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Evaluation of feed flavor supplementation on the performance of lactating high-prolific sows in a tropical humid climate

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ABSTRACT

Three hundred mixed parity sows of a high prolificacy genetic line were used to evaluate the impact of the supplementation of different levels of feed flavor during lactation on their productive and reproductive performance under tropical conditions. Sows were distributed in a completely randomized experimental design among 3 dietary treatments: control diet (T1) and other two diets with different levels of inclusion (T2 = 250 and T3 = 500 g/ton) of a feed flavor during 24 d lactation and WEI. The average minimum and maximum ambient temperatures and daily relative humidity measured during the experimental period were 17.4 and 34.7 °C, and 38.0% and 93.8%, respectively. The treatments influenced ($P < 0.001$) the sows voluntary feed intake, the T3 sows showed a higher intake than T2 and higher than T1 (6.60 *vs.* 6.02 *vs.* 5.08 kg/d, respectively). When compared among sows fed the feed flavor, the higher level of inclusion (T3) showed a +9.6% higher ($P < 0.001$) feed intake than T2 sows. The sows from T3 showed a higher ($P = 0.039$) number of weaned piglets when compared to T2 and higher than T1 (13.45 *vs.* 13.07 *vs.* 12.95, respectively). There was an effect of the treatment ($P < 0.001$) on litter daily gain where litters from T3 sows showed a higher daily gain when compared to T2 and T1 (3.37 *vs.* 2.75 *vs.* 2.58 kg/d, respectively). Average weaning weight was also higher ($P < 0.001$) for piglets from T3 sows when compared to T2 and T1 (7.00 *vs.* 6.16 *vs.* 5.86 kg, respectively). Average daily milk production was higher ($P < 0.001$) in the T3 sows when compared with the T2 and T1 fed sows (12.99 *vs.* 9.55 *vs.* 8.59 kg/d, respectively). The weaning-to-oestrus interval did not differ among treatments and averaged 4.3 d ($P > 0.10$). Respiratory frequency was influenced ($P = 0.027$) by treatments, whereas T3 sows showed on average a higher respiratory rate when compared with T2 and T1 (82.7 *vs.* 79.6 *vs.* 65.4 movements/min, respectively). The treatments influenced ($P < 0.001$) the rectal temperatures, where on average T1 sows showed lower values when compared to T2 and T3 fed sows (38.8 *vs.* 39.1 *vs.* 39.3 °C, respectively). In conclusion, this experiment has demonstrated that the strategic use of feed flavor to stimulate sows voluntary feed intake can benefit milk production and as a consequence improve litter performance all of which can help attenuate the negative effects of heat stress conditions on the nursing sow.

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1. Introduction

Climate is the first most limiting factor for reaching maximum production efficiency in hot climate regions. Under heat stress, sows reduce their appetite in order to reduce their heat production due to the thermal effect of feed. This reduction in voluntary feed intake has negative consequences on body reserves mobilization, milk production, and future reproductive and productive career of the sow (Dourmad et al., 1998; Renaudeau et al., 2008; Silva et al., 2009a).

In order to attenuate the negative effects of heat stress, many research trials in recent years have tried to study environmental and nutritional solutions to improve sow performance under heat stress conditions. Nutritional solutions offer a more viable alternative strategy that can be recommended to minimize the negative effects of heat stress. Diets with reduced protein content decrease heat production and may attenuate the effect of elevated temperature on feed consumption (Renaudeau et al., 2001; Le Bellego et al., 2002; Silva et al., 2009a). The increase of dietary nutrient density has been studied by several authors (McGlone et al., 1988; Schoenherr et al., 1989; Dove and Haydon, 1994; Quiniou et al., 2000; Silva et al., 2009a; Silva et al., 2009b) but without effective improvements on sow and litter performance.

In contrast, very little has been published on the effects of feed flavors on performance of sows. The strategic use of flavors could be beneficial to stimulate feed intake (Moser et al., 1987; Frederick and Van Heugten, 2006; Wang et al., 2014), offering the potentiality to improve milk production and litter performance under heat stress conditions. Therefore, the present study aimed to determine if the adverse affects of heat stress on lactating sows can be overcome by the use of a flavor added to the diet to stimulate feed intake and improve sow and litter performance under tropical humid climate.

1.1. Material and methods

1.1.1. Animals and experimental procedure

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 n. 131/2015.

The study was performed in the facilities of a commercial sow unit, located in the Southern part of Brazil, and was performed during summer, covering the period between December 2014 and March of 2015. According to Köppen (1948) classification, the climate of the region is Cwa (hot, temperate, rainy, and with dry winters and hot summers).

