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Temperature-Humidity Index Values and Their Significance on the Daily Production of Dairy Cattle in the North African Arid Region

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Abstract. Climate changes affect the economic viability of livestock. Therefore, this study aimed to characterize the heat stress in Holstein cattle raised in the arid region of Tunisia as well as to evaluate the effect of the temperature-humidity index (THI) on daily milk production and components. For this reason, 76940 monthly individual records collected from 1995 to 2018 from 3056 Holstein cows were used. THI calculated from ambient temperature and relative humidity was used as a measure of heat stress. To study the effect of THI on milk production, a repeated measures linear mixed model was used. Results showed a significant ($P<0.01$) decrease in daily milk yield, daily protein, and fat content in all cow's parity classes. For each point increase of the THI values beyond 64, milk yield, fat, and protein contains decreased by 0.32 kg, 0.09, and 0.06 %, respectively. Moreover, when the THI value varied from 64 to 85, fat content decreased by 29 %, protein by 17 %, and milk production by 30 %. Heat stress impact negatively milk production and milk components of dairy cows. These results can be a way to improve the length of productive life for Holstein dairy cattle in the hard climate. Serious management strategies are needed to improve dairy cow productivity and minimize the heat stress impact.

Keywords. Dairy cows, Heat stress, Milk production, Temperature.

1. Introduction

A thermal environment is one of the major non-genetic factors that can affect the performances of dairy cows (Nardone et al., 2010). Heat stress impacts highly economic profitability in dairy cows, it affects negatively both productive and reproductive traits and health and welfare (Djelailia et al. 2020; Djelailia et al. 2021; Fontoura et al. 2022). Regarding the gradual increase in humidity and temperature expected in the coming years, in the Mediterranean basin,

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temperature-humidity index (THI) variation and their impact become true. Yousef (1985) suggested that heat stress was defined as combined external forces on a homoeothermic animal that acts to destabilize body temperature, to an extent where the animal cannot dissipate enough metabolically produced or absorbed heat to maintain thermal equilibrium notably in high-performing animals having a substantial genetic quality, that are easily affected by heat stress (Bernabucci et al., 2014). Numerous research theorized the thermoneutral zone (the thermal balance between an animal and its surrounding atmosphere) for lactating dairy cows, as reported by Berman et al. (1985) and Roenfeldtn (1998) this thermoneutral zone is ranging from the lower critical temperature (LCT) to the upper critical temperatures (UCT) of 5°C and 25°C. Each time when the degrees surpass the thermal zone by either encroaching the upper or lower limit, an animal’s physiology becomes disturbed, for instance, milk production lessens and its composition gets modified (Johnson, 1980). When temperature levels are below or medium, the relative day-to-day cows’ production is stable, meaning that when they reach the threshold, they start to lower. (Armstrong, 1994.) The hot and humid environment that causes heat stress not only affects milk yield but also affects milk quality (Yue et al., 2020: M’Hamdi et al. 2021). As cited by McDowell et al. (1976), when temperatures change from 18 to 30°C, the efficiency of energy use for milk production is reduced by 35% and milk yields decrease by 15%. The first stage to understand and handle the impact of heat stress on dairy cows’ productivity is to use the THI. When THI values are beyond 72 correspondings to 22°C at 100% humidity, 25°C at 50% humidity, or 28°C at 0% humidity, milk production is altered by heat stress (DuPreez et al., 1990). Johnson (1980) argued that feed consumption and milk production begin to diminish when THI reaches 72. Du Preez et al. (1990) asserted that milk production drops in summer and increases in winter for Holstein cows by approximately 10% to 40%. In a study conducted under the Mediterranean climate of Tunisia, milk yields decline by 21% when THI increases from 68 to 78 during the summer period (Bouraoui et al., 2002). Two major objectives arise from this study. First, to determine heat stress influencing Holstein cattle raised in the dry region of Tunisia. Second, to assess the consequence of THI values on dairy cattle’s daily production and to determine the value of the THI threshold causing stress to cows.

2. Materials and Methods

In Tunisia, dairy cattle farming is concentrated in the north as well as in the center of the country, in contrast to the south because of the harsh climate conditions that belong to the lower arid bioclimatic stage. It has a desert climate characterized by an abnormally hot dry summer and a very cold winter. Twelve herds spread over the same administrative area situated in the southeast of Tunisia (Sfax) have been selected for this study. The selected herds, comprising only the Holstein cow breed was representative of the administrative area. Among these herds, each farm had several cows.

