Impact of heat stress on milk production performance of cattle in the suburban area of Ngaoundere, Cameroon

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Abstract

This study aims to assess the impact of heat stress on milk production of cattle under sudano-guinean climate in the suburban area of the city of Ngaoundere (Cameroon). It was carried out on 98 cattle of different breeds and sexes in order to determine their stress situation by measuring the level of cortisol in their blood plasma and by calculating the temperature-humidity index (THI). It was seen that, about half of the cattle (49.0%) are under stress according to their cortisol level (higher than 11.7 ng/ml). Gudali (75.9%) and Holstein (41. 7%) were more stressed than Montbeliard (38.2%) and cross breeds (34.8%). Females (54.3%) were more stressed than males (23.5%). Gudali and Montbeliard cattle were more susceptible to heat stress with a higher THI mean (70.4) than Holstein (69.5) and crossbreeds (68.9). There was a significant difference in THI among breeds whereas no difference in THI between sexes was observed. Stressed cows have lower daily milk production (7.81 L) than unstressed cows (19.9 L). Meanwhile, milk production decreases as THI increased.

Keywords: Dairy cows, heat stress, cortisol, temperature-humidity index, Cameroon

INTRODUCTION

While milk consumption per person averages 294 kg in developed countries, in Cameroon it is around 10 kg, as production is only 5.11 kg per capita, the difference is compensated by imports of dairy products which are constantly increasing (Bayemi *et al.,* 2005). For this reason, the development of dairy production in this country must be a priority. Holstein-Friesian and Jersey cattle were purchased in the United States in 1974, 1976 and 1981 and crossed with native zebus (white and red Fulani). In 1982, 87 purebred and crossbred cattle were distributed to farmers and missions, but the dairy industry is still a small-scale industry. The dairy industry requires a coordinated development strategy in order to remove the constraints weighing on rural production, to ensure remunerative prices and to encourage cooperatives to integrate the processing of milk and the marketing of the products.

The rise in temperatures, combined with the increase in the number of productive animals and the intensification of agriculture, including (but not limited to) that of emerging economies is a major environmental way (Renaudeau *et al.*, 2012). Indeed, heat stress has become a significant challenge for the global dairy industry, since dairy cows already have high internal heat loads from high milk production (Chebel *et al.*, 2004).

Heat stress is defined as a condition that occurs when environmental pressures exerted on an animal exceed its ability to dissipate heat, resulting in an increase in the animal's body temperature. It then follows an imbalance of its heat balance, which will have many consequences (Bernabucci *et al.*, 2010). In homeotherms, including cattle, maintaining an optimal body temperature is important for the proper functioning of the body (Bernabucci *et al.*, 2010). For the dairy cow, this implies maintaining a body temperature of around 38.9 ± 0.4°C, regardless of the climatic conditions to which the animal is exposed (Burfeind *et al.*, 2012). Maintaining this temperature requires a balance between the animal's heat gains and the losses of this heat to the environment (Collier and Gebremedhin, 2015).

Today, heat stress has become one of the biggest challenges facing dairy farmers in many parts of the world and in Cameroon in particular. Furthermore, heat stress is a critical problem endangering animal welfare and productivity in dairy farms. However, studies of climate change impacts have been based on a numerical model designed to understand the effects of heat stress conditions on individual animals. The results contributed significantly to improving herd management by providing guidance for defining targeted treatments based on cow characteristics. Knowledge of susceptibility to heat stress makes it possible to identify the animals most vulnerable to heat stress due to high temperature and humidity and therefore to implement specific strategies in order to mitigate their critical responses (M'hamdi *et al.*, 2012).