A total of 300 mixed parity sows of a high-prolificacy commercial genetic line (Landrace x Large White) from three successive batches of 100 sows each were used in this study. Within each batch, sows were distributed in a completely randomized experimental design among three dietary treatments (i.e. approximately 34 sows per treatment) according to parity order (1st, 2nd and 3rd – 4th parity), body weight and backfat thickness at farrowing. Each treatment consisted of 100 repetitions, with each animal considered as an experimental unit. The sows were allocated to one of the three treatments represented by a control diet (T1) and other two diets with different levels of inclusion (T2 = 250 and T3 = 500 g/ton; Table 1) of a commercial feed flavor (i.e. *Krave*™ *AP;* Nutriad Animal Feed Additives, Dendermonde, Belgium) during 24 d lactation and WEI. *Krave*™ *AP* is a proprietary mixture of chemically defined aldehydes, ketones, esters and sucrose formulated to impart a raspberry and vanilla flavor to the feed. The flavor was incorporated at the place of the equivalent amount of corn in the experimental diets. The sows remained in the experiment from farrowing to insemination (approx. 29 d). On d 110 of gestation, sows were transferred to a farrowing unit and housed in individual open-fronted farrowing pens (2.1 × 2.2 m) on a slatted metal floor and fed 2 kg/d of the control lactation diet (Table 1) until the day of farrowing. Variations in ambient temperature, relative humidity (RH), and photoperiod closely followed outdoor conditions. The dietary treatments were offered on the day after farrowing, after sows were weighed and their backfat thickness was measured. Sows were then submitted to a step-up feeding regime to stimulate a gradual feed intake increase up to day 7 post-farrowing, starting with 2 kg on day 1 post-farrowing and reaching 8 kg/d on day 7. The allowance increased by 1 kg each day. This feeding management was applied to avoid over-consumption at the beginning of lactation and agalactia problems (Silva et al., 2009c). After d 7 sows were fed 2 kg + 0.5 kg/piglet/d, which lead to an average feed allowance of 10 kg/d. The feeding troughs used were regular commercial models with a holding capacity of 10 kg of feed. Sows had *ad libitum* access to water throughout all the experimental period.

After birth, piglets were handled for tooth clipping, umbilical cord treatment and ear tagged for labelling. On d 3, they received an intramuscular injection of 200 mg of iron dextran. As necessary, cross-fostering was conducted within the first 48 h after birth to standardize litter size at 15 piglets among the sows from the same treatments. On d 10, male piglets were castrated. Piglets were not offered creep feed during the entire lactation period. Creep housing equipped with infrared lights provided supplemental heat for the piglets during the lactation period. At weaning, sows were moved to a breeding facility and were presented to a mature boar twice daily to detect onset of standing estrus. Sows were inseminated when positive to the back-pressure test. During the weaning-to-estrus interval, all sows were submitted to the same feeding management, receiving 3.5 kg/d of their respective lactation diet. The amount of feed allowed during this period was based on the previous *ad libitum* historical data of the farm.

1.1.2. Measurements and collected parameters

Variations in the environmental conditions inside the farrowing unit were recorded daily using data loggers (Model Log Tag HAXO-8, Auckland, New Zealand) placed in an empty crate at the centre of the farrowing unit at middle-body height. Sows were weighed using a digital scale (Líder Balanças Ltda., Mod. LD 2000E, Araçatuba, SP, Brazil), and backfat thickness was measured at P2 (65 mm from the dorsal line) using ultrasound equipment (Renco Lean-Meater, Renco Corporation, Minneapolis, USA) 24 h post-farrowing and at weaning in order to determine body weight and backfat thickness variation. The following litter parameters were collected at farrowing: total number of piglets born, born alive, stillborn, and mummies. Piglets were individually weighed using a

Table 1
Composition of the lactation experimental diets.[1]

Ingredients, kg	T1	T2	T3
Corn (7.8%)	59.66	59.63	59.61
Soybean meal (45%)	32.10	32.10	32.10
Soybean oil	4.50	4.50	4.50
Dicalcium phosphate	1.50	1.50	1.50
Limestone (36%)	1.20	1.20	1.20
Salt	0.55	0.55	0.55
Krave™ AP[2]	–	0.025	0.050
L-Lysine HCL	0.11	0.11	0.11
Minerals and vitamins[3]	0.38	0.38	0.38
Analyzed composition as fed,			
CP, %	19.7	19.7	19.7
CF, %	2.5	2.5	2.5
ME, MJ kg^{-1}	14.2	14.2	14.2
Calcium, %	0.91	0.91	0.91
Avail. Phosphorus, %	0.41	0.41	0.41
Sodium, %	0.23	0.23	0.23
Standardized digestible AA[4]			
Lysine, %	1.05	1.05	1.05
Met + Cys, %	0.58	0.58	0.58
Threonine, %	0.66	0.66	0.66
Tryptophan, %	0.21	0.21	0.21
Arginine, %	1.27	1.27	1.27
Valine, %	0.82	0.82	0.82

[1] T1 = control diet; T2 = control diet + 250 g/ton of feed flavor inclusion; T3 = control diet + 500 g/ton of feed flavor inclusion.
[2] Krave™ AP is a proprietary mixture of chemically defined aldehydes, ketones, esters and sucrose formulated to impart a raspberry and vanilla flavor.
[3] Mineral and vitamin mixture supplied (g/kg of diet): 10 of Cu (as CuSO4); 80 of Fe (as FeSO4·7H2O); 40 of Mn (as MnO); 100 of Zn (as ZnO); 0.6 of I (as Ca(IO3)2); 0.10 of CO (as CoSO4·7H2O); 0.15 of Se (as Na2SeO3); 5000 IU of vitamin A; 1000 IU of vitamin D3; 15 IU of vitamin E; 2 mg of vitamin K3; 2 mg of thiamine; 4 mg of riboflavin; 20 mg of nicotinic acid; 10 mg of d-pantothenic acid; 3 mg of pyroxidine; 0.02 mg of vitamin B12; 1.0 mg of folic acid; and 0.2 mg of biotin.
[4] Standardized digestible AA contents were calculated from the analysed AA content and estimated standardized digestibility coefficients from Brazilian Tables for Swine and Poultry Requirements (Rostagno, 2011).

