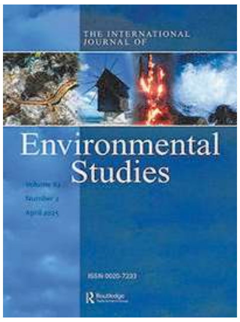

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ARTICLE

Fertility of indigenous "Atlas Brown" Algerian cattle under different heat stress levels

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ABSTRACT

This study investigates the impact of heat stress, measured by daily temperature-humidity index (THI), on the reproductive performance of native Algerian cows. We analysed fertility metrics from 3,847 artificial inseminations performed on 2,130 Atlas Brown cows. Results showed a total pregnancy rate (TPR) of 58.97%, a first-service conception rate (CR1stAI) of 24.41%, and a second-service conception rate (CR2ndAI) of 36.71%. Severe THI levels (>80) significantly decreased TPR by 26% and CR1stAI by 46%, but low and moderate THI had no significant impact. Heat stress did not significantly affect CR2ndAI and repeat breeding cows (RBC), though moderate and severe heat stress decreased CR2ndAI, and severe heat stress increased RBC. Moderate heat stress reduced the proportion of cattle with <30 days reproductive period. The study shows that Atlas Brown cattle are susceptible to high THI levels and perform well under low and moderate heat stress, suggesting the potential utility of indigenous breeds in high-THI regions.

KEYWORDS

Algeria; Atlas Brown cattle; genetic; reproduction; THI

Introduction

The main progenitor of Atlas Brown cattle is *Bos primigenius mauritanicus* [1]. It is considered a subset of Iberian cattle, generally described as the 'brown branch'. This subset is divided into rustic sub-ecotypes, their names being related to the regions where they live, such as Guelmoise, Cheurfa, Setifien, and Chelifien [2,3]. Atlas Brown cattle are central in the rural economy of households, representing one of the most significant livestock agricultural activities. But their exploitation remains relatively underdeveloped, characterised by extensive breeding and traditional processing methods [4,5]. These animals are mainly raised for meat production; the milk is mainly used for self-consumption and as feed for young animals [2,6,7].

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Sometimes, Atlas Brown cattle are integrated into semi-intensive dairy cattle farms, contributing to both meat and milk production [8].

Recent reports have confirmed that the Mediterranean region, especially Algeria, is particularly susceptible to the impacts of climate change [9]. Algeria's temperature increased throughout the 20th century and the extension of the desert climate is expected in the future [9,10]. Thermal stress causes physiological and metabolic disturbances, triggering various adaptive processes in affected animals [11–14]. These animals typically redirect energy from productive pathways to support essential adaptive mechanisms leading to increased health problems, production losses and welfare condition deterioration [11,15].

The adaptive responses of the cattle to temperature stress include changed feeding behaviour, less activity, increased respiration rate, panting, sweating, seeking shade, and increased water intake [11,16,17]. The heat stress (HS) reduces the developmental competence of oocytes, which compromises reproduction [18]. The HS disturbs the hormonal balance that is crucial for successful reproduction, particularly in reducing the luteinising hormone and progesterone levels [16,19–21], which leads to severe problems such as poor follicle development with a poor-quality oocyte [21,22], and problems related to maturity, silent oestrus [19], abnormal or weak embryo development [17,23], and pregnancy loss [21,24], resulting in a declining reproduction rate and losses for the cattle industry. In this regard, HS compromises the conception rate, the success of the first artificial insemination, and the number of services per conception [19,21,25,26]. The methods of recovery are insufficient to recover the normal reproduction rate [21,24].

The indigenous animal breeds are known to be adapted to local difficult environmental conditions [5,7,13,27–29]. They are characterised by tolerance to heat stress, infectious diseases and parasite tolerance [3,5,13,27,30,31]. These adaptations are caused by the special metabolism and morphological features, such as skin coat, and skin pore density that provide better body temperature regulation, protection from direct solar radiation, biting insects, and tick infestation [13,27,32]. Therefore, integrating native animals into food production systems enhances resilience to climate fluctuations [33]. Furthermore, they foster community cohesion and preserve cultural heritage. On a broader scale, these animals contribute to conserving genetic diversity and safeguarding agro-biodiversity, offering benefits nationally and globally [34]. This is unfortunately not the case at present, as we observe that Atlas Brown cattle in North Africa are among the African bovine ecotypes with an unknown risk status [35]. This applies to approximately 30% of the 1300 taurine and indicine breeds recorded worldwide [36]. Scientific reports analysing the situation of this population in North Africa confirm that the importation of improved breeds, massive crossbreeding, and the reduction of rangelands and meadow areas are rendering the Atlas Brown population at risk of extinction [3,5,37,38]. This is also the case in Algeria, where indigenous cattle have witnessed a gradual decline, dropping from 82% in 1986 to approximately 48% in 2016 in terms of the percentage of the national cattle population [7,39].

There is currently a gap in the available literature regarding the fertility and reproductive performance of the native Algerian cattle population. Therefore, our current research aims to assess the reproductive performance of Atlas Brown cattle under various agro-ecological conditions, with particular emphasis on fertility traits in relation to different heat stress levels.

