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Temperature–humidity index and reproductive performance of dairy cattle farms in Lima, Peru

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Abstract

Background: Heat stress results in a mild reduction in milk production, while long-term heat stress exposure can severely affect the productive and reproductive performance in dairy cattle.

Aim: To quantify the relationship between reproductive performance and temperature–humidity index in dairy cattle farms in Lima, Peru.

Methods: Monthly service, conception, and pregnancy rates were measured from four dairy farms in four different Lima localities as reproductive performance indicators, along with an index of heat stress and maximum daily temperature–humidity index (max THI), during a 3-year period. In order to establish the relationship between the max THI and the reproductive performance indicators, a multiple regression analysis was carried out, which considered farm and year as explicative variables.

Results: The regression model showed an adjusted R^2 of 33.5% with an estimated standard error of 5.75% and was highly significant ($p < 0.001$). The regression coefficients for max THI for the variables pregnancy rate and conception rate were significant ($p < 0.0001$). With every increasing unit of max THI, a 0.84% drop in the pregnancy rate and a 1.74% drop in the conception rate were estimated by the model. The regression coefficient of max THI for the service rate variable was not significant.

Conclusion: It was concluded that the increase in max THI significantly affected the reproductive performance of intensive dairy cattle farms in Lima.

Keywords: Reproductive performance, Temperature–humidity index, Dairy cattle, Heat stress.

Introduction

Homeothermy is the capability of an organism to maintain a stable body temperature independently of environmental fluctuations. However, when the homeothermy of an organism is disturbed, it experiences stress (Ruiz *et al.*, 2017). Heat stress occurs when the organism is incapable of getting rid of heat excess and as a result many physiological functions are affected. It has been widely known as one of the main factors that affect livestock animals' productivity, reproductive efficiency, and health on a global scale (Allen *et al.*, 2013; Boni *et al.*, 2014; Dash *et al.*, 2016). Short-term heat stress results in a mild reduction in milk production, while long-term heat stress exposure can severely affect the productive and reproductive performance in dairy cattle (St-Pierre *et al.*, 2003). The dairy industry suffers relevant economic losses every year due to heat stress. It has a negative impact on the productive and reproductive performances of dairy cattle, incrementing production costs and lowering

farmers' total annual income (St-Pierre *et al.*, 2003; Ruiz *et al.*, 2017).

Cows that undergo heat stress have two types of chilling mechanisms: non-evaporative (convection and conduction) and evaporative (sweating and panting). The non-evaporative mechanisms are not very efficient if the ambient temperature increases. Likewise, the evaporative mechanisms are inefficient when relative humidity is high (West, 2003). That is why places with hot and humid conditions do not allow the animal to dissipate enough body heat to prevent heat stress (Ruiz-García *et al.*, 2019). In Peru, previous studies have shown that cattle suffer heat stress in the warm seasons of the year in the northern and central regions of the country (Flamenbaum, 2011; Ruiz *et al.*, 2017). Lima, which is in the central coast, has a warm climate with high relative humidity almost the entire year, so cows are constantly under heat stress which affects their productive and reproductive performance. It has been previously determined that dairy cattle in the main

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production areas of Lima experience heat stress almost all year round (Ruiz *et al.*, 2017; 2019).

The temperature–humidity index (THI) effectively summarizes the combined effect of environmental temperature and relative humidity, and it is used as a heat stress indicator in humans and animals (Dash *et al.*, 2016). Heat stress is operationally defined when THI surpasses a species-dependent threshold, which for dairy cows has been determined at 70 units (St-Pierre *et al.*, 2003; Pinto *et al.*, 2020). It has been shown that maximum daily THI (max THI) is related with the adverse effects of heat stress on dairy cattle (Ravagnolo *et al.*, 2000). The impact of heat stress on the productive performance has been reported on dairy cattle of Lima showing a negative correlation between mean daily THI, and both milk production and milk total solids (Ruiz-García *et al.*, 2018). Implementation of appropriate cooling systems on dairy cattle farms in Peru has the potential to increase annual production by 10% (Flamenbaum, 2011). However, this percentage could be even higher, as there are no studies quantifying the impact of heat stress on the reproductive performance of dairy cattle in Peru. Thus, the objective of this study was to determine the relationship between max THI, an indicator of heat stress, and the reproductive performance of dairy cattle farms in Lima, Peru.