Animals, like humans, suffer in extreme heat and humidity. For livestock, extreme weather conditions can affect productivity and animal welfare (Thornton *et al.*, 2021). The effect on dairy cattle can be relatively easily determined because with twice daily milking any drop in yield can be quickly identified and has an immediate effect on the revenue generated. The consequences can be physiological and endocrine. Measurable physiological consequences include reduced feed intake, growth, fertility, milk production and eventual mortality (O'Brien *et al.*, 2010; Crescio *et al.*, 2010). On the other hand, the endocrine response to heat stress results mainly in an elevation of glucocorticoids (cortisol), aldosterone, antidiuretic hormone, thyroxine, prolactin and growth hormone (GH) (Dovolou *et al.,* 2023). These effects reduce herd productivity, with consequences on economic viability (St-Pierre and Jones, 2001). Furthermore, at the herd level, susceptibility depends on the breed and the genetic value of the herd. Generally, cows with high genetic potential (i.e selected for high milk yield) being proportionally more affected by heat stress (Bryant *et al.,* 2007). Certain breeds of cattle appear to be better acclimatized to warmer temperatures, with some beef cattle adapted to subtropical climates being better able to withstand prolonged periods of moderate heat stress (Boonprong *et al.*, 2008). Therefore, animals housed in climates of high temperature or high temperature combined with high relative humidity have a higher risk of heat stress. In dairy cattle, research suggests that heat stress occurs when the temperature-humidity index (THI) exceeds 68 (Collier *et al.*, 2006).

The general objective of the present work is to contribute to the evaluation of the impact of heat stress on the production performances of dairy cattle and how stress varies among breeds and sexes in the suburban area of Ngaoundere. Specifically, we determine their temperature-humidity index (THI) values, evaluate the cortisol levels in blood plasma of this animals as an indicator of stress and assess the impact of heat stress on milk production.

MATERIALS AND METHODS

Period and environment of study

The study took place from August 2022 to January 2023 in the suburban area of Ngaoundere, capital of the Vina division in the Adamawa region (Cameroon). Adamawa is a transition region between forested southern Cameroon and the Sudanian savannahs of northern Cameroon. It is located between 6°20' and 7°40' North latitude and 11° and 15° East longitude. It covers an area of 63,701 km^2. The climate is of the Sudano-Guinean type with a long rainy season from April to October and a dry season from November to March. The high altitude of the region gives a relatively cool climate with average temperatures of 25°C for the cold season and 31°C for the hot season. Monthly rainfall reaches 1500 mm in the rainy season. The Adamawa plateau is a privileged cattle raising area in the Sudanian zone because the dry season is less severe there than further North of the country.

Animal selection and data collection

A questionnaire was developed to determine the ability of dairy cattle farmers to recognize the stress suffered by their animals during production as well as the size of their different farms. Following this survey, a total of 98 animals was sampled: Gudali (29), Holstein (12), Montbeliard (34) and crossbreed (23). Then our questionnaire allowed to have information on the daily production of these animals as well as on their monthly production.

Determination of THI

Ambient temperature was taken immediately after blood samples were taken using a Kestrel 3000 Weather Meter. The abdominal temperature was taken during the sampling using an infrared thermos flash at the last rib of the right side of the animal. The calculation of the Temperature-Humidity Index (THI) was done using the formula proposed by National Research Council (NRC, 1971):

$$\mathbf{THI = (1.8 \times Tdb + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times Tdb - 26.8)]}$$

Where,

THI = temperature humidity index,

RH = relative humidity,

Tdb = dry bulb temperature.

In dairy cattle, research suggests that heat stress occurs when THI exceeds 68 (Collier *et al.*, 2006).

Blood collection and storage

Blood samples were taken from two reputable milk farms in the suburban area of Ngaoundere. From the animals, blood was collected from the jugular vein in collection tubes containing EDTA (ethylene diamine tetraacetic acid). EDTA is an anticoagulant, present in red cocked tubes, and has the role of capturing the Ca^{2+} ions, which are responsible for the course of coagulation. These samples were taken after having previously constrained the animal manually. Each blood sample was taken by breed, sex and age of the animal. After, the samples were placed in a cooler containing Ice Packs. These samples were transported to the Agricultural Research Institute for Development (IRAD) in Wakwa in a cooler containing Ice Packs, then centrifuged the same day and the plasma obtained was poured in Eppendorf tubes, labeled, then kept at a temperature of -20°C while waiting for the ELISA test.

