Hot environment on reproductive performance, immunoglobulins, vitamin E, and vitamin A status in sows and their progeny under commercial husbandry

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Abstract

Hot environments can affect feed intake and lactation, and the subsequent unavailability of important micronutrients to the newborn piglet can impair piglet growth, reduce the viability of newborn piglets and limit their subsequent performance. This work addresses the effects of hot environments (summer season) upon the reproductive performance of sows during gestation and lactation as well as on the serum levels of vitamins and the concentration of immunoglobulins in their litters in comparison with the winter season. Fourteen sows were evaluated over 100 ± 2 days of gestation in each season. The temperature and humidity index (THI) was used as an indirect measure of heat stress during gestation. The reproductive performance, milk yield, and body condition of the sows were recorded. The concentrations of vitamin E and vitamin A in piglets and in sow serum, colostrum, milk and feed were determined by HPLC; immunoglobulins were assessed by an ELISA. The THI index indicated that animals were subject to heat stress only in during the summer. Although the effect was not significant, there were a lower number of piglets at birth and at weaning and the milk yield in summer compared with winter. There was no difference ($p > 0.05$) in the body condition of sows between seasons. Season had an effect ($p < 0.05$) on the vitamin A concentration of postpartum sow serum (0.29 μg/mL in winter vs 0.21 μg/mL in summer) and on the vitamin E concentration before birth (2.00 μg/mL in winter vs 0.90 μg/mL in summer). Vitamin E in milk was higher ($p < 0.05$) in winter than in summer (2.23 vs 1.81 μg/mL). Serum levels of vitamins A and E in piglets at birth were lower ($p < 0.05$) in winter than in summer. The concentrations of immunoglobulins (IgG and IgA) in colostrum and milk were similar between seasons ($p > 0.05$), but the IgA in piglet serum was higher in winter than in summer ($p < 0.05$). High temperatures produced heat stress in sows, which affected certain aspects of production that can be translated into economic losses for this sector.

Keywords: Environmental temperature, Immunoglobulins, Reproductive performance, Vitamin A, Vitamin E

Background

High temperatures are adverse for pig production because pigs have a low transpiration rate that prevents the animals from reg-

ulating their internal temperature and maintaining it within the limits that allow satisfactory rates of production. Pigs use thermoregulation to maintain their body temperature within their thermal neutral zone (18℃ to 20℃). Thus, if the environmental temperature exceeds 25℃, pigs are subject to heat stress [1].

Moreover, gestation and lactation are both critical stages in which sows are more susceptible to heat stress. Several studies have reported that sows subjected to temperatures above their thermal neutral zone (≥ 25℃–35℃) under controlled conditions showed negative effects on reproductive performance, including decreased litter size and an increase in the time interval between weaning and the next litter. Furthermore, the restoration normal body temperature of the sows is irregular [2–4].

In addition, it has been observed that heat stress caused by temperatures above 30℃, can reduce the milk yield of sows [5,6], and in some components of milk and colostrum such as fatty acids and immunoglobulins can be diminished [7,8]. This decrease in the fatty acid content can affect the primary source of energy (i.e., the colostrum) during the first hours of life; also, the piglet acquires its immunity passively through colostrum, which is the primary source of protection against pathogens [9].

Furthermore, high temperatures can also affect the concentrations of vitamin A and vitamin E, among other nutrients. Vitamin E is the main antioxidant that protects cells against the free radicals that can generate oxidative stress. Vitamin A also works as an antioxidant, but its main effect is on the development of the embryo and foetus during the reproductive stage. During gestation and lactation, there is an increase in metabolic loads that cause significant systemic oxidative stress, which is related to the decrease in the availability of antioxidants such as vitamins A and E [10]. It has also been shown that stress plays a role in the physiology of infertility [11].

There are reports where the effect of heat stress on the parameters mentioned above was evaluated under conditions of controlled temperatures that were no higher than 35℃. However, it is important to evaluate how reproductive performance, the serum levels of vitamins A and E and the concentration of immunoglobulins during the gestation and lactation of sows and in their litters are affected under commercial husbandry in regions where environmental temperatures reach 40℃–50℃ [hot environments with high relative humidity (HR)], which are considered challenging environmental conditions.

Materials and Methods

All procedures involving animal handling were performed within the official Mexican guidelines for animal care (NOM-EM-051-ZOO-1995) [12]. The humane care of animals was ensured during immobilization.

Animals and housing animal

The experiment was conducted on a commercial farm where there were no special provisions to control the environmental conditions of the experimental animals. The pig farm was located in the southern portion of the state of Sonora, Mexico (27° 04' 51" N, 109° 26' 43" W). The sample analyses were conducted at the Research Centre for Food and Development (CIAD).

A total of 14 crossbred sows (Large White × Landrace) were used with parities ranging from 1 to 7. It is important to note that this wide range of parity occurred because the experiment was conducted under commercial conditions. The sows were evaluated at two different times. The sows selected had their gestation period during the winter-spring season and were evaluated upon completion of gestation during the summer season. The experiment lasted until weaning (21±3 days).

Diet composition

During gestation, the sows were given a diet of 3340 MCal / kg of metabolizable energy per day based on the recommendations of the NRC [13]. Due to farm management practices and seasonal effects, the diets were formulated with different energy contents for the summer and winter seasons (Table 1). During the lactation period, the sows were fed 4 kg of the lactation diet during the first seven days and 7 kg of feed during the remaining days of lactation. The feed was given once a day prior to parturition and twice a day after parturition. Water was available *ad libitum* during pregnancy and lactation.

