Determining feeder space allowance across feed forms and water availability in the feeder for growing-finishing pigs

Yuzhi Z. Li, BSc, MSc, PhD; Kimberly A. McDonald, BSc; Harold W. Gonyou, BSc, MSc, PhD

Summary

Objectives: To evaluate a method of determining the optimal feeder space allowance for pigs.

Materials and methods: Trial 1 used eight pens of 12 pigs to determine total eating time in pigs to estimate occupancy rates of a single-space feeder. Feed was provided in four combinations of feed form (mash versus pelleted) and water availability in the feeder (dry versus wet-dry). Eating behavior of pigs was video-recorded during both growing and finishing phases. Trial 2 used 560 pigs for the growing phase and 454 pigs for the finishing phase. Effects of feeder occupancy rate (< 80%, 95%, 110%, and 125% for the growing phase; 80%, 103%, and 125% for the finishing phase) on total eating time and growth performance were determined.

Results: Both feed form ($P < .01$) and water availability in the feeder ($P < .001$) affected total eating time and, consequently, feeder occupancy rate. Pigs spent more time eating a dry mash diet than any other diet by water combination during both growing ($P < .001$) and finishing ($P < .01$) phases. As feeder occupancy rate increased to above 80%, either eating time ($P < .05$) or growth performance ($P < .05$) decreased.

Implications: When testing levels of feeder space allowance and identifying the optimum, the designated number of pigs per feeder space should be determined according to feeder occupancy rates under different production settings. Optimal feeder space allowance should maintain both productivity and eating time of pigs.

Keywords: swine, eating behavior, feed form, feeder space

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Resumen - Determinar el espacio óptimo de comedero en base a las diferentes presentaciones de alimento y disponibilidad de agua del comedero para cerdos en crecimiento y finalización

Objetivos: Evaluar un método para determinar el espacio óptimo de comedero para cerdos.

Materiales y métodos: La prueba 1 utilizó ocho corrales de 12 cerdos para determinar el tiempo total de consumo de alimento en cerdos para valorar los índices de utilización de un comedero de una sola boca. El alimento se proveyó en cuatro combinaciones de forma de alimento (puré contra pellet) y la disponibilidad de agua en el comedero (seco contra seco-húmedo). Se video grabó la conducta de consumo de alimento de los cerdos durante las fases de crecimiento y finalización. La prueba 2 utilizó 560 cerdos para la fase de crecimiento y 454 cerdos para la fase de finalización. Se determinaron los efectos del tiempo de ocupación del comedero (< 80%, 95%, 110%, y 125% para la fase de crecimiento; 80%, 103%, y 125% para la fase de finalización), se determinó el tiempo total de consumo de alimento y desempeño de crecimiento.

Resultados: Tanto la presentación del alimento ($P < .01$), como la disponibilidad de agua en el comedero ($P < .001$) afectaron el tiempo total de consumo de alimento y, consecuentemente, el índice de ocupación del comedero. Los cerdos pasaron más tiempo consumiendo una dieta seca en puré que cualquier otra dieta por combinación de agua durante las fases de crecimiento ($P < .001$) y finalización ($P < .01$). Conforme aumentó el índice de ocupación del comedero a más de 80%, el tiempo de consumo de alimento ($P < .05$) o el desempeño del crecimiento ($P < .05$) disminuyeron.

Implicaciones: Cuando se prueben los niveles de disponibilidad de espacio del comedero para identificar el óptimo, el número de cerdos designados por comedero se debe determinar de acuerdo al tiempo de utilización y los escenarios de producción. El espacio óptimo de utilización debe mantener la productividad y el tiempo de consumo de alimento de los cerdos.

Résumé - Détermination de l'espace alloué à la mangeoire selon le type d'aliment et la disponibilité de l'eau dans la mangeoire pour des porcs en période de croissance-finition

Objectifs: Évaluer une méthode pour déterminer l'espace optimal à allouer aux porcs à la mangeoire.

Matériels et méthodes: Dans l'essai 1, huit enclos de 12 porcs ont été utilisés pour déterminer le temps total d'alimentation des porcs afin d'estimer les taux d'occupation de mangeoire à espace unique. L'aliment était fourni en quatre combinaisons de formes

YZL: West Central Research and Outreach Center, University of Minnesota, Morris, Minnesota.

KAM, HWG: Prairie Swine Center Inc, Saskatoon, Saskatchewan, Canada.

Corresponding author: Dr Yuzhi Z. Li, West Central Research and Outreach Center, University of Minnesota, 46352 State Hwy, Morris, MN 56267; Tel: 320-589-1711, ext 2125; Fax: 320-589-4870; E-mail: **yuzhili@umn.edu**. https://doi.org/10.54846/jshap/972

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(en pâté versus en granules) et de disponibilité d'eau dans la mangeoire (sec versus mouillé-sec). Le comportement des porcs s'alimentant était enregistré sur vidéo durant les phases de croissance et de finition. L'essai 2 a utilisé 560 porcs dans la phase de croissance et 454 porcs dans la période de finition. Les effets des taux d'occupation à la mangeoire (< 80%, 95%, 110%, et 125% pour la phase de croissance; 80%, 103%, et 125% pour la période de finition) sur le temps total d'alimentation et les performances de croissance ont été déterminés.

