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Maize silage as enrichment material improves the welfare of growing-finishing pigs in environmentally-friendly pens

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A R T I C L E I N F O

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A B S T R A C T

Provision of enrichment in welfare- and environmentally-friendly pig pens is important for sustainable pig production. The primary aim of the present experiment was to investigate the effects of maize silage as a singular enrichment compared to a combination of maize silage and chopped straw on behaviours important for determining pig welfare (play, locomotion, exploration, social contact, aggression, manipulation, eating, drinking, lying/sleeping, sitting/standing and nosing objects) in growing-finishing pigs (pigs, n = 432; batch, n = 2; pens n = 12 per batch). Secondly, the impact of drinker position (IN: two drinkers placed in the inside area; OUT: two drinkers in the outside area; IN_OUT: a drinker in each of the inside and outside areas; n = 8 pens per group) on pig behaviour was assessed. There were no statistically significant influences of enrichment treatments on behaviour. The OUT group performed less manipulation behaviour than the IN (mean difference = 2.65; 90 % highest density interval (HDI): 0.46, 4.84) and IN-OUT (mean difference = 2.88 HDI: 0.69, 5.15) groups, and drank more than the IN-OUT group (mean difference = -3.87; HDI: -6.76, -0.90). In addition, we found that a one standard deviation (~ 2 days) increase in observation days/pig age significantly decreased manipulation (log coefficient = -0.32; HDI: -0.42, -0.22) and aggressive behaviours (log coefficient = -0.46; HDI: -0.57, -0.36), but there was an increase in drinking (log coefficient = 0.13; HDI: 0.09, 0.18) and nosing objects (log coefficient = 0.12; HDI: 0.06, 0.18). Significant associations were also found for batch (season), as well as correlations between behaviours. In summary, our results showed that pig behaviours during the growing-fattening period were similarly expressed in the maize silage and combined maize silage and chopped straw treatments, suggesting that maize silage in environmentally-friendly pig pens is adequate in ensuring welfare standards. Furthermore, placing drinkers in the outside area reduced manipulation between pen-mates, thus, could improve pig welfare.

1. Introduction

Pigs were domesticated around 10,000 years ago, but their behavioural repertoire remains similar to their wild ancestors. Given the opportunity in a semi-natural environment, domestic and wild pigs spend 75 % of their time in activities such as foraging and exploration (Stolba and Wood-Gush, 1989), and species-specific behaviours such as rooting (21 %), grazing (31 %) and exploring surroundings (23 %, including locomotion, nosing and manipulating objects; Stolba and Wood-Gush, 1989). In man-made environments, pigs have constant access to water and high quality feed. As a result, they need less time for foraging, but are even more motivated to explore their environment (Day et al., 1995). Their basic behavioural needs must be fulfilled, therefore, by the provision of enrichment material in such environments. If enrichment material is not provided, pigs are more likely to engage in oral manipulation of their pen mates (i.e. biting, nosing and nibbling the body, tail and ears) or in aggressive behaviour (i.e. head knocks and biting between pen mates) (Beattie et al., 2001; Olsen, 2001; Scott et al., 2009), as well as biting pen fittings (Scott et al., 2006; Jensen and Pedersen, 2010).

Enrichment material should stimulate exploration and manipulation behaviours that fulfil pigs' behavioural needs (Jensen and Pedersen, 2007; Mkwanazi et al., 2019), and thus be edible (for eating), chewable (for taste or odour), investigable (for rooting), and manipulable/