digital scale (Líder Balanças Ltda., Mod. B150, Araçatuba, SP, Brazil) 24 h post-farrowing and at weaning to determine litter birth and weaning weights, and daily weight gain during lactation. All dead piglets during lactation were weighed in order to properly estimate growth rates and milk production. Rectal temperatures, skin surface temperatures (neck, thigh and mammary gland) and respiratory rate of a sub group of 50 sows in each treatment (i.e. approximately 16 sows from each batch according to parity order, body weight and backfat thickness at farrowing) were measured every Tuesday and Thursday at 07h00m, 12h00 m and 17h00 m (Silva et al., 2009c). The respiratory rate was determined for 1 min by counting the movements of the flank only on quiet animals. Skin surface temperatures were measured using a laser thermometer (Model Raytec Minitemp MT4, São Paulo, Brazil).

Every morning, feed refusals were collected, and fresh feed was immediately manually distributed once per day between 07h00 m and 08h00m. Feed consumption was determined as the difference between feed allowance and the refusals collected on the next morning. Every day, one sample of feed and feed refusals were collected daily for DM content measurement, and successive samples were pooled and stored at 4 °C for further analyses. The feed samples were analyzed for DM, ash, fat content (AOAC, 1990) and CP (N × 6.25 for feed) according to Dumas method (AOAC, 1990) and for crude fiber and for cell wall components (NDF, ADF, and ADL) according to Van Soest and Wine (1967) at the Animal Nutrition Laboratory of the Universidade Federal de Minas Gerais (Montes Claros, MG, Brazil). The experimental diets (Table 1) were mash and formulated based on maize, soybean meal (45% CP), soybean oil, and were supplemented with synthetic trace minerals, vitamins, and industrial amino acids, only varying the level of feed flavor inclusion. 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 (2011; Table 1).

1.1.3. Calculations and statistical analyses

Daily maximum, minimum, mean, and variance of daily ambient temperatures and relative humidities were averaged and analysed for the entire experimental period. Body protein, fat, and energy contents at farrowing and at weaning were estimated according to the equations of 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 × BW1.013 (kg), with a = 0.912 at farrowing and a = 0.905 at weaning; whereas P2 = P2 backfat thickness (mm). Protein, lipid, and energy losses during lactation were estimated as the difference between calculated values determined at weaning and farrowing. Average daily milk production estimation was based on litter growth rate and size during lactation, according to the equations of Noblet and Etienne (1989); estimated

Table 2
Impact of feed flavour on the performance of sows during 24 d of lactation (least-square means).[1]

Parameters	T1	T2	T3	SEM[2]	Statistics[3]
Number of sows	99	99	98		
Parity	2.4	2.4	2.4	0.06	
Lactation duration, d	23.3	23.3	23.5	0.05	
Av. daily feed intake (d1until weaning), kg/d	5.1c	6.0b	6.6a	0.03	TL***
Total feed intake, kg	116.9[a]	140.1[b]	151.9[c]	0.11	TL***
Body weight, kg					
At farrowing	232.1	231.2	231.9	0.31	
At weaning	213.9	212.1	214.0	0.10	
Weight change	−18.1	−19.0	−17.9	0.10	
Backfat thickness, mm					
At farrowing	16.8	16.8	16.9	0.11	
At weaning	14.9	14.7	14.9	0.06	
Back thickness change	−1.9	−2.1	−2.0	0.09	
Chemical composition of body change[4]					
Protein, kg	−2.87	−2.96	−2.79	0.08	
Lipids, kg	−2.58	−3.07	−2.61	0.06	
Energy, MJ	−354.12	−375.79	−354.64	0.44	
Body change, %	−7.80	−8.29	−7.68	0.07	
Weaning-to-estrus interval, d	4.3	4.2	4.5	0.06	

[1] T1 = control diet; T2 = control diet + 250 g/ton of feed flavor inclusion; T3 = control diet + 500 g/ton of feed flavor inclusion.
[2] SEM = standard error of the mean.
[3] Obtained by analysis of variance (PROCMIX including the effects of treatment (TL)).
[4] Calculated based on the equations of Dourmad et al. (1997). ***P < 0.001.

based on piglet average daily weight gain (g/d), the average number of piglets and the milk dry matter (19%) MP (kg/d) = ([0.718 × ADG − 4.9] × No. piglets)/0.19. Data were submitted to normality tests and analysed using a mixed linear model (PROC MIXED of SAS statistical package; SAS Inst., Inc, Cary, NC; version 9.2), considering the effects of treatment, batch, parity number, and their interactions on performance of sows and litters. The average daily rectal temperature and respiratory rate (defined as the mean of values measurements at 07h00 m and 12h00 m) measurements were pooled per sow over the lactation period. These data were analysed using GLM procedure of SAS, considering the effects of treatment, batch, parity number, 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, parity order and batch as main effects. The least squares means procedure (STDERR PDIFF option of SAS) was used to compare means when a significant F-value was obtained. The number of sows returning into estrus before and after 5 d post weaning were compared using a $\chi 2$ test (FREQ procedure of SAS). Mean values where compared by Tukey test and all results considered significant at P < 0.05.

2. Results

Average maximum and minimum temperatures and RH levels measured during the experimental period were 34.7 and 17.4 °C, and 89.4 and 38.0%, respectively. A total of 4 sows were removed from the study due to low litter size at weaning (< 9 piglets) and/or health problems. According to the experimental design, average parity was 2.45, and did not differ between treatments. No differences in lactation length were observed between treatments (23.4 d on average).