Material and methods

Study design

Data for the breeding study were sourced from individual cow records made available by the National Centre for Artificial Insemination and Genetic Improvement (CNIAAG). Initially, we proceeded to the data collection of information related to 3,847 artificial inseminations (AI) practised between 01 January, 2016, to 31 December on 2,130 on local Algerian "Atlas Brown" cows. These data were registered and subjected to initial examination for any eventual outliers that could have a significant effect on multiple regressions in the subsequent analysis. The animals belonged to 17 different departments (as shown in Figure 1) situated in two different agro-ecological areas, namely littoral and semi-arid areas. The database provides details such as cow identification number, the date of the first AI, the date of subsequent AI, pregnancy diagnosis, reproductive period, oestrus type, breed (local cattle), bull name, incidents of pregnancy losses, and calving dates.

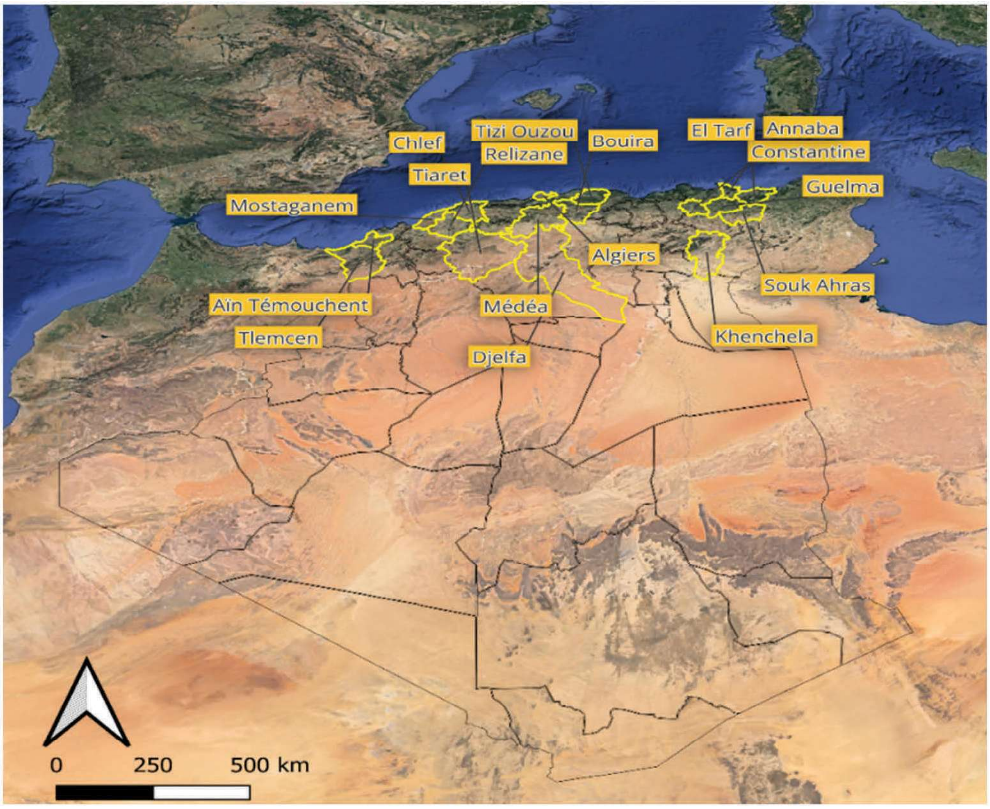

Figure 1. Map of Algeria showing the locations of origin of the studied local cattle.

Meteorological data

The mean daily data for the maximum ambient temperature and maximum relative humidity for each day in 2016 were obtained electronically from "Weather Underground" (https://www.wunderground.com/history). These data were instrumental in computing the Temperature-Humidity Index (THI) values for each day on which artificial insemination occurred; the THI was calculated using the following formula [40]:

$$THI = (1.8 \times MaxT + 32) - (0.55 - 0.0055 \times H) \times (1.8MaxT - 26)$$

Max T: maximum temperature in °C measured by a dry-bulb thermometer; RH: 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 zone THI <68, mild HS THI ranges between 68 and 71, moderate HS 72–79, and severe HS THI≥ 80 [41–43]. For cows, THI > 80 is recognised as extreme for cows and may turn dangerous, potentially harming their survival [44].

Fertility parameters

To gain a comprehensive understanding of the impact of the THI variations on reproductive performance, we meticulously measured several key parameters on all cows, including both pregnant and non-pregnant cows. These consisted of the total pregnancy rate (TPR), conception rate at the first (CR1stAI), second (CR2ndAI) artificial insemination, rate of repeat breeders' cows (RBC), apparent fertility index (AFI), services per conception (SPC), and reproductive period (RP: first to last AI interval). The TPR (%) was calculated by dividing the number of cows confirmed pregnant by the total number of inseminated cows for which pregnancy status was determined, expressed as a ratio. Pregnancy diagnosis, established through early ultrasonography examination, was further confirmed at least 60 days later by manual palpation examination. The CR1stAI (%) or CR2ndAI (%) represent the proportion of pregnancies achieved after the first or second insemination, respectively, compared to the total number of animals inseminated at least once. The RBC (%) represents the number of cows inseminated more than twice divided by the total number of inseminated cows. The AFI, also known as the total number of services per Conception (SPC), represents the frequency at which a cow is served and inseminated to achieve a successful conception during each parity. The reproductive period (RP) refers to the interval between the first and last artificial insemination for cows that have been inseminated at least once. These parameters offer valuable insights into the reproductive efficiency by evaluating the fertility performance of indigenous Algerian cattle [45,46]. The findings obtained were then compared to the standard values for dairy cattle recommended by Hanzen [45].