2.1. Datasets

A dataset with individual milk production traits was obtained from the genetic improvement direction of the Livestock and Pasture Office (OEP, Tunisia). In the first step, the milk yields and milk components (fat and protein contents) relative to 3056 Holstein cows were obtained monthly covered twenty-three years (1995 to 2018) from the control of the performance of the 12 farms. Besides, for data verification: duplicate records were deleted, and missing data were considered as such. Cows with fewer than three records or more than twelve records were removed from the dataset, and outliers for each parameter were excluded milk yields> 44.2 kg/day; fat content <2% or > 5%; protein content <2% or >5%. The output recorded after the 500th lactation day was deleted erased from the dataset. Days in milk were classified into four classes according to the stage of lactation: beginning (<120days), middle (120–180 days), end (181–300 days), and prolonged lactation (> 300 days). Heifers were put in the first class (P1), cows in lactation number 2 (P2), cows in lactation number 3 (P3), cows in lactation number 4 (P4), cows in lactation number 5 (P5). Cows in more than 5 lactations were considered in the fifth lactation. The variability of analyzed milk parameters for parity classes is presented in Table1. Following the test date, four subgroups of measuring the season were created: Winter as the first subgroup (S1: December, January, and February), spring as the second subgroup (S2: March, April, and May), summer as the third subgroup (S3: June, July, and August), autumn as the fourth subgroup (S4: September, October, and November), the same subdivision concerning the calving seasons. A dataset with records of ambient temperature (AT, in °C), and relative humidity (RH, percentage expresses dasadecimal) was electronically provided by the National Institute of Meteorology of Tunisia. The meteorological records (AT and RH) corresponded to the daily average values of daily data collected between 1985 and 2018. For each day, AT and RH were used to calculate the temperature-humidity index (THI) values were calculated using the equation by Kibler (1964): THI=1.8 AT-(1-RH) (AT-14.3)+32 where: AT – measured ambient temperature in °C, RH- relative humidity as a fraction of the unit. The THI was merged with milk production by assigning each dairy control to the same daily weather. THI was divided into classes from the final dataset to facilitate the statistical analysis. This classification aimed to have a better visualization of the effect of heat stress on the production of Holstein cows.

Table 1. Means±standard deviation of dataset used for analysis (n=76940).

Parameters	Parity				
	P1	P2	P3	P4	P5
Daily milk yield (kg)	18.22±7.51	19.85±8.82	20.20±9.17	19.84±9.12	17.94±9.18
Daily milk fat (%)	3.41±0.88	3.43±089	3.41±0.9	3.37±0.91	3.32 ±0.88
Daily milk protein (%)	3.04±1.39	3.04±1.42	3.03±1.41	2.99 ±1.41	3.04±1.44

2.2. Statistical Analysis

Statistical analysis was performed using repeated-measures linear models with PROC MIXED in SAS 9.4 (SAS Institute Inc., Cary, NC). Variables with significant F-tests ($P<0.05$) were retained in the model. The effect of farm (F_i), cows (C_j) and season (S_k) on dairy cows' production (as defined below) was evaluated using :

$$\mu + F_i + C_j + S_k + e_{ijk}$$

Following regression analysis, the significant differences in mean values for test-day milk yield between groups were estimated by the Bonferroni significant difference test. The model was

$$Y_{ijklmno} = \mu + THI_i + P_j + DIM_k + CS_l + (THI\ x\ P)_m + (THI\ x\ DIM)_n + (THI\ x\ CS)_o + e_{ijklmno}$$

Where: $Y_{ijklmno}$ = the dependent variable (milk yield, fat content or protein content) ; μ = overall mean; THI_i = fixed effect of THI classes (i=1,2,3,4,5); P_j= fixed effect of parity classes (j= 1,2,3,4,5); DIM_k = fixed effect of lactation stage (k=1,2,3,4); CS_l = fixed effect of calving season (l=1, 2,3,4); $(THI \times P)_m$= regression coefficient for the covariance of THI inside parity $(THI\times DIM)_n$ = regression coefficients for the covariance of THI inside lactation stage $(THI\times CS)_o$ = regression coefficient for the covariance of THI inside calving season; $e_{ijklmnop}$= random error.