Housing management in the farm

During gestation, the sows were housed in an open sided area, in individual crates. The sides of gestation area could be covered with curtains to block out the sun and when the temperature fell. Foogers and forced ventilation were used to control temperature and humidity in the area particularly in summer. On day 110 of gestation each sow was moved to a farrowing house. Each farrowing house has a cooling system, a heat exchanger with recirculated water to control the temperature during summer.

Reproductive performance

The parameters recorded for each litter immediately postpartum were the number of live and stillborn piglets and mummies; the number of piglets alive and dead at weaning was also documented. The weight of individual piglets was recorded at birth and on the day of weaning (21 d of age).

Table 1. Formulation of gestation and lactation diets [kg/t] in summer and winter season

Ingredients	Winter		Summer	
	Gestation	Lactation	Gestation	Lactation
Corn 8.2 (% CP)	650.00	660.00	352.50	320.50
Wheat 9.8 (% CP)	-	-	352.50	320.50
Soybean paste 46.45 (%)	170.00	240.00	140.00	290.00
Wheat bran	150.00	50.00	125.00	45.00
Fatty acids	5.00	20.00	5.00	20.00
Gestation supplement[1]	25.00	-	25.00	-
Lactation supplement[1]	-	30.00	-	30.00
Calculated analysis				
Metabolizable energy (MJ/kg DM)	13.27	13.98	13.56	14.40
Protein (%)	15.27	17.40	14.78	19.85
Lysine (%)	0.74	1.07	0.70	1.21
Fiber (%)	3.71	3.71	3.49	2.82
Total phosphorus (%)	0.57	0.58	0.55	0.57
Calcium (%)	0.61	0.63	0.68	0.70
Diet analysis				
Dry matter (%)	88.05	87.50	88.40	88.73
Crude protein (% DM)	14.93	18.71	15.74	19.36
Crude fat (% DM)	4.08	4.75	4.68	7.36
Vitamin A (mg/kg)	1.10	0.55	1.18	0.52
Vitamin E (mg/kg)	37.66	34.54	35.10	33.55

[1]This mixture of vitamins and minerals meets the requirements of the NRC (1998).

CP, crude protein; DM, dry matter.

Milk yield

Milk yield was calculated using an equation reported by Ferreira et al. [14], which includes the weight gain of the piglets (weight at 21 of age – weight at birth), the number of piglets per litter and the number of days of lactation:

$$\text{Milk yield} = \frac{[(4.27 \times \text{PWGP}) \times \text{No. of piglets}]}{\text{No. of days of lactation}}$$

where PWGP = piglet weight gain during the period. The value 4.27 is a constant that assumes that for each kilogram of litter weight gain, the sow produces 4.27 litres of milk [14].

Body condition of sows

Backfat was measured at the beginning of the experiment and at weaning using ultrasound PigLog105 (SFK-Technology Ud., Herlev, Denmark); the measurement was taken at the last rib, 65 mm from the dorsal line. The data were expressed in inches.

Sample collection

Blood samples were collected from the sows and from the piglets for the determination of vitamins A and E, IgG and IgA in serum.

Sampling for piglet serum at day 0 occurred twelve hours after colostrum intake and on day 21 (at weaning). Samples of colostrum and milk were obtained for the quantification of vitamins A and E, and immunoglobulins IgG and IgA. Fig. 1 shows the sample collection scheme for sows and piglets sampled for colostrum, milk and blood.

Vitamin E and vitamin A analysis

Different extraction techniques were used to quantify the vitamin E and vitamin A in serum, colostrum, and feed. For serum, the extraction of vitamins A and E followed the method described by Hess et al. [15]. For colostrum and in milk, the method used was described by Hidiroglou [16]. After the saponification of the feed, the extraction was conducted as described by Onibi et al. [17]. The quantification of vitamin E and vitamin A were conducted using an HPLC system equipped with a diode array detector (1260 Infinity, Agilent Technologies, Santa Clara, CA, USA) with a C18 Agilent Microsorb (100-3 C18, 100 × 4.6 mm) column. The mobile phase was isocratic [methanol: water (98:2, v/v)] at a wavelength of 325 nm and 290 nm for vitamin A and vitamin E, respectively. Purified standards (Sigma-Aldrich, St. Louis, MO, USA) were used to calculate vitamin A and vitamin E concentrations, which were expressed by volume (µg/mL).
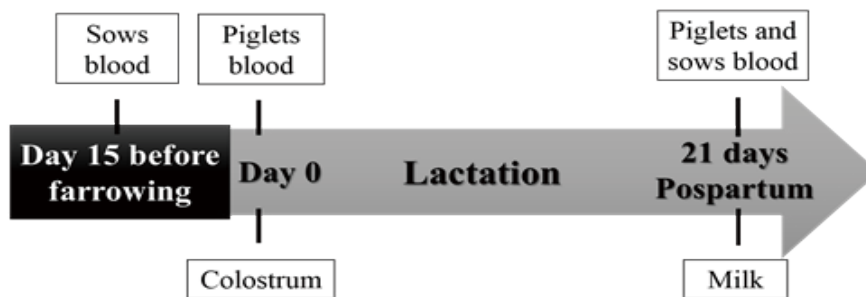
Fig. 1. This picture shows the collection times of blood, colostrum and milk samples in piglets and sow.

Quantification of immunoglobulins

IgG and IgA in the serum of piglets and in the colostrum and milk from sows were quantified by a sandwich enzyme-linked immunosorbent assay (ELISA). Kit Pig IgG ELISA (E101-104, Bethyl Laboratories, Montgomery, TX) and an ELISA Kit Pig IgA (E101-102, Bethyl Laboratories, Montgomery, TX), were used with slight modifications. The absorbance was measured at 450 nm using a Model 680 microplate reader (Bio-Rad Laboratories, Tokyo JP).

