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Feed flavour supplementation improves kinetics of intake and feeding behaviour pattern of lactating sows in a tropical climate

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HIGHLIGHTS

- Under tropical conditions, climatic factors, impact negatively on the performance and voluntary feed intake of lactating sows.
- Lactating sows modify their kinetics of feed intake and feeding pattern during the hot season to reduce the effects of high ambient temperatures.
- Change in kinetics of feed intake and feeding pattern impacts on their daily milk production and consequently on litter performance.
- Feed flavours offer the potential to change kinetics of feed intake and feeding pattern and increase sow lactation feed intake and as a consequence improve milk production and litter weight gain.

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ABSTRACT

A total of 60 mixed parity sows were used in our study to evaluate the impact of the supplementation of a feed flavour during lactation on their feeding behaviour under tropical climatic conditions. Sows were distributed in a 2 x 2 factorial experimental design: two seasons: hot and cool; and two diets: control diet and a diet with the inclusion of a feed flavour during 24 d lactation. The average relative humidity and ambient temperature for the cool season were 23.1°C and 56.5%, respectively. The corresponding values for the hot season were 26.2ºC and 70.1%. No interaction between season and diet composition was found for all traits. Daily feed intake was affected by season ($P < 0.001$), whereby the feed intake was lower during the hot season than in the cool season (5.66 *vs.* 7.23 kg/ d). The daily ingestion time was less in the hot than in the cool season (36.8 *vs.* 72.3 min/ d; $P < 0.01$) and the ingestion time per meal was also lower in the hot compared to the cool season (5.7 *vs.* 7.5 min/ meal; $P < 0.05$). The hot season also reduced ($P < 0.01$) rate of daily intake when compared to the cool season (36.8 *vs.* 72.3 g/ min). In both seasons, the proportion of total daily feed intake was higher from 00:00 to 10:00 am. The number of meals per day was not affected ($P > 0.10$) by dietary flavour inclusion. The average meal size was lower ($P < 0.05$) in sows fed the control diet when compared with flavour fed sows. Daily feed intake was greater ($P < 0.01$) in the flavour diet than in the control (6.42 *vs.* 5.36 kg/ d). The ingestion time was affected ($P < 0.05$) by the flavour, whereas sows from the control had a lower ingestion (58.4 vs. 46.6 min/ d). Sows receiving flavour showed a higher ($P < 0.01$) nocturnal (704 *vs.* 583 g/ meal) and diurnal (678 *vs.* 582 g/ meal) feed intake when compared to control fed sows. This study confirms that the feeding behaviour of the lactating sow is affected by seasonal variations of the tropical climate. Irrespective of season, the strategic use of feed flavour improved feed consumption and performance under tropical conditions.

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1. Introduction

Environmental temperatures are one of the most important factors that impact on the efficiency and performance of lactating sows under tropical climatic conditions. When temperatures extrapolate the sow's ideal comfort zone (i.e. 18 to 20°C), these animals will suffer from a reduced voluntary feed intake as a natural response to decrease heat production caused by the thermic effect of feed. The reduction in feed intake will have a detrimental impact on milk production and subsequent reproductive performance of the sows (Renaudeau et al., 2005; Silva et al., 2009a, 2009b and 2018). The use of feed additives, such as feed flavours offer the opportunity to improve sow lactation voluntary feed intake (Renaudeau et al., 2008; Wang et al., 2014; Silva et al., 2018) and as a consequence enhance milk production and decrease sow body mobilization during lactation. However, very little has been published on the benefits of the use of feed flavours on feeding behaviour of lactating sows (Silva et al., 2018). Therefore, to understand the control and regulation of feed intake and its interactions with feed additives in challenging environments, and to establish an adequate feeding strategy, it is important to study factors affecting feeding behaviour. Previous studies (Quiniou et al., 2000a,b) have described the critical role of the ambient temperature on the regulation of sow voluntary feed intake. For instance, when the temperatures rise above 22°C, a curvilinear reduction of voluntary feed intake can be expected, with an increased reduction of meal number and size when temperature are above 27°C. In addition, Quiniou et al. (2000a) demonstrated that daily fluctuating temperatures have a smaller impact on voluntary feed intake rather than constant daily temperatures when connected with the adaptation of the feeding behaviour. According to Quiniou et al. (2000a, 2000b), Gourdine et al. (2006) and Silva et al. (2009a, 2018), lactating sows kept under daily fluctuating temperatures, indicated that during cooler periods (i.e. evening and early morning), they are capable of increasing voluntary feed intake provided by the thermal amplitude, when during the cooler periods these animals could compensate the low diurnal voluntary feed intake. Therefore, the use of a feed flavour to improve the sensorial properties of the diet could be an opportunity to not only increase the sows' voluntary feed intake but to change feed intake patterns and kinetics of daily intake. The aim of the present study was to evaluate the effects of the use of a feed flavour added to the diet on the feeding behaviour of lactating sows in tropical climatic conditions.

2. Material and methods

All methods involving animal handling were realized in accordance with the regulations approved by the Institutional Animal Welfare and Ethics/Protection committee from the Universidade Federal de Minas Gerais (UFMG) under the protocol number 190/2019.