3. Results

3.1. Climatic Conditions in the Arid Region of Tunisia

Seasonally Mean maximum and minimum temperature (°C), RH calculated THI, and airspeed (km/h) by the different periods are shown in Table 2 and fig. 1. The RH tends to be inversely related to AT and THI, with a peak during winter (RH = 77.81%) and minimum value during summer (RH = 64.54%). The rise in AT induces an increase in evaporation and therefore a decrease of RH. The winter (figure1A) and spring (figure1B) indicated a shortage in heat stress conditions; meaning maximum and minimum AT values were 12.5, 17.85, and 7.15°C for winter and 17.77; 23.03, and 12.52 °C for spring. The RH rates were 77.81, 84.74, and 54.12% and 69; 79.2, and 3.4%, respectively. The average THI was 55.02 ± 1.22 and 62.81 ± 4.08 respectively for winter and spring. During the 33 years of this study, the dairy cattle were exposed to a hot period that lasted from summer (figure1C) which started from June (AT=26.7°C, THI=75.68) to September the first month of autumn (figure1D) season (AT=21.76°C, THI = 69). Both AT and THI values during this period indicated that the cows were under heat stress conditions. In contrast to the spring and winter

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periods, this heat stress lasts 85 days in summer and 38 days in autumn (starts the 6th day in June until the 9th day in October). Referring to the mean values of airspeed measured during different seasons, winter and spring showed the highest airspeed rate (7.03±0.45; 7.58±0.53 km/h, respectively). Summer and autumn showed the lowest mean values of airspeed (5.23±0.42, 5.74±0.39, respectively). Similar results of Yue et al. (2020) showed that the THI values in spring and summer above 72 cause heat stress in cows. However, in autumn and winter, when THI values were usually less than 72, the cows rarely experiencing heat stress.

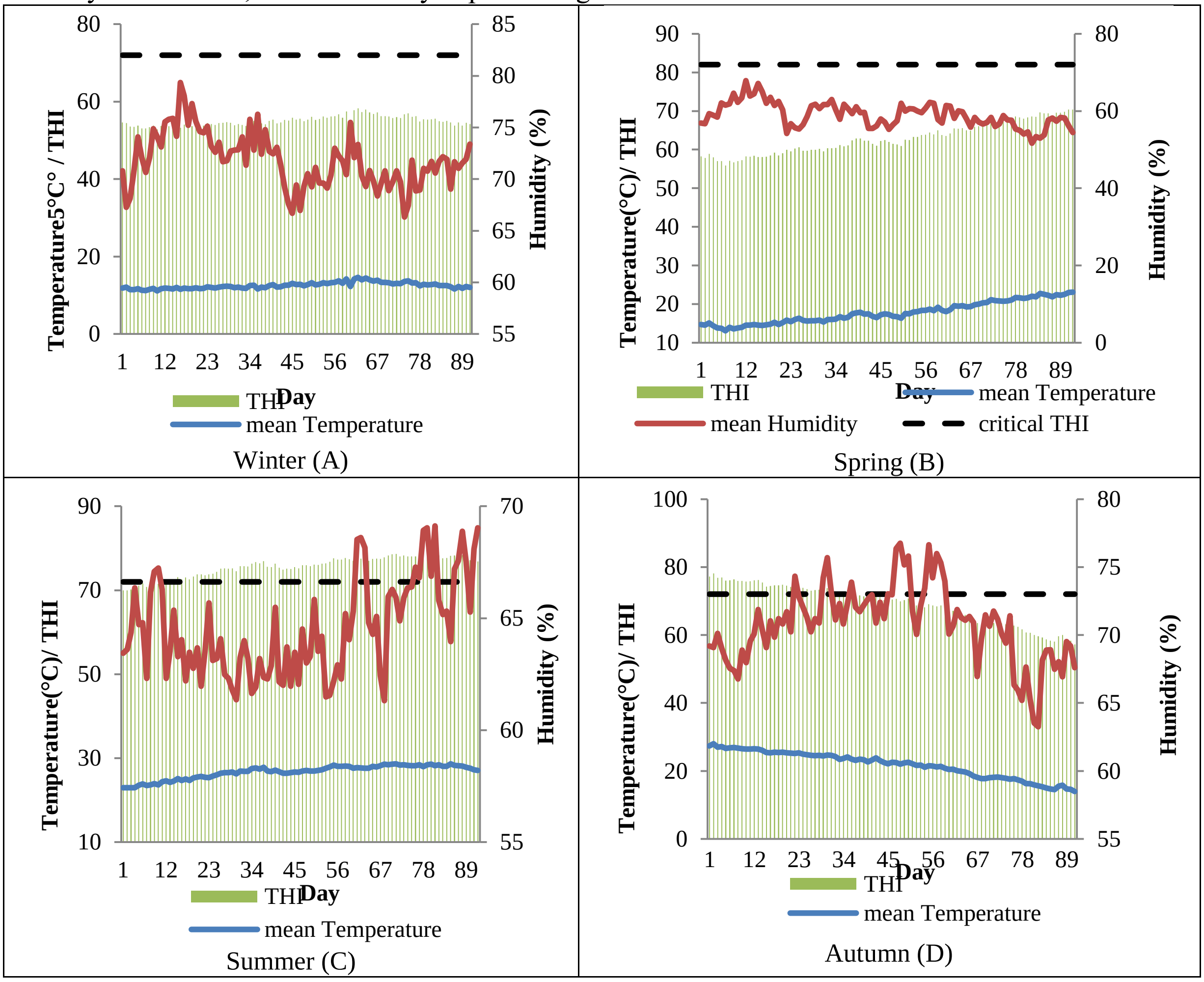

Figure 1. Average daily temperature (AT), relative humidity (RH) and temperature-humidity index (THI) during the seasons in a year.