Materials and Methods

Study site and time span

The study was conducted from August 2010 to July 2013 in the four main dairy cattle localities of Lima, Peru: Vegueta, Huacho, Lima, and Cañete. Meteorological data were obtained from the closest station to each farm run by the Peruvian National Service of Meteorology and Hydrology (SENAMHI). The stations consulted for this study were Vegueta (Estación Camay, 10°54'46.58"S, 77°38'56.03"W), Huacho (Estación Alcantarilla, 11°3'38.45"S, 77°33'0.38"W), Lima (Estación Villa Maria del Triunfo, 12°9'59.01"S, 76°55'11.99"W), and Cañete (Estación Pacaran, 12°51'81"S, 76°03'28.54"W). Meteorological data were used to estimate the mean monthly max THI.

Herd and barn

A total of four barns in four different localities of Lima were used for the study. All studied farms had at least 200 Holstein cows and were base-fed with forage and concentrated feed. All farms performed mechanical milking and artificial insemination. The chosen farms had updated records and expressed willingness to cooperate with the study. Reproductive records from four dairy cattle farms were used to obtain the monthly service, conception, and pregnancy rate per farm. The monthly conception, service, and pregnancy rate were obtained for each farm for the three study years. The farm from the locality of Huacho was defined as Farm 1 and had a population of 1000 cows; the farm from the locality of Cañete was defined as Farm 2 and had a population of 300 cows; the farm from the locality of

Vegueta was defined as Farm 3 and had a population of 1000 cows; and the farm from the locality of Lima was defined as Farm 4 and had a population of 800 cows.

Methodological description

Monthly THI per farm

Monthly max THI was calculated as the arithmetic mean of the daily max THI for each locality. The following formula was used:

$$\text{Daily max THI} = 0.81 \times T_{\text{max}} + \text{HR}_{\text{min}} / 100 \times (T_{\text{max}} - 14.4) + 46.4$$

where T_{max} is the maximum temperature registered in the day and HR_{min} is the minimum relative humidity registered in the day (Ravagnolo *et al.*, 2000; Ruiz-García *et al.*, 2018).

Monthly service rate per farm

The service rate was determined monthly as described by Fetrow *et al.* (1990) as follows:

$$\text{SR} = N / (\text{SD} / 21) \times 100$$

where N is the sum of all monthly services performed in selected cows for each farm and SD is the sum of days in the estrous cycle (DEC) of all selected cows for each farm in each month of the study.

Days of estrous cycle (DEC)

For cows that did not get pregnant during a given month, if they participated in the study during a given month: if $(\text{DIMf} - 60) \geq \text{DSM}$, then $\text{DEC} = \text{DSM}$ or if they partially participated in the study during a given month: if $(\text{DIMf} - 60) < \text{DSM}$, then $\text{DEC} = \text{DIMf} - 59$. For cows that did get pregnant during a given month: $\text{DEC} = \text{DSM} - \text{Days pregnant at the end of the month}$, where DIMf = days in lactation at the end of the studied month and DSM = total number of days of the studied month. In the case of using prostaglandin to reduce the estrous cycle interval, an adjustment of the DEC should be made, which consists of adding seven estrous cycle days for each prostaglandin dose used in each month of the study (Fetrow *et al.*, 1990).

Monthly conception rate per farm

The conception rate was determined as proposed by Fetrow *et al.* (1990):

$$\text{CR} = P / S \times 100$$

where P is the monthly quantity of pregnant cows from those that were inseminated for each farm and S is the monthly quantity of performed inseminations for each farm.

Monthly pregnancy rate per farm

The pregnancy rate was determined using the formula proposed by Ferguson and Galligan (2000):

$$\text{PR} = (\text{CR} \times \text{SR}) / 100$$

where CR is the conception rate of each farm from each month and SR is the service rate of each farm and month.