2.1. Animals and experimental procedure

The study was performed between January and October 2019 and was conducted in the farrowing facilities of the swine production farm of the University. The farm herd is based on commercial sows (TN70® Topigs Norsvin) with a standard health status following a regular vaccination program for all animals against *Mycoplasma hyopneumoniae*, parvovirosis, erysipelas, and leptospirosis. A total of 60 multiparous sows divided into 10 batches of 6 sows each were used. Sows were distributed in a 2 x 2 factorial experimental design with two seasons: hot and cool; and two diets: control diet and a diet with the inclusion (500 g/ton; Table 1) of a commercial feed flavour (i.e. Krave™ AP; Adisseo/Nutriad Animal Feed Additives, Dendermonde, Belgium) during lactation, with each animal considered as an experimental unit. Krave™ AP is a proprietary mixture of chemically defined aldehydes, ketones and esters formulated to impart a red fruit and vanilla flavour to the feed. All flavouring compounds in the mixture are approved for use in the European Union and listed in European Union Register of Feed Additives (pursuant to regulation (EC) No 1831/2003) Edition 03/2021 (291) Annex I (2, b).

Table 1
Composition of the experimental diet[1].

Ingredients	Lactation diet
Corn (8% CP)	63.75
Soybean meal (46% CP)	30.00
Soybean oil	1.900
Dicalcium phosphate	1.770
Calcitic limestone	1.023
Sodium cloride	0.400
Mineral premix[1]	0.150
Vitamin premix[2]	0.080
Mycotoxin binder[3]	0.200
L-Lysine (54.6%)	0.380
L-Threonine (99%)	0.100
L-Tryptophan (99%)	0.047
DL-Methionine (99%)	0.081
TOTAL	100
Analyzed composition, as fed	
Net Energy, Mcal/ kg	2.50
Lysine dig./ NE, g/1000kcal	4.20
Crude protein, %	18.82
Digestible Lysine, %	1.050
Digestible Met+Cys, %	0.630
Digestible Threonine, %	0.700
Digestible Tryptophan, %	0.220
Digestible Valine, %	0.890
Digestible Arginine, %	1.130
Total Calcium, %	0.950
Total Phosphorous, %	0.681
Digestible Phosphorus, %	0.330
Digestible Ca: P ratio, %	2.90
Sodium, %	0.350

[1] Copper sulphate (Copper 13.00 g/kg), Iron sulphate (Iron 100.00 g/kg), Manganese monoxide (Manganese 50.00 g/kg), Sodium Selenium (Selenium 184.00 mg/kg), Zinc sulphate (Zinc 95.00 g/kg), Calcium Iodine (Iodine 1000 mg/kg).

[2] Vitamin A (225,00000 UI/kg), Vitamin D3 (380,0000 UI/kg), Vitamin E (200,000 UI/kg), Vitamin K (10,000 mg/kg), Biotin (1,000 mg/kg), Folic acid (9,000 mg/kg), Nyacin (120,000 mg/kg), Pantotenic acid (60,000 mg/kg), Vitamin B2 (20,000 mg/kg), Vitamin B1 (8,000 mg/kg), Vitamin B6 (12,000 mg/kg), and Vitamin B12 (100,000 mcg/kg).

[3] Toxin binder composed by Fermentation extracts of *Saccharomyces cerevisiae*, citric acid, lactic acid, phosphoric acid, and propylene glycol.

Within each batch, sows were distributed among treatments according to body weight, backfat thickness and parity order (1st, 2nd and 3rd/ 4th parity) at 110 d of gestation. The sows remained in the experiment from farrowing to weaning (i.e. 24 d). On d 110 of gestation, the sows were housed individually in farrowing crates with controlled access to feed (following a stepdown feeding scheme 3.0 kg at d 110; 2.8 kg at d 111; 2.5 kg at d 112; 2.2 kg at d 113; 2.0 kg at d 114 and 2.0 kg at d 115) of the respective experimental diet until farrowing and *ad libitum* water availability throughout the entire experimental period. When needed, cross-fostering was realized within the first 48 h after birth to standardize litter size at 14 piglets among sows from the same treatment. Piglets were not allowed creep feed nor any milk replacer during the entire lactation period. Creep housing equipped with infrared lights provided supplemental heat for the piglets during the 24 d of the lactation period.

2.2. Measurements and collected parameters

Ambient temperature, Relative humidity (RH), and photoperiod followed closely the outdoor conditions. These variables where continuously recorded (1 measurement every 60 s) in the barns, using a data logger connected to a probe (Model Log Tag HAXO-8, Auckland, New Zealand) placed 1 m above the floor. Physiological parameters, such as rectal temperatures, skin surface temperatures (neck, thigh and mammary gland) and respiratory rate of all sows in each treatment were measured twice a week (i.e. Tuesday and Thursday) at 0700, 1400 and 1900 h.

Individual feeding behaviour was recorded during the *ad libitum* period (between d 1 and 23 post farrowing), using an Automated Intelligent Feeder (AIF; Gestal Solo, Jyga Technology, Canada). Each time that the sow activated a sensor installed in the trough, an amount of 150 g of feed was delivered by the computer. Sows were allowed to repeat this activation every 10 minutes to avoid spillage. After each visit, the time and amount of feed at the beginning and at the end of the visit were recorded. This data was continuously recorded by the system every 10 minutes. In addition to the electronic measurement of feed intake, morning refusals were manually collected and weighed at the same time, between 0730 and 0800 h, and the daily intake was determined as the difference between feed allowance and the refusals collected on the next morning. Periodic testing of AIF feed delivery systems was performed (in between batches) and systems were recalibrated when they exceeded 5% error. The day prior to weaning (i.e., d 23), sows had feed allowance restricted to 5 kg to standardize consumption for all sows for weighing at weaning.

