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Occurrence of heat waves and the prediction of feed intake of sows raised in a tropical environment

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ABSTRACT - The objective with this study was to estimate the voluntary feed intake (VFI) of sows during the occurrence of heat waves in the Triângulo Mineiro and Alto Paranaíba mesoregion, Minas Gerais, Brazil. The Instituto Nacional de Meteorologia (INMET) database was used to calculate the temperature-humidity index (THI) from 2008 to 2017 for Araxá, Frutal, Ituiutaba, Patos de Minas, Patrocínio, Uberaba, and Uberlândia, and the estimated VFI with and without effective occurrence of heat waves (EOH). An economic estimation of the revenue based on the VFI was performed. The data were analyzed by Friedman's non-parametric test (two-way non parametric analysis), using the significance level of 5%. The sows raised in Patrocínio showed a higher average prediction of VFI (6.611 kg without EOH and 5.743 kg with EOH) than Ituiutaba (6.424 kg without EOH and 3.969 kg with EOH) and Frutal (5.868 kg without EOH and 4.648 kg with EOH). In the classification "without EOH", the microregions of Araxá (6.502 kg), Uberaba (6.452 kg), and Uberlândia (6.478 kg) did not differ from the other cities, but "with EOH", Araxá (4.864 kg) differed from Patrocínio (5.743 kg). The reduction of VFI due to thermal stress represented a revenue reduction of R$ 74.60 per litter. The averages for predicted VFI were lower in the EOH category than in the probable occurrences of heat waves category for all cities. The predominance of heat waves reduces the VFI of sows, particularly in Ituiutaba and Frutal.

Keywords: bioclimatic zoning, heat stress, swine, THI

Introduction

The pork production chain in Brazil began to develop during the 1980s and 1990s due to the technological evolution and dissemination of production information (ABCS, 2016). Minas Gerais has the fourth largest swine herd in the country with 5.2 million animals, and 37% is located in the Triângulo Mineiro and Alto Paranaíba mesoregion (IBGE, 2017). In 2017, 504.9 thousand sows were housed, 5.4 million swine were slaughtered, and 464 thousand tons of pork were produced in Minas Gerais (IBGE, 2017).

In a hot environment, such as the Triângulo Mineiro region, heat stress can be a limiting factor for swine production. These animals do not have functioning sweat glands, so an increased respiratory rate is the main way that swine lose heat in hot environments (ABCS, 2014). When exposed to temperatures over 25 °C, there is a notable decrease in feed intake, lower milk production, reduced body mass gain, and a reduction in piglet growth (Quiniou and Noblet, 1999; Cabezón et al., 2017). Williams et al. (2013)

reported the thermoneutral zone for swine females from 18 to 20 °C and 24 to 30 °C as heat stress. Understanding the bioclimatic zoning of a prominent swine production region is an important animal performance parameter that can be used to make decisions about the design of facilities, use of cooling equipment, period of the year when heat care is important, and genetic choice and selection.

A thermal stress index, such as the temperature-humidity index (THI), can be used to establish classification criteria for the thermal environment and thermoneutral zone. The THI was developed by Thom (1959) as an index of human comfort and then adapted to describe thermal comfort for animals. The THI for sows was used by Wegner et al. (2016) in recent studies.

Another factor that may influence animal production is heat waves. Studies with other species show that the occurrence of heat waves can impair food intake and decrease performance in dairy cattle (Nascimento et al., 2014) and change the physiology of broilers (Mello et al., 2018). According to the Glossary of Meteorology (AMS, 1989), a heat wave is a period of extreme heat commonly followed by high air humidity, which can last for days. Robinson (2001) defined it as the period in which the indices for maximum daytime and minimum nighttime heat exceed the limits of the thermoneutral zone.

The objective with this study was to describe and analyze data from meteorological stations so that the occurrence of heat waves in Triângulo Mineiro and Alto Paranaíba, Minas Gerais, Brazil could be determined. Then, the association between heat waves and the prediction of voluntary feed intake (VFI) of sows in a tropical environment was analyzed.