Statistical analysis

Data were collected using Excel and organised into columns containing the following information: agro-ecological zone, date of insemination, daily THI, and THI classes as independent variables. The results of each insemination, the number of services per cow, and the reproductive period were considered dependent variables. Reproductive performance metrics, including the pregnancy rate, conception rate at the first, second artificial insemination, repeat breeders' cows, and fertility index, were calculated for each dairy cow and treated as the second group of categorical dependent variables. The data were then transferred to the SPSS (v. 26) analytical software for multiple analyses.

Using the Chi-square Test, we examined the comparison of insemination results, pregnancy diagnosis, and the results of the first, second artificial insemination, and repeat breeders' cows to THI classes. The Kruskal–Wallis analysis of variance (KW ANOVA) test was conducted to compare the SPC and RP means and determine the statistical differences in the averages of these parameters according to THI classes after evaluating the normality of distribution using the Kolmogorov-Smirnov and Shapiro–Wilk tests. Logistic and linear regression were employed to determine the effect of THI classes on the dependent variables. The general equations are as follows: $\text{Logit}(Y) = \alpha + \beta 1X1 + \beta 2X2$, where Y represents the PR, CR1stAI, CR2ndAI, RBC, and RP classes, α denotes the intercept parameter, and β signifies the logistic regression coefficients for the explanatory effects (X1, X2, the classes of THI and agro-ecological zone) incorporated in the statistical model. $Y1 = B0 + B1X1 + B2X2$, where Y1 represents the vector for reproductive performance (SPC and RP), and B0 represents the intercept. B1 and B2 are the regression coefficients for X1 (the THI) and X2 (agro-ecological zone). The AFI is used in general descriptive analysis. On the other hand, the SPC, which is an individual quantitative variable, would allow for comparing means between groups and applying linear regression to distinguish the nature and level of relationship between insemination frequency and THI level. Statistical significance was determined at a threshold of $p < 0.05$.

Results

Temperature humidity index outcomes

The study reveals significant monthly variations in the THI. From April to October, THI readings consistently exceed the critical threshold of 68, ranging between 69 and 87, indicating a period of heat stress for animals. Conversely, from November to March, THI levels remain below the critical point, ranging from 59 to 65, providing thermal comfort. July exhibits the highest THI value; December records the lowest.

Analysis of the regional THI data reveals statistically significant differences ($p < 0.001$) between littoral and semi-arid areas. Littoral regions, with an average THI of 73.31, are classified as stressful environments for animals. In these areas, heat stress conditions persist from April to October. Semi-arid regions, however, present a more moderate climate with an average THI of 69.41. Animals in these areas experience a shorter period of heat stress, mainly from May to October, with THI values ranging from 74 to 86 (supplementary Figure S1).

The effect of THI and agro-ecological region on TPR

The average pregnancy rate for the Algerian local breed was 58.97% (Table 1). There is a significant ($p < 0.05$) decline in TPR when the THI becomes more stressful for cows,

Table 1. Reproductive performances of atlas brown cows in relation to THI changes.

	Overall	< 68 No stress	68–71 Mild	72–79 Moderate	> 80 Severe	*p* value	Littoral	Semi-Arid	*p* Value
TPR (%)	58.97% 1256/2130	62.90% 373/593	57.14% 168/294	60.28% 305/506	55.63% 410/737	0.047	56.99% 1007/1767	68.60% 249/363	0.000
CR1st AI (%)	24.41% 520/2130	31.02% 170/548	23.68% 76/321	25% 122/488	19.66% 152/773	0.006	22.81% 403/1767	32.23% 117/363	0.018
CR2nd AI (%)	36.71% 591/1610	38.10% 144/378	29.80% 73/245	40.71 % 149/366	36.23% 225/621	0.445	34.97% 477/1364	46.34% 114/246	0.001
RBC (%)	14.23% 145/1019	13.25% 31/234	13.95 % 24/172	12.44 % 27/217	15.91% 63/396	0.348	14.32% 127/887	13.64% 18/132	1
AFI	1.74 ± 0.76	1.62 ± 0.74^{a}	1.72 ± 0.75$^{b, c}$	1.70 ± 0.69$^{a, b}$	1.86 ± 0.81^{c}	0.000	1.77 ± 0.791	1.61 ± 0.657	0.005
RP (days)	41.29 ± 4.4	42.25 ± 53.94 $^{a, b, c}$	36.64 ± 52.8^{a}	43.37 ± 49.71$^{b, d}$	40.79 ± 40.04$^{c, d}$	0.006	42.80 ± 49.589	34.06 ± 41.543	0.003
RP 0 days	28.09% 520/1851	32.69% 170/520	14.62% 76/520	23.46% 122/520	29.23% 152/520	0.001	77.5% 403/520	22.5% 117/520	0.001
0 < RP ≤ 30 days	28.58% 529/1851	24.58% 130/529	16.45% 87/529	24.76% 131/529	34.22% 181/529		84.31% 446/529	15.69% 83/529	
> 30 days	43.33% 802/1851	28.55% 229/802	9.97% 80/802	24.31% 195/802	37.16% 298/802		85.04% 682/802	14.96 120/802	

TPR: total pregnancy rate, CR1st AI: conception rate at first AI, CR2nd AI: conception rate at second AI, RBC: rate of repeat breeders' cows, AFI: apparent fertility index, RP: reproductive period, *p* (value): significance.