The diets were formulated based on corn, soybean meal, soybean oil, and were supplemented with synthetic trace minerals, vitamins, and industrial amino acids. The ratio between digestible essential amino acids and digestible lysine in the experimental diet were calculated to ensure that they were not below that of the ideal protein and to supply the nutritional requirements recommended for this animal category according to the Brazilian Tables for Swine and Poultry Requirements (Rostagno 2017; Table 1).

The sows were weighed using a digital scale (Líder Balanças Ltda., Mod. LD 2000E, Araçatuba, SP, Brazil) and backfat measured ultrasonically (Sunway, Shenzhen SUNWAY Medical Device Co. Ltd., Model Handscan V7, Shenzhen, China) at 65 mm from the midline at the point beside the shoulder and at the last rib on each flank within 24 h post farrowing. At weaning (24 d), sows were again weighed and backfat measured and moved to a breeding facility to detect onset of standing oestrus. The following litter parameters were collected at farrowing: total number of piglets born, born alive, stillborn, and mummies. Piglets were individually weighed using a digital scale (Líder Balanças Ltda., Mod. B150, Araçatuba, SP, Brazil) 24-h post-farrowing at the most, 36-h, 14 d and at weaning to determine litter birth and weaning weights, and daily weight gain during lactation.

2.3. Calculations and statistical analyses

The climatic variables were averaged for each batch. These data were used to divide the experimental period into 2 seasons (winter and summer) through a principal components analysis (PRINCOMP procedure, SAS Inst. Inc., Cary, NC) following methodology presented in Silva et al. (2009a).

Feed consumption per visit was calculated as the difference between the amounts recorded just before and after the visit. For each visit, feed consumption less than 50 g was considered an artifact caused by the movements of the sows on the slatted floor, and it was not taken into account for further calculations (Silva et al., 2009a). Ingestion time of feed per visit corresponded to the difference between the time at the end and at the beginning of the visit. Following the methodology described by Silva et al. (2009a), the daily feeding behaviour variables were calculated for each sow: number of meals per day, feed intake per day (g), total consumption time of feed (sum of the ingestion time and within-meal interval, min), rate of feed intake (total feed intake/total ingestion time, g/min), and feed intake per meal (g). For each replicate, sows were distributed among the crates that were equipped with the AIF stations. Effects of season, diet composition, batch, parity, and their interactions on sow and litter performance were tested according to ANOVA (GLM procedure of SAS).

During the *ad libitum* period (between d 1 and 23), a total of 7132 daily measurements of feeding behaviour variables were made on 60 sows. These data were pooled per sow on a daily basis and were analysed according to linear mixed model variance using the MIXED procedure of SAS/STAT, including the fixed effects of season, diet composition, day of lactation, and batch, and their interactions (Silva et al., 2009a). The average values of the feeding behaviour components per sow over the lactation period were calculated according to photoperiod (day *vs.* night) and were analysed according to a linear mixed model including the fixed effects of season, diet composition, batch, and their interactions. The effect of lactation stage on daily feed intake was tested with a mixed linear model (MIXED procedure of SAS) for repeated measurements with diet composition, season, and replicate as main effects.

In addition, a mixed model was used to analyse the fixed effects of season, diet composition, batch, and their interactions on the average hourly sow feed intake during lactation. Effects of season on feed ingestion were analysed by generating contrasts between adjacent hourly values (Silva et al., 2009a). For all analyses using the MIXED procedure, the sow was considered as a random effect and the repeated measurement option of the mixed procedure of SAS was used with an autoregressive covariance structure to take into account the correlations between repeated measurements carried out on the same animal. Means comparison was performed using the Tukey test for contrasts. Probability values ≤ 0.10 and > 0.05 were considered trends, whereas $P \leq 0.05$ was considered significant.

Body protein, fat, and energy contents at farrowing and at weaning were estimated according to the equations of Dourmad et al. (1997). Protein, lipid, and energy losses during lactation were estimated as the difference between calculated values determined at farrowing and at weaning.

Daily milk production over the lactation period was calculated from litter growth rate, litter size between d 2 and 24, and milk DM using the equation from Noblet and Etienne (1989). The effects of diet composition, parity number, and their interactions on sows and litter performance were tested according to a general linear procedure analysis of variance (GLM procedure of SAS). The least square means procedure (PDIFF option) was used to compare means when a significant F-value is obtained. The following statistical model was applied:

$$y_{hijk} = u_h + PO_{hj} + Treat_{hi} + b_{k_{(j)}}\left(BWF_k - \overline{BWF_j}\right) + e_{hijk},$$

were y_{hijk} represents the observed value for the parameter h with parity order i, treatment j and body weight at farrowing k; u_h is a general constant present in all observations related to the parameter h; PO_{hj} is the effect of party order j in the parameter h; $Treat_{hi}$ is the treatment effect i; $b_{h_{(j)}}$ is the linear regression coefficient for the effect of body weight at farrowing k for the parameter h; BWF_i is the effect of weight at farrowing i for the parameter h; $\overline{BWF}$ is the effect of weight at farrowing for the parameter h in treatment i and e_{hijk} is the residual associated with each observation.

3. Results

A total of 10 sows were removed from the study due to low litter size (<9 piglets) and/or health problems. No interaction ($P > 0.10$) between season and diet composition was found for all criteria studied. According to the experimental design, average parity was 3.3, and did not differ ($P > 0.10$) between treatments.