Statistical analysis

A multiple regression analysis was used. The residuals of the regression model for service, conception, and

pregnancy rates from the dairy cattle farms in Lima followed a normal distribution. The adjusted goodness of fit was determined for each model by assessing the correlation and determination coefficients, the regression error standard, and the Durbin–Watson test. An analysis of variance of the regression model was made and the regression coefficients were estimated. A Student’s *t*-test was used to determine if the regression coefficients were different from 0. The standardized regression coefficients were calculated. A level of significance of 5% was used in the present study for all statistical tests. The relationship between max THI and reproductive performance indicators were measured for the four dairy cattle farms using the next linear general model:

$$Y_i = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_2X_3 + e_i$$

where Y_i is a vector for reproductive performance (monthly service rate, conception rate, or pregnancy rate) with dimension 144×1 ; B_0 is the intercept; B_1 , B_2 , B_3 , and B_4 are the regression coefficients for X_1 , X_2 , X_3 , and X_2X_3 respectively; X_1 is a vector for the monthly max THI with dimension 144×1 ; X_2 is the codification matrix for farms with 144×3 dimensions, employing farm 4 as a reference group; X_3 is the codification matrix for years with 144×2 dimensions, employing year 3 as a reference group; and e_i is the random error.

Ethical approval

This study was approved by the Committee of Ethics in Research with Animals and Biodiversity de la Universidad Científica del Sur, Peru.

Results

Conception and pregnancy rate of the farms in Lima were closely related to max THI. During the warm season (January–April) max THI increased (between 75 and 78 units), while the conception and pregnancy rates from the dairy cattle farms in Lima decreased (TC: 20%–25%; TP: 8%–10%) (Fig. 1). Meanwhile, in the cold season (June–November) max THI decreased (68–74 units), while the conception and pregnancy rates increased (TC: 38%–42%; TP: 14%–20%). Contrarily, service rate remained stable throughout the year with no relationship to fluctuations in max THI.

The regression model for service rate presented an adjusted determinant coefficient of 25% with a standard error of 11.6%, while for conception rate it presented a 27.8% adjusted determinant coefficient with an 11.6% standard error (Table 1). The model for pregnancy rate presented an adjusted determinant coefficient of 33.5% with an estimated standard error of 5.8% (Table 1). The coefficients of determination indicate that about 25%, 28%, and 33% of the service, conception, and pregnancy rate variability were explained by the