specifically when the THI surpasses 68. The TPR decreased from 62.90% when THI < 68% to 57.14%, 60.28%, and 55.53% when THI ranged between 68 and 71, 72–79 and >80, respectively. TPR experienced significant ($p < 0.001$) increase from 56.99% to 68.60% in L and SA areas (Table 1). Furthermore, the pregnancy risk decreases with higher THI levels (Table 2). Compared to THI < 68, the TPR registered a non-significant ($p > 0.05$) decrease by factors of 0.786 0.895 for THI ranges between 68 and 71 and 72 and 79, respectively. And a significant ($p < 0.01$) decrease by a factor of 0.74 for THI > 80. Additionally, the interaction between THI and agro-ecological region showed a significant ($p < 0.001$) effect on TPR, an increase of 61.9% in SA areas is registered compared to L areas, with a continued significant ($p < 0.05$) decrease in severe heat stress (Table 3).

The effect of THI and agro-ecological region on CR1stAI

The CR1stAI for the Algerian local breed was 24.41% (Table 1). There were significant variations in CR1stAI with THI ($p < 0.01$) and agro-ecological ($p < 0.05$) changes. The CR1stAI declines from 31% to 23.68%, 25%, and 19.66% from comfortable zone to mild, moderate, and severe heat stress, respectively. The CR1stAI increased from 22.81% to 32.23% in L and SA areas. The logistic regression results revealed a non-significant reduction of 19.4% when cows are under moderate heat stress (Table 2). But, a significant decline of 43.9% and 46% in the likelihood of AI success for cows under mild and severe heat stress is registered. The changes in CR1stAI are also observed in the

Table 2. Logistic regression results showing the relationship of Atlas Brown cattle reproductive performances to different THI levels.

		B	S.E.	Wald	Sig.	Exp(B)	95% CI for EXP(B)
TPR (%)	< 68	Reference		7.93	0.047		
	68–71	−0.24	0.145	2.734	0.098	0.786	0.592–1.046
	72–79	−0.111	0.124	0.795	0.373	0.895	0.701–1.142
	> 80	−0.302	0.113	7.156	0.007	0.74	0.593–0.922
	Constant	0.528	0.085	38.571	0.000	1.695	
CR1st AI (%)	< 68	Reference		12.39	0.006		
	68–71	−0.578	0.233	6.156	0.013	0.561	0.355–0.886
	72–79	−0.216	0.217	0.987	0.32	0.806	0.526–1.234
	> 80	−0.616	0.194	10.129	0.001	0.54	0.369–0.789
	Constant	0.977	0.147	44.374	0.000	2.656	
CR2nd AI (%)	< 68	Reference		2.669	0.446		
	68–71	−0.264	0.212	1.548	0.213	0.768	0.507–1.164
	72–79	0.054	0.182	0.087	0.768	1.055	0.738–1.509
	>80	−0.106	0.163	0.424	0.515	0.899	0.653–1.238
	Constant	0.335	0.129	6.742	0.009	1.398	
RBC (%)	< 68	Reference		3.28	0.35		
	68–71	−0.04	0.369	0.012	0.914	0.961	0.466–1.981
	72–79	−0.02	0.358	0.003	0.955	0.98	0.486–1.977
	>80	0.421	0.311	1.836	0.175	1.524	0.828–2.804
	Constant	−0.15	0.245	0.372	0.542	0.861	

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

interaction between THI and agro-ecological areas' effect (Table 3). The CR1stAI significantly ($p < 0.05$) increased by 51.4% in SA compared to L.

The effect of THI and agro-ecological region on CR2ndAI

The overall CR2ndAI in local breeds was 36.71% (Table 1). The THI had non-significant effects on the CR2ndAI ($p > 0.05$). But, there was a slight decrease in the CR2ndAI in cows suffering from mild and severe heat stress (29.80% and 36.23%, respectively) compared to the comfortable zone (38.10%). In contrast, a minimal increase was observed in cows experiencing moderate heat stress, with 40.71% affected. Inversely a significant ($p = 0.001$) increase is observed in SA compared to L regions (46.34% Vs. 34.97%, respectively). The odds ratio results support these findings, indicating values of 0.768, 1.055, and 0.899 for mild, moderate, and severe heat stress compared to comfortable zones, respectively ($p > 0.05$) (Table 2). The explanatory model of the interaction in the effect of THI to the agro-ecological region shows a significant effect ($p < 0.05$). There is a significant ($p < 0.05$) increase by 78.4% in SA and no significant decrease in high THI levels (Table 3).

The effect of THI and agro-ecological region on RBC

The repeat breeding rate in the Atlas Brown breed was 14.23% (Table 1). The RBC rate registered an increase from 13.25% to 15.91% in comfortable and severe heat stress and a decrease from 14.32% to 13.64% in L and SA (Table 1) without significant impact of THI and agro-ecological region in these changes ($p > 0.05$). The Odds Ratio results (1.524 for THI > 80 (Table 2), and 1.022 for SA (Table 3) show an increase in RBC, but the results are not significant P > 0.05.

Table 3. Logistic regression results showing the associated impact of THI with agro-ecological regions on Atlas Brown cattle reproductive performances.