The cool season (autumn/ winter) was determined to be between May and August 2019, whereas the hot season (summer/ spring) corresponded from January to April and September to October 2019 period. The average minimum and maximum ambient temperatures and average RH for the hot season were 19.1 and 35.2°C, and 70.1%, respectively. The corresponding values for the cool season were 12.4

and 33.4°C, and 56.5%, respectively. The mean temperature values for hot and cool season were 26.2 and 23.1ºC, respectively (Table 2). The thermal amplitude observed for both hot and cool season were 16.1 and 21.0ºC, respectively. During the experimental period the sows were exposed to temperatures above 26°C on average 52.4 and 21.1% of the time, respectively for hot and cool season. As for temperatures above 30°C sows were exposed 30.5 and 9.4% of the time, respectively for hot and cool season.

The main performance traits of the sows measured during the feeding behaviour study are presented in Table 3. During lactation, average daily feed intake (ADFI) was lower during the hot season (5.56 *vs.* 6.80 kg/ d; $P < 0.001$). The observed reduction in the average daily milk yield was associated with a reduced litter growth rate and reduced piglet weaning weight (10.62 *vs.* 12.60 kg/ d; 2.44 *vs.* 2.80 kg/ d; and 6.82 *vs.* 7.33 kg respectively, for the hot and cool season; $P < 0.05$). Average daily feed intake was higher for the sows fed the feed flavour diet when compared with those fed the control diet (6.42 *vs.* 5.36 kg/ d, respectively; P = 0.01). There was an effect of treatment ($P < 0.05$) on litter daily gain were litters from sows fed the flavour showed a higher daily gain when compared to control (2.68 *vs.* 2.50 kg/ d respectively; Table 3). Average weaning weight was also higher ($P < 0.01$) for piglets from flavour fed sows when compared to control (7.26 *vs.* 6.71 kg respectively; Table 3). Average daily milk production was also higher ($P < 0.05$) in the flavour fed sows (11.66 *vs.* 10.53 kg/ d respectively; Table 3). According to the analyses performed, no interaction was observed ($P > 0.10$) between season and diet composition for the lactation feeding behaviour traits.

3.1. Effect of Season on Feeding Behaviour in Lactating sows

The performance of multiparous sows measured for the effects of season on feeding behaviour are presented in Table 4 and Table 5. The daily ingestion time was lower in the hot than in the cool season (36.8 *vs.* 72.3 min/ d, respectively; $P < 0.01$) and the ingestion time per meal was also lower in the hot compared to the cool season (5.7 *vs.* 7.5 min/ meal, respectively; $P < 0.05$). The hot season also showed a lower ($P < 0.01$) rate of daily intake when compared to the cool season (36.8 *vs.* 72.3 g/ min, respectively). The ratio between voluntary feed intake and the required daily feed intake based on the sow's daily nutrient needs was also lower for the sows during the hot season (66 *vs.* 90%, respectively for hot and cool season). Table 9 shows the effect of light pattern on the feeding behaviour of lactating sows. Irrespective of season, sows showed a higher diurnal feed intake (3.43 *vs.* 2.75 kg/ d), whereas meal frequency was not affected (4.2 meals/ d, on average). On a daily comparison of feed intakes or variations from day to day, sows during cool season showed a higher ($P < 0.05$; Fig. 1) voluntary feed intake from d 9 to d 24 compared to the hot season. The nycthemeral voluntary feed intake pattern peaked twice daily (within 24 h) irrespective of the season. The two peaks were observed between 0000 and 1000 h and between 1500 and 1800 h, respectively (Fig. 2). The size of the peak differed ($P < 0.05$) and the hourly feed intakes were higher during the cool season compared with the hot season from 0000 until 0900 h, 1600 h, and 1700 h (Fig. 2). As for the hot season the peak at 1800 h was higher ($P < 0.05$) than for the cool season. Irrespective of season sows showed a higher diurnal feed intake pattern (55.2 *vs.* 44.7%, respectively for diurnal and nocturnal). In addition, sows also showed a higher proportion of daily voluntary intake between 00:00 and 10:00 am, which was equivalent to 83% of the total daily feed intake.

Table 2
Main characteristics of climatic variables[1].

Item	Season Hot	Cool
Temperature, °C		
Minimal	19.1	12.4
Maximal	35.2	33.4
Mean	26.2	23.1
Amplitude	16.1	21.0
Relative humidity, %		
Minimal	35.7	23.4
Maximal	93.5	91.8
Mean	70.1	56.4
Amplitude	57.8	68.4
Days of exposure to >26 °C, %	52.4	21.1
Days of exposure to >30 °C, %	30.5	9.4

[1] Seasons correspond to the means of daily values of ambient temperature and relative humidity. Cool season: May to August 2019. Hot season: January to April 2019 and September to October 2019.

Table 3
Effect of feed flavour and season on the performance of sows during 24 d of lactation (least-square means).

