, M., 2020. Effect of the seasons on the change of morphological, histo-cytological and hormonal parameters of the thyroid gland in cattle in Algeria. J. Vet. Sci. Anim. Husb. 8 (2), 1–9.

Rajamanickam, K., Leela, V., Suganya, G., Basha, S.H., Parthiban, M., Visha, P., Elango, A., 2022. Thermal cum lipopolysaccharide-induced stress challenge downregulates functional response of bovine monocyte-derived macrophages. J. Therm. Biol. 108, 103301. https://doi.org/10.1016/j.jtherbio.2022.103301.

Rhoads, M.L., 2020. Effects of periconceptional heat stress on primiparous and multiparous daughters of holstein dairy cows. Theriogenology 150, 458–463. https://doi.org/10.1016/j.theriogenology.2020.03.015.

Rodríguez-Godina, I.J., García, J.E., Morales, J.L., Contreras, V., Véliz, F.G., Macías-Cruz, U., Avendaño-Reyes, L., Mellado, M., 2024. Effect of heat stress during the dry period on milk yield and reproductive performance of holstein cows. Int. J. Biometeorol. 1–8. https://doi.org/10.1007/s00484-024-02633-5.

Rolando, P.L., Sandoval-Monzón, R.S., Montenegro, M.P., Ruiz-García, L.F., 2022. Temperature–humidity index and reproductive performance of dairy cattle farms in Lima, Peru. Open Vet. J. 12 (3), 399–406. https://doi.org/10.5455/OVJ.2022.v12.i3.14.

Sammad, A., Umer, S., Shi, R., Zhu, H., Zhao, X., Wang, Y., 2020. Dairy cow reproduction under the influence of heat stress. J. Anim. Physiol. Anim. Nutr. 104, 978–986. https://doi.org/10.1111/jpn.13257.

Shi, R., Brito, L.F., Liu, A., Luo, H., Chen, Z., Liu, L., Guo, G., Mulder, H., Ducro, B., van der Linden, A., Wang, Y., 2021. Genotype-by-environment interaction in holstein heifer fertility traits using single-step genomic reaction norm models. BMC Genom. 22 (1), 1–20. https://doi.org/10.1186/s12864-021-07496-3.

Siatka, K., Sawa, A., Krężel-Czopek, S., Piwczyński, D., Bogucki, M., 2017. Effect of some factors on number of services per conception in dairy cows. J. Vet. Sci. Technol. 8 (1). https://doi.org/10.4172/2157-7579.1000465, 4.

Singh, S.P., Kumar, A., Sourya, N., 2021. Effects of heat stress on animal reproduction. Int. J. Fauna Biol. 8, 16–20. https://www.faunajournal.com/archives/2021/vol8issue2/PartA/8-2-3-478.pdf.

Souames, S., Berrama, Z., 2020. Factors affecting conception rate after the first artificial insemination in a private dairy cattle farm in North Algeria. Vet. World 13 (12), 2608. https://doi.org/10.14202/vetworld.2020.2608-2611.

Souames, S., Hanzen, C., Detilleux, J., Kaidi, R., 2015. Survey of artificial insemination practices in Algeria. Res. J. Vet. Pract. 3 (1), 1–9. https://doi.org/10.14737/journal.rjvp/2015/3.1.1.9.

Tadesse, B., Reda, A.A., Kassaw, N.T., Tadeg, W., 2022. Success rate of artificial insemination, reproductive performance and economic impact of failure of first service insemination: a retrospective study. BMC Vet. Res. 18 (1), 1–10. https://doi.org/10.1186/s12917-022-03325-1.

Tamboli, P., Chaurasiya, A.K., Upadhyay, D., Kumar, A., 2023. Climate change impact on forage characteristics: an appraisal for livestock production. In: Singhal, R.K., Ahmed, S., Pandey, S., Chand, S. (Eds.), Molecular Interventions for Developing climate-smart Crops: a Forage Perspective. Springer, Singapore. https://doi.org/10.1007/978-981-99-1858-4_10.

Toledo-Alvarado, H., Cecchinato, A., Bittante, G., 2017. Fertility traits of holstein, brown Swiss, simmental, and alpine grey cows are differently affected by herd productivity and milk yield of individual cows. J. Dairy Sci. 100 (10), 8220–8231. https://doi.org/10.3168/jds.2016-12442.

USDA, 2020. United States department of agriculture, 2020. Algeria: dairy and products annual. https://www.usda.gov/.

Weather Underground, 2016-2021. Monthly history. https://www.wunderground.com/history(Consulted online in: June 2024).

Yerou, H., Zoghlami, M., Madani, T., Benamara, N., Rehal, M., 2021. Impact de l'indice température-humidité sur les paramètres de reproduction de vaches Holsteins en zone semi-aride de l'Ouest algérien. Livest. Res. Rural Dev. 33. http://www.lrrd.org/lrrd33/10/33123houa.html.

Zeroual, A., Assani, A.A., Meddi, M., 2017. Combined analysis of temperature and rainfall variability as they relate to climate indices in northern Algeria over the 1972–2013 period. Hydrol. Res. 48 (2), 584–595. https://doi.org/10.2166/nh.2016.244.

Zeroual, A., Assani, A.A., Meddi, M., Alkama, R., 2019. Assessment of climate change in Algeria from 1951 to 2098 using the Köppen–Geiger climate classification scheme. Clim. Dyn. 52 (1-2), 227–243. https://doi.org/10.1007/s00382-018-4128-0.

Zittis, G., Hadjinicolaou, P., Almazroui, M., Bucchignani, E., Driouech, F., El Rhaz, K., Kurnaz, L., Nikulin, G., Ntoumos, A., Ozturk, T., Proestos, Y., Stenchikov, G., Zaaboul, R., Lelieveld, J., 2021. Business-as-usual will lead to super and ultra-extreme heatwaves in the Middle East and North Africa. npj Clim. Atmos. Sci. 4 (1), 20. https://doi.org/10.1038/s41612-021-00178-7.