Résultats: La forme de l'aliment ($P < 0,01$) et la disponibilité de l'eau dans la mangeoire ($P < 0,001$) ont affecté le temps total d'alimentation et, par conséquent, les taux d'occupation à la mangeoire. Les porcs ont passé plus de temps à consommer une diète sèche en pâté que n'importe quelle autre combinaison de diète et d'eau autant durant la période de croissance ($P < 0,001$) que de finition ($P < 0,01$). À mesure que le taux d'occupation à la mangeoire augmentait au-dessus de 80%, il y avait une diminution soit du temps d'alimentation ($P < 0,05$) ou des performances de croissance ($P < 0,05$).

Implications: Lors de l'évaluation de l'espace à allouer à la mangeoire pour identifier ce qui serait optimum, le nombre de porcs par espace de mangeoire devrait être déterminé en fonction des taux d'occupation à la mangeoire sous différents paramètres de production. L'espace optimal à allouer à la mangeoire devrait voir à maintenir la productivité et le temps d'alimentation des porcs.

Optimal feeder space allowance should not only maintain performance and welfare of pigs, but should also achieve the maximal potential of the feeder. When attempting to determine optimal feeder space allowance, researchers have opted to assign arbitrary pig-to-feeder space ratios and concluded their findings exclusively on the basis of these selected ratios.[1,2] In fact, the maximum potential of a feeder, which is defined as the maximal number of pigs that can be fed from it, is primarily a reflection of the total amount of time that each pig needs to spend eating on a daily basis (total eating time). Many factors affect the amount of time needed for pigs to consume their feed,[3] such as feed form (mash versus pelleted),[4] availability of water in the feeder (dry versus wet-dry),[5,6] body weight and age,[7] and eating behavior[8,9] of the pigs. The optimal feeder space allowance, which is defined as the maximal number of pigs sharing one feeding space without reduction in performance and well-being of the pigs,[4,5] may vary with these influencing factors. Consequently, it is difficult for researchers to arbitrarily select pig-to-feeder-space ratios in order to identify the ideal ratio and the optimal feeder space allowance for pigs at different production settings. The "ideal way" to determine how many pigs can be fed from a single-space feeder is to keep increasing the number of pigs until it results in a drop in productivity or eating time. This type of testing is expensive and time consuming. However, if a standard test could be developed, it would prove to be invaluable for both researchers and producers. That is, researchers could employ the test to investigate optimal feeder space allowance for pigs under different production settings, and producers could perform the test on farm to determine the maximal potential of existing feeders. The goal of this study was to develop and validate such a standard test. It was hypothesized that pigs might change their total eating time as they grow, and with feed form and water availability in the feeder provided, consequently changing feeder occupancy rate (percentage of the cumulated time period that a feeder is occupied by pigs over a 24-hour period)[5] and optimal feeder space allowance. The objectives of this study were to determine total eating time in pigs fed mash or pelleted diets from feeders with or without a water source in the feeder (dry or wet-dry) during both growing and finishing phases; to estimate feeder occupancy rates on the basis of total eating time; and to evaluate effects of feeder occupancy rate on eating behavior and growth performance of pigs. Eventually, the optimal feeder space allowances that do not limit eating behavior, feed intake, or growth, while maintaining the maximum feeder occupancy rate, were estimated.

Materials and methods

The study was conducted on the 600-sow farrow-to-finish facility of the research farm of the Prairie Swine Center in Saskatoon, Saskatchewan, Canada. The University Committee of Animal Care and Supply of the University of Saskatchewan reviewed and approved the protocol for this study to ensure adherence to the guidelines of Canadian Council on Animal Care.[10]

Trial 1

The first trial was to determine the total amount of time that a single-space feeder is in use by small groups of pigs fed diets in different forms (mash versus pelleted) from feeders with or without a water source in the feeder (dry versus wet-dry). The data were extrapolated to estimate feeder occupancy rate for pigs that were provided with each combination of feed form and water availability in the feeder. Ninety-six pigs (body weight mean ± standard deviation [SD] 21.4 ± 2.40 kg; PIC Canada Ltd, Winnipeg, Manitoba) were weighed individually, sorted, and assigned to eight pens on fully slatted floors, each pen providing 12.2 m^2 (1.0 m^2 per pig), excluding space occupied by the feeder. Pigs were randomly allotted (by random number generator) within sex and weight categories such that each pen housed six barrows and six gilts, and the average weight and variation in weight within each pen were similar. Two pens were then randomly assigned (by random number generator) to each of four treatment combinations: mash diets fed from a dry feeder (DM), mash diets fed from a wet-dry feeder (WM), pelleted diets fed from a dry feeder (DP), and pelleted diets fed from a wet-dry feeder (WP). Both the dry and wet-dry feeders were single-space, shelf-type feeders (Crystal Spring, Model # F2000; St Agatha, Manitoba, Canada) for growing-finishing pigs, as described by Gonyou and Lou.[5,11] The dry feeders had the same design as the wet-dry feeders except that there was no nipple drinker in the dry feeder. Both the dry and wet-dry feeders provided feed access, by means of gravity, on a shelf approximately 25 cm above the feeder pan. The area of the feeder pan measured 38 cm × 38 cm for all feeders. Pigs had ad libitum access to a barley- and soybean-meal-based diet in a two-phase feeding program formulated according to National Research Council (NRC) standards.[12] For the initial 6 weeks of the trial (growing phase; initial weight [± SD] = 21.4 ± 2.40 kg, end weight = 59.4 ± 4.91 kg), the diet was formulated to contain 3.26 Mcal digestible energy (DE) per kg and 16.8% crude protein (CP). The diet for the second phase (finishing phase; initial weight = 59.4 ± 4.91 kg, final weight = 100.0 ± 9.66 kg) was formulated to contain 3.21 Mcal DE per kg and 16.1% CP. Pens with a dry feeder had one nipple drinker on the wall opposite the feeder. For pens with a wet-dry feeder, the only source of water was one water nipple located in the feeder, and no additional drinker was provided. Pigs were housed in the same mechanically ventilated room. Temperature in the room was controlled to the thermoneutral zones for pigs.[13] Light period was 12 hours daily. Room temperature, feeders, drinkers, and animal health were checked twice daily, in the morning and afternoon. Feed added to the feeders was recorded on a pen basis. Remaining feed and individual pigs in each pen were weighed every 2 weeks, from which average daily gain (ADG) and average daily feed intake (ADFI) were calculated. When pigs were removed from the trial, the date and reason for removal were recorded.