The treatments influenced (P < 0.001) the sows voluntary feed intake, the T3 sows showed a higher intake than T2 and higher than T1; and T2 showed a higher intake when compared to control (6.60 *vs.* 6.02 *vs.* 5.08 kg/d, respectively; Table 2). When compared among sows fed the feed flavor, the higher level of inclusion (T3) showed a +9.6% higher (P = 0.039) feed intake than T2 sows. The lactation BW and backfat losses were not influenced (P > 0.10) by treatments (19.38 kg and 2 mm, on average), as shown in Table 2. The chemical composition of body weight loss was not influenced (P > 0.10) by the treatments (2.87 kg; 2.75 kg; and 361 MJ; respectively for body protein, lipids and energy losses; Table 2).

Litter size and average piglet weight after cross-fostering were not influenced (P > 0.10) by the treatments (14.8 and 1.36 kg, on average). As for the litter size at weaning, T3 sows showed a higher (P = 0.038) number of weaned piglets when compared to T2 and higher when compared to T1 (13.45 *vs.* 13.07 *vs.* 12.95 respectively; Table 3). There was an effect of treatment (P < 0.001) on litter daily gain were litters from T3 sows showed a higher daily gain when compared to T2 and T1 (3.37 *vs.* 2.75 *vs.* 2.58 kg/d respectively; Table 3). Average weaning weight was also higher (P < 0.001) for piglets from T3 sows when compared to T2 and T1 (7.00 *vs.* 6.16 *vs.* 5.86 kg respectively; Table 3). Average daily milk production was higher (P < 0.001) in the T3 sows when compared with the T2 and T1 fed sows (12.99 *vs.* 9.55 *vs.* 8.59 kg/d respectively; Table 3). The weaning-to-estrus interval did not differ among treatments and averaged 4.3 d (P > 0.10; Table 2).

The results of the physiological parameters and surface temperatures obtained from sows during the lactation period are shown in Table 4. Respiratory frequency was influenced (P = 0.027) by treatments at all stages of measurement, whereas T1 sows showed on average a lower respiratory rate when compared with T2 and T3 (65.4 *vs.* 79.6 *vs.* 82.7 movements/min respectively). The treatments

Table 3
Impact of feed flavor on the performance of litters during 24 d of lactation (least-square means).[1]

Parameters	T1	T2	T3	SEM[2]	Statistics[3]
Litter size					
At farrowing	15.0	15.2	14.1	0.05	
At 48h	14.8	14.8	14.8	0.03	
At weaning	12.9[b]	13.1[ab]	13.4[a]	0.04	TL*
Piglet average weight, kg					
At farrowing	1.35	1.39	1.39	0.01	
At 48h	1.39	1.37	1.34	0.02	
At weaning	5.86[c]	6.16[b]	7.00[a]	0.03	TL***
Piglet weight gain, $g\,d^{-1}$	210[b]	220[b]	260[a]	0.18	TL***
Litter weight gain, kg/d	2.58[b]	2.75[b]	3.37[a]	0.02	TL***
Milk production[4], kg/d	8.59[b]	9.55[b]	12.99[a]	0.06	TL***

[1] T1 = control diet; T2 = control diet + 250 g/ton of feed flavor inclusion; T3 = control diet + 500 g/ton of feed flavor inclusion.
[2] SEM = standard error of the mean.
[3] Obtained by analysis of variance (PROCMIX including the effects of treatment (TL)).
[4] Daily milk production calculated considering litter weight gain (DWG), litter size, and milk dry matter content (19%) applied to the equation adapted from Noblet and Etienne (1989). MP (kg/d) = ([0.718 × DWG − 4.9] × n. piglets)/0.19. ***P < 0.001; *P < 0.05.

Table 4
Impact of feed flavour on the physiological parameters and surface temperatures of sows during 24 d of lactation (least-square means).[1]

Parameters	T1	T2	T3	SEM[2]	Statistics[3]
Number of sows	50	50	50		
Respiratory rate, breaths/min.	65.4[a]	79.6[b]	82.7[b]	0.22	TL*
Rectal temperature, °C	38.8[a]	39.1[b]	39.2[b]	0.02	TL***
Mammary gland temperature, °C	35.6	36.0	35.9	0.04	
Thigh temperature, °C	34.9	35.3	35.0	0.04	
Neck temperature, °C	34.9	34.9	34.6	0.04	

[1] T1 = control diet; T2 = control diet + 250 g/ton of feed flavor inclusion; T3 = control diet + 500 g/ton of feed flavor inclusion.
[2] SEM = standard error of the mean.
[3] Obtained by analysis of variance (PROCMIX including the effects treatment (TL)). ***P < 0.001; *P < 0.05.

influenced (P < 0.001) the rectal temperatures at all measured moments, where on average T1 sows showed lower values when compared to T2 and T3 fed sows (38.8 *vs.* 39.1 *vs.* 39.3 °C respectively). None of the surface temperatures were influenced (P > 0.10) by the treatments.

3. Discussion

The effect of high ambient temperature on the performance of lactating sows is well known in the literature (Black et al., 1993; Renaudeau et al., 2003; Silva et al., 2009a) w ises above the evaporative critical temperature of the sow (i.e., 22 °C, Quiniou and Noblet, 1999). Under our tropical humid conditions, the average minimum and maximum temperatures observed frequently exceeded 22 °C. In addition, the 22 °C value proposed by the later authors was established at low values of RH, and it probably overestimates the upper limit of the zone of thermoneutrality when the RH is close to 100%. Therefore, lactating sows suffered from heat stress most of the time during our experiment.

