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Impact of heat stress on the dairy cattle milk quality in two bioclimatic stages in Algeria

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Abstract

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In recent years, global warming is a major concern for the agricultural sector. Heat stress impairs welfare and productive performance of dairy cattle .It negatively affects milk quality altering its nutritive value. This study aimed at assessing the impact of seasonal microclimatic conditions on milk quality of Holstein cows. The study was carried out in two dairy cattle farms located in eastern Algeria belonging to two different semi-arid and humid bio-climatic stages during the four seasons of the year 2021. Temperature and relative humidity were recorded and used to calculate the humidity index (THI), which was used as an indicator of the degree of heat stress. The relationship between the temperature-humidity index (THI) and the overall quality criteria of raw milk from Holstein cows was assessed by monitoring the physico-chemical and microbiological parameters of raw milk. The summer average THI values reached in the two regions exceeding 25°C and the 72 critical points for the Holstein breed thus demonstrate that the cows were exposed to heat stress with a summer average of 29.3°C and 75.8 for the semi-arid region and 26.33°C and 75.4 for the humid region. The analysis of variance showed that fat is significantly affected ($p < 0.001$) by heat stress. This is expressed by a drop in seasonal averages during the summer season (30.2±0.97 for region A and 29.9±0.49 for region B) as well as a highly significant negative correlation ($p < 0.001$, $r = -0.823$) between THI and fat for the humid region. Similarly, a highly significant seasonal effect was observed, characterized by a drop in the summer average protein levels (25.3 ± 2.12 for region A and 22.4 ± 1.82 for region B) with a negative correlation ($p < 0008$, $r = – 0.723$) for the semi-arid region. The analysis of the variance of the total flora showed a significant difference ($p < 0.0005$) between the two regions and highly significant difference ($p < 0.0001$) between the different seasons. Regarding total coliforms, the analysis of variance showed highly significant season effect in region B ($p < 0.0004$). It is therefore essential to adopt management strategies to reduce the negative consequences of heat stress in dairy cows and limit the economic losses for the dairy sector.

Keywords: dairy cattle; heat stress; milk composition; temperature-humidity Index

Introduction

Climate change represents one of the major dangers for the survival of several species and ecosystems as well as the sustainability of the farming system around the world. The increase in temperatures during the 20th century was of the order of 0.74°C globally (IPCC, 2014; Zoghlami et al., 2022).

Like the rest of the world, Algeria is exposed to climate change and water scarcity, the impact of which on fodder production and the technical and economic performance of dairy cattle farming systems is inevitable. This climate change has caused an alarming rise of 1.5 to 2°C for Algeria, more than double the global average increase, as well as a drop in precipitation of around 10 to 20% (Yerou et al., 2019, 2021, 2022) .

Heat stress is a real concern and one of the greatest challenges faced by dairy farmers (Kadzere et al., 2002), as it endangers animal welfare (West et al., 2003; Cook el al., 2007) and affects negatively the productivity on farms (Rhods et al., 2007; Dimov et al., 2017). High temperature and humidity lead to loss of appetite (Bernabucci et al., 2014) which decreases rumination time (Hoffman et al., 2020).

In lactating cows, feed intake begins to decline at air temperatures of 25-26°C. Indeed, rumination is a metabolic heat-generating process, the decrease of which reduces body temperature, allowing cows to adapt to higher ambient temperatures.

However, as small amounts of food are ingested, milk production also decreases. This effect is particularly evident in high-yielding breeds such as Holstein, where heat stress can lead to a 10-40% reduction in yield. In addition to quantity, quality is also impacted (Caffara, 2020).

Heat stress causes significant physiological and metabolic dysfunctions that negatively affect dairy cows' productive abilities to dissipate heat, cows spend more time standing than normal,their rest and feeding are disrupted, thus increasing legs in the weeks following periods of heat stress (Lacetera, 2018). Cases of clinical mastitis are also more frequent in the event of stress (Nickerson et al., 1987; Vitali et al., 2020), moreover it is associated with changes in the composition of the milk, the number of somatic cells (Preez, 1990). This causes heavy economic losses for the dairy sector (Bernabucci, 2014). For the Holstein breed, studies have shown that heat stress occurs when the humidity and temperature index exceeds 72.

The objectives of this study were to determine the microclimatic conditions in two climactic regions of Algeria as well as to evaluate the effect of temperature-humidity index on quality of raw milk from Holstein cows.

Materials and Methods

Study area and meteorological data

The study was conducted in two cattle farms at the level of Batna and Skikda two regions of northeastern Algeria with two different bioclimatic floors.