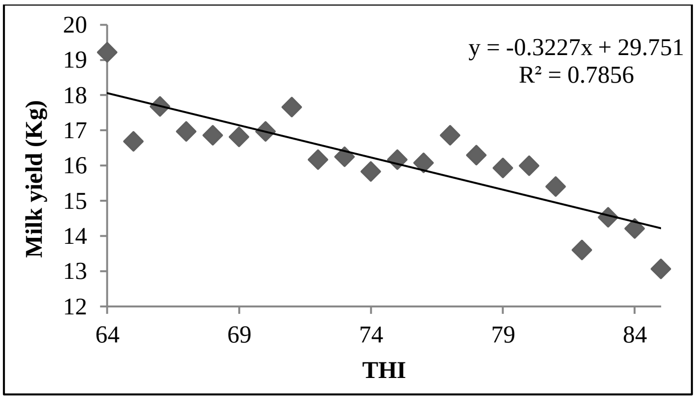

Figure 2. Relation of milk yield to average THI.

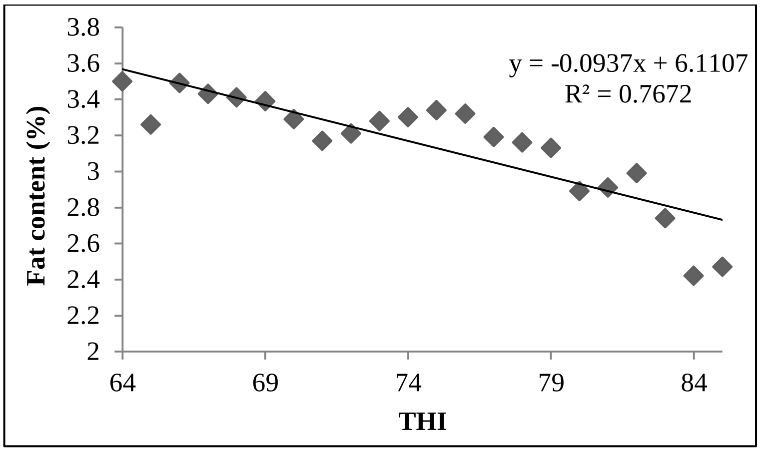

Figure 3. Relation of fat content to average THI.

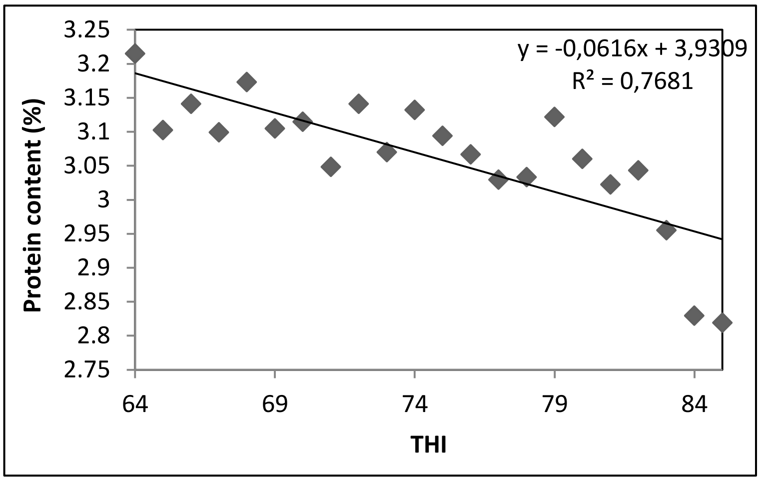

Figure 4. Relation of protein content to average THI.

Table 2. Environmental conditions during different seasons of the year (means ± standard deviation).