Based on the net energy system for pigs, heat increment from metabolic utilization of digestible crude protein (DCP) is significantly higher than for starch or ether extract (40 *vs.* 18 and 10% of the ME content; Noblet et al., 1994). The higher heat increment generated by the DCP is partly related to the deamination of excess of amino acids for the urea synthesis (Renaudeau et al., 2008). In addition, the increase in CP supply is associated with a higher protein turn over which enhances heat production. It can then be hypothesized that an increase in voluntary feed intake would contribute to enhance metabolic heat production. Since an increase in the respiratory rate is one of the main physiological mechanisms used by pigs to increase heat loss to the environment, the extra heat increment generated by the higher feed intake (+24% on average) observed in the T2 and T3 when compared to T1 sows, lead to an increased respiratory frequency (+15 movements/min on average) as a response mechanism to dissipate the extra heat generated by the thermal effect of feed. According to literature, the rectal temperature can be assumed as the result of the entire thermoregulation process and an indication of homeothermy stability (Curtis, 1983). The higher rectal temperature observed for T2 and T3 sows when compared to T1 is a response of the effect of increased voluntary feed intake and consequently higher net heat increment. Still, the sows from all three treatments showed a rectal temperature inside the physiological limit for this animal category (38.8–39.4 °C; Curtis, 1983), indicating that even though they were under heat stress there still was potential for increasing feed intake, and thus, the feed flavor stimulated this increase without compromising the homeothermy maintenance. This higher feed intake under heat stress conditions observed in our study indicated that the threshold for sow intake capacity is probably higher than the observed value for the control group and this could be related to the thermal amplitude measured in the farrowing rooms during our study (i.e. 17.3 °C). This daily thermal variation could have allowed sows to compensate during the cooler periods of the day, evening and night the lower diurnal feed intake. According to Silva et al. (2009c) under naturally fluctuating temperatures, 2 peaks of feeding activity occur in lactating sows during the day under tropical climatic conditions. One is observed in the early period of the day and the other before beginning of the night. These observations suggest that feeding pattern activity of lactating sows under heat stress conditions is mainly driven by light intensity and temperature changes in the farrowing room.

Although higher surface temperatures are attributed to an increase in peripheral blood circulation as a way to dissipate body heat, no differences in these variables were observed among treatments. Nevertheless, our observed values are very similar to those observed in literature for sows kept under heat stress conditions (Quiniou and Noblet, 1999; Collin, 2000; Renaudeau et al., 2003; Silva et al., 2009c). The earlier authors reported rises in the surface temperatures of lactating sows when the environmental temperature exceeded the upper critical zone.

In pigs, peripheral senses especially the smell, the taste and the oral somatosensing (oranasal sensing) interpret stimuli important to feed quality and nutritional value (Dulac, 2000; Forbes, 1998; Roura et al., 2008a,b). According to Roura and Tedó (2009), food oronasal stimulation in pigs has been often referred to as food flavor sensing or palatability and is mediated by peripheral senses known as somatosensing, smell and taste. Physical characteristics of feed and ingredients have an impact on feed palatability through the stimulation of the somatosensing system (Roura and Tedó, 2009). In addition, the identification of food sources through smell and taste cues require establishing a link between odour stimulating molecules and the nutritional value of the food (Shepherd, 2006). The sense of smell seems to be the most developed of all the senses in pigs (Morrow-Tesch and McGlone, 1990). Pigs show an olfactory system with extremely high sensitivity compared to other animals (Roura and Tedó, 2009). The taste system is defined as the oral chemosensory system that recognises a diverse repertoire of non-volatile compounds. Not less than five different tastes have been defined and are widely accepted: sweet, umami, salty, sour and bitter (Roura and Tedó, 2009). Stimulation of taste cells is mediated through transmembrane taste receptors. Each taste bud seems to recognize all basic tastes, nevertheless any single cell expresses only on family of taste receptors (Dulac, 2000; Huang et al., 2006; Mombaerts, 2000).

Pigs react with caution to novel food sources. Bitter tastes elicit a strong neophobic feeding behaviour (Mawson et al., 1993). As for sweetness, it is considered a pleasurable taste in pigs and is related to carbohydrates such as sugars (Roura and Tedó, 2009). Several studies (Danilova et al., 1999; Hellekant and Danilova, 1999; Tinti et al., 2000) have shown that both *Chorda tympani* and *Glossopharingeal* nerves exhibit large responses to sweeteners such as fructose, sucrose, lactose, maltose, glucose and galactose. Several aldehydes, ketones, esters and even inorganic acids present a sweet taste (Maynard et al., 1965). According to Jones et al. (2000), five odourised foods which are categorized by humans as sweet (i.e. almond oil, peach, raspberry, vanilla and strawberry) have a good acceptance by pigs. These same authors examining the effects of a range of 15 odourised visible foods in growing pigs observed that vanilla and raspberry flavours did not influence negatively feed intake. The findings presented by the previous authors are consistent with the pig preference values for sweeteners observed by Glaser et al. (2000). Therefore, we can infer that in our study, the use of feed flavor composed by aldehydes, ketone, ester compounds, vanilla and raspberry notes, which of all provided a sweetening taste stimulated the oronasal sensing mechanisms and improved sow feeding behaviour, increasing voluntary feed intake. This positive effect of feed flavors could be beneficial for the modern prolific sow that, although bred to be very productive, often exhibit a reduced feed intake capacity as a result of the genetic selection for higher feed efficiency (Bergsma et al., 2009).