When pigs weighed between 35 and 45 kg during the growing phase, the feeder area in each pen was video-recorded for two consecutive 24-hour periods. Within each pen, pigs' activities were video-recorded by two cameras (Panasonic WV-BP120; Osaka, Japan) installed above the feeder, a quad input device (Panasonic WJ-410), and a time-lapse recorder (Panasonic AG-6730; recording 10 images per second). A second set of video recordings was taken for two consecutive 24-hour periods in the finishing phase, when the pigs weighed between 90 and 100 kg, to determine the effect of pig size on time spent eating and to determine whether this effect was consistent across the treatments. During video-recording periods, the normal lighting schedule was maintained; however, supplemental low-level light (a 40-watt light bulb) was used to illuminate the feeder area to assist video-recording. The video-recordings were analyzed using instantaneous sampling at 5-minute intervals in order to determine time spent eating.[13] All data were summarized and expressed as total eating time per day per pig.[14] Eating was defined as a pig having its head in the feeder.[5] Eating rate was calculated for each pen on the basis of ADFI and total eating time.

Table 1 (Trial 1): Total eating time and estimated feeder occupancy rate of growing and finishing pigs when eating different forms of feed (mash versus pelleted) from single-space feeders with or without presence of water in the feeder (dry versus wet-dry feeders)*

	Mash		Pellets		
	Dry	Wet-dry	Dry	Wet-dry	SEM
No. pens	2	2	2	2	NA
No. pigs per pen	12	12	12	12	NA
Total eating time (min/pig/d)†					
Growing pigs‡	106.5	72.5	75.9	78.6	4.6
Finishing pigs§	105.7	63.5	65.2	64.6	4.6
Estimated feeder occupancy rate (%)¶					
Growing pigs‡	88.8	60.4	63.3	65.5	3.8
Finishing pigs§	88.1	52.9	54.3	53.8	3.8

* Pigs in each pen were video-recorded for two consecutive 24-hour periods.
† Total amount of time that a pig spent eating (defined as a pig having its head in the feeder) over a 24-hour period.
‡ Growing pigs weighed 35 to 45 kg.
§ Finishing pigs weighed 90 to 100 kg.
¶ Percent of the time that the feeder was expected to be used by pigs daily to consume the amount of feed that maximized growth performance, calculated using the equation feeder occupancy rate (%) = (number of pigs × total eating time (min/day/pig) ÷ (1440 min/d × 100%).
SEM = standard error of the mean; NA = not applicable, descriptive variables; min = minute(s); d = day.

Trial 2

Using the behavior data collected from Trial 1 (Table 1), the number of pigs required to create various levels of feeder occupancy rate under each previously outlined feeding condition was calculated. Feeder occupancy rates were estimated using the equation

$$\text{Feeder occupancy rate (\%)} = \text{number of pigs in the pen} \times \text{total eating time (minutes per pig per day)} \div (24 \text{ hours} \times 60 \text{ minutes}) \times 100\%$$

The feeder occupancy rate was defined as 100% when the feeder was expected to be used 24 hours a day by the pigs. In other words, 100% feeder occupancy rate means that the single-space feeder was occupied by a pig at any given time over a 24-hour period. During the growing phase, the lowest level of feeder stocking capacity was maintained at 12 pigs per feeder (referred to as the "standard feeder occupancy rate" (Table 2) for all combinations of feed form and water availability in the feeder, in order to verify results from Trial 1. This standard occupancy rate was equivalent to approximately 88%, 60%, 63%, and 65% feeder occupancy rate for DM, WM, DP, and WP diet treatments, respectively. In addition to the standard occupancy rate, three feeder occupancy rates of approximately 95%, 110%, and 125% for each combination of feed form and water availability were included to evaluate the optimal feeder space allowance during the growing phase. During the finishing phase, feeder occupancy rates were reduced to approximately 80%, 103%, and 125% for the DM, WM, and DP treatments due to barn space restrictions. For the same reason, only feeder occupancy rates of 80% and 125% were represented in the WP treatment. Feeder occupancy rates exceeding 100% were tested in anticipation that pigs would, to some degree, adapt to feeder crowding by eating faster, and to ensure that the highest occupancy rates would result in reduced productivity. During the finishing phase, all combinations of feed form and water availability in the feeder included a feeder occupancy rate of 80%, allowing a comparison of feed form and water availability in the feeder treatments under uncrowded feeding condition.[5] Table 2 outlines the number of pigs used to generate estimated feeder occupancy rates for each combination of feed form and water availability in the feeder during both growing and finishing phases. Pigs were from the same source as for Trial 1.