Temperature and Humidity Index (THI)

We used the temperature and humidity index (THI) as an indirect measure to determine whether the sows were subject to heat stress. This index uses environmental temperature and HR as an indicator of heat stress [1]. This index was used during gestation for both the summer and winter seasons. The environmental temperatures and HR were recorded using a HOBO data logger, Model H-8 (Bourne, MA, USA), installed in the gestation area, which is an open area. The THI values were calculated using the following equation [18].

$$THI = [(1.8T) + 32] - [0.55 (HR / 100)] \times [((1.8T) + 32) - 58]$$

where:
T: temperature (℃)
HR: relative humidity (%)

The relationship between THI and heat stress was as follows: if the score derived from the equation was 67 to 70, there was moderate heat stress; from 71 to 76 was considered severe heat stress and a value greater than or equal to 77 was considered extreme heat stress (ThermoTool, Group CCPA, Janze, France).

Experimental design and statistical analysis

A longitudinal study was conducted using the same pregnant sows from winter to summer. An analysis of variance was performed using general linear models procedure (GLM ANOVA) with the season as a fixed effect, parity and milk production as covariates, to determinate the effect by season, for initial and final weight in the piglets, litter size (birth and weaning), live born piglets, dead piglets at weaning. For milk yield, the model include the parity and initial back fat thickness as a covariate. For vitamins and immunoglobulins content in colostrum, milk and serum the GLM ANOVA was used, including season as fixed effect and baseline levels as covariates. Data of stillborn and mummies were evaluated using proportion test to estimate the effect of season. The results were considered significant if the level of probability of the Type I error was less than or equal to 0.05. Data analyses were performed in the statistical package NCSS version 2007 (Number Cruncher Statistical System for Windows, Kaysville, UT, USA).

Results

Temperature and Humidity Index (THI) in winter and summer

The THI for the winter and summer seasons is shown in Fig. 2. The months from November to March were considered winter, and the lowest THI was recorded in January (Fig. 2a). The average temperature was 17.52 ± 6.70 ℃, and the average HR was 62.59 ± 21.80%. The THI calculated during these months is shown in Fig. 2a; the values obtained during this time showed that the sows were not subject to heat stress, because the monthly average THI of each month during pregnancy was below 67. In addition, Fig. 2b shows the THI of the coldest and hottest hour of the day during the month of January, which was the coldest month during this season (57.86 ± 1.53 THI, on average).

During the months that corresponded to the summer season, from April to August, the average temperature was 33.7 4.90 ℃, and the average HR was 52.47 ± 15.80%. At the end of April, gestation began and the observed THI was 67 ± 1.43, which is not considered heat stress, whereas May had a THI of 71.47 ± 3.26, which indicated severe heat stress. During the months of June,
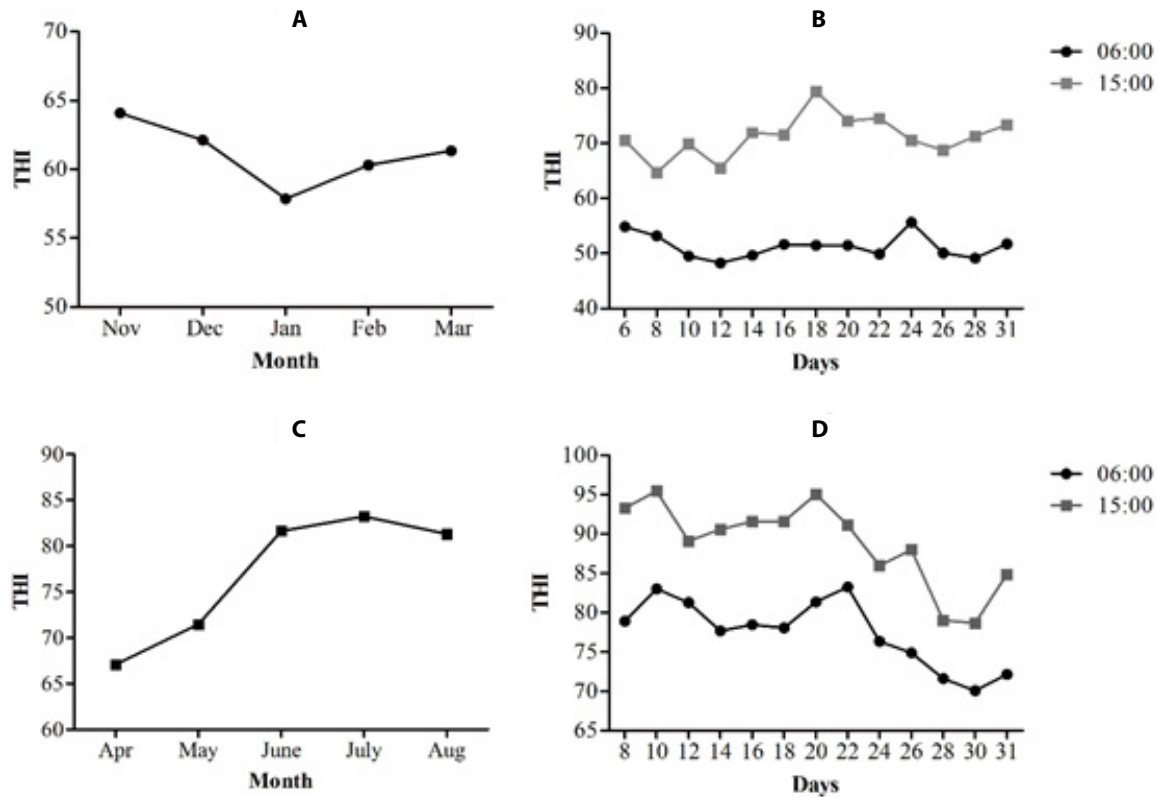
Fig. 2. The image panel indicates THI of winter and summer season per month (A, C) and the coldest and hottest hour of these (B, D). The graph indicates the coldest hour with circles (6:00), while the hottest hour is indicated by boxes (15:00). THI, temperature and humidity index.