Parameters	Seasons			
	Winter	**Spring**	**Summer**	**Autumn**
Temperature, minimum (°C)	7.15 ± 0.86	12.52 ± 2.91	21.39 ± 1.57	16.84 ± 4.17
Temperature, maximum (°C)	17.85 ± 0.83	23.03 ± 2.71	32.05 ± 1.73	26.67 ± 3.61
Average temperature (°C)	12.50 ± 0.78	17.77 ± 2.79	26.72 ± 1.62	21.76 ± 3.88
Days average temperature> 25 °C	-	-	76	23
RH, minimum (%)	54.12 ± 5.11	33.4 ± 5.02	29.5 ± 5.36	42.3 ± 3.02
RH, maximum (%)	84.74 ± 8.05	79.2 ±8.04	71.8 ± 11.21	79.45 ± 8.03
RH, average (%)	77.81 ± 2.61	69 ± 3.20	64.54 ± 2.15	68.74 ± 2.80
THI, minimum	51.52 ± 1.60	59 ± 2.04	72.58 ± 3.75	64.85 ± 4.14
THI, maximum	57.47 ± 2.08	68.25 ± 1.85	79.45 ± 2.02	74.29 ± 1.75
Average daily THI	55.02 ± 1.22	62.81 ± 4.08	75.65 ± 2.43	69.07 ± 5.82
Number days daily THI > 72	-	-	85	38
Air speed (km/h)	7.58 ± 0.53	7.03 ± 0.45	5.23 ± 0.42	5.74 ± 0.39

(THI: temperature-humidity index, RH: relative humidity; winter: December, January, and February; spring: March, April, and May; summer: June, July, and August; autumn: September, October, and November).

3.2. The Effect of Heat Stress on Milk Production and Milk Composition

Table 3 shows the effect of exceeded THI on daily milk production and components regarding parity classes. The parity affects significantly milk yield (P<0.01). An important observation made was that cows that were in the fifth lactation were more marked by THI. When THI was at 70, the fifth

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lactation milk yield was higher than the first lactation; it declined to the first lactation level when THI reached 78. The maximum milk yield was observed in the third parity (20.98 ± 9.32) kg. The heat stress affects significantly milk yield (P<0.01). Regarding THI classes, daily milk production varied between 18.58-20.98, 16.96-18.44, 17.94-19.65, 16.44-18.8, 14.53-17.04 kg, respectively from the first to the fifth class of THI. The optimum milk yield was obtained with the first class of THI. This milk level decreases with increasing THI, it was noticed that heifers were more tolerant to THI increase. The highest amount of daily loss was 4.5 kg/cow/day. It was determined in multiparous particularly the fifth parity (5 kg/cow/day) from 70 THI value to 80 THI value and more. Parity and THI affect significantly milk content (P<0.01). Regarding THI classes, daily fatvaried between 3.46-3.52 %, 3.18-3.39 %, 3.17-3.34 %, 3.02-3.21 % and 2.59-2.9 %, protein contents varied between 3.22-3.27 %, 3.11-3.18 %, 3.11-3.17 %, 3.15-3.22 % and 3.03-3.09 % respectively from the first to the fifth class of THI. It was observed that the heifers were more sensitive to the THI compared to multiparous. While the third lactation milk content was similar at THI 70 to the first lactation.

Table 3. Effect of THI classes on production parameters in relation to parity classes (means ± standard deviation).