To evaluate effect of feeder occupancy rate on eating behavior and growth performance of pigs, two identical grower-finisher rooms were used for Trial 2, with each treatment combination represented in both rooms. The rooms had fully slatted floors, were mechanically ventilated to achieve thermoneutral conditions, and were managed as in Trial 1. Pen size varied with the number of pigs in the pen such that each pig had the same floor space allowance. Floor space allowance was calculated on the basis of the predicted final weight of the pigs in that growth phase using this equation:

$$\text{Floor area } (m^2) = 0.035 \times \text{BW (kg)}^{0.667}$$

The resulting floor space allowance was 0.54 m^2 and 0.76 m^2 per pig for the growing

Table 2 (Trial 2): No. of pigs per single-space feeder for estimated feeder occupancy rate when feed was offered in different forms (mash versus pelleted) from feeders with or without presence of water in the feeder (dry versus wet-dry)

	Mash		Pellets	
Estimated feeder occupancy rate (%)*	**Dry**	**Wet-dry**	**Dry**	**Wet-dry**
Growing pigs (No. of pigs per pen)				
Standard†	12	12	12	12
95	13	19	18	17
110	15	22	21	20
125	17	25	24	23
Finishing pigs (No. of pigs per pen)				
80	11	18	18	18
103	14	23	23	ND
125	18	28	28	28

* Percent of the time that the feeder was expected to be used by pigs daily to consume the amount of feed that maximized growth performance was calculated using the equation occupancy rate (%) = (number of pigs × total eating time (min/d/pig) ÷ 1440 min/d × 100%), where total eating time was defined as the pig having its head in the feeder. The estimated feeder occupancy rate was defined as 100% when the feeder was expected to be used all the time by pigs in a pen under uncrowded feeding conditions or when feeder access was deemed to not be limiting.

† The standard group was designed to validate results of Trial 1 using group size of 12 pigs per single-space feeder. The estimated feeder occupancy rate was 88%, 60%, 63%, and 65% for pigs fed with dry mash, wet-dry mash, dry pelleted, and wet-dry pelleted diets, respectively.

ND = Not done due to restrictions of barn space.

and finishing phases, respectively. Feeders were the same as those used in Trial 1. As in Trial 1, pens with a wet-dry feeder had one water nipple in the feeder as their only water source, while pens with a dry feeder were equipped with two nipple drinkers located on the opposite side of the pen from the feeder. Feed formulation was the same as in Trial 1 and remained consistent across treatments.

Five hundred and sixty pigs (21.3 ± 3.43 kg) without visible signs of compromised health were randomly assigned (by random number generator) within sex and weight categories, such that the average weight and variation in weight within each pen were similar at the beginning of the growing phase. The numbers of barrows and gilts within a pen were equal when total pig number was even, or differed by one when total number was odd. Two pens were randomly assigned (by random number generator) to each treatment combination (feeder occupancy rate × feed form × water availability in the feeder) for both growing and finishing phases. Pigs remained in the growing phase for 6 weeks. The pigs were then weighed individually and sorted by sex and weight. Among them, 454 pigs (60.6 ± 7.14 kg) without obvious signs of compromised health were selected for data collection in the finishing phase. These pigs were allocated randomly (using a random number generator) within sex and weight categories to each treatment pen without consideration of previous treatment during the growing phase. The treatments for the finishing phase were continued for only 4 weeks (final weight of pigs = 92.8 ± 9.66 kg) due to restrictions of barn space. Feed was weighed as it was added to the feeders on a pen basis. Individual pigs and any remaining feed in each pen were weighed every 3 weeks during the growing phase and every 2 weeks during the finishing phase.

During the growing phase, when pigs reached between 35 and 45 kg, all feeders were video-recorded for two consecutive 24-hour periods, as in Trial 1. During the third week of the finishing phase, when the pigs weighed between 75 and 85 kg, feeders were again video-recorded for two consecutive 24-hour periods. As in Trial 1, video recordings were analyzed using instantaneous sampling at 5-minute intervals in order to determine total eating time.

Data analysis

All data were analyzed using mixed linear regression and using the Mixed and Glimmix procedures of SAS (SAS Institute Inc, Cary, North Carolina), with pen as the experimental unit. Two separate analyses were conducted. The first analysis examined effects of feed form and water availability in the feeder on total eating time of pigs under the standard (growing phase) or 80% capacity (finishing phase). For this purpose, data from both Trial 1 and Trial 2 were used. For the growing phase, all pens containing 12 pigs were included in the analysis. For the finishing phase, the data from pens containing 12 pigs in Trial 1 and pens with 80% feeder stocking capacity in Trial 2 were used. Initial analyses were conducted to compare differences in eating behavior and growth performance between the two trials. No significant differences were detected (all $P > .10$), and the data from the two trials were combined. The model included feed form, water availability in the feeder, and their interaction as fixed effects, with trial and room serving as random effects. The second analysis was conducted to evaluate the effect of feeder occupancy rate on pigs under each combination of feed form and water availability in the feeder. In this case, only data from Trial 2 were used. The same model, but separate analyses, were conducted for the growing and finishing phases, respectively. The model included feeder occupancy rate, feed form, water availability in the feeder, and their interactions as fixed effects, with room as the random effect. Differences between means were tested by PDIFF using a Tukey test with adjustment for multiple comparisons. Significant differences were identified at $P < .05$ and trends at $P < .10$.