July and August the THI values were greater than 80 ± 7.50; this indicates extreme heat stress (Fig. 2c). The month of July showed the highest THI of the summer (83.21 ± 3.92). The THI was also calculated for the coldest hour of the day (6:00; THI 78 ± 3.45, on average) and the warmest hour (15:00; THI 89 ± 4.80) for the month of July, both of which were classified as extreme heat stress (Fig. 2d). On the farm, owners use foggers in gestation area and cooling system in farrowing house in the summer season as a strategy to mitigate high temperatures. However, the humidity contributes to some extent to the stress that occurs during this time.

Reproductive performance

Table 2 shows the parameters of reproductive performance for each season. Although the winter season had a higher number of piglets per litter compared with the summer season, when the proportions of these reproductive parameters were analysed, no statistical difference was found between the seasons ($p \geq 0.05$). The proportion of live-born piglets was 93.8% and 91.9% in summer and winter, respectively ($p \geq 0.05$).

In addition, Table 2 shows the weights of the piglets at birth and at weaning in the two seasons. No significant differences were found between summer and winter ($p \geq 0.05$). The weights recorded were within the range of average weights based on previous studies [19]. Those authors conducted a study of the survival of newborn piglets and suggested that piglets with a birth weight of < 1.22 kg were of low weight and those with a birth weight of 1.42 kg were average, which is similar to the results obtained for both seasons in this study.

Milk yield

There were no differences in milk yield between winter and summer ($p \geq 0.05$) see Table 2. However, in summer, there was a decrease in milk yield of 0.84 kg/day, which is physiologically important. It is important to note that this tendency for a decreased milk yield would have been more significant if the groups had included a larger number of sows in the experiment; unfortunately, our experiment was conducted under commercial conditions, and this was the number of sows available. Nevertheless, these results show a clear decrease in milk production during the summer.

Body condition of the sows

The body condition of the sows was evaluated by measuring the dorsal fat thickness. Fig. 3 shows the dorsal fat thickness of the sows before at day 100 of gestation (initial) and at 21 days post-

Table 2. Reproductive performance of piglets during winter and summer

Parameter	Winter	SEM	Summer	SEM	p-value
At birth					
Litter size[1]	11.97	0.84	12.37	0.91	0.75
Live born piglets/litter[1]	11.18	0.75	11.28	0.81	0.92
Stillborn piglets/litter[2]	0.21		0.33		0.57
Mummified piglets/litter[2]	0.57		0.75		0.63
Weight (kg)[1]	1.42	0.03	1.38	0.03	0.32
Weaning (day 21)					
Litter size[1]	10.34	0.34	10.27	0.37	0.89
Dead piglets/litter[1]	0.84	0.74	1.013	0.80	0.87
Weight (kg)[1]	6.33	0.10	6.25	0.11	0.58
Milk yield (kg/d)[1]	11.17	0.69	10.36	0.79	0.45

[1]ANOVA GLM ($p < 0.05$).
[2]Reproductive parameters were analyzed using proportions during two seasons.
SEM, standard error of the mean.
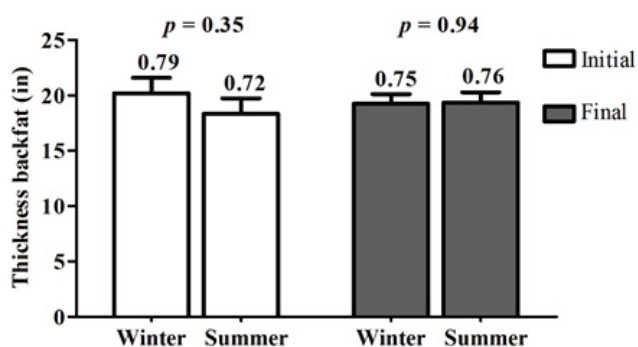
Fig. 3. This bar graph illustrates the backfat thickness in inches (in) of sows before farrowing (Initial) and 21 days postpartum (Final), the letter *p* shows significance ($p < 0.05$).

partum (final) for both seasons, and no differences ($p \geq 0.05$) were found between seasons; the initial and final values of the sows were also within the normal range (0.67–0.78 in) as reported Coffey et al. [20].

Vitamin A and vitamin E
Gestation and lactation diets
Table 1 shows the vitamin A and E content in the diets of pregnant and lactating sows for both seasons. The vitamin E content of the feed for these stages was below the recommendation of 44 mg/kg of feed, whereas the vitamin A content was approximately equivalent to the recommended value, i.e., 1.2 mg/kg of feed during gestation and 0.6 mg/kg of feed during lactation [21].

Serum, colostrum and milk in sows
The vitamin E and vitamin A content in the serum of sows at day 100 of gestation and at 21 days postpartum is shown in Table 3.

The vitamin E content in sow serum was lower in summer than in winter at 100 days of gestation ($p < 0.001$); however, at day 21 post-partum there was no difference between the seasons. In contrast, the vitamin A content was lower ($p < 0.001$) in summer than in winter at 21 days postpartum, and no differences were found between winter and summer at day 100 of gestation. Table 3 also shows the vitamin E and A content in colostrum and milk. There was no effect of season for colostrum ($p \geq 0.05$). In contrast, milk had an increased vitamin E content in winter compared with summer ($p < 0.001$). There were no significant differences in vitamin A content between seasons for either colostrum or milk (Table 3).