Determination of cortisol in blood plasma by ELISA test

Blood cortisol was shown to be a very sensitive index of heat stress indicating the onset of poor tolerance of severe climates. Before proceeding with the assay, all the reagents (reference plasma and controls) were brought to room temperature. The wells of the microplates were formed for each reference plasma, control and unknown sample to be assayed in duplicate. Unused micro well strips in the foil bag were replaced, sealed and stored. 0.025 ml (25 ul) of reference plasma and control was poured into the assigned well, 0.050 ml (50 ul) of ready-to-use Cortisol Enzyme Reagent was added to all wells. The microplate was swirl gently for 30 seconds to mix, then 0.050 ml (50 ul) Cortisol Biotin Reagent was added to all wells and microplate swirled again gently for 30 seconds to mix well. The plate was then covered and incubated for 60 minutes at ambient temperature. The contents of the microplate were discarded by decantation and the plate wiped with absorbent paper. 350 ul Wash Buffer was then added and the decanted wells (tap and blot), this procedure was repeated two more times for a total of three washes. 0.100 ml (100 ul) of working substrate solution was added to all wells (work substrate). The reagents were always added in the same order to minimize differences in reaction times between wells. The plate was then incubated at room temperature for fifteen minutes and then 0.050 ml (50 ul) of Stop Solution was added to each well and mixed gently for 20 seconds. The absorbance in each well is read at 450 nm (using a reference wavelength of 620 nm to minimize well imperfections) in a microplate reader. The result was read within thirty minutes after adding the stop solution. The reference value is between 0.5 to 11.7 ng/ml (Gellrich *et al.*, 2015).

Data analysis

Statistical analysis was performed using R® software. The Shapiro-Wilk test was used to test the normality of observations or values. One-way analysis of variance (ANOVA) was used to compare the means of milk production and to compare the means of blood cortisol levels between the different breed and sex. Differences between means were tested using Duncan's test. For non-normal data, the Krustal-Wallis test was used to compare the different means. All data were represented as mean ± SD (Standard Deviation) at the 5% threshold (P-value < 0.05).

RESULTS

Variation of THI according to breed and sex

Table 1 presents the variation in THI according to breed and sex. With an average THI of 70.4, Gudali and Montbeliard cattle are more subject to heat stress than Holstein and cross-breed cattle; which record respective THIs of 69.5 and 68.9 (P<0.05). There is no significant difference in THI between sexes (P>0.0 5).

Variations in daily milk production according to the THI

Table 2 shows the variation in daily milk production with respect to THI values. Cows with a THI of 68.8 record a daily milk production of 16.5 L. However, the average daily milk production of cows with a THI of 70.4 is 13.3 L. Thus, milk production increased when the THI decreases. Milk production varies opposite to THI (P>0.05).

Stress status of the cattle after cortisol assay in blood plasma

According to cortisol assay in blood plasma, 49.0 % of the animals (48 cattle) are under stress in relation to their high cortisol level which was between 16.2 ng/ml to 32.5 ng/ml with an average of 24.4 ng/ml against 51.0 % (50 cattle) for non stressed cattle. Their cortisol level is between 2 ng/ml to 10 ng/ml with an average of 6 ng/ml which reflects the standard according to Gellrich *et al.* (2015) which is between 0.5 to 11.7 ng/ml.

Variation in stress status by breed and sex after cortisol assay

Table 3 illustrates stress status of cattle by breed and sex. After cortisol assay, Gudali (75.9 %) and Holstein (41.7%) were more stressed than Montbeliard (38.2%) and cross breeds (34.8 %) (P<0.05). With regard to sex, females (54.3 %) were more stressed than males (23.5 %) (P<0.05).

Table 1: Variation of the THI according to breed and sex

Factors	Variables	Number of animals	THI (Mean ± Standard Deviation)	95% CI	P-value
Breed	Gudali	29	70.4 ± 0.00[c]	[70.0 - 70.4]	0.000*
	Holstein	12	69.5 ± 0.85[b]	[68.9 - 70.0]	
	Montbeliard	34	70.4 ± 0.00[c]	[70.0 - 70.4]	
	Cross-breed	23	68.9 ± 0.34[a]	[68.7 - 69.0]	
Sex	Male	17	70.0 ± 0.72	[69.7 - 70.4]	0.552
	Female	81	69.9 ± 0.76	[69.8 - 70.1]	

Significant difference;[a; b; c:] values with different letters are significantly different (P < 0.05); CI: confidence interval; THI: Temperature and humidity index.