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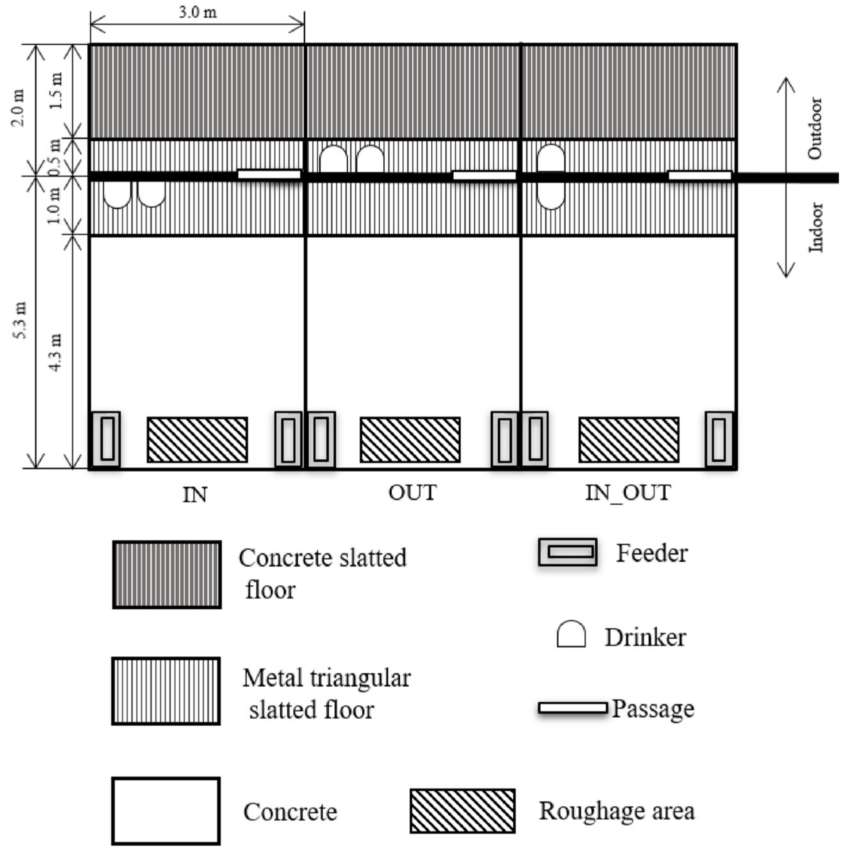

Fig. 1. Pen layout, roughage area, drinker treatments and symbols used to describe pen areas.

deformable (changing structure; Van de Weerd et al., 2003, Olsen et al., 2000). According to the EU directive (Directive 2008/120/EC, The Council of The European Union, 2008), enrichment materials include straw, hay, sawdust, mushroom, compost, and peat, as well as any of other material that fulfil pigs' basic behavioural needs. If one material is not fulfilling the above requirements, a combination of materials could be required, preferably by using materials with some nutritional benefits (Jensen and Pedersen, 2007).

Besides the provision of enrichment, welfare-friendly pig pens should consist of sufficiently large areas that are comfortable to lie on during the entire growing period, as well as access to areas designated for eliminating. Underneath the eliminating area, a manure belt is preferably used in combination with a biofermenter system to reduce the environmental impact of pig farming. The biofermenter ideally uses maize silage to produce fertilizer and renewable energy (methane gas) from pig waste for sustainable pig production. Nonetheless, enrichment materials to improve pig welfare are not always compatible with the optimal functioning of pig production systems (van de Weerd and Day, 2009), including biofermenter systems. In general, straw is the most common enrichment material (Tuyttens, 2005) and long-stemmed straw is considered the best enrichment material for pigs (van de Weerd and Day, 2009; Buijs and Muns, 2019). However, straw is impractical for many pig production systems because it blocks drains (i.e. slats; van de Weerd and Day, 2009; Gifford et al., 2007) and makes the handling of manure more difficult, issues that are exacerbated by long straw. As a compromise, researchers have compared the efficacy of chopped straw as an enrichment material compared to long-stemmed straw (e.g. Day et al., 2008; Bulens et al., 2015; Lahrman et al., 2015). While better for the functioning of pig production systems than long straw, and more desirable for maintaining pig welfare than barren environments (Day et al., 2008), whether chopped straw is a suitable enrichment material requires more research (Lahrmann et al., 2015). Studies have also investigated the enrichment potential of maize silage. Jensen and Pedersen (2007) found that maize silage in combination with chopped straw to be one of the most highly-valued enrichment materials by pigs in an operant conditioning task, even over chopped straw alone. However, the authors did not compare their maize silage with chopped straw condition to a singular maize silage treatment. If maize silage is comparable as an enrichment material to combinations of maize silage and chopped straw, it could both fulfil the behavioural needs of pigs and maintain the optimal functioning of farm biofermenter systems.