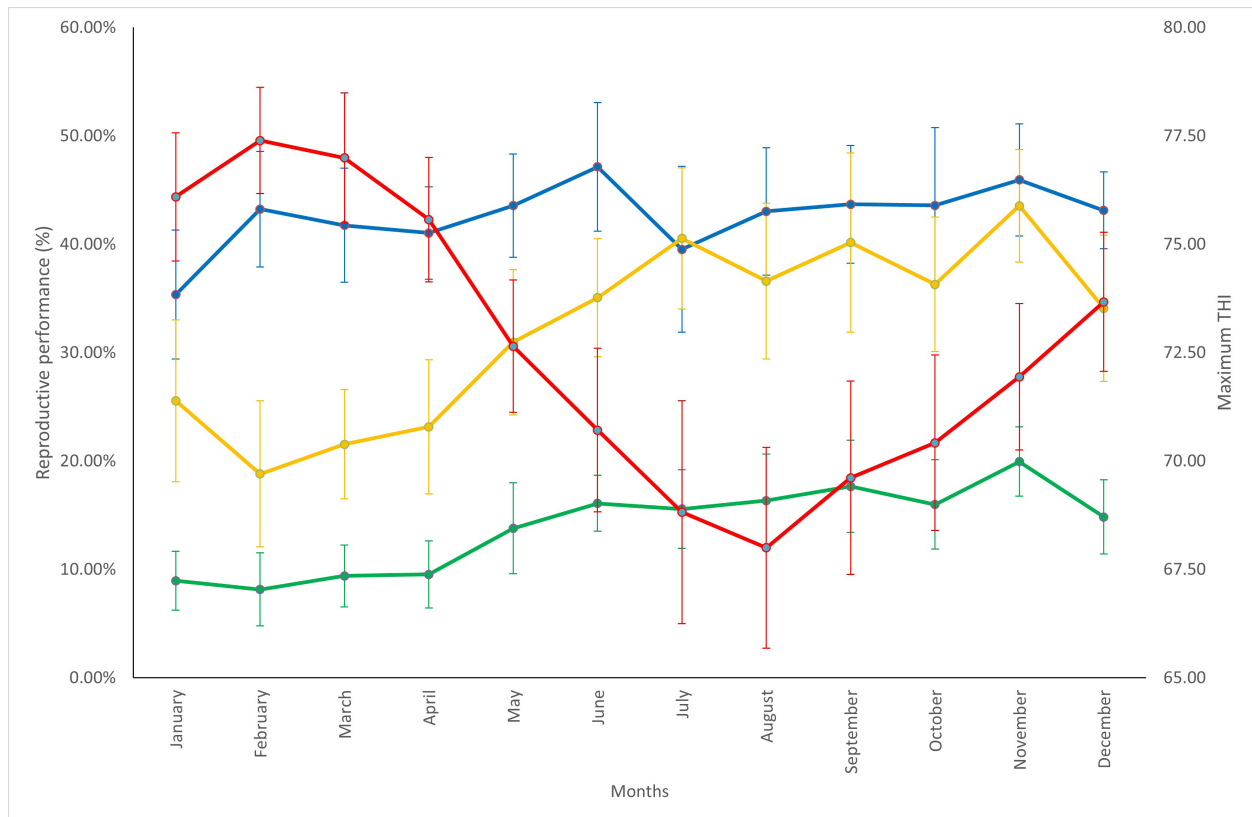


Fig. 1. Relationship between monthly service rate (blue line), conception rate (yellow line), pregnancy rate (green line), and max THI (red line) in different months of the year.

Table 1. Goodness of fit estimates for the regression model for service, conception, and pregnancy rate of dairy farms in Lima.

Dependent variable	MSR	MSE	<i>p</i>	<i>R</i> (%)	<i>R</i> ² (%)	Adj <i>R</i> ² (%)	SEE	Durbin-Watson
Service rate	372.67	74.98	<0.001	55.93	31.29	24.99	8.66%	2.15
Conception rate	744.61	133.31	<0.001	58.18	33.85	27.79	11.55%	1.84
Pregnancy rate	231.71	33.10	<0.001	62.50	39.07	33.49	5.75%	1.90

MSR, Mean square due to regression; MSE, Mean square error; *p*, *p*-value; *R*, Coefficient of correlation; *R*², Coefficient of determination; Adjusted *R*², Adjusted coefficient of determination; SEE, Standard error of estimate.

regression models, respectively (Table 1). Likewise, the regression variance analysis indicated that the models presented have a high level of significance ($p < 0.001$). Thus, service, conception, and pregnancy rates are satisfactorily explained by the employed models in the study.

In the multiple linear regression analysis for service, conception, and pregnancy rates for the dairy farms in Lima, the regression coefficient for max THI was negative (Table 2). While the regression coefficient of max THI for service rate was not significant ($p = 0.13$), it was highly significant for conception and pregnancy rates ($p < 0.001$). We observed a 1.74% and 0.84% decrease in conception and pregnancy rate for every increasing unit of max THI, respectively. Max THI presented the highest semi-partial correlation for conception and pregnancy rates (−0.46 and −0.42, respectively) (Table 2). Likewise, max THI presented an inverse relationship with conception and pregnancy rates in the studied dairy farms in Lima. An increasing unit of max THI standard deviation caused a reduction in 0.57 and 0.52 standard deviation units for conception and pregnancy rates, respectively. In the service rate model, max THI only presented a correlation coefficient of −0.11 with the dependent variable. In support to the multiple linear regression models, the monthly service, conception, and pregnancy rates decreased as the max THI increased (Fig. 2).