Variable	Diet Control	Flavour	Season[ŧ] Hot	Cool	RSD[1]	Statistics[2]
Number of sows	23	27	32	18	-	-
Average Parity	3.5	3.2	3.5	3.1	2.2	P***
Lactation length, d	24.0	24.0	24.0	24.0	-	-
ADFI (d 1until weaning), kg/ d	5.36	6.42	5.56	6.80	0.82	T**, S***, P***
Body weight, kg						
At farrowing	239.3	237.7	235.9	254.4	39.4	P***
Weight variation	-17.03	-19.14	-20.0	-26.7	18.5	0.682
Backfat thickness, mm						
At farrowing	13.9	13.6	13.9	13.7	1.2	0.287
Back thickness variation	-0.3	-0.3	-0.1	0.2	1.6	0.425
Litter size at weaning	11.2	11.2	11.1	11.4	3.7	G*
Litter growth rate, kg/ d	2.50	2.68	2.44	2.80	0.10	T*, S**
Weaning BW, kg/ piglet	6.71	7.26	6.82	7.33	0.3	T**, S*
Milk production, kg/ d	10.53	11.66	10.62	12.60	0.91	T*, S**

[3]Estimated from equations published by Dourmad et al. (1997). Protein (kg) = 2.28 (2.22) + 0.178 (0.017) × empty BW – 0.333 (0.067) × P2 (RSD = 1.9); lipids (kg) = −26.4 (4.5) + 0.221 (0.030) × empty BW + 1.331 (0.140) × P2 (RSD = 6.1); energy (MJ) = −1.075 (159) + 13.67 (1.12) × empty BW + 45.98 (4.93) × P2 (RSD = 208). Empty BW (kg) = a × BW 1.013 (kg), with a = 0.912 at farrowing and a = 0.905 at weaning. P2 = P2 backfat thickness (mm).
[1] RSD= residual standard deviation.
[2] Obtained by analysis of variance (GLM including the effects of parity (P), batch (G), season (S) and treatment (T)). ***P < 0.001; **P < 0.01; *P < 0.05.
[ŧ] Cool season: May to August 2019. Hot season: January to April 2019 and September to October 2019.

Table 4
Effect of feed flavour and season on feeding behaviour of lactating sows during 24 d of lactation (least-square means).

Parameters	Diet Control	Flavour	Season[ŧ] Hot	Cool	RSD[1]	Statistics[2]
Number of sows	23	27	32	18	-	-
No. of meals/ d	9.2	9.3	7.2	9.7	2.3	S**
Feed intake, g/ meal	583	690	786	746	105	T*, G*
Rate of feed intake, g/ min	87	91	65	100	31	S**
Ingestion time						
Min/ d	46.6	58.4	36.8	72.3	16.2	T*, S**
Min/ meal	5.1	6.3	5.1	7.5	2.5	S*

[1] RSD= residual standard deviation.
[2] Obtained by analysis of variance (GLM including the effects of season (S), parity (P), batch (G) and treatment (T)).***P<0.001; **P<0.01; *P<0.05.
[ŧ] Cool season: May to August 2019. Hot season: January to April 2019 and September to October 2019.

Table 5
Effect of feed flavour and season and light pattern on feeding behaviour of lactating sows during 24 d of lactation (least-square means).

Parameters	Diet		Season[‡]			
	Control	Flavour	Hot	Cool	RSD[1]	Statistics[2]
Number of sows	23	27	32	18	-	-
No. of meals/ d [3]						
Day	5.2	5.1	4.1	5.2	1.5	0.432
Night	4.0	4.2	3.1	4.5		
Meals/ time, %						
00:00 – 06:00	40.4	42.9	38.4	44.9	-	-
06:00 – 10:00	41.4	41.2	42.7	39.9	-	-
10:00 – 18:00	15.1	12.7	14.6	13.3	-	-
18:00 – 00:00	3.1	3.0	4.3	1.9	-	-
Diurnal proportion of feed intake, %	56.5	53.9	57.3	53.2	-	-
Nocturnal proportion of feed intake, %	43.5	45.9	42.7	46.8	-	-
Feed intake, g/ d [3]						
Day	3,029[a]	3,458[b]	3,243	3,616	635	T*, S***,
Night	2,333[a]	2,958[b]	2,317	3,184		L**, G*
Feed intake, g/ meal [3]						
Day	582[a]	678[b]	790	740	256	T**
Night	583[a]	704[b]	779	752		
Ingestion time, min/ d						
Day	26.3[a]	31.5[b]	21.1	38.5	11.5	S*, T*
Night	20.3[a]	26.9[b]	15.7	33.8		

[1] RSD= residual standard deviation.
[2] Obtained by analysis of variance (GLM including the effects of season (S), parity (P), daytime (L), batch (G) and treatment (T)). ***P<0.001; **P<0.01; *P<0.05.
[3] Day= 06:00 am – 17:59 pm; Night= 18:00 pm – 05:59 am
[‡] Cool season: May to August 2019. Hot season: January to April 2019 and September to October 2019.

3.2. Effect of feed flavour on feeding behaviour in lactating sows

The performance of multiparous sows measured for the effects of the feed flavour on feeding behaviour are presented in Tables 4 and 5. The dietary flavour inclusion did not affect ($P > 0.10$) the number of meals per day. Sows fed the control diet showed a reduced average meal size (-107 g/ meal) when compared with flavour fed sows. The ingestion time was affected ($P < 0.05$) by the treatments, whereas sows from the control showed a lower value (58.4 *vs.* 46.6 min/ d, respectively cool and hot season). Sows receiving flavour showed a higher nocturnal (704 *vs.* 583 g/ meal) and diurnal (678 *vs.* 582 g/ meal) feed intake when compared to control fed sows. Irrespective of treatment sows showed a higher diurnal feed intake pattern (55.2 *vs.* 44.7%, respectively for diurnal and nocturnal). Nevertheless, the sows also showed a higher proportion of daily voluntary intake between 00:00 and 10:00 am, which was equivalent to 82.3% of the total daily feed intake. On a daily comparison of feed intakes or variations from day to day, sows fed the flavour showed a higher ($P < 0.05$; Fig. 3) voluntary feed intake from d 3 to d 24 compared to control fed sows. From a comparison of hourly feed intakes or variations from hour to hour (during 24 h), both treatments showed a two daily peaks in the nycthemeral pattern of feed intake. However, the size of these peaks differed, whereas the hourly feed intakes were higher ($P < 0.05$) for flavour fed sows when compared with the control from 0000 until 0800 h and 1800 h (Fig. 4).