Pig behaviour is also influenced by a range of additional endogenous and exogenous factors that are important to consider beyond the provision of enrichment material. Our recent study demonstrated that the location of drinker position is important for reducing pen fouling (Ocepek et al., 2018). The placement of drinkers in the outside area compared to the inside area resulted in a cleaner solid area for lying, which would be expected to lead to lower ammonia emissions, less time needed for manual cleaning, and improved pig welfare (clean lying area). However, whether drinker position can mediate the basic behavioural needs (i.e. foraging, exploration) of pigs is still not well documented. Furthermore, seasonal or daily temperature variation can also affect pigs social strategies (e.g. higher temperatures lead to fewer social contacts; Huynh et al., 2005), and pig behaviour demonstrates plasticity over time due to, for example, age effects (Lahrmann et al., 2015).

The primary aim of the present experiment was to investigate the effects of maize silage as a singular enrichment compared to a combination of maize silage and chopped straw on pig behaviour (play, locomotion, exploration, social contact, aggression, manipulation, eating, drinking, lying/sleeping, sitting/standing and nosing objects). Secondly, the impact of drinker position on pig behaviour was also assessed. Thirdly, we examined the importance of season (batch), day (within a batch), and temperature on the occurrence of behaviour.

2. Materials & methods

The experiment took place at the Pig Innovation Centre in Sterksel (Wageningen University & Research) and conducted in accordance with the Animal Experiments Committee of Wageningen University, the Netherlands. Approval from an ethical review board was not required for this study.

2.1. Experimental design

In a 2 × 3 factorial design, we studied the impact of 1) maize silage (control) as a singular enrichment material or in combination with chopped straw, and 2) placing two drinkers in the inside pen area (IN), two drinkers in the outside pen area (OUT), and one drinker inside and one drinker outside (IN_OUT; Fig. 1), on play, locomotion, exploration, social contact, aggression, manipulation, eating, drinking, lying/sleeping, sitting/standing and nosing objects.

2.2. Animal, housing and feeding strategy

Animals, housing, and feeding strategy are described in detail in Ocepek et al. (2018). Pigs (n = 432) were assigned to 24 pens over two batches (October-January, February-June) and kept in groups of 18 (9 entire males + 9 females). The pigs' mean starting weights (± SE) and length of growing-finishing period, respectively, were 23.0 ± 0.2 kg and 100 days in the first batch, and 24.7 ± 0.2 kg and 94 days in the second batch. Each group was housed in a 21.9 m^2 pen (0.88 m^2/pig inside and 0.33 m^2/pig outside; Fig. 1). Each pen had a rope (replaced approximately once per week) and a ball hanging on a chain. According to our research design (2 × 3), maize silage was provided in all the pens, starting with 3.0 kg and gradually increasing to 9.0 kg per pen per day at the end of the fattening period. In half of the pens (n = 12; n = 6 per batch; n = 2 per drinker position in one batch; IN, OUT, IN_OUT), additional straw was provided, starting with 0.5 kg and gradually increasing to 1.5 kg per pen per day at the end of the fattening period. Straw and maize silage were manually provided twice per day, in the morning at approximately 09:00 and in the afternoon at approximately 15:00 h, in two equally-sized portions (half of the daily amount at each time) on the rectangular "silage area" shown in Fig.1.

2.3. Data collection

The temperature was continuously measured with four loggers (Smartlink 155 KNM-THD-RS485-C, Keithly, Gorinchem, the Netherlands) placed in the middle of inside and outside areas on each side of the house at a height of 1.2 m.

Pigs were continuously video-recorded for a day (00:00 – 23:59 h) every two weeks (Wednesdays; n = 13 days). Video cameras (Samsung SCO-2080RN, 811 × 508 P, 161 Samsung Techwin Co., Ltd., Gyeonggi-do, Korea, n = 12) were mounted on the wall, each covering two inside or two outside pen areas. The behaviours were recorded from continuous observations during the first quarter of every hour. All behavioural analyses were conducted by one trained (by five months of analysing similar study data) observer (MB), using Observer software (The Observer XT 10, Noldus Information 174 Technology, Wageningen, the Netherlands). From the videos, the behaviours listed in Table 1 were recorded.