Material and Methods

The study was carried out in the following cities: Araxá (19°60' S, 46°94' W, altitude: 1018 m), Frutal (20°03' S, 48°93' W, altitude: 543 m), Ituiutaba (18°95' S, 49°52' W, altitude: 540 m), Patos de Minas (18°52' S, 46°44' W, altitude: 950 m), Patrocínio (18°99' S, 46°98' W, altitude: 978 m), Uberaba (19°71' S, 47°96' W, altitude: 778 m), and Uberlândia (18°91' S, 48°25' W, altitude: 875 m), located in the Triângulo Mineiro and Alto Paranaíba, Minas Gerais, Brazil.

First, the dry bulb temperature and relative humidity data were collected at 9.00, 15.00, and 21.00 h from 2008 to 2017 from the Instituto Nacional de Meteorologia (INMET) in Triângulo Mineiro and Alto Paranaíba. The Frutal weather station was deactivated in 2013 and the Ituiutaba weather station in 2015. Therefore, data from these stations were analyzed up until these sites were deactivated.

The data from seven meteorological stations, one in each city, were analyzed and used to represent Triângulo Mineiro and Alto Paranaíba. The dew point temperature (T_{dp}) was calculated from the dry bulb temperature in Celsius degree (°C) and the relative humidity (RH) was expressed in percentage (%), using the following equations according to Silva (2000): Saturation pressure at dry bulb temperature P_s (T_{db}):

$$P_S (T_{db}) = 0.61078 (10)^{7.5 T_{db} (T_{db} + 237.5)^{-1}} \tag{1}$$

Partial vapor pressure (P_p):

$$P_p = \frac{RH (P_s (T_{db}))}{100} \tag{2}$$

Dew point temperature (T_{dp}):

$$T_{dp} = 273.15 (1/ 0.971452 - 0.057904 (\log P_p)) - 273.15 \tag{3}$$

Then, the THI was determined for each time (9.00, 15.00, and 21.00 h), according to Thom (1959) by the equation:

$$THI = T_{db} + 0.36 T_{dp} + 41.2 \tag{4}$$

The bioclimatical zoning of the Triângulo Mineiro and Alto Paranaíba mesoregion was determined by calculating the daily average THI (9.00, 15.00, and 21.00 h) for each year studied.

A graphical representation of the monthly average THI recorded at the meteorological stations from 2008 to 2017 was produced. The mean values for THI were classified as: < 74, normal; 75 to 78, alert; 79 to 83, danger; and ≥ 84, emergency, according to Wegner et al. (2016). Therefore, risk THI values were considered to be ≥ 75 (alert, danger, and emergency), and the number of THI risk events during the hours analyzed were calculated for 2008 to 2017.

The data was used to descriptively analyze the effective occurrences of heat waves (EOH). A heat wave event was based on a THI higher than 74 and a temperature equal to or higher than 25 °C according to Quiniou and Noblet (1999), which occurred during some part of the day for at least three consecutive days. Data showing only THI values higher than 74 for at least three consecutive days, in at least one of the hours analyzed, were considered probable occurrences of heat waves (POH).

Based on the study by Quiniou and Noblet (1999), the possible body weight (BW) of the sows were determined by dividing them into five weight categories (220, 240, 260, 280, and 300 kg). The VFI (g/d) calculation for each city was then analyzed using the equation proposed by Quiniou and Noblet (1999):

$$VFI = -49,052 + 1,213\,T - 31.5\,T^2 + 330\,BW - 0.61\,BW^2 \qquad (5)$$

in which T = average daily temperature (°C).

The economic loss was estimated based on the productive consequences of VFI translated into milk production and weight of weaning piglets. For this estimate, we used the difference between litter weight of sows in thermal comfort and heat stress, verified by Ribeiro et al. (2018), and then multiplied by the market price of the piglet's kilogram.