Piglet serum
The vitamin E and vitamin A content of piglet serum is shown in Table 4. The concentrations of vitamins A and E in the serum of newborn piglets 12 h after consuming colostrum were significantly higher in summer than in winter. At 21 days after birth, there were no differences in the contents of either vitamin between seasons.

Immunoglobulins IgG and IgA
Colostrum and milk of the sows and piglet serum
The immunoglobulin (IgG and IgA) values in colostrum and milk by season are shown in Table 5; there was no effect ($p > 0.05$) of season for IgG and IgA concentrations. However, in milk, there was a tendency ($p = 0.07$) towards a decreased IgA content in the summer compared with winter. The IgG content in piglet serum at day 0 (at birth, 12 h after consuming colostrum) and at 21 days of age was not different between seasons. However, the IgA content in piglet serum was lower in summer ($p < 0.001$) compared with winter at day 0 and at day 21. In addition, there was an effect of parity on immunoglobulin values; the difference is because

Table 3. Seasonal changes of vitamin A and E concentrations on sows serum, colostrum and milk

	Winter	SEM	Summer	SEM	*p*-value
Vitamin A µg/mL					
Serum					
Gestation (100 d)	0.19	0.01	0.19	0.01	0.772
Post-partum (21 d)	0.29	0.01	0.22	0.01	< 0.001
Colostrum	1.38	0.15	1.23	0.15	0.503
Milk	0.42	0.02	0.38	0.02	0.25
Vitamin E (µg/mL)					
Serum					
Gestation (100 d)	2.00	0.10	0.90	0.10	< 0.001
Post-partum (21 d)	1.40	0.16	0.96	0.18	0.39
Colostrum	8.48	0.68	8.29	0.69	0.92
Milk	2.23	0.11	1.81	0.12	0.03

SEM, standard error of the mean.

Table 4. Seasonal changes of vitamin E and A concentrations on piglets serum

Piglet serum	Winter	SEM	Summer	SEM	*p*-value
Vitamin A (µg/mL)					
Day 0[1]	0.08	0.001	0.10	0.001	0.01
Day 21	0.20	0.001	0.19	0.001	0.75
Vitamin E (µg/mL)					
Day 0[1]	0.69	0.11	1.12	0.12	0.01
Day 21	2.61	0.30	3.25	0.32	0.17

[1]Piglets serum was collected 12h after the collection of colostrum samples.

SEM, standard error of the mean.

Table 5. Concentration of IgG and IgA in colostrum and milk and piglet serum winter and summer

	Winter	SEM	Summer	SEM	*p*-value
Colostrum IgG (mg/mL)[1]	36.30	3.22	35.41	3.22	0.85
Colostrum Ig A (mg/mL)[1]	3.19	0.77	2.21	0.83	0.39
Milk IgA (mg/mL)[2]	1.41	0.19	0.86	0.20	0.07
Piglets serum IgG (mg/mL)					
Day 0	11.75	1.18	9.18	0.83	0.19
Day 21	2.25	0.75	2.40	0.61	0.93
Piglets serum IgA (mg/mL)					
Day 0	0.05	0.00	0.01	0.00	<0.001
Day 21	0.11	0.01	0.004	0.01	<0.001

[1]Colostrum collected after birth (0 hours).

[2]Milk collected 21 days post-partum.

SEM, standard error of the mean.

this study was conducted under commercial conditions and was adapted to farm management, thus the parity effect could not be controlled. We found that parity had an effect (*p* < 0.001) on colostrum IgG concentration (Table 5). First parity sows had lower (*p* < 0.001) colostrum IgG concentrations when compared with sows with 2 or more parities. Moreover, parity had an effect (*p* < 0.01) on the IgA content of milk.

Discussion

In the two groups of pregnant sows studied under conditions of commercial confinement during different seasons (winter and summer), we found that sows were subject to moderate to severe heat stress in summer but not in winter, based on the THI indexes obtained.

Under changing climate conditions, the occurrence of high temperatures and their intensification in arid regions could affect some production parameters in pigs, primarily during the reproductive stage under commercial conditions, even if the animals were adapted and housed in installations designed to ameliorate these extreme temperatures [22]. Moreover, the genetic variability both within and among pig populations has an effect on heat tolerance. Gourdine et al. [23] reported that Large White sows have some thermoregulatory traits that allow them to tolerate heat stress and mitigate its effects on health.

During gestation, high temperatures and high HR promote the impairment of some health parameters, and; thus, a lack of constant monitoring and management of environmental factors such as temperature and humidity could be reflected in production losses, which translate into economic losses.

Reproductive performance

Despite the non-significance on the parameters of reproductive performance between seasons, our data showed a lower number of live-born piglets (135 vs 157) and weaned pigs (123 vs 141) in summer than in winter, which implies an impact on production and economic losses in the summer season. Moreover, a greater number of piglets were born dead or as mummies in the summer than in the winter season, as well as, a smaller number of piglets at weaning in the summer season ($p > 0.05$). However, from the standpoint of production, this decrease in weaned animals is important, reflecting economic losses at the production level; for example, in the United States, the mortality of sows and growing pigs leads to an annual loss of $300 million [24]. We estimate the economic losses in the farm, extrapolating the number of piglets weaned from the 14 sows to the total (400) in both seasons, and the losses in summer season would reach 514 piglets representing 85,000 US dollars approximately. This estimation value was calculated based on the hogs average price for slaughter, 1.49 US dollar per kilogram live weight, considering 110 kg of weigh per animal to slaughter [25]. Most of the reports, regarding the effect of heat stress involve temperatures from 30℃–35℃ and low HR, or they are related to animals that have not been adapted to a wide range of temperatures. In a review by Bianca [26], the author mentions that warm temperatures (34℃) favour the development of the piglet during lactation; however, our results showed that at warmer

temperatures, an increase in mortality (9.2% in summer vs 8.1% in winter) was observed.