4. Discussion

In our study the season impacted on performance traits of the sows and their litters and were found to be lower in the hot compared to the cool season. In agreement with our findings, Silva et al. (2009a and 2009b) also showed that sows reduced ADFI (i.e. -1.092 kg/ d), milk production (i.e. -1.10 kg/ d), litter growth rate (i.e., -398 g/ d) and piglet weaning weight (i.e. -450 g) during the hot season in comparison to the cool season. Several studies (Quiniou and Noblet, 1999; Renaudeau and Noblet, 2001; Renaudeau et al., 2003; Gourdine et al., 2006; Silva et al., 2009c; Choi et al, 2019) have reported the negative effects of high ambient temperatures and the interactions with high RH on feed intake and performance of lactating sows and their litters.

For the whole lactation period, piglet growth rate, milk production and ADFI recorded in our study were comparable with the values obtained by Silva et al. (2018) that studied the use of the same feed flavour at the same level of inclusion on the performance of lactating sows under a very similar climatic condition (246 *vs.* 260 g/ d for piglet growth, respectively; 11.66 *vs.* 12.99 kg/ d for milk yield; and 6.4 *vs.* 6.6 kg/ d for ADFI, respectively). In agreement with Silva et al. (2018), it can be inferred that the feed flavour used in both studies, activated the oronasal sensing mechanisms induced by taste and changed sow feeding behaviour, increasing voluntary feed intake and consequently improving litter performance traits. In addition to these findings, Jones et al. (2000), reported that pigs have a good acceptance for five odorized sweet foods (i.e., vanilla, strawberry, peach, raspberry and almond oil). These same authors stated that among these foods, pigs have a natural preference for vanilla and raspberry flavours.

4.1. Effect of season on feeding behaviour in lactating sows

Normally 2 peaks of feeding activity occur during the day under

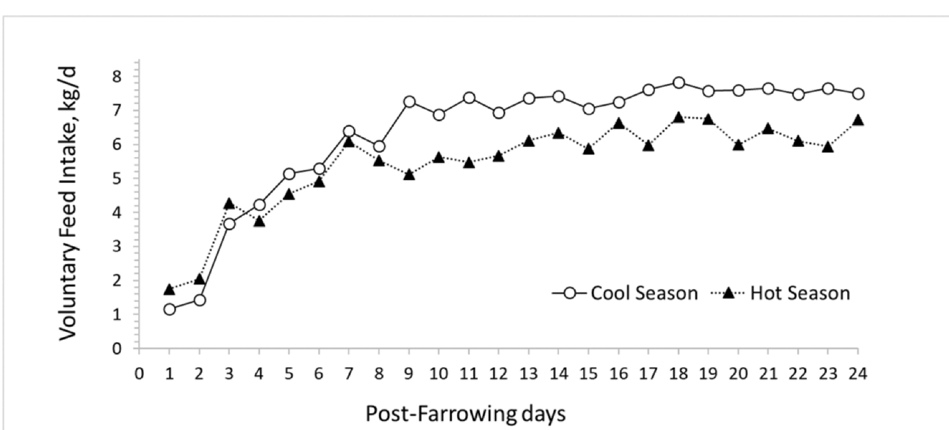

Fig. 1. Daily feed intake during Cool and Hot season. Feed intake differed between seasons from d 9 to 18 and from d 20 to 24 (P < 0.05). A total of 17 and 31 sows were used for Cool and Hot respectively.

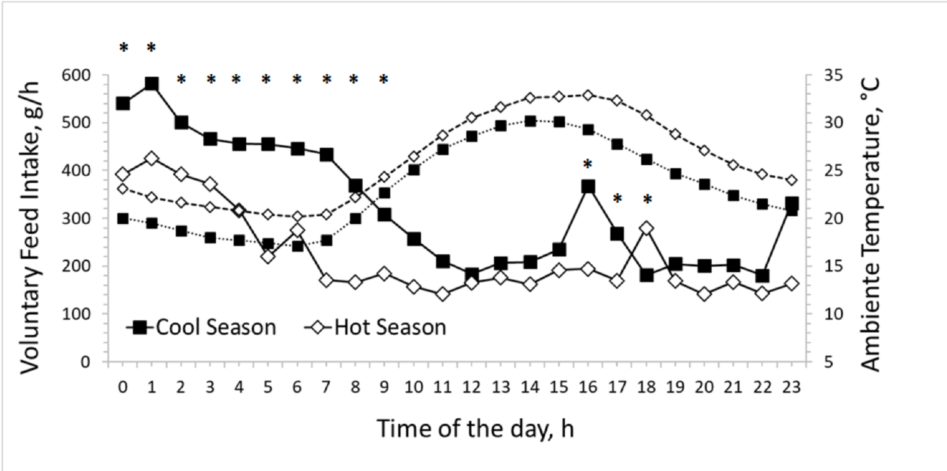

Fig. 2. Effect of season and time of day on the daily fluctuations of ambient temperature (dotted lines) and daily feed intake in lactating sows (solid lines). Each point is an input (least squares means) of 18 sows in the cool season and 32 sows in the hot season. Feed intake differed between seasons on hourly feed consumption from 0000 to 0900 and 1600, 1700 and 1800 (*; $P < 0.05$).