2.4. Data analysis

We were not concerned with diurnal patterns of behaviour (but see Ocepek et al., 2018) so day was chosen as the statistical unit of analysis. The behavioural variables (total counts of behavioural occurrences each day for each pen) were analysed using a multivariate, multilevel Poisson-lognormal regression model as described by Chib and Winkleman (2001). The model accounts for the correlations between the 11 Poisson-distributed behaviours by including an observation-level random-effect capturing overdispersion for each behaviour, which were modelled in an 11 × 11 covariance matrix (see the supplementary materials for a more formal model definition). Random intercepts were also included for pen. The expected value for each behaviour was predicted by a linear function (using a log link) of an intercept parameter, observation day/pig age (standardised, i.e. centered around the mean and divided by the standard deviation), batch number (mean centered), average daily temperature from the inside and outside loggers (standardised), silage type (coded as corn = -0.5, combination = 0.5), and drinker treatment (coded using sum contrast coding). Missing temperature recordings were present for the first observation day of the first batch for all pens and for certain pens on the sixth day of the first batch and first day of the second batch (20 % of temperature recordings were missing in total). For the missing first day, first batch temperature recordings, we imputed the mean of the second day first batch temperature recordings. For the remaining missing values, we imputed the average of the present temperature recordings on those days from the other pens.

We tested for an interaction between silage type and drinker treatment by comparing models with the interaction (model 1) to a model without the interaction (model 2), including all the other predictors above. Moreover, batch and temperature had a moderate correlation (r = 0.48), so we compared models with both predictors (model 2) to models without batch included (model 3), without temperature included (model 4) and neither batch nor temperature included (model 5). Model comparison was evaluated using approximate leave-one-out-cross validation (LOO; Vehtari et al., 2019), a measure of the model's out-of-sample predictive ability.

The model was written in the probabilistic programming language Stan (model code supplied in the supplementary materials). Parameters were estimated with four Hamiltonion Monte Carlo chains, each with a warmup period of 5000 iterations (discarded) and a sampling period of 5000 iterations, leaving 20,000 samples from the posterior distribution for inference (all chains converged with R-hat statistics < 1.01). Prior distributions were weakly informative to aid convergence (see model code). The model was run and all results calculated in R (R Core Team, 2019) using the *Rstan* package, version 2.17.4 (Stan Development Team, 2018). LOO values were computed using the *loo* package (Vehtari et al., 2019). Parameters were summarised using their mean and 90 % highest density interval (HDI, the 90 % most probable parameter values), where a HDI that does not include zero indicates a significant relationship. Regression coefficients are presented on the log scale for continuous predictor variables (e.g. observation day), denoted $ß_{log}$, and as the estimated difference in the number of behavioural observations for categorical predictors (e.g. differences between batches), denoted $ß_{diff}$. Regression coefficients can be transformed to their implied percentage increase of decrease in behaviour using $100(e^B - 1)$.

3. Results

Model 4, the model with no interaction between batch and silage type, and including only batch number and not temperature, had the lowest LOO value (Fig. 2).

The most common behaviour observed was lying/sleeping (82.6 % of the time; Fig. 3) followed most prominently by exploration (5.2 %), eating (4.5 %), sitting/standing (2.6 %) and locomotion (2%).

Enrichment material did not significantly influence the number of observations of any behaviour. The IN ($ß_{diff}$ = 2.65; HDI: 0.46, 4.84) and IN_OUT ($ß_{diff}$ = 2.88 HDI: 0.69, 5.15) groups displayed more manipulation behaviour than the OUT group. The OUT group had more observations of drinking than the IN_OUT group ($ß_{diff}$ = -3.87; HDI: -6.76, -0.90).

Observation day (1–6 in each batch) was negatively related with manipulation ($ß_{log}$ = -0.32; HDI: -0.42, -0.22; Fig. 4) and aggression ($ß_{log}$ = -0.46; HDI: -0.57, -0.36), but positively related with drinking

Table 1
Ethogram.