The experimental data were analyzed in a randomized block design (two-way ANOVA), establishing the treatments as the local (cities) and the blocks as the weights (220, 240, 260, 280, and 300 kg). The previous analysis of the mathematical model residues of ANOVA with two factors (Two-way anova: $Y_{ij} = \mu + B_j + T_i + e_{ij}$, in which Y_{ij} is the quantitative response variable, μ is the general average, B_j is effect of block j, T_i is effect of treatment i, and e_{ij} is the standard error) indicated a non-normal distribution. Friedman's non-parametric test was performed to verify statistical inferences on possible differences in VFI among the cities analyzed. All tests were performed using the Action® 2.9 tool, considering the significance level of 5%.

Results

A THI of 74 is considered to be the limit of the thermoneutral zone for sows. In the microregions of Frutal, Ituiutaba, Uberaba, and Uberlândia, the average THI of all years was ≥ 74 in January, February, March, October, November, and December. However, the other cities did not have THI ≥ 74 in any of these months (Figure 1).

The Triângulo Mineiro and Alto Paranaíba mesoregion, when all the studied microregions were considered, had an annual mean THI within the thermoneutral zone for sows. However, the maximum THI recorded over the last ten years was in the risk category but did not last for more than five days out of a total of 3653 days (Table 1).

Ituiutaba at 09.00 h was the city with the highest number of days with an alert and danger THI, and Frutal was the only one where there was an emergency THI, but that occurred only on one day during the studied period. Among the analyzed hours, the one that had the highest number of days with a risk THI was 15.00 h. The results also showed that Frutal and Ituiutaba had more days in the emergency category during the study period than the other cities (Table 2). At 15.00 h, Araxá, Patos de Minas, Patrocínio, Uberaba, and Uberlândia showed alert THI on more than a thousand days between 2008 and 2017. Uberaba, at 15.00 h, had the greatest number of days in the danger THI category. The number

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of days with a risk THI at 21.00 h was lower than for 9.00 and15.00 h. It should be noted that at 21:00 h, Patrocínio had no days in risk THI over the last ten years, and the city with the highest prevalence of days in risk THI was Frutal (Table 2).
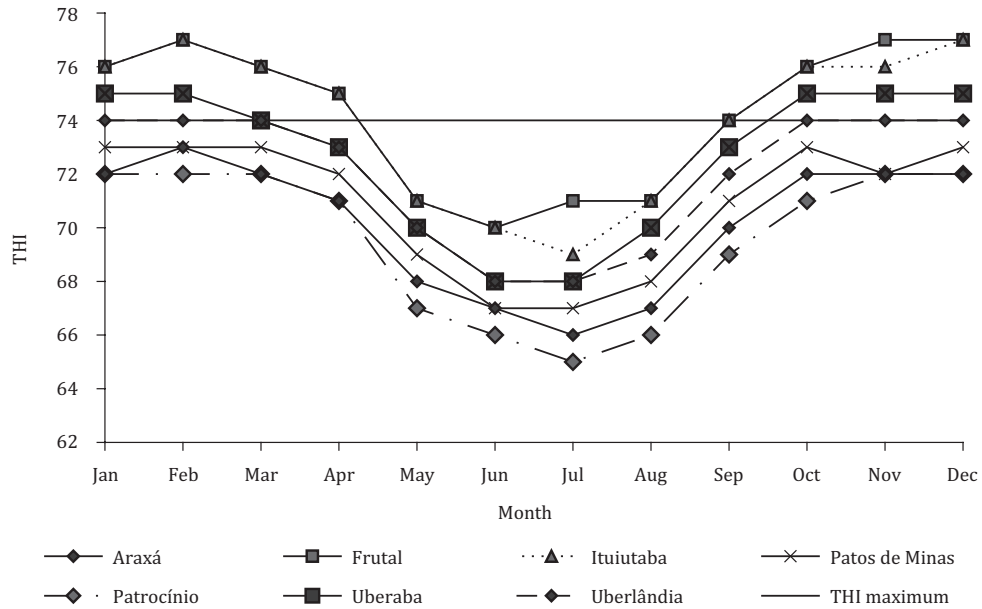
Figure 1 - Behavior of the monthly average temperature-humidity index (THI) of Triângulo Mineiro and Alto Paranaíba mesoregion, Minas Gerais, Brazil, from 2008 to 2017.