Results

A total of three pigs from three pens were removed from Trial 1, and 15 pigs from 12 pens were removed from Trial 2 due to compromised health, with no more than two pigs removed per pen. There was no evidence that the number of pigs removed from the study was associated with feed form, water availability in the feeder, or feeder stocking-capacity treatments.

Effects of feed form and water availability in the feeder

Growing phase (body weight 20 to 60 kg). There was an interactive effect of feed form by water availability in the feeder on ADG ($P < .01$; Table 3). Pigs fed DM diets gained less weight than pigs on any other treatment combination. Pigs using a wet-dry feeder had better gains than those using a dry feeder ($P < .001$). There was no effect of feed form on ADG. Both feed form and water availability in the feeder affected ADFI, with pigs fed mash diets having higher ADFI ($P < .01$) than pigs fed pelleted diets, and pigs using wet-dry feeders having higher ADFI ($P < .01$) than pigs using dry feeders. There was an interactive effect between feed form and water availability in the feeder ($P < .05$) on ADFI, with pigs fed WM diets having higher intake than pigs on any other treatment. Pigs fed pelleted diets had better gain:feed than pigs fed mash diets ($P < .05$). Water availability in the feeder did not affect feed efficiency. In general, pigs fed mash diets spent more time eating than those fed pelleted diets ($P < .01$). Additionally, pigs using a dry versus wet-dry feeder had longer total eating time ($P < .001$). The primary source of variation was attributable to the interactive effect between feed form and water availability in the feeder ($P < .001$), with pigs fed DM diets spending more time eating than those on any other treatment combination. Pigs using a wet-dry feeder ate faster than those using a dry feeder ($P < .001$). Again, the primary source of variation was attributable to the interactive effect between feed form and water availability in the feeder ($P < .001$), with pigs fed DM diets having the lowest eating rate and pigs fed WM diets having the highest eating rate.

Finishing phase (body weight 60 to 100 kg). Pigs using a wet-dry feeder had higher ADG ($P < .01$; Table 3) than those using a dry feeder. Feed form did not affect ADG, and there was no interaction between feed form and water availability in the feeder. Pigs fed mash diets had greater ADFI ($P < .05$) than those fed pelleted diets. Additionally, pigs using a wet-dry feeder had greater ADFI ($P < .01$) than those using a dry feeder. Pigs fed pelleted diets had better gain:feed ($P < .05$) than pigs fed mash diets. Water availability in the feeder did not affect feed efficiency, and there were no interactive effects of feed form and water availability in the feeder on feed efficiency. Pigs fed DM diets had longer total eating time ($P < .001$) and ate more slowly ($P < .001$) than pigs on any other treatment. In general, pigs fed mash diets spent more time eating ($P < .001$) than those fed pelleted diets; and pigs using a dry feeder had longer total eating time

Table 3 (Trial 1 and Trial 2): Effect of feed form (mash versus pelleted) and water availability in the feeder (dry versus wet-dry) on performance and eating behavior of pigs using single-space feeders*

	Mash		Pellets			*P*		
Parameter	**Dry**	**Wet-dry**	**Dry**	**Wet-dry**	**SEM**	**Form†**	**Water availability‡**	**Interaction**
Growers								
No. pens	**4**	**4**	**4**	**4**	**NA**	**NA**	**NA**	**NA**
ADG (kg)	0.771[b]	0.848[a]	0.812[a]	0.825[a]	0.023	.35	< .001	< .01
ADFI (kg)	2.11[b]	2.37[a]	2.08[b]	2.16[b]	0.055	< .01	< .01	.04
Gain:feed	0.369[b]	0.363[b]	0.393[a]	0.387[a]	0.035	.02	.48	.98
TET (min/pig/day)	106.9[a]	71.6[b]	81.8[b]	79.3[b]	2.85	< .01	< .001	< .001
ER (g/pig/minute)	19.7[c]	33.4[a]	25.9[b]	27.2[b]	3.71	.99	< .001	< .001
Finishers								
No. pens	**4**	**4**	**4**	**4**	**NA**	**NA**	**NA**	**NA**
ADG (kg)	0.837[c]	0.924[ab]	0.882[b]	0.957[a]	0.047	.14	< .01	.81
ADFI (kg)	2.73[b]	3.06[a]	2.64[b]	2.79[b]	0.100	.03	< .01	.22
Gain:feed	0.307[b]	0.303[b]	0.334[a]	0.346[a]	0.025	.02	.79	.55
TET (min/pig/day)	106.5[a]	66.6[b]	67.0[b]	65.1[b]	2.98	< .001	< .001	< .001
ER (g/pig/min)	25.6[b]	46.7[a]	39.5[a]	43.4[a]	3.14	.06	< .001	< .01

* Data were derived from 12 pigs/feeder in both Trial 1 and Trial 2 for the growing phase, and 12 pigs/feeder in Trial 1 and 80% feeder occupancy rate in Trial 2 for the finishing phase.