Behaviour	Element	Description
Eating		Head is inside one of the two feeders.
Drinking		The drinker nipple is inside the mouth.
Lying/sleeping		Lying prone or on the side with eyes open or closed.
Locomotion		Forward movement by walking or running, without expressing exploration or social interaction with pen-mates.
Sitting/standing		Either sitting or standing and not displaying any other behaviours.
Exploration		Manipulating material on the floor by rooting, pawing, sniffing, chewing, and carrying.
Nosing objects		Pressing their nose against or sniffing pen objects and/or pen walls.
Social contact		Snout is used to touch pen-mate's body surface, not including belly nosing.
Play*	Gambol	Running across the pen, occasionally accompanied by nudging pen-mate gently.
	Pivot	Jump or whirl around to face in a different direction.
	Scamper	Run with vertical and horizontal bouncy movement.
	Hop	Front feet or all four feet off the pen floor, facing the same direction.
Manipulation*	Mounting	Placing front legs on pen-mate's body.
	Biting	Single or repeated snaps or teeth bites, directed toward head or body of pen-mates.
	Belly nosing	Manipulating pen-mate's belly by vagarious up and down head movement.
	Ear and tail biting	Chewing/biting pen-mate's ear or tail.
Aggression*	Push	Mutual rapid movements of head towards pen-mate.
	Biting	Mutual single or repeated snaps or teeth bites, directed toward head or body of pen-mates.
	Head knocks	Mutual pushing or butting of sides of heads facing in the same directions.

* Behavioural variables were computed as the summation of their different elements.

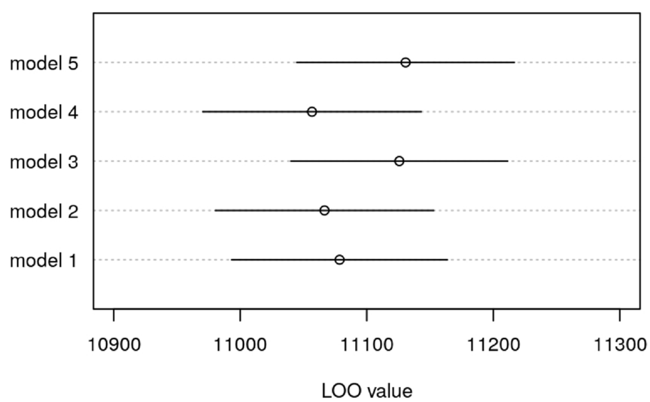

Fig. 2. Leave-one-out (LOO) cross-validation values for the five competing models (see Data Analysis for model descriptions), where lower values indicate better out-of-sample predictive performance. Model 4 has the lowest value (11056.7; SE: 86.3).

($ß_{log}$ = 0.13; HDI: 0.09, 0.18) and nosing objects ($ß_{log}$ = 0.12; HDI: 0.06, 0.18).

Differences in the number of behavioural observations in the first batch compared to the second (i.e. batch 1 estimate – batch 2 estimate) were significantly different for social contact ($ß_{diff}$ = 4.78; HDI: 2.98, 6.41), play ($ß_{diff}$ = -2.37; HDI: -3.87, -0.83), lying/sleeping ($ß_{diff}$ = 23.07; HDI: 8.02, 38.46), sitting/standing ($ß_{diff}$ = -3.84; HDI: -7.51, -0.21), eating ($ß_{diff}$ = -5.29; HDI: -7.86, -2.65), nosing objects ($ß_{diff}$ = 2.58; HDI: 1.29, 3.82), exploration ($ß_{diff}$ = 13.76; HDI: 8.66, 19.04), and aggression ($ß_{diff}$ = -2.51; HDI: -3.47, -1.51).

Holding other predictors in the model constant, there were significant negative correlations between locomotion and social contact (rho = -0.19; HDI: -0.36, -0.01), locomotion and sitting/standing (rho = -0.31; HDI: -0.48, -0.15), manipulation and exploration (rho = -0.24; HDI: -0.41, -0.07), lying/sleeping and social contact (rho = -0.37; HDI: -0.57, -0.18), lying/sleeping and play (rho = -0.32; HDI: -0.49, -0.14), lying/sleeping and sitting/standing (rho = -0.37; HDI: -0.56, -0.19), and lying/sleeping and exploration (rho = -0.43; HDI: -0.60, -0.26). There were significant positive correlations between social contact and manipulation (rho = 0.34; HDI: 0.17, 0.52), social contact and sitting/standing (rho = 0.28; HDI: 0.10, 0.46), aggression and social contact (rho = 0.26; HDI: 0.07, 0.46), and aggression and play (rho = 0.26; HDI: 0.07, 0.44).