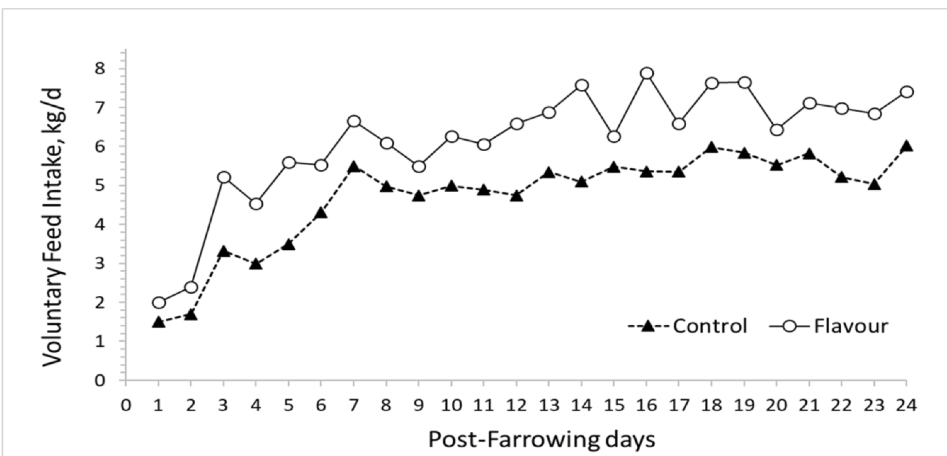

Fig. 3. Effect of diet composition and time of day on daily feed intake in lactating sows. Feed intake differed between diets from d 3 to 24 ($P < 0.05$). A total of 15 and 16 sows were used for Control and Flavour respectively.

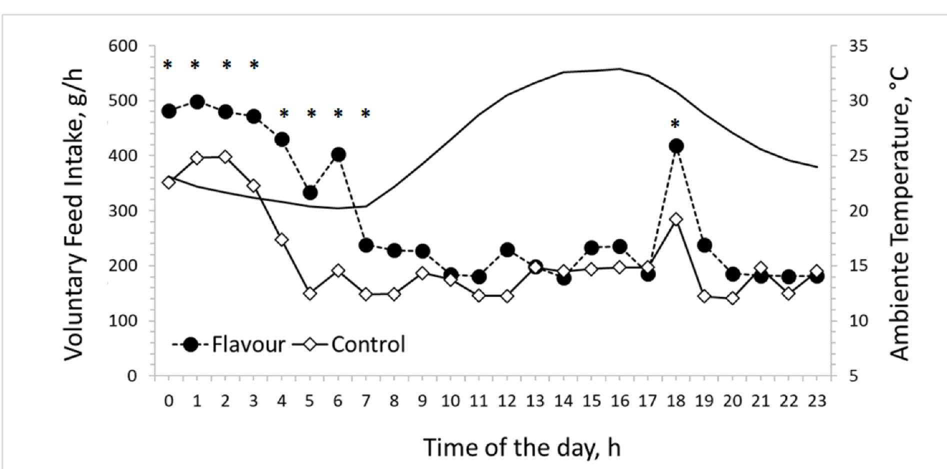

Fig. 4. Effect of diet composition and time of day on daily feed intake in lactating sows. Each point is an input (least squares means) of 25 sows in the cool season and 25 sows in the hot season. Feed intake differed between diets on hourly feed consumption from 0000 to 0800 and 1800 (*; $P < 0.05$). The top solid line represents the average daily pattern of the ambient temperature.

natural environmental temperatures (Renaudeau et al., 2003a; Gourdine et al., 2006; Silva et al., 2009a). Whereas one peak can be observed early in the morning and a second peak observed end of the afternoon or beginning of the night. Our findings are in agreement with these observations, indicating that the feeding pattern activity of the sows is driven by ambient temperature and photoperiod variation in the farrowing room.

During our study, the seasonal daily temperature and RH kinetics affected the sows feeding pattern. According to several studies (Renaudeau et al., 2003b; Gourdine et al., 2006; and Silva et al., 2009a) conducted under similar conditions as ours, sows can compensate the lower feed intake during the hotter periods of the day by increasing feed intake during the cooler periods. During the current experiment, the sows were unable to increase nocturnal consumption (i.e. 44.7 *vs.* 55.3% respectively for nocturnal and diurnal feed intake). In agreement to our findings, Silva et al. (2009a) also observed similar feeding behaviour pattern (i.e. 44% nocturnal feed intake). Differently from these findings, Gourdine et al. (2006) observed that more than 50% of the total daily feed intake occurred during the nocturnal period. In addition to these findings, Choi et al. (2019) observed that night feeding in lactating sows under heat stress improved feed intake (i.e. +6%). In our study, on average 55.3% of daily feed intake occurred during the diurnal period, whereas the value was greater in the hot season (57%) than in the cool season (53%). The differences observed between both studies, can be related to the fact that the hot season temperatures registered during our study were lower than the ones reported by the Gourdine et al. (2006) (on average, 26 *vs.* 28°C), therefore providing better ambient conditions for our sows to increase voluntary feed intake during the diurnal period. These findings indicate that the nycthemeral feeding pattern in lactating sows are influenced by the climatic conditions.