In many instances these sows consume less feed during lactation than is actually required for their maintenance and milk production. If feed consumption is not adequate hyper-prolific lactating sows nursing large litters suffer from excessive body weight mobilisation. As a consequence, the intense catabolism of body tissues can negatively impact on their milk production; litter performance and next litter size (Patterson et al., 2011).

Under adverse climatic conditions, such as hot weather, sows will further decrease appetite during lactation, thus contributing to the decrease in milk production. Therefore, the addition of feed flavor compounds may increase voluntary feed consumption and help alleviate lactation demands (Frederick and Van Heugten, 2006). Our findings agree with this statement, where sows fed the feed flavor showed a higher feed intake than the control sows (i.e. +24% on average for T2 and T3). When voluntary feed intake was compared among sows fed different levels of feed flavor, it is clear the beneficial effect of the flavor on stimulating feed intake at a higher level of inclusion (i.e. +9.6% more intake). Similarly, Wang et al. (2014) evaluating the comparative effects of sodium butyrate and flavors on feed intake of lactating sows observed that the voluntary feed intake of sows fed feed flavor tended to increase by almost 10% in relation to the control and sodium butyrate groups. The later authors confirmed in their experiment that feed flavor can improve sow feed intake, and higher feed intake of sows further improved growth performance of piglets, resulting in higher individual and litter weaning weights of piglets.

The average daily weight gain during suckling and average weaning weight of piglets and litters were higher for the sows fed the feed flavor. These results are attributed to the fact that the piglets would have benefitted from the increased milk production of the sows due to the higher voluntary feed intake. Similarly, Wang et al. (2014) observed that weaning weight of nursing piglets increased by 5.83% when sows were fed a feed flavor in comparison to the control group. It is generally accepted that insufficient feed intake by sows during lactation may compromise milk production (Wang et al., 2014) and impact negatively on sow performance and reduce subsequent productivity (Koketsu et al., 1996; Eissen et al., 2003; Sulabo et al., 2010). In comparison with control sows, the milk production of the feed flavor fed animals increased, suggesting that it can be directly connected to an increase of nutrient availability for milk production due to the increase in voluntary feed intake (+11.1 g lysine/d and +14.9 MJ ME/d). As BW loss was not affected by the treatments, we can assume that the sows improved their efficiency of using energy from the feed for milk production. Our hypothesis can be confirmed by the fact that the ME used for milk production by the T3 sows was lower than the relative ME for production for the T1 and T2 sows (7.2 *vs.* 8.4 *vs.* 8.9 MJ/d/kg, respectively). Wang et al. (2014) also observed that sows supplemented with feed flavor increased productivity, without impacting on body condition, confirmed by the observed similar backfat thickness at weaning for all groups. Still in agreement with our hypothesis, Noblet et al. (1990) and Silva et al. (2009a) observed that sows were more efficient to produce milk from feed energy than from energy mobilized from body stores in the hot climate, with no effects on chemical composition of body weight loss.

Several studies have shown the relation between weaning-to-estrus interval and energy intake during lactation (Foxcroft et al., 1995; Patterson et al., 2011). However, independently of feed intake pattern, 90% of hyper-prolific sows tend to present estrus within 3–5 days after weaning (Patterson et al., 2010; Schenkel et al., 2010; Patterson et al., 2011). Our findings confirm the observations of Vinsky et al. (2006) and Patterson et al. (2011) that hyper-prolific sows, independent of voluntary intake levels and/or body tissue catabolism, presented heat almost immediately after weaning. This could be partially due to the genetic selection against weaning-to-estrus interval (Vinsky et al., 2006; Bergsma et al., 2009). In conclusion, it seems that even if sows are kept under heat stress conditions, there is still a threshold for increasing feed intake probably provided by the thermal amplitude, when during the cooler periods (i.e. evening and early morning) sows could compensate low diurnal feed intake if properly stimulated. Our findings lead us to believe that the strategic use of a feed flavor to manipulate the sensorial properties of feed is a viable strategy to increase the sows' voluntary feed intake and benefit milk production and as a consequence improve litter performance all of which can help attenuate the negative effects of heat stress conditions on the nursing sow.