			B	S.E.	Wald	Sig.	Exp(B)	95% CI for EXP(B)	P
TPR (%)	Constant		0.431	0.088	23.777	0.000	1.539		0.000
	Region	Littoral				Reference			
		Semi-Arid	0.482	0.123	15.242	0.000	1.619	1.271–2.062	
	THI	< 68	Reference		6.552	0.088			
		68–71	-0.197	0.146	1.817	0.178	0.821	0.617–1.094	
		72–79	-0.094	0.125	0.565	0.452	0.91	0.713–1.163	
		>80	-0.278	0.113	6.002	0.014	0.757	0.607–0.946	
CR1stAI (%)	Constant		0.885	0.153	33.667	0.000	2.423		0.002
	Region	Littoral				Reference			
		Semi-Arid	0.415	0.198	4.37	0.037	1.514	1.026–2.233	
	THI	<68	Reference		11.191	0.011			
		68–71	−0.536	0.234	5.239	0.022	0.585	0.37–0.926	
		72–79	−0.213	0.218	0.956	0.328	0.808	0.527–1.239	
		>80	−0.597	0.194	9.441	0.002	0.55	0.376–0.805	
CR2ndAI (%)	Constant		0.285	0.128	4.966	0.026	1.33		0.015
	Region	Littoral				Reference			
		Semi-Arid	0.579	0.18	10.331	0.001	1.784	1.253–2.539	
	THI	<68	Reference		1.233	0.745			
		68–71	−0.093	0.214	0.189	0.664	0.911	0.599–1.387	
		72–79	−0.106	0.176	0.359	0.549	0.9	0.637–1.271	
		>80	−0.18	0.163	1.228	0.268	0.835	0.607–1.149	
RBC (%)	Constant		−0.144	0.226	0.403	0.525	0.866		0.935
	Region	Littoral				Reference			
		Semi-Arid	0.021	0.361	0.004	0.953	1.022	0.504–2.071	
	THI	<68	Reference		0.827	0.843			
		68–71	0.142	0.416	0.116	0.733	1.152	0.51–2.603	
		72–79	0.3	0.333	0.81	0.368	1.35	0.703–2.592	
		> 80	0.161	0.292	0.303	0.582	1.174	0.663–2.08	

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

The effect of THI and agro-ecological region on SPC and AFI

The present study revealed an average Fertility Index (AFI) of 1.74 ± 0.768 in the Atlas Brown cattle population, with THI levels and agro-ecological regions significantly affecting this parameter ($p < 0.001$, $p < 0.01$, respectively). AFI showed an increase with higher THI levels (Table 1), with values of 1.62 ± 0.749 for THI < 68, and 1.72 ± 0.757, 1.70 ± 0.696, and 1.86 ± 0.818 for THI range between 68 and 71, 72–79, and THI > 80, respectively. The results showed a decreased AFI in SA compared in L region (1.77 ± 0.791 and 1.61 ± 0.657, respectively). Additionally, the results demonstrated that the Services per Conception (SPC) are influenced by THI, as indicated by a significant increase in SPC by 0.007 ($p <$ 0.001) for each incremental point in THI above 68 (Figure 2(b)). Table 4 showed that the interaction between THI and agro-ecological region significantly affected SPC, expressed by a significant decrease (B = –0.127, P < 0.05) in SA compared to L, and a significant increase in SPC (B = 0.219, P < 0.001) for THI > 80 compared to THI < 68.

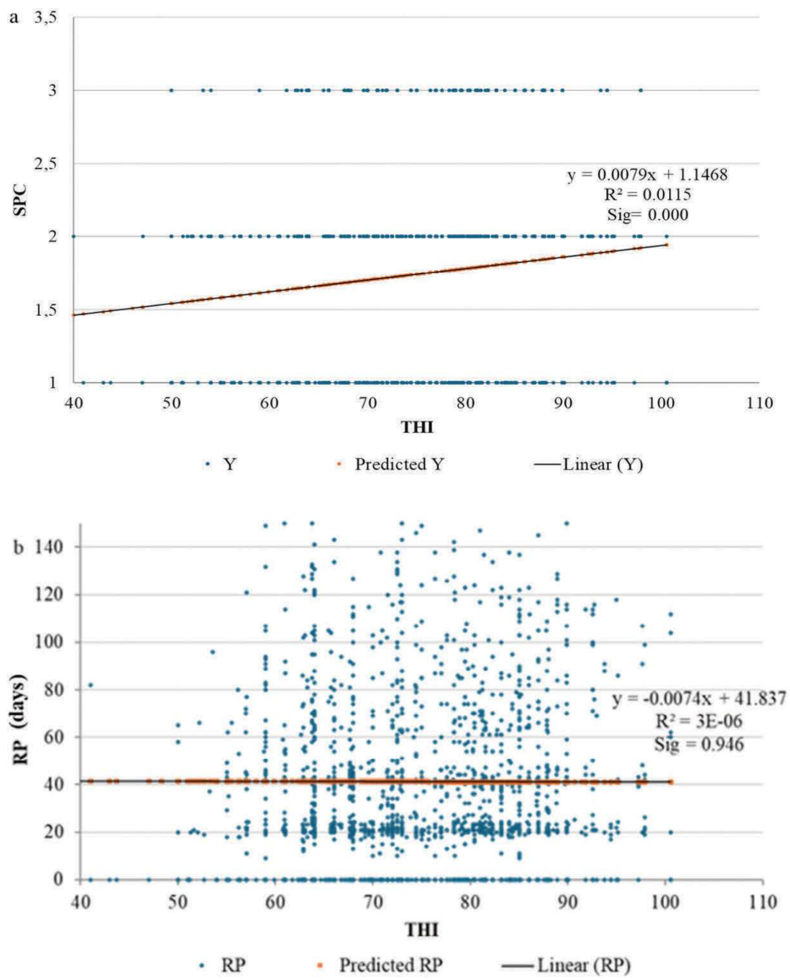

Figure 2. Simple linear regression results showing the relationship of SPC (a) and RP (b) with THI in Atlas Brown cattle.