Parity	Parameters	THI classe				
		≤70	70<THI≤75	75<THI≤78	78<THI≤80	THI>80
P_1	Daily milk yield (kg)	18.58^{DA}(7.66)	17.59^{DC}(7.40)	17.94^{DB}(7.01)	16,63^{DC}(6.74)	16.46^{DD}(7.06)
	Daily fat content (%)	3.51^{A}(0.85)	3.33^{AB}(0.84)	3.17^{AC}(0.9)	3.05^{AD}(0.96)	2.59^{AE}(0.87)
	Daily protein content (%)	3.27^{AA}(0.47)	3.18^{AB}(0.44)	3.11^{AC}(0.4)	3.15^{AB}(0.44)	3.03^{AD}(0.41)
P_2	Daily milk yield (kg)	20.44^{BA}(8.38)	18.29^{BC}(8.67)	19.60 ^{B}(8.13)	19.02 ^{BC}(8.22)	16.23^{BD}(7.41)
	Daily fat content (%)	3.5^{AA}(0.89)	3.3^{AB}(0.87)	3.18^{AC}(0.84)	3.21^{AD}(0.9)	2.84^{AE}(0.92)
	Daily protein content (%)	3.23^{AA}(0.49)	3.16^{AB}(0.45)	3.12^{AC}(0.37)	3.17^{AB}(0.44)	3.06^{AD}(0.38)
P_3	Daily milk yield (kg)	20.98^{AA}(9.32)	18.44^{AC}(8.71)	19.65^{AB}(8.72)	17.35^{AC}(8.46)	17.04^{AD}(8.24)
	Daily fat content (%)	3.52^{AA}(0.9)	3.25^{AB}(0.85)	3.34^{AC}(0.89)	3.17^{AD}(0.9)	2.83^{AE}(1.04)
	Daily protein content (%)	3.26^{AA}(0.49)	3.18^{AB}(0.47)	3.17^{AC}(0.41)	3.22^{AB}(0.54)	3.07^{AD}(0.42)
P_4	Daily milk yield (kg)	20.61^{BA}(9.47)	17.75^{BC}(8.17)	19.08^{BB}(8.20)	18.8^{BC}(9.57)	15.95^{BD}(7.12)
	Daily fat content (%)	3.5^{AA}(0.9)	3.18^{BB}(0.84)	3.29^{BC}(0.85)	3.02^{BD}(1.05)	2.9^{BE}(1.08)
	Daily protein content (%)	3.22^{BA}(0.51)	3.11^{BB}(0.44)	3.11^{BC}(0.37)	3.17^{BB}(0.45)	3.07^{BD}(0.42)
P_5	Daily milk yield (kg)	19.64^{CA}(9.55)	16.96^{CC}(8.09)	19.09^{CB}(8.54)	16.44^{CC}(7.44)	14.53^{CD}(7.29)
	Daily fat content (%)	3.46^{BA}(0.87)	3.39^{AB}(0.85)	3.33^{AC}(0.83)	3.12^{AD}(1.01)	2.84^{AE}(0.97)
	Daily protein content (%)	3.26^{AA}(0.46)	3.16^{AB}(0.4)	3.12^{AC}(0.37)	3.17^{AB}(0.46)	3.09^{AD}(0.42)

THI : temperature-humidity index. The values within the classes of parity and THI marked with the different letters differ significantly (p<0.01).

4. Discussion

The findings reached in this study affirm the correlation between climatic conditions, milk production as well as chemical features of milk (Bouraoui et al., 2002; Prasad et al., 2012; Bertocchi et al., 2014: Tao et al., 2018; Yue et al., 2020; Fontoura et al. 2022). The parity affects

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significantly milk yield (P<0.01). Berman (2005) reported that high-yielding cows are more impacted by heat stress. He also suggested that if milk yield grows from 35 to 45 kilograms per day, stress threshold temperature has to be lowered by 5 °C in cows based on present results, regarding parity classes milk yield increased by 14 % between first and third parity and it decreased by 8 % between third and fifth parity. The heat stress affects significantly milk yield (P<0.01). The milk level decreases with increasing THI, it was noticed that the heifers had better tolerance to an increase in THI. The highest amount of daily loss (18 %), was determined in multiparous particularly the fifth parity (20 %) from 70 to 80 THI value and more. The decline in milk yield under heat stress conditions has been highlighted in earlier studies, DuPreez et al. (1990) and Itoh et al. (1998) confirmed that the exposure of dairy cows to high values of THI causes a reduction of 10 to 34 % in milk yield. Parity and THI affect significantly milk content (P<0.01). Regarding parity classes, milk components in heifers increased by 26 % and 7 % for fat and protein content, respectively. While it increased by 18 % and 5 % for fat and protein content respectively for multiparous particularly the third parity 19 % for fat and 6% for protein content). It was observed that the heifers were more sensitive to the THI compared to multiparous. While the third lactation milk content was similar at THI 70 to the first lactation. Yet, the animal’s age plays an important role in comfort as young animals are more impacted by stress. Gantner et al. (2011) observed a high significance (p<0.01) as to the THI value and parity impacts, decline in daily fat and protein content in heifers, and high significance (P<0.01). A decrease of daily milk yield, protein content and daily fat was observed in cows in the second lactation. The calving season significantly affected milk yield (P<0.05). While there is no significance between the calving season with milk contents (P>0.05). Van Eetvelde et al. (2017) report that the calving season has a significant effect on milk production, because heifers calved in winter produce less than heifers calved in any other season. However, high significance (P<0.01) between DIM (days in milk) and of analyzed productive parameters (Table 4). The observed increases in these parameters were within previously reported values observed for heat stressed lactating cows (Becker et al., 2020).