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References

AOAC, 1990. Official methods of analysis. The Association of Official Analytical Chemists, 15th edition. pp. 1106 Washington, DC.
Bergsma, R., Kanis, E., Verstegen, M.W.A., Van Der Peet-Schering, C.M.C., Knol, E.F., 2009. Lactation efficiency as a result of body composition dynamics and feed intake in sows. Livest. Sci. 125, 208–222.
Black, J.L., Mullan, B.P., Lorschy, M.L., Giles, L.R., 1993. Lactation in the sow during heat stress. Livest. Prod. Sci. 35, 153–170.
Collin, A., 2000. Effets de la temperature ambiante élevée sur le metabolism energétique du porcelet Thèse. France. INRA, Unité mixte de recherches sur le veau et lê porc, Ecole Supérieure Agronomique de Rennes, France.
Curtis, S.E., 1983. Environmental Management in Animal Agriculture. State University Press, Ames 409 p.
Danilova, V., Roberts, T., Hellekant, G., 1999. Responses of single taste fibers and whole chorda tympani and glossopharyngeal nerve in the domestic pig, sus scrofa. Chem. Sens. 24, 301–316.
Dourmad, J.Y., Etienne, M., Noblet, J., Causeur, D., 1997. Prediction de la composition chimique des truies reproductrices a partir du poids vif et de l'epaisseur de lard dorsal. Journees de la Recherche Porcine 29, 255–262.
Dourmad, J.Y., Etienne, M., Noblet, J., 1998. Reconstitution of body reserves in multiparous sows during pregnancy: effect of energy intake during pregnancy and mobilization during the previous lactation. J. Anim. Sci. 74, 2211–2219.
Dove, C.R., Haydon, K.D., 1994. The effect of various diet nutrient densities and electrolyte balances on sow and litter performance during two seasons of the year. J. Anim. Sci. 72, 1101–1106.
Dulac, C., 2000. The physiology of taste, vintage 2000. Cell 100, 607–610.
Eissen, J.J., Apeldoorn, E.J., Kanis, E., Verstegen, M.W.A., Greef, K.H., 2003. The importance of a high feed intake during lactation of primiparous sows nursing large litters. J. Anim. Sci. 81, 594–603.
Forbes, J.M., 1998. Dietary awareness. Appl. Anim. Behav. Sci. 57, 287–297.
Foxcroft, G.R., Aherne, F.X., Clowes, E.C., Miller, H., Zak, L.J., 1995. Sow fertility: the role of suckling inhibition and metabolic status. In: Ivan, M. (Ed.), Animal Science Research and Development: Moving Toward a New Century. Centre for Food and Animal Research, Ottawa, Canada, pp. 377–393.
Frederick, B., Van Heugten, E., 2006. Palatability and flavors in swine nutrition. NC state swine extension. Anim. Sci. Fac. 1–4 ANS02–8215.
Glaser, D., Wanner, M., Tinti, J.M., Nofre, C., 2000. Gustatory responses of pigs to various natural and artificial compounds known to be sweet in man. Food Chem. 68, 375–385.
Hellekant, G., Danilova, V., 1999. Taste in domestic pig, sus scrofa. J. Anim. Physiol. Anim. Nutrit. 82, 8–24.
Huang, A.L., Chen, X., Hoon, M.A., ChadrashekarJ, J., Guo, W., Trankner, D., Ryba, N.J.P., Zuker, C.S., 2006. The cells and logic for mammalian sour taste detection. Nature 442, 934–938.
Jones, J.B., Carmichael, N.L., Wathes, C.M., White, R.P., Jones, R.B., 2000. The effects of acute simultaneous exposure to ammonia on the detection of buried odourized food by pigs. Appl. Anim. Behav. Sci. 65, 305–319.
Köppen, W., 1948. Climatología: Con Un Estudio De Los Climas De La Tierra. Fondo de Cultura Econômica, Mexico 479 p.
Koketsu, Y., Dial, G.D., Pettigrew, J.E., King, V.L., 1996. Feed intake pattern during lactation and subsequent reproductive performance of sows. J. Anim. Sci. 74, 2875–2884.
Le Bellego, L., Noblet, J., van Milgen, J., 2002. Effect of high temperature and low protein diets on performance of growing-finishing pigs. J. Anim. Sci. 80, 691–701.
Mawson, R., Heaney, R.K., Zdunczyk, Z., Kozlowska, H., 1993. Rapeseed meal-glucosinolates and their antinutritional effects. Part II. Flavour and palatability. Die Nahrung 37, 336–344.
Maynard, A.A., Pangborn, R.M., Roessler, E.B., Anson, M.L., Mrak, E.M., Chichester, C.O., 1965. Principles of sensory evaluation of food. In: Maynard, A.A., Pangborn, R.M., Roessler, E.B. (Eds.), The Sense of Taste. Academic Press INC. Elsevier Inc., USA.P, Cambridge, Massachusetts, pp. 28–144.
McGlone, J.J., Stansbury, W.F., Tribble, L.F., 1988. Management of lactating sows during heat stress: effects of water drip, snout coolers, floor type and a high energy-density diet. J. Anim. Sci. 66, 885–891.
Mombaerts, P., 2000. Better taste through chemistry. Nat. Genet. 25, 130–132.
Morrow-Tesch, J., McGlone, J.J., 1990. Sources of maternal odors and the development of odor preferences in baby pigs. J. Anim. Sci. 68, 3563–3571.
Moser, R.L., Cornelius, S.G., Pettigrew, J.E., Hanke, H.H., Heed, T.R., Miller, K.P., 1987. Influence of postpartum feed method on performance of lactating sows. Livest. Prod. Sci. 16, 91–99.
Noblet, J., Etienne, M., 1989. Estimation of sow milk nutrient output. J. Anim. Sci. 67, 3352–3359.
Noblet, J., Dourmad, J.Y., Etienne, M., 1990. Energy utilization in pregnant and lactating sows: modelling of energy requirements. J. Anim. Sci. 68, 562–572.