With regard to milk production, although the values were not significantly different between winter and summer, summer production was lower. From a physiological standpoint, this decrease could be important because there was a loss of 0.84 kg/day of milk. These results are consistent with those reported by Silva et al. [5], who observed that when lactating sows were exposed to heat stress (29.4℃), they produced 1 kg less of milk per day than those at 20℃. Silva et al. [27] found a similar effect when sows were placed in an environment similar to their thermoneutral zone (a cold floor at 17℃). Sows without this cooling system had a milk production of 8.05 kg / day compared with 10.20 kg / day for sows with this cooling system.

Additionally, the studies conducted by Silva et al. [27] and Williams et al. [28] also reported a decrease in milk production under conditions of high controlled temperatures, and they suggested that this is related to a thinner layer of back fat before parturition. Although there were no significant differences in the present study, lower milk production will undoubtedly result in decreased energy consumption by the piglet and will probably result in a loss of body weight. The lower the weight of the piglets at weaning, the more difficult it will be to achieve the final desired weight of the pig, which will require a greater investment in both time and feed for the piglet to reach the weight required for slaughter and sale.

In contrast to our results, the marked differences in reproductive performance parameters such as milk yield, live weight of piglets and mortality reported in other studies when the animals were above their thermoneutral zone occurred because those studies were conducted under controlled environmental temperatures to which the animals were not well adapted. In contrast, our experiment under commercial husbandry conditions did not control environmental temperatures, and the animals were adapted to higher temperatures.

Vitamin A and vitamin E
Vitamin E in feed
The vitamin E content was lower in the summer diet than in the winter diet, and it was lower than the level recommended by the NRC [21], which recommends an increase to at least 50 mg / kg feed in combination with higher quality fatty acids in the summer; this value is recommended because during this time, greater oxidation of fatty acids and vitamin E occurs, although the feed typically contains antioxidants to prevent oxidation.

Serum, colostrum, and milk in sows
Our results showed a lower concentration of vitamins E and A in the serum and milk of sows during the summer; however, these

data are within the reported range of animals exposed to temperatures below those in our experiment, with the exception of those reported by Pinelli-Saavedra [29], who worked under conditions similar to our experiment (above 40°C in the summer season). These low values of vitamin E in serum and milk could be attributed to heat stress in the sows, because heat stress can produce oxidative stress [10] and the reduction in vitamin E levels in the serum could then be reflected in the vitamin E content of the milk.

The values of vitamin A and vitamin E in colostrum, milk and serum observed in our study are similar to those reported by other authors [29–33].

Vitamin contents in piglet serum

The high vitamin A and vitamin E content in piglet serum at birth during the summer was unexpected. We hypothesized that because their thermoneutral zone was 34°C, newborn piglets subjected to warm temperatures would rapidly acquire mobility, find the nipples of their dam and begin to consume the initial colostrum secretions, which contain a high concentration of nutrients, including vitamins A and E. In contrast, when the ambient temperature drops, the piglets pile up together to retain heat; they exhibit chills and require more time for colostrum intake [1,22,26]. Despite these seasonal differences in behaviour observed at birth, seasonal differences in vitamins levels were not observed at weaning. In the case of vitamin E, this could be because the milk offered by the dams was higher in vitamin E during the winter. Moreover, it is clear that colostrum and milk strongly influence the vitamin E content in piglet serum at weaning. With regard to vitamin A, no differences were found between seasons and the environmental conditions also helped. The values of vitamins A and E in piglet serum for both seasons and the sampling times were consistent with those reported by Pinelli-Saavedra [29], Håkansson et al. [31], Debier et al. [32] and Sivertsen et al. [34].

Immunoglobulins

Passive immunity from the sow's mammary gland secretions is transferred to piglets through colostrum and milk and is an important form of protection to improve the survival of progeny. In this study, one of the aims was to evaluate piglet serum immunoglobulin content under commercial husbandry conditions. Therefore, our study was adapted to the farm management, and we included a mixed population of primiparous and multiparous sows. We found an effect of parity on colostrum IgG and on IgA in milk. Both immunoglobulins had higher values in multiparous than in primiparous sows. The IgG content of colostrum obtained in our study is consistent with the values reported by Cabrera et al. [35], who found that parity had a significant ($p < 0.001$) effect on colostrum IgG concentration and was 5% higher in multiparous

sows than in primiparous counterparts. With regard to the effect of parity on IgA in colostrum and milk, our data are consistent with those reported by Leblois et al. [36], who reported that parity had an effect on the IgA content in milk but not in colostrum.

However, there is little information related to the effect of hot environmental conditions on the immunoglobulin content in colostrum, milk and piglet serum; this is a critical stage of immunological development when piglets are dependent upon maternal antibodies to fight potential infectious agents. Our results showed a significant decrease in the level of IgA in colostrum and milk ($p < 0.05$), and although there was not a significant seasonal difference, there was a decrease in IgG in colostrum during the summer (35.42 vs 36.30 mg/mL). One possible explanation is that the physiological effects of heat stress increase the production of reactive oxygen species (ROS), which increases the overall load in the body [37]. Immune cells are susceptible to damage by ROS, thus immunoglobulin production by plasma cells could be impaired.