Table 4. Linear regression results showing the associated impact of THI with agro-ecological regions on Atlas Brown SPC.

			B	S.E	Beta	T	Sig.	CI (95%)	P
SPC	(Constant)		1.783	0.08		22.338	0.000	1.626–1.94	0.000
	Region	Littoral	Reference						
		Semi-Arid	−0.127	0.055	−0.066	−2.334	0.02	−0.234 - −0.02	
	THI	< 72	Reference						
		68–71	0.085	0.071	0.038	1.186	0.236	−0.055–0.224	
		72–79	0.082	0.06	0.045	1.359	0.174	−0.036–0.2	
		>80	0.219	0.055	0.136	3.96	0.000	0.11–0.327	

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

The effect of THI on RP

Table 1 shows that the overall rate of cows with RP > 30 days (43.33%) is higher than that of cows with RP equal to 0 days (28.09%) and cows with 0 < RP ≤ 30 days (28.58%). The RP of the studied cows is significantly affected by THI levels ($p < 0.01$). The results demonstrated an insignificant decrease in RP by 0.007 ($p < 0.001$) for each incremental point in THI above 68 (Figure 2(b)). Furthermore, the rate of cows that had 0 days of RP decreased significantly with the increase in THI: from 32.69% when THI <68, to 14.62% when THI is between 68 and 71, 23.46% when THI is between 72 and 79, and 29.23% when THI > 80. The rate of cows with 0 < RP ≤ 30 increased from 24.58% to 34.22% when comparing THI < 68 and THI > 80. The insemination days with THI > 80 showed a significant increase in the rate of cows with RP >30 days (37.16%) compared to those inseminated on days with comfortable THI levels (28.55%). Furthermore, the results showed that the agro-ecological region significantly ($p = 0.001$) affected the RP, with the L area registering a higher rate of animals with the three RP categories.

The combination of THI levels and agro-ecological region increases the likelihood of a reproductive period (RP) between 0 and 30 days by 50.3% in the L region compared to the SA area (B = 0.408, P < 0.05). This probability decreases by 43.9% when THI is below 68 compared to THI above 80 (B = −0.414, P = 0.01). For RP greater than 30 days, the agro-ecological region in relation to THI increases the probability by 64.7% in L compared to SA (B = 0.499, P = 0.001), whereas the probability significantly decreases by 28.8% for THI < 68 (B = −0.34, P < 0.05) and by 47.3% for THI between 68 and 71 (B = −0.641, P = 0.001) (Table 5).

Discussion

Climate change is one of the most urgent challenges the world faces. Several studies predict a further future decrease in total annual rainfall by 15–30% [9,47] and an expansion of desert climates at the expense of the temperate northern zones. This shift is attributed to both rising temperatures and declining precipitation [9,48]. These effects are likely to be severe, pervasive, and irreversible in the coming years [49], posing significant risks to livestock production, crop yields, and overall food and nutrition security [50]. Heat stress, in particular, can lead to decreased animal productivity, health problems, and higher mortality rates, increasing the challenges faced by the agricultural sector [51]. To mitigate these impacts, the FAO [52] recommends promoting the use of local genetic resources, which are often better adapted to local climatic conditions. Using

Table 5. Logistic regression results showing the associated impact of THI with agro-ecological regions on Atlas Brown cattle RP.

			B	S.E	Wald	Sig.	Exp(B)	95% CI for Exp(B)	P
0 < RP ≤ 30 days		Intercept	−0.164	0.173	0.899	0.343			0.000
	Region	Semi-Arid	Reference						
		Littoral	0.408	0.16	6.474	0.011	1.503	1.098–2.058	
	THI	>80	Reference						
		72–79	−0.094	0.167	0.315	0.575	0.91	0.656–1.264	
		68–71	−0.056	0.192	0.084	0.772	0.946	0.649–1.379	
		< 68	−0.413	0.161	6.601	0.01	0.661	0.482–0.907	
> 30 days		Intercept	0.256	0.157	2.66	0.103			
	Region	Semi-Arid	Reference						
		Littoral	0.499	0.145	11.773	0.001	1.647	1.239–2.19	
	THI	>80	Reference						
		72–79	−0.193	0.153	1.59	0.207	0.825	0.611–1.113	
		68–71	−0.641	0.189	11.476	0.001	0.527	0.364–0.763	
		< 68	−0.34	0.143	5.668	0.017	0.712	0.538–0.942	

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

these resilient genetic resources can enhance the sustainability and productivity of agricultural systems, helping to secure food resources under changing climate conditions. This approach not only supports biodiversity but also strengthens the resilience of food production systems against the adverse effects of climate change.