The first step to understanding how to manage heat stress is to establish the threshold at which cattle undergo. The THI thresholds found in the literature vary from 50 to 74. In a study of Italian Holstein dairy cattle, Bernabucci et al. (2014) found a threshold of 50, and Collier et al. (2011) found 60. Johnson et al. (1962) also deduced that when THI exceeds 70, a linear reduction in milk yield occurs. In the research of Bouraoui et al. (2002) in Mediterranean climatic conditions of Tunisia, lactating Holstein cows reduced their milk yield and DMI (Dry Matter Intake) when the THI is over 69. However, Ravagnolo et al. (2000) and Thatcher et al. (2010) defined that THI = 72 as the upper critical value above which production traits began being modified. In the United States environment, Bohmanova et al. (2007) found a THI threshold of 72 in Georgia and 74 in Arizona. However, recent research suggests that the TCZ for lactating cows is shifting to a lower THI threshold, with cows experiencing heat stress when THI exceeds 68 (Zimbelman et al., 2009; Tao et al., 2018). This shift in THI can be attributed to the increased genetic potential for milk production of modern dairy herds (Brito et al., 2021) and the inherent heat sensitivity of high-producing dairy cows (Aguilar et al., 2010). In the present study, the THI threshold that cows are stressed is above 64, whenever there was a slight increase of one point above 64 in the THI value, milk yield decreased by 0.32 kg per cow per day (Figure 2). The variation in daily milk yield could be attributed to a large part of heat stress. The relationship is rather significant, as represented by the correlation coefficient (r = –0.88, P < 0.01). The decline in daily milk by -0.32 kg per day, in this research, was lower than the -0.41kg proclaimed by Bouraoui et al. (2002), and similar to the results of Ingraham et al. (1979) in tropical climate (-0.32 kg). In the same context, Bohmanova et al. (2007) claimed that a unit of increase in THI was responsible for various decrease rates in milk production that ranged between -0.23 and -0.59 kg, higher than 0.26 kg per cow for each point beyond 70 reported by Johnson (1980). Collier et al. (2011) showed that the daily milk yield decreased around 2.2 kg/day when the THI values increased from 65 to 73. With every increase above 72, milk yield decrease by 0.2 kg (Ravagnolo et al., 2000). It was observed by Schneider et al. (1988) that during heat stress, dairy placed in the same chamber for experimental purposes, consumed less feed (13.6 vs. 19.4 kg/day), but rather more water (86.0 vs. 81.9 l/day) and had a drop in milk production (16.5 vs. 20.0

kg/day) than cows placed in a neutral thermal environment. Bouraoui et al. (2002) observed that daily THI was negatively consistent with milk production (r =-0.76) and feed intake (R = -0.24.). As previously mentioned, heat stress leads to a decrease in the feed intake of dairy cows (Ammer et al., 2018). Heat stress may be the cause of decreasing milk production because of low nutrient intake and uptake by the portal drained viscera of the cow. Nutrient metabolism could be altered by blood flow shifted to peripheral tissues for cooling purposes and contribute to lowering milk yield during hot weather. The authors assume that the delay between intake and utilization of consumed nutrients, related to altering feed intake or changes in the endocrine status of the cow could be delayed in production by the impact of climatic variables.

Highly significant ($P<0.01$) decrease of fat and protein content due to enhanced THI (Table 4). Because of heat stress, milk fat and milk protein percentage decrease as well (r = –0.86 and –0.84 for fat and protein content respectively). When the THI value was above 64 and there was a point increase, a decrease in fat and protein content of 0.09 % (Figure 3) and 0.06 % (Figure 4) per cow per day, respectively was observed. Bertocchi et al. (2014), observed in a seven years retrospective study on milk's seasonal variations, a negative interaction between THI, fat, and protein concentration when THI reached 50.2 and 65.2 for fat and protein, respectively. The drop in milk contents of this study is high compared to the results of Rejeb (2014) that states that under the heat stress conditions of Tunisia when the THI increases from 65.6 to 83.9, the Holstein cow's fat content goes from 37.9 to 36.5 g / kg. Bouraoui et al. (2002) reported that the fat content of dairy cows decreases from 35.8 to 32.4 between spring and summer. The study of Bellagi et al. (2017) showed that with each unit of THI the fat content decreases by 0.1 g/kg. The latter authors attributed this drop in fat content observed during the period of heat stress in Tunisia, a significant drop in food intake, thus leading to rations lower in fiber during the summer. In our study, the effect of thermal stress on the fat content is more pronounced than that reported by Rejeb (2014), Bouraoui et al. (2002), and Bellagi et al. (2017). This difference can be attributed to differences in climatic conditions at higher THI levels in an arid environment and maybe at the different genetic potential of animals.