4. Discussion

Provision of enrichment in welfare- and environmentally-friendly pig pens is important for sustainable pig production. The first aim of our paper was comparing the effect of maize silage as a singular environmental enrichment to a combination of maize silage and chopped straw on pig behaviours important for determining their welfare (play, locomotion, exploration, social contact, aggression, manipulation, and ear-and tail biting, eating, drinking, lying/sleeping, sitting/standing and nosing objects). Based on previous studies, one could only assume that the combination of maize silage and chopped straw would be more enriching for the pigs, maintaining their interest for a longer period of time, and therefore the pigs would express more exploration, play, and locomotion than when provided with maize silage only (e.g. Jensen and Pedersen, 2007). Interestingly, our data showed that all eleven behaviours were similarly expressed in the maize silage treatment and in the combined maize silage and chopped straw treatment. One could argue that the amount of chopped straw provided in the current study was not enough for pigs to express more positive behaviours and to suppress aggression and manipulation of pen-mates. We provided 83 g of chopped straw per pig, whereas Lahrmann et al. (2015) provided 100 g/pig and in Day et al. (2008) provided 400 g/pig. However, providing larger amounts of straw than we used in this study was impractical because it risked blocking the slurry-based manure systems. Moreover, there are studies documenting that much smaller amounts of straw (i.e. 5 – 15 g/pig) than provided here can improve pig welfare by, for instance, reducing aggression and manipulation behaviours of pen mates (Zonderland et al., 2008; Munsterhjelm et al., 2009). It is also documented that maize silage can fulfil the basic behavioural needs of pigs (i.e. exploration) better than chopped straw (Olsen et al., 2000; Jensen et al., 2010). In the present study, we demonstrated that adding chopped straw in addition to maize silage did not result in any further improvement of pig welfare. As discussed by Olsen (2001), silage is more heterogeneous and nutritive and, thus, may stimulate more exploration behaviours in pigs than straw. Thus, our results suggest that provision of maize silage in environmentally-friendly pig pens is adequate for ensuring welfare standards.

We further tested the importance of drinker position on the pigs' behavioural expressions. Our recent study documented that placing drinkers in the outside pen area is important for reducing pen fouling and thus maximizing pig welfare (Ocepek et al., 2018). In the present study, pigs in pens with drinkers in the outside area displayed less manipulative behaviour compared to groups with drinkers placed in the