The objective of our study is to evaluate the effect of heat stress on the fertility performance of Atlas Brown cows, one of the most important African indigenous cattle populations [53]. We aim to investigate the relationship of Temperature-Humidity Index (THI) on the day of artificial insemination (AI), as an indicator of heat stress conditions, and heat stress-related factor (agro-ecological region) with reproductive parameters as dependent variables.

Our results revealed an adequate TPR of 58.97% compared to the dairy cattle threshold of 60% [45]. This result was higher than those obtained by Oliveira et al. [54] and Nishimwe et al. [55] in large- and small-scale dairy farms (45. 5% and 42.2%, respectively). In mild and moderate HS levels, we recorded a non-significant decrease of the TPR by 21.4% and 10.5%, respectively. A significant effect of THI on TPR was observed in the severe HS category, with a 26% decline in TPR when THI > 80. Numerous studies have shown that the hot season, characterised by high THI, significantly reduces PR because of the heat stress experienced by cows [19,25,56–61]. The studied local cattle breed, the Algerian "Brune de l'Atlas" appears well-adapted to the North African Mediterranean climate and demonstrates tolerance to mild and moderate THI levels. Particularly for studies conducted in Mediterranean climate conditions on exogenous dairy cattle breeds, a decline in the pregnancy rate by 1.0% to 3.0% was observed with each increase of one THI point for animals experiencing heat stress (HS) (THI > 68) [62]. Our previous studies demonstrated a significant negative impact ($p < 0.001$) of THI > 72 compared to THI ≤ 72 on conception rate for both Prim'Holstein (−17%) and Montbéliarde (−15%) [63,64]. The PR fluctuation according to THI levels was reported to decrease from 34.1% to 15.7% when THI rose from 69 to 74 [60]. In contrast, there was an increase of 0.1% to 1.0% in PR for each THI point in animals living under a cooling system [62].

There was also evidence of the impact of cattle production systems PR. The indigenous Algerian "Brune de l'Atlas" cattle are oriented towards meat production but are also used in crossbreeding programmes within dairy farming systems [2,65]. Beef cattle expressed a 62% decrease in PR when THI levels exceeded 72 [59]. Furthermore, in Thai beef cattle, there was a decrease from 67.74% to 49.12% at THI levels of 77 and 81, respectively [66]. Particularly, results in indigenous African cattle contrast with our findings showing that the animals respond negatively to HS at high THI levels. Baladi Egyptian cows which undergo heat stress showed a lower PR of 35.71% at THI ≥78 compared to those in the group not stressed by heat (64.29%) [67]. Additionally, a study conducted on Sahiwal animals showed a decrease of 50% in PR in response to increasing THI value over 80 [68]. Furthermore, the results demonstrated a significant increase in TPR in SA compared to L regions. This was consistent with previous studies that showed the important effect of the environment on the success of AI, with the semi-arid region showing the highest likelihood [69,70].

The registered overall CR1stAI for the Algerian local breed was 24.41%. This value is lower than 40% recommended as objective [45]. Our results were lower than those obtained in previous studies conducted in semi-arid and northern Algeria by Mouffok et al. [69] and Souames and Berrama [71] on improved dairy cattle. These changes may be related to the studied cattle breeds and their performances. The overall CR2ndAI was 36.71% with a non-significant effect of THI, and significant increase in SA compared to L regions. Our study showed a significant decrease in conception rate at first insemination with the increased THI level, especially in mild and severe HS with THI exceeding 80, and in SA areas that were found with lower THI levels. Numerous studies have shown a negative effect of THI on the CR1stAI showing that each point increase in THI value above 67 was associated with a decrease of 1.39% and 1.74% in CR1stAI, respectively, in Tunisa [25] and Peru [61]. Sahiwal animals, indigenous cattle of Pakistan and India, showed a reduction from 55% at low THI <70 to 26% at high THI > 80 in conception rate with a decreasing odds ratio indicating the greater effect of THI value on conception rate of Sahiwal animals [68].

The rearing conditions in the southern Mediterranean area impact the fertility and fecundity of the dairy herd and pose serious challenges for cows [70,72], as well as the necessary forage production [73]. The significantly reduced PR and CR1stAI at high THI levels may be attributed to increased body temperature, leading to fertilisation failure or embryonic loss. This is further linked to a negative energy balance, altered ovarian follicular dynamics, decreased oestrus detection rates, and impaired oviductal function, affecting cows' potential to conceive even following embryo transfer [56,59,74,75]. Heat stress interferes with hormonal balance, notably lowering luteinising hormone and progesterone levels. This disruption leads to poor follicle development and low-quality oocytes, follicular maturity issues, silent oestrus, abnormal or weak embryo development and implantation, and ultimately pregnancy loss [16–24,76,77]. These factors contribute to a declining reproduction rate and significant losses for the cattle industry [21,78,79].

A significant negative effect in autochthonous Atlas Brown cattle is associated with a THI level ≥80, a threshold for negative fertility expression compared to lower levels, denotes the high adaptive responses of African breeds to climatic challenges. This adaptation occurs at cellular and physiological levels, using proteins that protect cells and prevent protein denaturation under heat stress, genes that protect against cytotoxicity and damage, and genes active in feed intake, metabolism, energy balance, and energy expenditure [13,80,81]. In non-improved indigenous cattle populations, such as the

Sahiwal and Atlas Brown breeds, the impact of heat stress on fertility is generally lower. These breeds possess thermotolerance mechanisms, including more efficient heat dissipation, better hydration strategies, regulated metabolism, and genetic adaptations that help maintain reproductive functions under high temperatures. These inherent thermotolerance mechanisms allow indigenous cattle to withstand heat stress, resulting in fewer fertility problems compared to non-indigenous breeds [13,27,30,80–82].