Table 1 - Minimum, average, and maximum annual values of the temperature-humidity index (THI) from 2008 to 2017 in Triângulo Mineiro and Alto Paranaíba mesoregion, Minas Gerais, Brazil

City	Minimum THI	Average THI	Maximum THI
Araxá	51	70	84
Frutal	54	74	89
Ituiutaba	53	74	88
Patos de Minas	56	71	82
Patrocínio	52	70	82
Uberaba	52	73	84
Uberlândia	52	72	89

Table 2 - Number of occurrence of the temperature-humidity index (THI) of risk (alert, danger, and emergency) from 2008 to 2017 in Triângulo Mineiro and Alto Paranaíba mesoregion, Minas Gerais, Brazil

City	Alert			Danger			Emergency		
	09.00	15.00	21.00	09.00	15.00	21.00	09.00	15.00	21.00
Araxá	71	1357	27	2	301	0	0	1	0
Frutal	519	456	431	94	596	37	1	101	1
Ituiutaba	824	781	374	137	1119	4	0	133	0
Patos de Minas	277	1469	15	0	393	0	0	0	0
Patrocínio	241	1260	0	0	106	0	0	0	0
Uberaba	790	1314	221	47	1171	2	0	74	0
Uberlândia	453	1615	269	2	422	3	0	1	0

Alert = THI from 75 to 78; danger = THI from 79 to 83; emergency = THI ≥ 84.

All the cities had more than 14 annual heat waves. Ituiutaba and Uberaba had the highest number, and Frutal and Patrocínio had the lowest (Table 3). The number of POH was lower than the EOH in five of the seven cities, but the probable days of heat waves (PDH) were higher than the effective days of heat waves (EDH) (Table 3). January, February, March, October, November, and December had the highest numbers of heat waves and the highest THI.

The sows raised in Patrocínio showed a higher average prediction of VFI (6.611 kg without EOH and 5.743 kg with EOH) than Ituiutaba (6.424 kg without EOH and 3.969 kg with EOH) and Frutal (5.868 kg without EOH and 4.648 kg with EOH) (Table 4). In the classification "without EOH", the microregions of Araxá (6.502 kg), Uberaba (6.452 kg), and Uberlândia (6.478 kg) did not differ from the other cities, but in category "with EOH", Araxá (4.864 kg) differed from Patrocínio (5.743 kg). The averages for predicted VFI were lower in the EOH category than in the POH category for all cities (Table 4).

In Brazil, the average market value per kilo of weaned piglet was R$ 13.30 (US$ 3.21) in September of 2019, and when the reduction in litter weight of a sow raised under heat stress is considered (0.561 kg per piglet), explained by lower milk production of sows, there was a loss of R$ 7.46 (US$ 1.80) per piglet and R$ 74.60 (US$ 18.01) per litter. If a farm with 1,000 sows is considered, this is equivalent to a revenue reduction of R$ 74,600.00 (US$ 18,016.37) per production cycle.