The region A (Batna) is located in the Algerian North east between the geographical coordinates 35° 33' N 06° 10'. The climate is semi-arid, with four distinct seasons. According to meteorological station of region during 2021, the average annual temperature is 16.5°C, the average minimum of January 5°C, the average maximum of August 39°C. Annual precipitation is 316 mm.

The region B (Skikda) is located in the Algerian North. Between the geographical coordinates 36° 35' N 06° 50' E. The climate is of the relatively mild temperate humid type, influenced by the Mediterranean Sea. According to meteorological station of region during 2021, the average annual temperature is 19.7°C, the average minimum of January 14°C, the average maximum of August 28°C. Annual precipitation is 512 mm.

Data set and animal management

The research protocol and the animal care were in accordance with the Directive of institute of veterinary el khroub on the protection of animals used for scientific purposes.

The study was carried out at the level of two dairy farms with a capacity of 50 Holstein cows each distributed in two regions with different climates but having a semi-impeded breeding method with the same conditions of nutrition, care and lactation stage. The cows were treated mechanically, had free access to water and received a ration composed of good quality forage and supplementation in concentrated according to the recommendations for dairy cows. A daily sample of raw milk is collected per farm after the morning milking at the milk collection level for physico-chemical and microbiological analyzes during the four seasons of the year 2021.

The temperature humidity index (THI) was calculated on the basis of meteorological data from the national meteorological office of the two regions for the year 2021 and calculated according to the formula proposed by the National Research Council (1971).

$$THI = (1.8 \times T + 32) - (0.55 - 0.0055 \times RH) \times (1.8 \times T - 26),$$

where T = air température in dégrées Celsius. RH = relative humidity in percent.

This index indicates the level of heat stress as a function of ambient temperature it expressed in the form of a score where three levels of thermal stress can be distinguished according to the THI value:

Thermal comfort < 72; Mild stress 72–78; Severe stress > 78

The THI was calculated on the basis of meteorological data from the national meteorological office of the two regions for the year 2021. The months have been grouped into four seasons: spring (March, April, May), summer (June,

Table 1. Microclimate conditions during measuring the months of experimental periods in accordance to the regions (semi-arid (A) and humid (B)

	Regions /Parameters								
	Months	Region semi-arid (A)				Region humid (B)			
		T, C°	H, %	P, mm	THI	T, C°	H, %	P, mm	THI
Spring	March	9	69	61	49.9	14	76	82	57.3
	April	14	66	39	57.8	15	77	66	58.9
	May	19	66	39	67.8	19	77	78	65.2
Summer	June	27	39	13	73	24	74	12	72
	Jully	31	35	1	78.3	27	66	1	76.4
	August	30	33	18	76	28	68	5	78.1
Autumn	September	25	49	3	71.7	27	76	5	77.7
	October	15	71	3	58.9	22	71	15	69.4
	November	8	80	20	44.7	17	75	74	62
Winter	December	5	73	4	42.7	15	72	19	58.9
	January	7	83	54	42.6	14	73	104	57
	February	8	69	61	48.6	15	72	51	58.9

T = temperature (C °), RH = relative humidity (%), P = precipitation (mm), THI = temperature-humidity index

July, August), autumn (September, October, November) and winter (December, January, February). Table 1 presents the data of the environmental conditions as well as the monthly THI during the experimental periods.

Statistical analysis

The effect of fixed factors, region (A) semi-arid, (B) humid and season (spring, summer, autumn, winter) and also their interaction, on the various studied parameters (density, pH, acidity, temperature, fat, protein, total coliforms), were analyzed using a Two-way analysis of variance. Tukey's multiple comparisons test was conducted to test significance between means of the different subgroups. Differences were considered significant when $p < 0.05$. All mean values are expressed as the mean ± standard error of mean (SEM.). Correlation coefficients (Pearson correlations) between different milk parameters and THI were calculated. All analyses were performed using Graph Pad Prism 7.00 software.

Results

Environmental conditions during the experimental periods

The seasonal average temperature (T), relative humidity (RH) and calculated temperature-humidity index (THI) during the experimental periods are shown in Table 2.

Comparing the seasonally averages of microclimatic parameters in analyzed regions, highest ambient temperatures highest relative humidity and the highest values of temperature humidity index (THI), were determined in arid-region. The severity of heat stress is correlated to both ambient temperature and humidity level.

Indeed spring, autumn and winter were characterized by the lack of heat stress (except the month of September of the region B (Table 1) condition which was characterized by the upper critical temperature and THI for Holsteins of 25-26°C and 72, respectively.