From our study, it was observed that each degree increase in temperature corresponded to a reduction in sow daily feed intake of 524 g/ d. Similar to our findings, Silva et al. (2009a) observed a reduction in daily feed intake of 462 g/ d. In contrast to these observations, Quiniou and Noblet (1999) between 25 and 27°C with a 50 to 60% RH reported a reduction in feed intake equivalent to 254 g/ d per degree Celsius. The higher reduction per degree Celsius found in our study is a direct consequence of the increased relative humidity amplitude observed during our study (30 to 93%). In this sense one can infer that the RH amplitude can accentuate the negative effect of elevated ambient temperatures.

The daily number of meals averaged 9.7 (d 1 and 24) during the cool season. Our findings are higher than the values obtained by Renaudeau et al. (2003b) between d 6 and 27 (8.8 meals/ d) and Silva et al. (2009a) between d 6 and d 26 (8.1 meals/ d). In addition, meal size was also higher in our study (766 *vs.* 649 *vs.* 718 g/ meal respectively for the current study, Silva et al., 2009a and Renaudeau et al., 2003b). Differently from Gourdine et al. (2006) and Silva et al. (2009a), in our study, an increase of meal size was associated to a decrease in daily voluntary feed intake in the hot season (+ 40 g/ meal), whereas the number of meals were reduced (- 2.5 meals/ d) compared to the cool season. The season had an influence on the rate of feed intake in the present study, sows during the hot season showed a lower rate of feed intake (- 35 g/ min). Our findings are in agreement with results obtained by Renaudeau et al. (2003b), Gourdine et al. (2006) and Silva et al. (2009a). As a consequence, the reduction in sow daily voluntary feed intake in the hot season was associated with a reduced ingestion time (72.3 *vs.* 36.8 min/ d, respectively, for the cool and the hot season).

4.2. Effect of feed flavour on feeding behaviour in lactating sows

Independent of the season considered and except for number of meals and rate of feed intake, the use of the feed flavour affected the other feeding behaviour components. Sow and litter performance was improved by the use of the feed flavour, which is in agreement with the results reported by Silva et al. (2018). The higher daily voluntary feed intake observed for the sows fed the flavour diet was associated with a greater meal size when compared with the control (690 *vs.* 583 g/ meal).

The increase in feed consumption during the first and second peaks of feeding explain the higher voluntary feed intake for the flavour fed sows. Independent of the dietary treatment, feed consumption seemed to be limited by the ambient temperature in the afternoon when compared to late night and early morning. These observations indicated that sows were not able to compensate for feed intake during the afternoon due to the limiting effects of the heat stress associated with a higher heat increment from the diet. Nevertheless, the sows fed the flavour diet still showed a higher feed intake peak when compared to the control in the afternoon. Flavour fed sows also showed a higher total ingestion time compared to the control (58.4 *vs.* 46.6 min/ d). The ingestion was also influenced by the feed flavour and was higher for both day (+5.2 min/ d) and night (+ 6.6 min/ d) periods compared to the control fed sows.

Pigs have a very well developed sense of smell (Morrow-Tesch and McGlone, 1990). Compared to other production animals, the olfactory system of pigs shows an extremely high sensitivity (Roura and Tedó, 2009). The pig's taste system (oral chemosensory) is capable of recognizing a diverse repertoire of non-volatile compounds. Pigs detect and accept five different tastes: sweet, umami, salty, sour and bitter (Roura and Tedó, 2009). Among these tastes, they react very positively to sweet, which is considered a pleasurable taste and can be related to energy sources from carbohydrates such as sugars (Roura and Tedó, 2009). Previous authors (Danilova et al., 1999; Hellekant and Danilova, 1999; Tinti et al., 2000) have described that responses to sweeteners such as fructose, sucrose, lactose, maltose, glucose and galactose are associated with both Glossopharingeal nerves and Chorda tympani. In addition, according to Maynard et al. (1965) several esters, ketones, aldehydes and inorganic acids can present a sweet taste. Based on these previous findings, we can infer that the feed flavour used in our study, which is based on flavour notes that provide a sweetening taste, stimulated the oronasal sensing mechanisms and changed sow feeding behaviour, increasing meal size, ingestion time and daily feed intake throughout lactation. As cited by Silva et al. (2018), this positive effect of feed flavours on the feeding behaviour is highly beneficial for high producing sows that are more susceptible to suffer from high ambient temperatures during lactation.

In conclusion, the present study confirms that under tropical conditions, high ambient temperatures, impact on the performance, voluntary feed intake and feeding behaviour of lactating sows. Our findings also suggest that sows modify their feeding behaviour pattern during the hot season as a mechanism to reduce the effects of high ambient temperatures. In addition, even if sows are kept under heat stress conditions, they are capable of increasing voluntary feed intake provided by the thermal amplitude, when during the cooler periods these animals could compensate the low diurnal voluntary feed intake if properly stimulated. Irrespective of season, feed flavours can be used to enhance the sensorial properties of feed and improve the lactating sows' feeding behaviour and voluntary feed intake, all of which will increase milk production and litter performance under tropical climatic conditions.

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Declaration of Competing Interest

The authors declare no conflict of interest

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