† Mash versus pelleted feed.

‡ Dry versus wet-dry feeders.

SEM = standard error of the mean; ADG = average daily gain; ADFI = average daily feed intake; gain:feed = weight gain per unit of feed intake; TET = total eating time of pigs, referring to total amount of time that pigs spent eating daily; ER = eating rate of pigs, based on ADFI and TET; min = minute(s); NA = not applicable, descriptive variables.

abcd Means within a row with no common superscript differ (Tukey tests adjusted for multiple comparisons; $P < .05$).

($P < .001$) than those using a wet-dry feeder. Pigs using a wet-dry feeder ate faster ($P < .001$) than those using a dry feeder; and pigs fed pelleted diets tended ($P < .10$) to eat faster than pigs fed mash diets. The primary source of variation was attributable to the interactive effect between feed form and water availability in the feeder.

Effects of feeder occupancy rate, feed form, and water availability in the feeder

The *P* values for effects of feeder occupancy rate, feed form, and water availability in the feeder for both the growing and finishing phases are presented in Table 4.

Growing phase. Across feed form and water availability in the feeder combinations, an increase in feeder occupancy rate led to a decrease in ADG ($P < .001$; Table 5). Feeder occupancy rate interacted with water availability in the feeder to influence ADG ($P < .05$; Table 4). Pigs using wet-dry feeders had a larger decrease in ADG (from 0.812 kg at 80% feeder occupancy rate to 0.680 kg at 125% feeder occupancy rate, SEM (standard error of the mean) = 0.013; $P < .001$) than those using dry feeders (from 0.773 kg at 80% feeder occupancy rate to 0.707 kg at 125% feeder occupancy rate, SEM = 0.013; $P < .05$) as feeder occupancy rate increased. There was no interactive effect of feeder occupancy rate and feed form on ADG.

Overall, ADFI decreased when feeder occupancy rate increased from 80% to 125% ($P < .001$; Table 5). There was no interactive effect of feeder occupancy rate and feed form or water availability in the feeder on ADFI. Feeder occupancy rate did not affect gain:feed, and there was no interactive effect of feeder occupancy rate and feed form or water availability in the feeder on feed efficiency.

As feeder occupancy rate increased, total eating time decreased ($P < .001$; Table 5). Feeder occupancy rate did not interact with feed form, but tended to interact with water availability in the feeder ($P < .10$; Table 4) with an effect on total eating time. Pigs using dry feeders tended to have a larger reduction in total eating time than pigs using wet-dry feeders as feeder occupancy rate increased. An increase in feeder occupancy rate tended ($P < .10$) to increase eating rate. There was no interaction of feeder occupancy rate with feed form or water availability in the feeder.

Finishing phase. Across feed forms and water availability in the feeder, ADG decreased when feeder occupancy rate increased ($P < .001$; Table 5). Feeder occupancy rate interacted with water availability in the feeder ($P < .01$; Table 4) to influence ADG. As feeder occupancy rate increased, pigs using wet-dry feeders had a larger reduction in ADG (0.989,[a] 0.653,[b] and 0.608[b] kg at 80%, 103%, and 125% feeder occupancy rate, respectively, SEM = 0.029; $P < .001$) than those using dry feeders (0.893,[a] 0.835,[ab] and 0.726[b] kg at 80%, 103%, and 125% feeder occupancy rate, respectively, SEM = 0.029; $P < .01$; means with no common superscript differ).

Across feed form and water availability in the feeder combinations, ADFI decreased ($P < .001$; Table 5) as feeder occupancy rate increased. Feeder occupancy rate tended ($P = .052$; Table 4) to interact with feed form to influence ADFI, with pigs fed mash diets tending to have a larger reduction in ADFI than pigs fed pelleted diets as feeder occupancy rate increased. Feed efficiency was not affected by feeder occupancy rate.

Total eating time decreased ($P < .001$; Table 5) as feeder occupancy rate increased across feed forms and water availability in the feeder. Feeder occupancy rate interacted ($P < .05$; Table 4) with feed form. Pigs fed mash diets had a larger decrease in total eating time than pigs fed pelleted diets as feeder occupancy rate increased. Feeder occupancy rate tended ($P = .051$) to interact with water availability in the feeder to influence total eating time. As feeder occupancy rate increased,

Table 4 (Trial 2): *P* values derived from data analyzed using mixed linear regression for effects of feeder occupancy rate, feed form, and water availability in the feeder on performance and eating behavior of pigs using single-space feeders

Parameter	Occupancy*	Form†	Water availability‡	Occupancy × form	Occupancy × water availability
Growing pigs					
ADG (kg)	< .001	.25	.06	.95	.04
ADFI (kg)	< .001	.08	< .01	.71	.89
Gain:feed	.60	< .01	.053	.74	.13
TET (min/pig/day)	< .001	< .001	< .001	.16	.09
ER (g/pig/min)	.08	.07	< .001	.24	.73
Finishing pigs					
ADG (kg)	< .001	< .01	.16	.14	< .01
ADFI (kg)	< .001	.42	.31	.052	.12
Gain:feed	.57	.12	.39	.44	.29
TET (min/pig/day)	< .01	< .001	< .001	.04	.051
ER (g/pig/minute)	.55	< .001	< .01	.06	.16

* Percent of the time that the feeder was expected to be used by pigs according to total eating time under uncrowded conditions.
† Mash versus pelleted feed.
‡ Dry versus wet-dry feeders.
ADG = average daily gain; ADFI = average daily feed intake; gain:feed = weight gain per unit of feed intake; TET = total eating time of pigs, which refers to total amount of time that pigs spent eating daily; ER = eating rate of pigs, which was based on ADFI and TET; min = minute(s); d = day.