Table 3 - Occurrence of probable and effective heat waves and their duration in days, occurring per year for each meteorological station in Triângulo Mineiro and Alto Paranaíba mesoregion, Minas Gerais, Brazil

City	Range of years	POH	PDH	EOH	EDH	Number of heat waves/year
Araxá	2008-2017	193	1406	187	1374	18.7
Frutal	2008-2013	71	1021	86	1005	14.3
Ituiutaba	2008-2015	180	1863	194	1821	24.2
Patos de Minas	2008-2017	205	1610	223	1570	22.3
Patrocínio	2008-2017	168	1008	168	1005	16.8
Uberaba	2008-2017	284	2337	287	2304	23.0
Uberlândia	2008-2017	243	1771	245	1749	17.4

POH - probable occurrence of heat waves; PDH - probable days of heat wave; EOH - effective occurrence of heat waves; EDH - effective days of heat wave.

Table 4 - Mean, median, and standard deviations of voluntary feed intake (VFI) of swine matrices, with and without effective occurrence of heat waves (EOH) in Triângulo Mineiro and Alto Paranaíba mesoregion, Minas Gerais, Brazil

City	VFI without EOH (kg)			VFI with EOH (kg)		
	Mean	Median	Standard deviation	Mean	Median	Standard deviation
Araxá	6.478	6.502abc	0.610	4.521	4.864bc	0.639
Frutal	5.844	5.868c	0.610	4.626	4.648bc	0.610
Ituiutaba	6.401	6.424c	0.611	3.946	3.969c	0.610
Patos de Minas	6.577	6.601ab	0.610	5.602	5.627ab	0.610
Patrocínio	6.587	6.611a	0.610	5.719	5.743a	0.610
Uberaba	6.428	6.452abc	0.610	5.314	5.338abc	0.610
Uberlândia	6.453	6.478abc	0.610	5.193	5.218abc	0.610

Medians followed by different letters in the same column differ by Friedman's test (P<0.05).

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Discussion

The Triângulo Mineiro and Alto Paranaíba mesoregion covered three of the climatic classes established by Köppen (1948). According to Sá Júnior (2009), they are: tropical humid savannah climate (Aw), humid temperate climate with dry winter (Cwa), and humid temperate climate with dry winter and moderately warm summer (Cwb). However, 78% of the total area of Triângulo Mineiro and Alto Paranaíba is classified as Aw. Frutal and Ituiutaba are characterized only by Aw climate. In Araxá, Cwa preponderates. Aw climate is prevalent in Patrocínio, Patos de Minas, Uberaba, and Uberlândia.

In this study, the months with the highest THI in all cities were January to March and October to December, i.e., summer and spring, because during this period, the temperature and humidity are high, which is characteristic of the climate in the mesoregion. The lowest THI occurred in late fall and winter, i.e., between May and August, which is the driest period of the year with less hours of solar incidence. This is due to the winter solstice (Hardy et al., 1998). According to Machado et al. (2016), the highest values for maximum daily THI in Brazil are found in summer and spring. In temperate regions, the THI is higher in summer and the fall, i.e., from June to September (Iida and Koketsu, 2013; Iida and Koketsu, 2014; Könyves et al., 2017).

In tropical regions, sow performance is lower than for females raised in temperate countries, such as Western Europe and the United States. This can be explained, in part, by the climatic challenges prevailing in hot regions (ABCS, 2014). In temperate areas, the heat stress caused by heat waves occurs in summer, whereas in tropical areas, heat stress occurs throughout the year, and is more severe when associated with high air humidity (Renaudeau et al., 2008).

Even with these challenges, the mesoregion studied has an annual average THI that is ideal for sow production. However, it is not clear whether the performance of these animals is still not negatively affected, because there is a considerable variation between the minimum and maximum THI, and the annual average THI does not show the real behavior of this index at different times of the year.

Several factors influence this thermal environment, such as solar irradiance, water vapor in the atmosphere, wind, and cloudiness (Pereira et al., 2002). In this study, the occurrence of the risk THI for sows at 15.00 h was higher than for the other hours, which was possibly due to solar radiation being higher during the afternoon after the radiant energy had peaked. It was at this time that the maximum THI for the last ten years occurred.