Discussion

In the present study, both conception and pregnancy rates had an inverse relationship with max THI, indicating that heat stress is an important factor affecting reproductive performance in Lima's dairy farms. These results agree with previous studies reported around the world, where it has been widely acknowledged that heat stress is an important factor affecting dairy cattle reproductive performance (St-Pierre et al., 2003; Allen et al., 2013; Dash et al., 2016).

The results showed that both conception and pregnancy rates from dairy farms in Lima dramatically decreased during the warm season (January–April). The conception rate decreased to 20% and pregnancy rate decreased below 10% during the months (February and March) where max THI reached its highest values. This effect was similar with what has been reported by several other studies, which evidence a lower conception rate in the summer month in comparison with the winter month conception rates in different parts of the world

(Garcia et al., 2007; Huang et al., 2008; Mellado et al., 2014; Schüller et al., 2014). Likewise, the pregnancy rates were below the levels recommended by Ferguson and Galligan (2000), who recommend a 28% rate to obtain a birth interval of 13 months.

The results of this study agree with other studies in that it demonstrates that heat stress negatively affects reproductive parameters, such as conception rate, service rate, pregnancy rate, number of open days, and embryonic mortality (Roth et al., 2000; Amundson et al., 2006; De Rensis et al., 2015; Monteiro et al., 2016; Schüller et al., 2016; Sandoval et al. 2017). However, Amundson et al. (2006) evaluated the pregnancy rate as a reference reproductive parameter in beef cattle. Pregnancy rate allows dairy farms to have a complete and dynamic evaluation of their cow's pregnancy status (Fetrow et al., 2007; Brett and Meiring, 2014; Sandoval et al., 2017). Pregnancy rate is calculated by multiplying the service rate by the conception rate. The linkage between environmental stressors and pregnancy rate in Lima's dairy farms, shown in the present study, calls for the need to implement appropriate cooling systems in Lima's dairy farms, which are currently lacking.

Heat stress in cattle result in alterations in the hypothalamus–hypophysis–ovary axis, producing changes at an endocrine level (Howell et al., 1994; Shehab-El-Deen et al., 2010; Roth and Wolfenson, 2016). Low secretion of luteinizing hormone (LH), inhibin, and high follicle-stimulating hormone (FSH) secretion has been previously associated with heat stress (Roth et al., 2000). Reduced estradiol secretion from the follicle, and a reduced follicular dominance has also been observed, and is reflected on the appearance of silent heats during the warm season (Roth et al., 2000). Likewise, the induced alteration in the antral small follicles affects the normal function of the preovulatory follicle, which reduces estradiol production and follicular dominance (Shehab-El-Deen et al., 2010; Roth and Wolfenson, 2016). Hence, THI increment affects the normal follicular development and the preovulatory LH wave surge, producing a late or absent ovulation (Roth and Wolfenson, 2016; López-Gatius and Hunter, 2017). For these reasons, the conception rate of inseminated cows is reduced, and consequently lowers the pregnancy rate. Nevertheless, in our study, service rate and max THI showed a nonsignificant inverse relationship. Most probably, this is a consequence of the estrous synchronization

Table 2. Regression model analysis results for service, conception, and pregnancy rate for the dairy farms in Lima.