Regarding the effect of season on immunoglobulins in piglet serum, we observed that IgA values were significantly lower in summer compared with winter, and although the same pattern was observed, the effect was not significant for IgG. IgA antibodies are important at the intestinal barrier as an immunoexclusion mechanism of antigens and help to protect against infectious agents. A possible explanation for the decrease in both immunoglobulins could be due to the reduction in colostrum intake, which reduced the concentration of colostrum-derived antibodies in the newborn piglets. Additionally, Machado-Neto et al. [8], reported that when sows were exposed to heat a few days before and during parturition, their piglets showed a significant decrease in plasma immunoglobulins. This detrimental effect might be caused directly by the inhibition of absorption of immunoglobulins by cortisol, but it is also possible that the piglets born from heat-stressed sows consumed less colostrum [38].

Another aspect to consider is that there may be significant variation in the concentration of immunoglobulins among different animals from the same litter, because the concentration of immunoglobulins depends on factors such as the amount of colostrum available, the level of consumption by the piglet and the speed with which they consume the initial secretions of colostrum [9,39]. In addition, a reduction in the vitamin A serum concentration in postpartum sows might explain the lower IgA concentration in milk and in the serum of weaned piglets, when passive immunity, as well as the piglet's own antibody production, is important, because retinoic acid (a vitamin A metabolite) is involved in mucosal IgA production [40].

Regarding the limitations of this study as it was conducted in a commercial farm, we had to adapt to management of the farm, thus, we could not control the range of parity, the number of sows

used and the environmental temperatures and HR only the strategies used in the farm to ameliorate the adverse effects of severe high temperatures. Despite of this, we found a negative effect of hot weather in some parameters such as vitamin E and vitamin A contents in sows serum and milk and Ig A in piglets.

Conclusion

Despite the pregnant sows experienced heat stress in extremely hot weather according to the THI values obtained, our experiment under commercial husbandry conditions showed that the animals seem to be adapted to higher temperatures due to the strategies used from the farm to ameliorate the adverse effects of hot weather. However, we found that some parameters measured were affected in the summer season. We found the hot weather had a negative effect on the serum levels of vitamin E and vitamin A in sows at the gestation stage, and it affected their milk content. Moreover, the concentrations of IgA in piglet serum at birth and weaning were decreased in summer; this could compromise intestinal health and make them susceptible to infectious diseases.

Regarding reproductive performance there was no significant effect of summer, but an economic impact can be demonstrated at the production level because there was a smaller number of live piglets per litter, both at birth and at weaning, and a decrease in milk production, which may have contributed to the lower number of weaned piglets in summer.

The results of this study are therefore relevant to practical pig production in hot climates and may guide the search for future strategies that mitigate the impact of thermal stress on nutritional and immune status and on pig production performance.

Availability of data and material
Upon reasonable request, the datasets of this study can be available from the corresponding author.

Authors' contributions
Conceptualization: Pinelli-Saavedra A.
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Ethics approval and consent to participate
All procedures involving animal handling were performed within the official Mexican guidelines for animal care (NOM-EM-051-ZOO-1995). The humane care of animals was ensured during immobilization. The experimental work was carried out in commercial farm.

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References

1. Wegner K, Lambertz C, Das G, Reiner G, Gauly M. Climatic effects on sow fertility and piglet survival under influence of a moderate climate. Animal. 2014;8:1526-33.
2. Gou Z, Lv L, Liu D, Fu B. Effects of heat stress on piglet production/performance parameters. Trop Anim Health Pro. 2018;50:1203-8.
3. Almond PK, Bilkei G. Seasonal infertility in large pig production units in an Eastern-European climate. Aust Vet J. 2005;83:344-6.
4. Suriyasomboon A, Lundeheim N, Kunavongkrit A, Einarsson S. Effect of temperature and humidity on reproductive performance of crossbred sows in Thailand. Theriogenology. 2006;65:606-28.
5. Silva BA, Noblet J, Oliveira RF, Donzele JL, Primot Y, Renaudeau D. Effects of dietary protein concentration and amino acid supplementation on the feeding behavior of multiparous lactating sows in a tropical humid climate. J Anim Sci.

2009;87:2104-12.

6. Renaudeau D, Noblet J. Effects of exposure to high ambient temperature and dietary protein level on sow milk production and performance of piglets. J Anim Sci. 2001;79:1540-8.

7. Lucy MC, Safranski TJ. Heat stress in pregnant sows: thermal responses and subsequent performance of sows and their offspring. Mol Reprod Dev. 2017;84:946-56.

8. Machado-Neto R, Graves CN, Curtis SE. Immunoglobulins in piglets from sows heat-stressed prepartum. J Anim Sci. 1987;65:445-55.

9. Rooke JA, Bland IM. The acquisition of passive immunity in the new-born piglet. Livest Prod Sci. 2002;78:13-23.

10. Berchieri-Ronchi CB, Kim SW, Zhao Y, Correa CR, Yeum KJ, Ferreira AL. Oxidative stress status of highly prolific sows during gestation and lactation. Animal. 2011;5:1774-9.

11. Ruder EH, Hartman TJ, Goldman MB. Impact of oxidative stress on female fertility. Curr Opin Obstet Gynecol. 2009;21:219-22.

12. Norma Oficial Mexicana. Tratado Humanitario en la movilizacion de animales. Ciudad de Mexico (Mexico): SAGARPA; 1995. No. NOM-051-ZOO-1995.

13. NRC [National Research Council]. Nutrient requirements of swine. Washington, DC: National Academies Press; 1998.

14. Ferreira AS, Costa PMA, Perreira JAA, Gomes JC. Estimativas de producao de leite de porca. Revista Brasileira de Zootecnia. 1988;17:203-11.