Table 2. Seasonal averages of ambient temperature, relative humidity and temperature-humidity index (THI) in dairy farm throughout the study period (means ±SEM) in semi-arid and humid region

Region Parameters						
Seasons	Semi-arid (A)			Humid (B)		
	Seasonal average T, °C	Seasonal average RH, %	Seasonal average THI	Seasonal average T, °C	Seasonal average RH, %	Seasonal average THI
Spring	14±0.85	66.7±1.65	58.3±0.99	16±0.84	76.7±1.75	60.4±0.43
Summer	29.3±0.57	35.7±2.46	75.8±0.63	26.3±0.57	69.3±2.47	75.4±0.59
Autumn	16±0.63	66.7±1.58	58.3±0.86	22±0.65	74±1.75	69.7±0.79
Winter	6.6±0.77	74±1.9	44.6±0.92	14.7±0.83	72.3±1.95	58.2±0.9

T = temperature, RH = relative humidity, THI = temperature-humidity index

Table 3. Physico-chemical results of the milk samples analyzed during the four seasons in semi-arid (A) and humid (B) region

	Region	Spring	Summer	Autumn	Winter	Season effect	région effect	Normes JORA2017
Acididy, °D	A	17.1±0.96	16.4±0.42	16.4±0.63	16.9±0.91	NS	***	16–18
	B	18.2±0.24	18.3±0.25	16.6±0.66	16.7±0.66	***		
Density	A	1028±0.33	1028±0	1028±00	1028±0.44	NS	NS	1028/1030
	B	1030±0.6	1026±0.7	1029±1.28	1029±0.87	NS		
pH	A	6.58±0.02	6.69±0.03	6.61±0.3	6.49±0.52	NS	NS	6.4–6.8
	B	6.66±0.11	6.56±0.11	6.67±0.15	6.67± 0.05	Ns		
Fat, g/l	A	32.8±1.8	30.2±0.97	32.8±1.48	32±2.31	****	***	35–45
	B	30.7±1.23	29.±0.5	32.4±1.43	32±2.31	****		
Protein, g/l	A	30.1±2.26	25.3±2.12	30.8±2.95	39.8±2.11	****	***	30–34
	B	25.1±2.6	22.4±1.82	27.6±2.13	38.3±3.94	****		
THI	A	58.3	75.8	58.3	44.6	***	*	
	B	60.4	75.5	69.7	58.2	***		

NS: non-signifiant, * : p < 0.05; ** : p < 0.01, *** : p < 0.001.

The combined effect of ambient temperature and relative humidity of the air, which are the main origins of heat stress (moderate to severe), is spread over the 3 months (June, July and August) of summer for the region A and 4 months (June, July, August and September) for region B) (Table 1).

Meanwhile, the highest average seasonal temperature values (29.3±0.57) were recorded during summer and decreased gradually to reach a minimum of (6.6±0.77) during winter for region A and between (41.7±0.83) in summer at (26.3±0.57) in winter for region B.

On the other hand, the average seasonal THI is (75.8±0.63) in summer to (44.6±0.92) in winter for region A and (75.4±0.59) in summer to (58.2±0.9) in winter respectively for region B (Table 2), the highest THI is 78.3 (July) for region A and 78.1 (August) for region B. We also noted high THI values in September of 77.7 for region B (Table 1).

The effects of heat stress on physico-chemical parameters

The physico-chemical results of the analyzed milk samples are mentioned in Table 3. The acidity results show values varying from (16.4 ±0.63) in autumn to (17.1±0.96) in spring for region A and (16.6±0.66) in autumn and winters and (18.35±0.37) in spring for region B. A slight increase in acidity in spring (18.2±0.24) and summer (18.3±0.25) in region B with light stress values in summer of around 75.8 for region A and 75. 5 for region B.The pH of the milk analyzed shows average values of (6.6±0.02) for region A and (6.7±0.005) for region B. The average milk density measured is (1028±0.2) for region A and (1028±0.9) for region B. The fat content of the milk samples varies between (30.2±0.97) g/l (summer) and (32.8±1.48) g/l (spring and autumn) with an annual average of (32±1.7) g/l for region A and (29±0.5) g/l (summer) and (32±2.31)g/l (Winter) with an annual average of (31.23±2.6) g/l for region B; The protein content of milk varies from (25.3±2.12) g/l (summer) to (39.8±2.11) g/l (winter) with an annual average of (31.5±2.36) g/l for region A and from (22.4±1.82) g/l (summer) to (38.3±3.94) g/l (winter) with an annual average of (28.36±2.61) g/l for region B (Table 3).