Independent variable	Service rate				Conception rate				Pregnancy rate			
	β (95% CI)	St β	p	Sp R	β (95% CI)	St β	p	Sp R	β (95% CI)	St β	p	Sp R
(Constant)	62.91 (34.7–91.1)		<0.001		148.78 (111.2 –186.4)		<0.001		69.76 (51.0–88.5)		<0.001	
Max THI	-0.31 (-0.7–0.1)	-0.137	0.130	-0.110	-1.74 (-2.3 to -1.2)	-0.566	<0.001	-0.457	-0.84 (-1.1 to -0.6)	-0.523	<0.001	-0.422
Farm1/Farm4	8.44 (1.4– 15.5)	0.367	0.019	0.172	5.22 (-4.2 to 14.6)	0.167	0.273	0.078	4.89 (0.2–9.6)	0.301	0.041	0.141
Farm2/Farm4	-7.37 (-14.9 to 0.2)	-0.320	0.055	-0.140	19.91 (9.8 –30.0)	0.637	<0.001	0.278	5.50 (0.5 –10.5)	0.339	0.032	0.148
Farm3/Farm4	9.28 (2.0– 16.5)	0.403	0.013	0.183	14.05 (4.4 –23.7)	0.449	0.005	0.204	9.10 (4.3 –13.9)	0.561	<0.001	0.255
Year1/Year3	-6.03 (-13.0–1.0)	-0.285	0.091	-0.123	2.08 (-7.3 –11.4)	0.072	0.660	0.031	-1.06 (-5.7 to 3.6)	-0.071	0.654	-0.031
Year2/Year3	-0.30 (-7.3 to 6.7)	-0.014	0.932	-0.006	-0.69 (-10.1 to 8.7)	-0.024	0.885	-0.010	-0.59 (-5.3 to 4.1)	-0.039	0.804	-0.017
Farm1/Farm4* Year1/Year3	6.37 (-3.5 to 16.3)	0.177	0.206	0.092	11.52 (-1.7 to 24.7)	0.235	0.087	0.123	7.53 (1.0 –14.1)	0.296	0.025	0.154
Farm2/Farm4* Year1/Year3	17.42 (7.5–27.3)	0.483	0.001	0.252	-4.93 (-18.1 to 8.3)	-0.101	0.461	-0.053	4.10 (-2.5 to 10.7)	0.161	0.220	0.084
Farm3/Farm4* Year1/Year3	-0.68 (-10.6 to 9.2)	-0.019	0.893	-0.010	-3.79 (-17.0 to 9.4)	-0.077	0.571	-0.040	-2.27 (-8.8 to 4.3)	-0.089	0.496	-0.047
Farm1/Farm4* Year2/Year3	-1.19 (-11.1–8.7)	-0.033	0.812	-0.017	4.04 (-9.2 to 17.2)	0.082	0.546	0.043	1.05 (-5.5 to 7.6)	0.041	0.753	0.022
Farm2/Farm4* Year2/Year3	5.89 (-4.0 to 15.8)	0.163	0.242	0.085	-9.67 (-22.9 to 3.6)	-0.197	0.150	-0.103	-1.51 (-8.1 to 5.1)	-0.059	0.650	-0.031
Farm3/Farm4* Year2/Year3	-7.91 (-17.8 to 2.0)	-0.219	0.117	-0.114	-2.76 (-16.0 to 10.5)	-0.056	0.680	-0.029	-3.72 (-10.3 to 2.9)	-0.146	0.267	-0.076

β , Regression coefficients; 95% CI, 95% confidence interval; St β , Standardized regression coefficients; p, p-value; Sp R, Semi-partial correlation coefficient.