Table 5 (Trial 2): Effect of feeder occupancy rate across feed form and water availability in the feeder on performance and eating behavior of pigs using single-space feeders

	Feeder occupancy rate (%)*					
Parameter	**STD**	**95**	**110**	**125**	**SEM**	***P***
Growing pigs						
No. pens†	8	8	8	8	NA	NA
ADG (kg)	0.793[a]	0.775[a]	0.737[b]	0.693[c]	0.013	< .001
ADFI (kg)	1.92[a]	1.83[ab]	1.76[bc]	1.65[c]	0.045	< .001
Gain:feed	0.414	0.424	0.420	0.422	0.008	.60
TET (min/pig/day)	86.4[a]	79.3[b]	73.7[c]	65.2[d]	1.81	< .001
ER (g/pig/minute)	23.0[f]	23.7[ef]	24.5[ef]	26.0[e]	1.28	.08
	Feeder occupancy rate (%)*					
Parameter	**80**	**103**		**125**	**NA**	**NA**
Finishing pigs						
No. pens†	8	6		8	NA	NA
ADG (kg)‡	0.941 ± 0.039[a]	0.778 ± 0.047[b]		0.667 ± 0.039[b]	NA	< .001
ADFI (kg)	2.72 ± 0.14[a]	2.30 ± 0.15[b]		2.14 ± 0.14[b]	NA	< .001
Gain:feed	0.342 ± 0.027	0.341 ± 0.029		0.324 ± 0.027	NA	.57
TET (min/pig/day)	77.8 ± 3.48[a]	67.9 ± 4.16[ab]		57.9 ± 3.48[b]	NA	< .01
ER (g/pig/minute)	36.4 ± 2.2	35.2 ± 2.5		38 ± 2.2	NA	.55

* Percent of the time that the feeder was expected to be used by pigs according to total eating time under uncrowded conditions.
† No. of pigs per pen for each feeder stocking capacity; described in Table 2.
‡ Mean ± standard error of the mean (SEM).
NA = not applicable; STD = standard group size (12 pigs per single-space feeder, regardless of feed form or feeder design); ADG = average daily gain; ADFI = average daily feed intake; gain:feed = weight gain per unit of feed intake; TET = total eating time of pigs, referring to total amount of time that pigs spent eating daily; ER = eating rate of pigs, calculation based on ADFI and TET.
[abcd] Means within a row with no common superscript differ (Tukey test adjusted for multiple comparisons; $P < .05$).
[ef] Means within a row with no common superscript tend to differ (Tukey test adjusted for multiple comparisons; $P < .10$).

pigs using dry feeders tended to have a larger decrease in total eating time than pigs using wet-dry feeders. Feeder occupancy rate did not affect eating rate in finishing pigs.

Discussion

In this study, we explored a novel method of determination of feeder space allowance for pigs. This method emphasizes that, in order for researchers to identify the optimal feeder space allowance, the treatment levels of feeder space to be examined should be based on the eating behavior of the pigs, and then feeder occupancy rate can be determined. Eating behavior can be determined using small groups of pigs under uncrowded feeding conditions. On the basis of results of previous studies,[1,5,7] 12 pigs eating from a single-space feeder were chosen for the uncrowded feeding condition. Gonyou and Lou[5] demonstrated that there was no difference in growth performance when 12 pigs were fed from a single-space dry feeder versus a single-space wet-dry feeder, or from a single-space feeder versus a double-space feeder. Likewise, Hyun and Ellis[1,7] reported that there was no difference in growth performance between eight pigs and 12 pigs fed from a single-space feeder. Hyun and Ellis[1,7] also demonstrated that when 12 pigs were fed mash diets from a dry feeder, they occupied the feeder 83% of the time during the growing period, and 74% of the time during the finishing period. Pigs may spend less time eating and have a lower occupancy rate of the feeder when provided pelleted wet-dry diets than when provided dry mash diets. As a result, the uncrowded feeding condition was designed at approximately 80% or lower feeder occupancy rate across feed form and feeder design treatments in this study. Accordingly, both 12 pigs per single-space feeder and 80% feeder occupancy rate were considered uncrowded feeding conditions.