Noblet, J., Fortune, H., Shi, X.S., Dubois, S., 1994. Prediction of net energy value of feeds for growing pigs. J. Anim. Sci. 72, 344–354.
Patterson, J.L., Cameron, A.C., Smith, T.A., Kummer, A.B., Schott, R.L., Greiner, L.L., Connor, J.F., Foxcroft, G.R., 2010. The effect of gonadotrophin treatment at weaning on primiparous sow performance. Swine Health Prod. 18, 196–199.
Patterson, J.L., Smit, M.N., Novak, S., Wellen, A.P., Foxcroft, G.R., 2011. Restricted feed intake in lactating primiparous sows. Effects on sow metabolic state and subsequente reproductive performance. Reprod. Fertil. Dev. 23, 889–898.
Quiniou, N., Noblet, J., 1999. Influence of high ambient temperatures on performance of multiparous lactating sows. J. Anim. Sci. 77, 2124–2134.
Quiniou, N., Gaudré, D., Rapp, S., Guillou, D., 2000. Influence de la température ambiante et de la concentration en nutriments de l'aliment sur les performances de lactation de la truie primipare. Journée des Recherches Porcines en France 32, 275–282.
Renaudeau, D., Quiniou, N., Noblet, J., 2001. Effects of exposure to high ambient temperature and dietary protein level on performance of multiparous lactating sows. J. Anim. Sci. 79, 1240–1249.
Renaudeau, D., Noblet, J., Dourmad, J.Y., 2003. Effect of ambient temperature on mammary gland metabolism in lactating sows. J. Anim. Sci. 81, 217–231.
Renaudeau, D., Silva, B.A.N., Gourdine, J.L., Noblet, J., 2008. Nutritional Routes to Attenuate Heat Stress in Pigs, Livestock and Global Climate Change. 17–20/05/08, Hammamet, Tunisia.
Rostagno, H.S., 2011. In: Rostagno, H.S. (Ed.), Brazilian Tables for Poultry and Swine: Composition of Feedstuffs and Nutritional Requirements. Press Universidade Federal de Viçosa (UFV), Viçosa, Brazil, pp. 251 Translated by Bettina Gertum Becker.
Roura, E., Tedó, G., 2009. Feed appetence in pigs: an oronasal sensing perspective. In: Torrallardona, D., Roura, E. (Eds.), Voluntary Feed Intake in Pigs. Wageningen Academic Publishers, Wageningen, NL, pp. 105–140.
Roura, E., Humphrey, B., Tedo, G., Ipharragerre, I., 2008a. Unfolding the codes of short-term feed appetence in farm and companion animals, a comparative oronasal nutrient sensing biology review. Canad. J. Anim. Sci. 88, 535–558.
Roura, E., Holt, R., Klasing, K.C., 2008b. Identification of the porcine umami taste receptor dimer responsible for the taste of amino acids. J. Anim. Sci. 81 (Suppl. 1), 203–213.
Schenkel, A.C., Bernardi, M.L., Bortolozzo, F.P., Wentz, I., 2010. Body reserve mobilization during lactation in first parity soes and its effect on second litter size. Livest. Sci. 132, 165–172.
Schoenherr, W.D., Stahly, T.S., Cromwell, G.L., 1989. The effects of dietary fat or fiber addition on energy and nitrogen digestibility in lactating, primiparous sows housed in a warm or hot environment. J. Anim. Sci. 67, 473–481.
Shepherd, G.M., 2006. Smell images and the flavour system in the human brain. Nature 444, 316–321.
Silva, B.A.N., Oliveira, R.F.M., Donzele, J.L., Fernandes, H.C., Lima, A.L., Renaudeau, D., Noblet, J., 2009a. Effect of floor cooling and dietary amino acids content on performance and behaviour of lactating primiparous sows during summer. Livest. Sci. 120, 25–34.
Silva, B.A.N., Noblet, J., Donzele, J.L., Oliveira, R.F.M., Primot, Y., Gourdine, J.L., Renaudeau, D., 2009b. Effects of dietary protein level and amino acid supplementation on performance of mixed-parity lactating sows in a tropical humid climate. J. Anim. Sci. 87, 4003–4012.
Silva, B.A.N., Noblet, J., Oliveira, R.F.M., Donzele, J.L., Primot, Y., Renaudeau, D., 2009c. Effects of dietary protein level and amino acid supplementation on the feeding behavior of multiparous lactating sows in a tropical humid climate. J. Anim. Sci. 87, 2104–2112.
Sulabo, R.C., Tokach, M.D., DeRouchey, J.M., Dritz, S.S., Goodband, R.D., Nelssen, J.L., 2010. Influence of feed flavors and nursery diet complexity on preweaning and nursery pig performance. J. Anim. Sci. 88, 3918–3926.
Tinti, J.M., Glaser, D., Wanner, M., Nofre, C., 2000. Comparison of gustatory responses to amino acids in pigs and in humans. Lebensmittel Wisssenschaft und Technologie 33, 578–583.
Van Soest, P.J., Wine, R.H., 1967. Use of detergents in the analysis of fibrous feeds. IV: determination of plant cell-wall constituents. J. Assoc. Off. Anal. Chem. 50, 50–55.
Vinsky, M.D., Novak, S., Dixon, W.T., Dyck, M.K., Foxcroft, G.R., 2006. Nutritional restriction in lactating primiparous sows selectively affects female embryo survival and overall litter development. Reprod. Fertil. Dev. 18, 347–355.
Wang, J., Yang, M., Xu, S., Lin, Y., Lianqiang, C.H.E., Zhengfeng, F.A.N.G., Wu, D.E., 2014. Comparative effects of sodium butyrate and flavors on feed intake of lactating sows and growth performance of piglets. Anim. Sci. J. 85, 683–689.