15. Hess D, Keller HE, Oberlin B, Bonfanti R, Schuep W. Simultaneous determination of retinol, tocopherols, carotenes and lycopene in plasma by means of high-performance liquid chromatography on reversed phase. Int J Vitam Nutr Res. 1991;61:232-8.

16. Hidiroglou M. Mammary transfer of vitamin E in dairy cows. J Dairy Sci. 1989;72:1067-71.

17. Onibi GE, Scaife JR, Murray I, Fowler VR. Use of α-tocopherol acetate to improve fresh pig meat quality of full-fat rapeseed-fed pigs. J Am Oil Chem Soc. 1998;75:189-98.

18. National Weather Service Central Region [NWSCR]. Livestock hot weather stress. Kansas City (MO): NWSCR; 1976. Regional Operations Manual Letter C-31-76.

19. Baxter EM, Jarvis S, D'Eath RB, Ross DW, Robson SK, Farish M, et al. Investigating the behavioural and physiological indicators of neonatal survival in pigs. Theriogenology. 2008;69:773-83.

20. Coffey RD, Parker GR, Laurent KM. Assessing sow body condition. Lexington (KY): University of Kentucky; 1999.

21. NRC [National Research Council]. Nutrient requirements of swine. Washington, DC: National Academies Press; 2012.

22. Renaudeau D, Collin A, Yahav S, de Basilio V, Gourdine JL, Collier RJ. Adaptation to hot climate and strategies to alleviate heat stress in livestock production. Animal. 2012;6:707-28.

23. Gourdine JL, Mandonnet N, Giorgi M, Renaudeau D. Genetic parameters for thermoregulation and production traits in lactating sows reared in tropical climate. Animal. 2017;11:365-74.

24. St-Pierre NR, Cobanov B, Schnitkey G. Economic losses from heat stress by US livestock industries. J Dairy Sci. 2003;86:E52-E77.

25. Confederacion de Porcicultores Mexicanos, A.C. 2012. Confederacion de Porcicultores Mexicanos (porcimex). http://www.porcimex.org. Accessed 27 Sept 2019.

26. Bianca W. The significance of meteorology in animal production. Int J Biometeorol. 1976;20:139-56.

27. Silva BAN, Oliveira RFM, Donzele JL, Fernandes HC, Abreu MLT, Noblet J, et al. Effect of floor cooling on performance of lactating sows during summer. Livestock Sci. 2006;105:176-84.

28. Williams AM, Safranski TJ, Spiers DE, Eichen PA, Coate EA, Lucy MC. Effects of a controlled heat stress during late gestation, lactation, and after weaning on thermoregulation, metabolism, and reproduction of primiparous sows. J Anim Sci. 2013;91:2700-14.

29. Pinelli-Saavedra A. Vitamin E and vitamin C supplementation of sows in a hot environment: effects on reproductive performance, piglet tissue levels and aspects of immune status [Ph.D. Thesis]. Aberdeen (UK): University of Aberdeen; 2001.

30. Mersman HJ, Pond WG. Hematology and blood serum constituents. In: Pond WG, Mersmann HJ, editors. Biology of domestic pig. Ithaca (NY): Cornell University Press; 2001. p.566-7.

31. Hakansson J, Hakkarainen J, Lundeheim N. Variation in vitamin E, glutathione peroxidase and retinol concentrations in blood plasma of primiparous sows and their piglets, and in vitamin E, selenium and retinol contents in sows' milk. Acta Agric Scand A Anim Sci. 2001;51:224-34.

32. Debier C, Pottier J, Goffe C, Larondelle Y. Present knowledge and unexpected behaviours of vitamins A and E in colostrum and milk. Livest Prod Sci. 2005;98:135-47.

33. Sosnowska A, Kawecka M, Jacyno E, Kolodziej-Skalska A, Kamyczek M, Matysiak B. Effect of dietary vitamins E and C supplementation on performance of sows and piglets. Acta Agric Scand A Anim Sci. 2011;61:196-203.

34. Sivertsen T, Vie E, Bernhoft A, Baustad B. Vitamin E and selenium plasma concentrations in weanling pigs under field conditions in Norwegian pig herds. Acta Vet Scand. 2007;49:1.

35. Cabrera RA, Lin X, Campbell JM, Moeser AJ, Odle J. Influence of birth order, birth weight, colostrum and serum immu-

noglobulin G on neonatal piglet survival. J Anim Sci Biotechnol. 2012;3:42.

36. Leblois J, Massart S, Soyeurt H, Grelet C, Dehareng F, Schroyen M, et al. Feeding sows resistant starch during gestation and lactation impacts their faecal microbiota and milk composition but shows limited effects on their progeny. PLoS One. 2018;13:e0199568.

37. Kasanuma Y, Watanabe C, Kim CY, Yin K, Satoh H. Effects of mild chronic heat exposure on the concentrations of thiobarbituric acid reactive substances, glutathione, and selenium, and glutathione peroxidase activity in the mouse liver. Tohoku J Exp Med. 1998;185:79-87.

38. Kelley KW, Easter RA. Nutritional and environmental influences on immunocompetence. In: Miller ER, Ullrey DE, Lewis AJ, editors. Swine nutrition. Boston: Butterworth-Heinemann; 1991. p.401-13.

39. Devillers N, Farmer C, Le Dividich J, Prunier A. Variability of colostrum yield and colostrum intake in pigs. Animal. 2007;1:1033-41.

40. Mora JR, Iwata M, Eksteen B, Song SY, Junt T, Senman B, et al. Generation of gut-homing IgA-secreting B cells by intestinal dendritic cells. Science. 2006;314:1157-60.