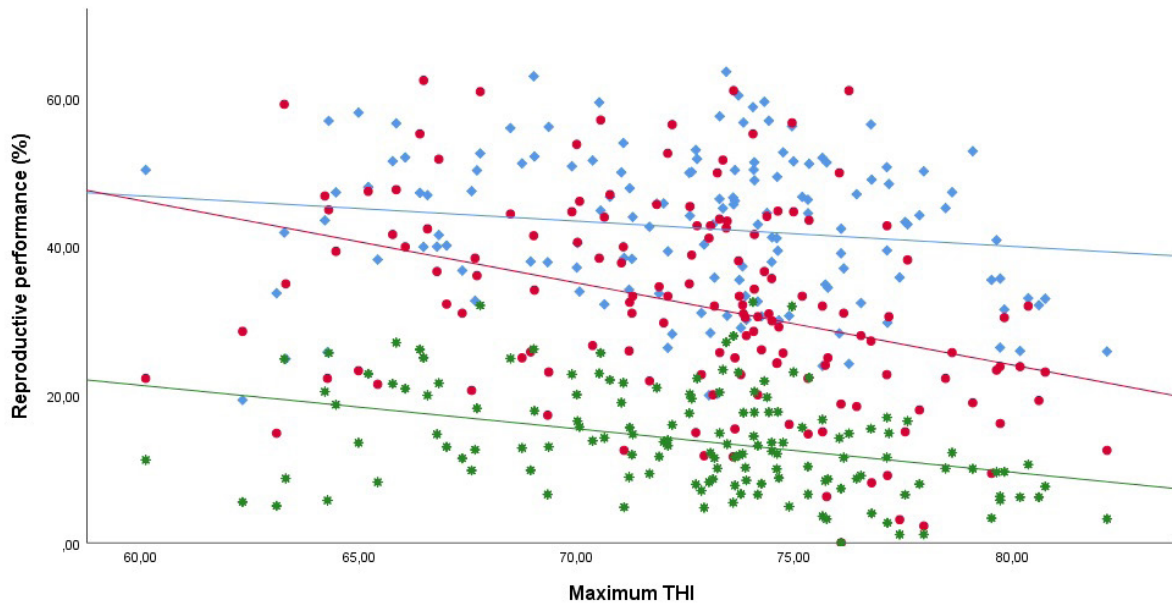


Fig. 2. Scatter plots between service rate (blue color), conception rate (red color), pregnancy rate (green color), and the maximum temperature–humidity index. Lines represent the fitted estimated regression following the maximum temperature–humidity index ($SR = 65.037 - 0.309 * \text{max THI}$; $CR = 158.576 - 1.740 * \text{max THI}$; and $PR = 74.519 - 0.835 * \text{max THI}$). SR: service rate; CR: conception rate; and PR: pregnancy rate.

and fixed time artificial insemination programs used in Lima's farms.

However, other studies have reported that the effect of heat stress was expressed mainly in the reduction of the estrous duration and intensity (Badinga *et al.*, 1985; Nebel *et al.*, 1997; Roth and Wolfenson, 2016). In Florida, USA, a study found out that the percentage of silent heats during the summer months (June–September) was from 76% to 82%, while in the winter months (October–May) this percentage dropped between 44% and 65% (Thatcher and Collier, 1986). It has been contemplated that the main reason why the estrous expression is reduced in summer is due to the animals' lack of physical activity, trying to reduce the heat production while lowering the overall heat detection by the observer (Boni *et al.*, 2014). This agrees with a previous report that cows under chronic heat stress conditions remain in the stationary position most of the time, with the intention to dissipate heat (Allen *et al.*, 2015).

Likewise, early postpartum heat stress increases the risk of negative energy balance by lowering body condition scores, decreasing the dominant follicular diameter and the follicular fluid, and producing lower quality oocytes and ovarian granulosa cells, which ultimately results in lower fertility (Shehab-El-Deen *et al.*, 2010) and in the increment of open days (Boni *et al.*, 2014). It has been identified that heat stress during oocyte maturation and ovulation results in a deleterious effect on embryonic development (Ealy *et al.*, 1993; Putney *et al.*, 1989; Silva *et al.*, 2013). After ovulation, heat stress affects the luteal

progesterone production, which modifies the oviduct and uterus microenvironment compromising embryo survival (Howell *et al.*, 1994). Furthermore, it has been found that heat stress affects bovine embryo development by decreasing the development rates, raising the apoptotic blastomeres percentages, and lowering the expression of important genes for embryonic survival (Silva *et al.*, 2013). Also, heat stress negatively affects oocyte quality (López-Gatius and Hunter, 2017), maturation, fertilization (Roth and Wolfenson, 2016), embryonic development (Silva *et al.*, 2013), and its survival (Roth and Wolfenson, 2016). Altogether, it lowers the chances of impregnating the served cows. This is the reason why Lima's dairy farms pregnancy rates are so heavily affected during the summer months where max THI reached mean values above 75 units. It was concluded that the increase in max THI significantly affects the cows' reproductive performance in dairy farms located in Lima. With every increased unit of max THI, monthly conception and pregnancy rate decreased by 1.74% and 0.84%, respectively.

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Conflict of interest

The authors declare that there is no conflict of interest.

Authors' contributions

All authors conceived the study, wrote the paper, and participated in monitoring the results. All authors read and approved the final manuscript.

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