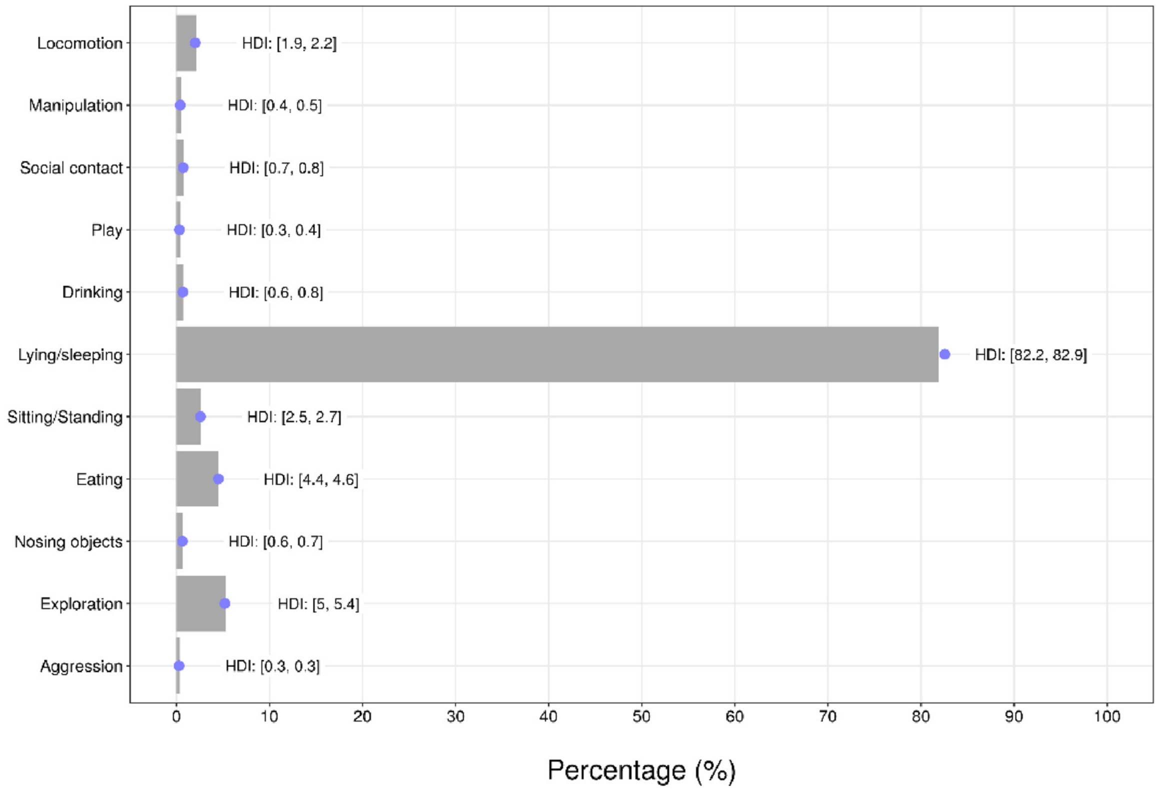

Fig. 3. Percentages of different behaviours recorded. Grey bars show the sample means, blue dots indicate the model estimates for comparison, and 90 % highest density interval (HDI) estimates are given in brackets.