Table 2: Variation in daily milk production with respect to THI values

Factor	Variables	Number of animals	Daily milk production (Mean ± Standard Deviation)	95% CI	P-value
THI	68.8	25	16.5 ± 6.5 L	[13.8 - 19.1]	0.094
	70.4	27	13.3 ± 7.0 L	[10.5 - 16.0]	
	Total	52	14.8 ± 6.9 L	[12.9 - 16.7]	

CI: confidence interval

Table 3: Stress status of cattle by breed and sex after cortisol essay

Factors	Variables	Number of animals	Number of stressed subjects	Stress status after cortisol assay (%)	95% CI	P-value
Breed	Gudali	29	22	75.9 [b]	[59.3 - 92.4]	0.006*
	Holstein	12	5	41.7 [b]	[8.9 - 74.4]	
	Montbeliard	34	13	38.2 [a]	[21.0 - 54.5]	
	Crossbreed	23	8	34.8 [a]	[13.7 - 55.8]	
Sex	Male	17	4	23.5 [a]	[1.0 - 46.0]	0.021*
	Female	81	44	54.3 [b]	[43.2 - 65.4]	

**: Significant difference;[a; b:] values with different letters are significantly different (P < 0.05); CI: confidence interval.*

Influence of stress on milk production after cortisol assay

After cortisol assay in blood plasma, unstressed cows have an average daily milk production of 19.9 L (Table 4). On the other hand, stressed cows recorded an average daily milk production of 7.8 L (P<0.05).

DISCUSSION

Heat stress is caused by any combination of environmental parameters producing conditions that are higher than the temperature range of the animal's thermal neutral zone. The survival and performance of an animal during heat stress periods depend on several weather factors, especially temperature and humidity. Extended exposure to excess heat reduces feed consumption, milk production and breeding efficiency (Nzeyimana *et al*., 2023; Chen *et al*., 2024). The present work focused on measuring the impact of heat stress on dairy cattle production performances in the suburban area of Ngaoundere. Cortisol level and temperature-humidity index (THI) were used as indicators of heat stress, and their relation or impact on milk production was measured. Cortisol is a hormone that is released in response to stress and can affect metabolism, immunity and reproduction. THI is a measure that takes into account both temperature and humidity to estimate the level of stress cows will experience based on environmental conditions. Hence both cortisol and THI are commonly used as indicators of heat stress in dairy cattle (Becker *et al*., 2020).

Gudali and Montbeliard cattle breeds had higher THI mean (70.4) than Holstein (69.5) and cross breeds (68.9), indicating more heat stress for the latter. There is a significant difference in THI among breeds whereas there is no significant difference in THI between sexes. These results imply that some breeds are more exposed to or less tolerant of high temperature and humidity than others, which could be related to their coat color, body size or adaptation to different climates (Becker *et al*., 2020). Moreover, cows with a THI of 68.8 recorded a daily milk production of 16.5 L, whereas, the average daily milk production of cows with a THI of 70.4 was 13.3 L. Thus, milk production increases when the THI decreases, as reported by Bouraoui *et al.* (2002). West (2003) and Spire *et al.* (2004) reported also that under hot conditions, milk production was negatively affected by THI. Bernabucci *et al.* (2014) showed in a study on the effects of heat stress in Italian Holstein dairy cows that milk, fat and protein yields have similar trends, highlighting the negative effect of a high THI on production traits. Likewise, Cowley *et al.* (2015) reported that when THI levels drop outside the thermal comfort zone, dairy cows begin to experience heat stress and begin to reduce milk production. There is therefore evidence that heat stress has an impact on various parameters of milk production, particularly in terms of reduced milk production (Polsky and von Keyserlingk, 2017; Galán *et al.,* 2018). Lactating dairy cows have an increased sensitivity to heat stress compared with no lactating (dry) cows, due to milk production elevating metabolism. Moreover, because of the positive relationship between milk yield and heat production, higher yielding cows are more challenged by heat stress than lower yielding animals. When a cow becomes heat stressed, an immediate coping mechanism is to reduce DMI (dry matter intake), causing a decrease in the availability of nutrients used for milk synthesis. Simultaneously, there is an increase in basal metabolism caused by activation of the thermoregulatory system. Mild to severe heat stress can increase metabolic maintenance requirements by 7 to 25%, further exacerbating both the existing metabolic stress and the decrease in milk production (Polsky and Von Keyserlingk, 2017).

Cortisol levels in blood plasma showed that 49.0% of animals (48 cattle) are under stress according to their high cortisol level which was between 16.2 ng/ml to 32.5 ng/ml with an average of 24.4 ng/ml, above the reference value which is between 0.5 to 11.7 ng/ml (Gellrich *et al*., (2015). Du Preez (2000) found that plasma cortisol concentrations are higher in heat-stressed lactating dairy cows than in lactating dairy cows maintained at a temperature of 22°C. This is in line with our results as a high cortisol levels were observed in stressed cows than in non-stressed cows. Also, our results showed that heat stress occurs when cows have more heat than they can get rid, which leads to more stress, lower milk production and a higher rate of diseases. This is consistent with the definition of heat stress and its reported effects on dairy cattle (Becker *et al*., 2020).