The overall RBC for Atlas Brown cattle was 14.23%. This was within the range of 10% to 24% mentioned by Hanzen [45]. Our results were higher than the previous findings by Mouffok et al. [69] of 6.9% in a semi-arid area. A non-significant increase in RBC rate with THI was registered (13.25% vs. 15.91% for comfortable and severe heat stress (HS) conditions, respectively, with an odds ratio (OR) of 1.524) and further in different agro-ecological regions.

The average AFI in the Atlas Brown cattle was 1.74 ± 0.768, which is lower than the higher limit threshold [45]. A significant increase in AFI was observed in higher THI level classes and in L regions ($p < 0.05$). Previous studies showed higher mean fertility indices in dairy cattle from western Algeria (Akkou et al. [83]: 1.85 ± 1.17) and the humid Algerian region of El Tarf (Haou et al. [72]: 2.05 ± 1.45). Conversely, a lower level of 1.3 ± 0.9 was registered in the study by Souames and Berrama [71] in the semi-arid region of Algeria. When evaluating the impact of THI levels on the frequency of services per conception, we recorded a significant increase of 0.007 for each point increase in THI over 68. The effect of THI on fertility has been mentioned in many previous studies. Pregnancy per service was lower with lower levels of THI [25] and the number of services per conception increased from 2.44 to 3.02 with an increase in THI from 58 to 80 [84].

A prior study carried out in two distinct ecosystems in Algeria showed that in stressful and warmer areas, cows must be inseminated more often to achieve conception (arid area vs. semi-arid area) [70]. The HS could affect the number of artificial inseminations (service per pregnancy) not only on the day of breeding but also if the cows were exposed during the dry period [85]. Inversely, Rolando et al. [61] found no effect of THI on the services rate. Multiple studies showed that local breeds can perform well in adverse climatic conditions like the local harsh arid and semi-arid environment, high temperature, drought, and feed and water scarcity [5,7,27,30,32,86], and also under extreme cold [31]. Bernabucci *et al.* [32] showed that indigenous dairy breeds are typically less susceptible to disease than imported bovine breeds because of their metabolism, which is linked to excessive heat production and the challenges of sustaining isotherms in hot regions. The local breeds are more robust and genetically better adapted to their environment [86]. Furthermore, a previous study in China showed that indigenous cattle have different genes related to immunity, genes that modulate inflammation, plasma cell differentiation, promote the HCC cell migration, genes related to heat stress that help in the adaptation to humid and hot environments, and the regulation of the expression of heat shock, protein genes and genes to enhance efficient recovery of cells challenged by thermal stress, in regard to reproduction, development and body weight [30].

The evaluation of the RP is important because of its implications for various reproductive parameters such as the conception rate at first artificial insemination, calving intervals, milk production and breeding costs [87,88]. Our study revealed a notable decrease in the proportion of cows with an RP between 0 and 30 days, as well as those surpassing 30 days, particularly under mild THI levels. This suggests that there is a possibility of reducing the number of cows exceeding the reproductive period threshold during mild and comfortable HS conditions. Our findings align with previous research conducted by Sammad *et al.* [16] and Shi *et al.* [89], which demonstrated that elevated THI levels extend the interval between the first and last insemination in dairy cattle. These studies reported an increase in the number of services and prolonged inter-service intervals, consequently impacting and elongating the RP [16,89–91]. Moreover, Sammad *et al.* [16] and Tadesse *et al.* [91] observed an escalation in the inter-service period during heat stress, which significantly disrupts the RP by hindering oestrus detection and impeding follicular development [89,91]. This disruption is compounded by reduced animal activity levels, making oestrus detection in dairy cattle even more challenging [92].

Conclusion

The Atlas Brown breed has shown remarkable adaptability in maintaining reproductive performance under heat stress, with adverse effects becoming evident mainly at high THI levels. Specifically, a decrease in pregnancy rate was observed only when THI reached or exceeded 80, a critically dangerous threshold for improved dairy cattle. Moderate heat stress had negligible impact on the conception rate at first artificial insemination, and there were no significant effects observed on the conception rate at second artificial insemination or the frequency of repeat breeders. Our study revealed a significant reduction in the proportion of Atlas Brown cattle with a reproductive period exceeding the recommended threshold under mild heat stress levels, compared to severe heat stress conditions. This underscores the breed's ability to maintain reproductive performance under less extreme heat stress conditions. Our findings highlight the potential advantage of using local breeds like the Atlas Brown in regions with very high THI levels, as they demonstrate resilience and reliability in maintaining reproductive efficiency even in challenging environmental conditions. Atlas Brown cattle emphasise the need to conserve this fundamental genetic resource and promote its use in genetic improvement solutions to mitigate the effects of climate change in North Africa.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Author contributions

G.D.E. and K.T. conceived and designed the study; B.A. and H.F.A. made available the artificial insemination data, F. A. and G.D.E., and A.M. analysed the data; F.A. and G.D.E. wrote and corrected the paper. All authors read and approved the manuscript.

Ethical statement

The authors confirm that the research did not involve any animal treatment or manipulation, adhering to strict ethical guidelines for animal welfare, ensuring no harm to the animals in any way.

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