Summer and spring showed the highest occurrences of heat waves compared with the thermoneutral zone for sows. Furthermore, the POH number was lower than the EOH number in some cities. This was probably due to the shorter amplitude of the EOH duration compared with POH, i.e., there were fewer consecutive days with temperatures above 25 °C and a THI > 74, but there were more individual days with these characteristics.

The reduction in feed intake is influenced by several factors, such as physiological (body mass, sex, breed, and external factors) and facilities, such as feed programs and climatic conditions (ABCS, 2014). In all the cities, during EOH days, the daily mean VFI estimate for sows was lower than during POH days. This result can be explained, in part, by heat stress, because sows decrease their appetite so that they can reduce the endogenous heat generated by food. According to Reece (2008), food produces heat during all the metabolic stages, and at the end of the process, the energy generated by the food is converted into heat that will dissipate into the environment.

Sows raised under temperature above 25 °C, to reduce their VFI, have lower milk yields, and produce lighter piglets at weaning (Muns et al., 2016; Cabezón et al., 2017; Ribeiro et al., 2018). Lower feed intake in sows under high ambient temperature can be minimized by combining crude protein reduction with essential amino acid supplementation and energy addition (Renaudeau and Noblet, 2001; Renaudeau et al., 2012). Diets with low crude protein and high energy in the hottest hours of the day, and control diet in the coolest hours of the day under high daily cyclic ambient temperatures have been studied (Fraga et al., 2019).

Other strategies can be adopted to reduce the harmful effects of heat stress on sows. These include the use of cooled floor in the maternity cage, which contributes to conduction heat transfer, improving intake capacity and productive performance of lactating sows (Lima et al., 2011). Air cooling in the maternity room is also another recommended alternative, as it increases food intake, reflecting on higher milk production and weight of weaning piglets (Kiefer et al., 2012). Finally, selecting sows to increase heat tolerance, improving welfare and productivity (Bunz et al., 2018) is an interesting genetic strategy. It is important to know the economic impact of heat stress and make the correct decisions of what measures to take and the value of the investment to make to improve the breeding profitability.

The differences between VFI of sows in the mesoregion cities can be explained by the microclimate characteristics of a given city and by altitude effects, which directly influence temperature. The largest reduction in feed intake of sows with and without EOH occurred in the two lower altitude cities (Ituiutaba and Frutal), because lower altitude regions have higher solar irradiation levels than higher altitude regions.

An ideal thermal environment for sows after breeding should also minimize the harmful effects of heat, ensure their welfare, and enable the animals to display their natural behavior (ABCS, 2014). Therefore, knowing the thermal environment in a mesoregion and the occurrence of heat waves means that the periods when the animals will or will not be within the thermoneutral zone can be identified. This allows decisions to be taken on facility adaptations, cooling equipment, dietary changes, and genetic choices that improve adaptation to the region. Therefore, bioclimatic zoning is an important tool that can be used to help design and/or prepare a suitable thermal environment for sow breeding and avoid negative impacts on their production and welfare.

However, future studies will be necessary to verify if there will be reduction in feed intake in sows raised on commercial farms in the Triângulo Mineiro and Alto Paranaíba region during the periods of effective occurrence of heat waves.

Conclusions

Heat waves constantly occur in the Triângulo Mineiro and Alto Paranaíba mesoregion, with a higher prevalence between January and March and October and December, which also have higher monthly average temperature-humidity indices. The predominance of these events reduces the voluntary feed intake of sows, particularly in Ituiutaba and Frutal.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: M.R.B.M. Nascimento. Data curation: A.A. Brito and R.B. Silva. Formal analysis: M.R.B.M. Nascimento. Methodology: A.A. Brito and M.R.B.M. Nascimento. Project administration: A.A. Brito. Supervision: M.R.B.M. Nascimento. Writing-original draft: A.A. Brito. Writing-review & editing: A.A. Brito, J.P.R. Bueno, F.G.O. Nascimento, C.A. Moraes and M.R.B.M. Nascimento.

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