We also observed that Gudali (75.9%) and Holstein (41.7%) were more stressed than Montbeliard (38.2%) and cross breeds (34.8%) and females were more stressed than males. These results suggest that there is variation in the susceptibility to heat stress among different breeds and sexes of cattle, which could be due to genetic, physiological, or behavioral factors (Becker *et al.,* 2020). Meanwhile, high cortisol levels in Holstein breed could also be explained by the fact that Holstein cows have higher blood, milk and urine cortisol levels than other breeds (Nedić *et al.,* 2017). Moreover, it is seen that unstressed cows have an average daily milk production of 19.9 L. On the other hand, stressed cows recorded an average daily milk production of 7.8 L. These results indicate that heat stress has a negative impact on milk production, which could be mediated by reduce feed intake, altered metabolism, hormonal changes, or impaired mammary function (Becker *et al*., 2020).

Table 4: Influence of stress on milk production after cortisol assay in blood plasma

Factors	Variables	Effective	Daily milk production in liter (Mean ± Standard Deviation)	95% CI	P-value
Stress status after cortisol assay	Unstressed cows	30	19.9 ± 4.0 [b]	[18.4 - 21.4]	0.000*
	Stressed cows	22	7.8 ± 1.9 [a]	[7.0 - 8.6]	
	Total	52	14.8 ± 6.9	[12.9 - 16.7]	

**: Significant difference;[a; b:] values with different letters are significantly different (P < 0.05; CI: confidence interval).*

CONCLUSION

Heat stress has a negative impact on milk production, which could have important economic implications for the dairy industry. Therefore, considering all the negative effects associated with heat stress and the current and future environmental challenges associated with climate change, this indicates a need to identify and select animals that are more resilient to these environmental stressors.

REFERENCES

Bayemi P.H., Bryant M.J., Perera B.M.A.O., Mbanya J.N., Cavestany D., Webb E.C. (2005). Milk production in Cameroon: A review. *LRRD Newsletter.*, 17: Art. #60.

Becker C.A., Collier R.J., Stone A.E. (2020). Invited Review: physiological and behavioral effects of heat stress in dairy cows. *J. Dairy Sci.,* 103: 6751-6770.

Bernabucci U., Biffani S., Buggiotti L., Vitali A., Lacetera N., Nardone A. (2014). The effects of heat stress in Italian Holstein dairy cattle. *J. Dairy Sci.*, 97: 471-486.

Bernabucci U., Lacetera N., Baumgard L.H., Rhoads R.P., Ronchi B., Nardone A. (2010). Metabolic and hormonal acclimation to heat stress in domesticated ruminants. *Animal,* 4: 1167–1183.

Boonprong S., Choothesa A., Sribhen C., Parvizi N., Vajrabukka C. (2008). Productivity of Thai Brahman and Simmental-Brahman crossbred (Kabinburi) cattle in central Thailand. *Int. J. Biometeorol.*, 52: 409–415.

Bouraoui R., Lahmar M., Majdoub A., Djemali M., Belyea R. (2002). The relationship of temperature-humidity index with milk production of dairy cows in a Mediterranean climate. *Anim. Res.*, 51: 479-491.

Bryant J.R., López-Villalobos N., Pryce J.E., Holmes C.W., Johnson D.L. (2007). Quantifying the effect of thermal environment on production traits in three breeds of dairy cattle in New Zealand. *N.Z. J. Agric. Res.,* 50: 327-338.

Burfeind O., Suthar V.S., Heuwieser W. (2012). Effect of heat stress on body temperature in healthy early postpartum dairy cows. *Theriogenology,* 78: 2031–2038.

Chebel R.C., Santos J.E.P., Reynolds J.P., Cerri R.L.A., Juchem S.O., Overton M. (2004). Factors affecting conception rate after artificial insemination and pregnancy loss in lactating dairy cows. *Anim. Reprod. Sci.*, 84: 239–255.