However, Knapp and Grummer (1991) found that heat stress conditions were not responsible for a decrease in fat percentage. They added that this decrease could be the result of the use of total mixed rations that have presumably alleviated milk fat depression related to heat stress. Emery (1978) indicated that reduced ruminal pH may reduce milk fat synthesis. Cows exposed to higher THI showed lower milk yield. Therefore, a dilution effect of heat stress on milk characteristics can be excluded. In the study of Smith et al. (2013), protein percentage decreased from 3.2 to 3.1 and 3.6 to 3.5% for Holsteins and Jerseys experiencing heat stress, respectively. Heck, et al. (2009) studied the effect that seasons had on milk components in Dutch dairy milk and concluded that milk true protein content was rather more sensitive depending on the season than other milk characteristics, with the lowest value reached in June (3.21%) and the highest value reached in December (3.38%). In Tunisia, Bouraoui et al. (2002) found that during spring and summer, milk protein percentage declined noticeably by 2.96 vs 2.88 % respectively, because of heat stress). Besides, Bellagi et al. (2017), reported a significant decrease in protein content in response to high THI (-1.40 g / kg between winter and summer), a regression of -0.06 g / kg THI. Tao et al. (2018) reported that the variation of milk fat and protein was due to the feeding system, stage of lactation, and level of heat stress. The decrease in energy and protein intake because of decreased feed may have occurred as the main cause of the decline in milk protein observed in the current study during the hot season that leads to metabolic changes in the mammary gland. The mammary gland blood flow reduces protein precursor supply and nutrient partitioning of the mammary gland, altering protein synthesis (Gao et al., 2017). Cowley et al. (2015) suggested that heat stress effects on the synthesis of mammary glands produced a decrease in the percentage of protein. In the present study. the results shown in table 5 indicated that the decrease in milk yield, fat, and protein content started at a THI value of 64, for THI values between 65 and 70, milk yield dropped by 13 %, fat by 7 %, and protein content by 5 % while it dropped by almost 17 %, 9 %, and 7 % respectively, when the THI values reached 75. When THI was between 79 and 81, losses were 19 %, 18 %, and 11% respectively for milk yield, fat, and protein content. When THI attained the maximum values of 85, milk yield decreased maximally by 30 %, fat 29 %, and protein content by 17 %. These findings are in correlation with those of Bouraoui et al. (2002) that indicates that when THI values reached 80 or more, a maximum decrease in milk yield happened. Many studies (Johnson, 1980; Lemerle et al., 1986; Wiersma, 1990; Bouraoui et al., 2002; Rejeb, 2014: M'Hamdi et al. 2021) declared that when THI exceeds 72, a slight decline in milk production was observed and when THI exceeds 76, it decreased sharply.

Heat stress affects negatively the performance of dairy cows that are imported from regions having a moderate climate notably in Europe and North America to Africa and Asia that have a tropical and subtropical climate. Holstein cow's milk production starts to decline when the THI reaches 64 in the dry conditions characterizing Tunisia. An intensity of THI value provokes a noticeable decrease (P<0.01) of daily milk production and protein content. Hence. the milk yield, fat, and protein contents are brought down to 0.32 kg, 0.09 %, and 0.06 % per cow and per day respectively. The results of this research can help to take the needed precautions to lessen the drawbacks of an arid environment on dairy cows since they are mostly impacted by heat stress during summer and autumn. Measures that can be taken against heat stress include building sheds, providing a fresh place for cattle, switching feed, and the time when feed is given, using several feed additives, giving fresh water, and providing fans.

Table 4. Effects of parity, days in milk, calving season and temperature-humidity index (THI) on milk yield and milk component.

Parameters	Means	SEM[s]	THI	Parity	THIxParity	DIM	THIxDIM	CS	THIxCS
Milk yield (kg/day)	19.19	0.07	***	***	***	***	***	**	**
Fat (%)	3.88	0.09	***	***	***	***	***	NS	NS
Protein (%)	3.45	0.03	***	***	***	***	***	NS	NS

s: Standard error of the mean, THI: temperature-humidity index, DIM: days in milk, CS: calving season. ***P < 0.01 **P < 0.05 NS (non-significant) P > 0.05

Table 5. Milk production, fat and protein content decrease (%) in relation to THI.

THI value	Decrease (%)		
	Milk	Fat	Protein
64	0	0	0
65	12	2	2
66	7	4	3
67	10	3	5
68	12	3	2
69	11	9	4
70	13	5	4
71	8	8	5
72	15	7	3
73	14	6	5
74	15	4	3
75	17	4	4
76	15	5	7
77	12	9	6
78	16	10	7
79	17	12	9
80	15	17	11
81	19	18	9
82	28	14	10
83	23	21	9
84	25	27	14
85	30	29	17

THI: temperature-humidity index.

Conflicts of interest

The authors declare no conflicts of interest.

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