Table 4. Results of microbiological analyzes of the milk samples analyzed during the four seasons in semi-arid (A) and humid (B) region

Parameters (CFU/ml)	Région	Spring	Summer	Autumn	Winter	Season effect	Région effect	Normes JORA 2017
Flores totales (10^5)	A	0.13 ±0.02	0.40±0.01	0.35±0.09	0.18±0.04	***	***	m = 3.10^5 M = 3.10^6
	B	0.13 ±0.03	0.35±0.05	0.12 ±0.02	0.18±3.30	***		
Coliformes (10^2)	A	3 .25 ±2.31	7.59±2.23	5.44 ±11.1	5 .7±1.18	***	NS	m = 5.10^2 M = 5.10^3
	B	5±2.75	6.9±2.37	5.7 ±1.6	5.32±2.07	NS		
THI	A	58.3	75.8	58.3	44.6	***	*	
	B	60.4	75.4	69.7	58.2	***		

FTMA: total aerobic mesophilic flora,CFU: Colony Forming Unit, m: minimum number of germs accepted, M: maximum germ count accepted

Hygienic aspect of raw milk

The results of the microbiological analyzes of the milks analyzed expressed in CFU/ml are presented in Table 4.

The samples taken show a load of microorganisms in the total flora which varies from ($0.13.10^5 \pm 0.02.10^5$) CFU/ml in spring to ($0.40.10^5 \pm 0.01.10^5$) CFU/ml in summer for region A and ($0.13.10^5 \pm 0.03.10^5$) CFU/ml in summer ($0.35.10^5 \pm 0.05.10^{5)}$ CFU/ml in winter for region B. The milks analyzed show a minimum load of total coliforms of ($3.25\ .10^2 \pm 2.32.10^2$) CFU/ml in spring and ($7.59.10^2 \pm 2.23.10^2$) CFU/ml in winter for region A and ($5.01.10^2 \pm 2.75.10^2$) CFU/ml in spring at ($6.80.10^2 \pm 2.37.10^2$) CFU/ml in winters for region B. These results confirm a strong heterogeneity between the different milk samples analyzed the standards set by the national Algerian law which are 10^5 CFU/ml (Jora, 2017) (Table 4).

Discussion

The heat tolerance of dairy cows depends on factors intrinsic to the animal (age, body mass, stage of lactation, physiological state, milk production, genetics), but also on extrinsic factors (the climate in which the animals are raised) (Ouellet et al., 2021; Kadzere et al., 2002).

The period from the beginning of June to the end of august for region A and from June to the end of September for region B was extraordinarily hot in 2021. The obtained data are consistent with those of Bouraoui et al. (2002), which indicated the presence of heat stress in summer (average T and THI were 29.8 ± 2.5 and 78.0 ± 3.23). Indeed the temperature and summer THI values in the two regions (29.33C°, 75.8) for region A 26.33°C and 75.4 for region B) (Table 2) exceeding 25°C and 72 points criticisms for the Holstein breed thus demonstrate that the cows were exposed to heat stress during this period with the consequences of a drop in production performance already reported by Yerou et al. (2021).

Our results are in agreement with the work of Bouraoui et al. (2002); Bertocchi et al. (2014); Bellagi et al. (2017); Yerou et al. (2021), who so reported that cows suffered heat stress during the summer in regions with a Mediterranean climate. The increase in THI is not limited to the three months of summer (June, July, and August) but can so extend to the months of May and September (Table 1), which was observed in region B where the THI has reached (77.7). This observation was reported by Brouček et al. (2006) who reported an increase in the THI during the period from May to September probably due to heat waves or heat waves which caused the extension of the hot period including the month of September.