Chen L., Thorup V.M., Kudahl A.B., Stergaard S. (2024). Effects of Heat Stress on Feed Intake, Milk Yield, Milk Composition, and Feed Efficiency in Dairy Cows: A Meta-Analysis. *J. Dairy Sci.,* 107: 3207-3218.

Collier R.J., Dahl G.E., VanBaale M.J. (2006). Major Advances Associated with Environmental Effects on Dairy Cattle. *J. Dairy Sci.,* 89: 1244-1253.

Collier R.J., Gebremedhin K.G. (2015). Thermal biology of domestic animals. *Annu. Rev. Anim. Biosci.*, 3: 513–532.

Cowley F.C., Barber D.G., Houlihan A.V., Poppi D.P. (2015). Immediate and residual effects of heat stress and restricted intake on milk protein and casein composition and energy metabolism. *J. Dairy Sci.*, 98: 2356-2368.

Crescio M.I., Forastiere F., Maurella C., Ingravalle F., Ru G. (2010). Heat-Related Mortality in Dairy Cattle: A Case-Crossover Study. *Prev. Vet. Med.*, 97: 191-197.

Dovolou E., Giannoulis T., Nanas I., Amiridis G.S. (2023). Heat Stress: A serious disruptor of the reproductive physiology of dairy cows. *Animals*, 13: 1846.

Du Preez J.H. (2000). Parameters for the determination and evaluation of heat stress in dairy cattle in South Africa. *Onderstepoort J. Vet. Res.*, 67: 263-271.

Galán E., Llonch P., Villagrá A., Levit H., Pinto S., Del Prado A. (2018). A systematic review of non-productivity-related animal-based indicators of heat stress resilience in dairy cattle. *Plos One*, 13: e0206520.

Gellrich K., Sigl T., Meyer H.H., Wiedemann S. (2015). Cortisol levels in skimmed milk during the first 22 weeks of lactation and response to short-term metabolic stress and lameness in dairy cows. *J. Anim. Sci. Biotechnol.*, 6: 31.

M'hamdi N., Bouallegue M., Frouja S., Aloulou R., Brar S.K., Hamouda M.B. (2012). Effects of environmental factors on milk yield, lactation length and dry period in Tunisian holstein cows'. Milk production - an up-to-date overview of animal nutrition, management and health. *Intech Open Journals*.

National Research Council. (1971). A Guide to Environmental Research on Animals. Washington, DC: The National Academies Press (NAP).

Nedić S., Pantelić M., Vranješ-Đurić S., Nedić D., Jovanović L., Čebulj-Kadunc N., Kobal S., Snoj T., Kirovski D. (2017). Cortisol concentrations in hair, blood and milk of holstein and Busha cattle. *Slov. Vet. Res.*, 54: 163-172.

Nzeyimana J.B., Fan C., Zhuo Z., Butore J., Cheng J. (2023). Heat stress effects on the lactation performance, reproduction, and alleviating nutritional strategies in dairy cattle: a Review. *J. Anim. Behav. Biometeorol.*, 11: 1-7.

O'Brien M.D., Rhoads R.P., Sanders S.R., Duff G.C., Baumgard L.H. (2010). Metabolic adaptations to heat stress in growing cattle. *Domest. Anim. Endocrinol.*, 38: 86-94.

Polsky L., von Keyserlingk M.A.G. (2017). Invited review: effects of heat stress on dairy cattle welfare. *J. Dairy Sci.,* 100: 8646-8657.

Renaudeau D., Collin A., Yahav S., de Basilio V., Gourdine J.L., Collier R.J. (2012). Adaptation to hot climate and strategies to alleviate heat stress in livestock production. *Animal*, 6: 707-728.

Spires D.E., Espagne J.N., Sampson J.D., Rhoads R.P. (2004). Use of physiological parameters to predict milk yield and feed intake in heat-stressed dairy cows. *J. Therm. Biol.,* 29: 759-764.

St-Pierre N.R., Jones L.R. (2001). Forecasting herd structure and milk production for production risk management. *J. Dairy Sci.*, 84: 1805–1813.

Thornton P., KNelson G., Mayberry D., Herrero M.. (2021). Increases in extreme heat stress in domesticated livestock species during the twenty-first century. *Global Change Biology* (GCB)., 27: 5762-5772.

West J.W. (2003). Effects of heat-stress on production in dairy cattle. *J. Dairy Sci.*, 86: 2131-2144.