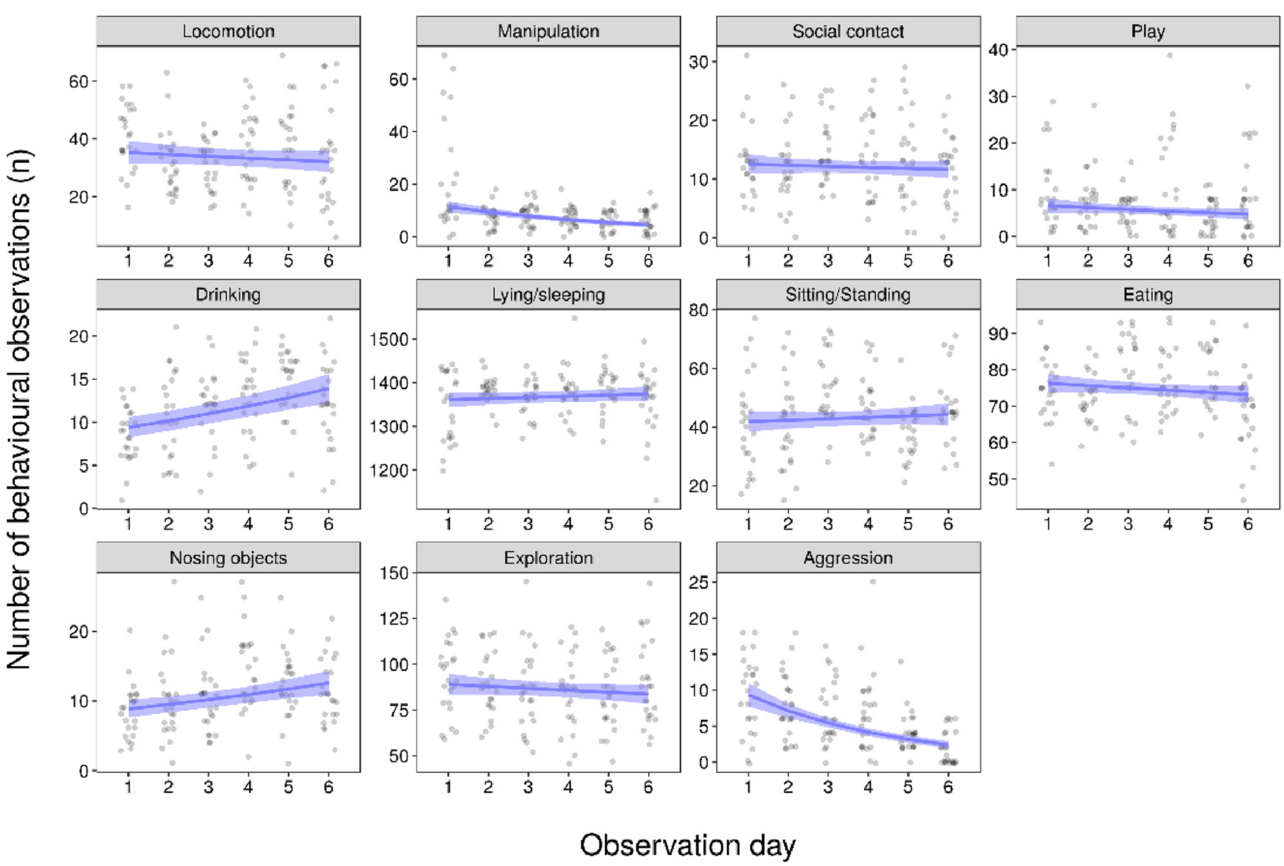

Fig. 4. The relationship between observation day (across batches) and the number of observations of behaviour. Blue lines show the mean posterior estimate, and blue bands the 90 % highest density interval (HDI).

inside or in both inside and outside areas. To the best of our knowledge, there is no other published study on the effect of drinker position on the range of pig behaviours considered here. One explanation for our results is that because pigs in pens with drinkers in the outside area spent longer outside, they performed more behaviours in the outside area, such as drinking, urination and defecation (Ocepek, et al., 2018). Thus, pigs in these groups would have been more equally distributed between the inside and outside areas, leading to less crowding and fewer occurrences of manipulating pen mates.

We further examined the importance of season (batch), day/age (within a batch), temperature, and the interaction between enrichment material and drinker position on pig behavioural expression. Using leave-one-out cross validation, the model with the best out-of-sample predictive accuracy excluded temperature and the interaction between enrichment material and drinker position. Because temperature was moderately positively correlated with season, our model selection indicates that season is a better predictor than temperature alone for explaining variation in the pigs' patterns of behaviours.

We found an effect of pig age (i.e. observation day 1–6 in each batch, approximately a 12 week period) on certain behaviours. Notably, pigs exhibited less aggression and manipulation of pen mates with age, and became more focused on nosing objects and drank more. These results are only partly consistent with previous studies. For example, Day et al. (2008) reported a decrease a number of behaviours, including aggression, play fighting, nosing and straw-directed behaviours, over a 10 week period. Similarly, Lahrmann et al. (2015) reported that 40 kg pigs rooted and exhibited straw-directed behaviours more than 80 kg pigs (a 9 week period), and Bulens et al. (2015) found that growing pigs interacted less with straw dispensing applications over a two-week period. However, Lahrmann et al. (2015) found no effect of age on other behaviours such as feeding/drinking, pen mate-directed or aggressive behaviours. The effect of age on pig behaviour would, therefore, welcome greater clarity through replication attempts of some of the previous findings.

With respect to the differences between batches, there were more social contacts, lying/sleeping, nosing objects, and exploration in batch1 compared to batch 2, but less play, sitting/standing, eating, and aggression. Batch 1 data were collected between October and January, whereas batch 2 data were collected between February and June. As mentioned above, our model selection found that batch number alone was a better predictor than temperature for explaining behavioural variation. Thus, these results might be better explained by differences between seasons, which includes temperature but also humidity and sunshine duration. More detailed studies are required to understand inter-batch variation, requiring a larger number of batches than studied here.

5. Conclusions

The results of this study demonstrated that pig behaviour during the growing-fattening period were similarly expressed in the maize silage and in the combined maize silage and chopped straw treatments. Therefore, maize silage may provide an optimal material for maintaining pig welfare and the functioning of biofermenter systems. The placement of drinkers in the outside area compared to the inside and both inside and outside areas was found to be beneficial for pigs because it resulted in less oral manipulation of pen mates. We further confirmed previous reports that pigs were less aggressive and manipulated pen less mates with age. We suggest that further research focuses on other sources of behavioural variation, notably seasonal variation.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.applanim.2020.105043.

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