The region effect is highly significant in the spring ($p < 0.001$) and in summer ($p < 0.001$) and not significant for the other seasons; likewise, the season effect is very significant ($p < 0.001$) at the level of region B (Table 3). Climatic data indicate that Holstein cows raised in a humid semi-arid region are exposed to heat stress with values exceeding the critic threshold of 72 from June to August for region A and from June to September for region B. Environment factors such as temperature, relative humidity, solar radiation and air movement, and so their interactions, often limit the performance of dairy cows (West et al., 2003). Moreover climatic conditions can so affect the physic-chemic parameters of milk examined which showed a decrease with increasing THI values, which is in agreement with the work of Bernabucci et al. (2010); Bertocchi et al. (2014); Hill &Wl (2015); Zeinhom et al. (2016); Nasr & El-Tarabany (2017); Matlah et al. (2017); Zoglami et al. (2022). The acidity of the milk makes it possible to control the state of its freshness as well as the hygienic quality of the milking. Indeed, the higher the acidity, the less fresh the milk. The results show a highly significant difference ($p < 0.0001$) between the two regions, the average acidity values of the milk in the two regions A and B are respectively (16.4± 0.42 D°) and (18.3±0.25 D°), these values that different remain close to the results obtained by Baiche &Khellil (2018) (16 ±0D°) and the results obtained by Seffal (2011) (16.9 ± 0.69D°) comply with the standards given by AFNOR (2001) and Jora (2017). The work of Summer et al. (1999) report a decrease in acidity values in summer. This difference between the two regions would probably be due to the content of casein, mineral salts and ions, the hygienic conditions during milking, the total microbial flora and its metabolic activity and the handling of the milk as well as the difference of the bioclimatic stage (semi-arid and humid). The correct pH values of milk vary around 6.65 to 6.68. The values obtained in your study are within this range and meet AFNOR (2001) standards (6.6 and 6.8). Similarly Abeni et al. (1993) reported an increase in milk pH and a decrease in titrable acidity when cows were subjected to heat stress with a score greater than 75. The average density values are below AFNOR standards (1030-1032). According to the bibliography, the density is all the lower as the milk is rich in fat. The low density in summer in region B could be explained with the THI value (75.48) demonstrating heat stress.

The average fat content was in agreement with the interval of 28.5 to 32.5 g/l for the two regions A and B is lower than the standards put forward by AFNOR (2001) which are (34 to 36 g /I). There was a very significant difference ($p < 0.001$) in spring for the two regions and a significant difference ($p < 0.0015$) between spring and autumn for region A and a highly significant difference for ($p = 0.002$) in spring summer in region B.

The analysis of variance showed that fat is significantly affected ($p < 0.001$) by heat stress, which was reported by Bernabucci et al. (2015) and Summer et al. (2019) THI correlates negatively with fat content ($p = 0.001$, $r = 0.823$) for region B. Our results contradict those of Cowley et al. (2015) who found no differences for fat content between cows under normal conditions and those under heat stress.

Heat stress not only decreases the amount of butterfat but also affects the protein content of milk. Indeed the ANOVA results showed a highly significant seasonal effect ($p < 0.001$) of the THI level on the protein level ($p < 0.001$). The protein level is negatively correlated with the THI ($p = 0.008$,$r = 0.723$) in region A. Heat stress reduces the capacity of the mammary glands for protein synthesis, by reducing the casein content of milk.(Bernabucci et al.,2015; Cowleyet al.,2015). Indeed the decrease or increase in THI has caused a drop in protein content due to their roles in the milk coagulation these changes can cause disruptions in the milk processing process Summer et al. (2018). Our results agree with those of Bouraoui et al. (2002); Bertochi et al. (2014); Nasr et al. (2017). In the same context, an American study Ravagnolo et al. (2000) demonstrated that each unit increase in THI corresponded to a decrease of 9 g of protein. The composition of the milk is therefore impacted by heat stress, which will have repercussions on the processing properties, the organoleptic quality, the selling price of the milk and economic losses for the breeder.

Microbiological analyzes always inform us about the overall hygienic quality of raw milk, thus reflecting hygienic practices in handling and production. The analysis of the variance of the total flora showed a highly significant difference ($p < 0.001$) between the two regions and between the seasons for region A and non-significant between the two regions A, B. Similarly, a significant influence of THI on coliforms has been observed, expressed by a significant increase in the averages during the summer season due to the multiplication of microorganisms with the increase in ambient temperatures. Thus the increase in thermal stress accelerates bacterial multiplication, and increases the risk of disease.

These results suggest that heat stress can increase the risk of infection in cows either by decreasing host resistance or by increasing host exposure to pathogens, created by favorable conditions for their growth and spread.

Conclusion

The heat stress undergone by cows of the Holstein breed in semi-arid and humid climatic conditions, during the summer season where the THI are higher than 72 in the majority of the time with an extension which can reach 4 months of the year causes an overall decrease in well-being, productivity with a decrease in the fat content and protein levels as well as the evolution of the total FMAT flora ,thus leading to a drop in the price of milk and consequently a reduction in the profitability of the dairy sector. Given the current climate changes, which threaten food production of bovine origin, it is therefore essential to maintain the quality and quantity of animal milk by modifying management systems in order to adapt to new climatic conditions.

Ultimately, the survival of dairy farms to climate change will depend on their ability to ensure animal comfort and to implement a targeted and adapted adaptation strategy during extreme events.

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