The interactive effect of feed form and water availability in the feeder on eating behavior and growth performance were determined during both growing and finishing phases. The performance data were consistent with previous findings[3,6,15] that pigs fed from wet-dry feeders had higher ADG and ADFI than did those fed from dry feeders. By testing a wide variety of feeders, Gonyou and Lou[5] found that wet-dry feeders consistently produced pigs with higher ADG and ADFI than dry feeders, indicating the improved productivity was likely due to the provision of water at the feeder. Bergstrom et al[16] demonstrated that the benefit of wet-dry feeders to improve ADG in pigs was diminished when the same wet-dry feeders were used as dry feeders (water source removed). An interactive effect between feed form and water availability in the feeder on ADG and ADFI in growing pigs was observed in the current study, that is, wet-dry feeders increased ADG and ADFI when pigs were fed mash diets, but not when pigs were fed pelleted diets. This interaction could be attributable to several

factors. One factor could be the increased feed wastage by pigs fed a dry mash diet.[17] When feeding a mash diet, water consumption is much higher than when feeding a pelleted diet from a dry feeder,[4] and the pigs would have to interrupt feeding more often in order to drink.[18] This interrupted feeding leads to an increase in the number of times the pig enters and exits the feeder, increasing the chance of more feed being wasted. In contrast, a wet-dry feeder allows pigs to either mix feed with water before eating (the water thereby acting as a lubricant) or drink while eating at the feeder because water is at the feed source.
Either way, this will decrease feed wastage and the number of times that the pig must exit the feeder.[5,19] A pelleted diet, even fed from a dry feeder, presumably does not become as sticky, according to our on-farm observations, so the pig is more likely to eat without having to interrupt its meal with many drinks, decreasing the total time required for eating and decreasing feed wastage and the number of feeder exits.

The current study demonstrated that both feed form and water availability in the feeder affected total eating time, and consequently, feeder occupancy rate. Pigs fed mash diets spent more time eating than did pigs fed pelleted diets. The provision of water at the feeder reduced total eating time, especially in pigs fed mash diets. In agreement with our results, Laitat et al[4] noted that pigs fed a dry pelleted diet had shorter total eating time than did those fed a dry mash diet. Gonyou and Lou[5] reported a 17% decrease in total eating time when water was made available at the feeder and mash diets were fed. In agreement with Laitat et al,[4] results of the current study suggested that water availability at the feeder had more impact on eating time when pigs were fed mash diets rather than pelleted diets. With this information and the data from the current study, it can be inferred that when pelleted diets are fed, eating behavior is less influenced by the presence of water within the feeder than when mash diets are fed. The possible reasons for this are similar to the rationale for changes in productivity. That is, the stickiness of the mash diet necessitates an increase in water consumption, thereby adding time to the meal by increasing the number of intra-meal intervals. When water is provided at the feeder, intra-meal intervals would be dramatically decreased when a mash diet is fed. The fact that consumption of pelleted diets requires less water likely shortens total eating time by decreasing the number of visits to the feeder required to finish a single meal. It is also true that pigs can consume dry pelleted diets at a faster rate than dry mash diets, and these effects may be additive. So if pigs can eat pelleted diets faster without requiring frequent water breaks, it would seem to follow that the dramatic effect of a wet-dry feeder on mash diets would not be seen when a pelleted diet is fed.

Due to these effects on total eating time, the number of pigs needed to generate a designated level of feeder space allowance differs depending on the feed form and water availability in the feeder. For example, according to results of this study, 11 finishing pigs will be needed to generate 80% feeder occupancy rate for a single-space feeder when DM diets are fed, whereas 18 pigs will be needed when WM diets are fed. In addition, since pigs spent more time eating DM diets, increasing the number of pigs per feeder space will result in a dramatic increase in feeder occupancy rate, compared with that when pigs are eating other diets. Using the traditional method of assigning fixed pig-to-feeder-space ratios to evaluate feeder space allowance when pigs are eating different forms of feed from feeders with or without presence of water in the feeder will result in differences in feeder occupancy rate, which consequently may change the eating behavior of the pigs and might result in misleading conclusions. In contrast, the method explored in this study suggests that different pig-to-feeder-space ratios should be based on the feed form and water availability in the feeder.

This study further confirmed that pigs eat faster as they grow.[5] Although finishing pigs had higher ADFI, they spent a similar or shorter time eating, depending on the feed form and water availability in the feeder, than is spent by growing pigs. As a result, depending on feed form and water availability in the feeder, 17 to 25 pigs were needed during the growing phase, whereas 18 to 28 pigs were needed during the finishing phase, to design 125% feeder occupancy rate in the current study. By using designed levels of feeder occupancy rate instead of a set number of pigs per feeder space, the extent to which pigs could adapt their eating patterns to crowding at the feeder and the influence of feed form and water availability in the feeder on this ability could be examined.

Across all feed forms and water availability in the feeder treatments, ADG was greatly reduced during both growing and finishing phases as feeder occupancy rate increased. However, pigs fed different forms of feed from feeders with or without water source in the feeder responded differently to the increase in feeder occupancy rate. In general, pigs fed WM diets showed the greatest response, followed by pigs fed WP diets during both growing and finishing phases. In contrast, pigs fed DM diets were not significantly affected by an increase in feeder occupancy. It is possible that, while the estimated feeder occupancy rate remained the same, small group sizes for the dry mash treatment allowed these pigs to be more flexible in modifying their eating behavior to maintain growth performance. This is supported by the fact that, in the current study, although total eating time decreased significantly regardless of feed form or water availability in the feeder, a pig fed a DM diet at 125% feeder occupancy rate still spent approximately 25 minutes per day longer eating than did pigs on any other treatment at the same feeder occupancy rate. Nielsen et al[20] found that pigs stocked at 5, 10, 15, or 20 per feeder space and fed a dry mash diet had remarkably different eating behaviors, such as the number of feeder visits, duration of feeder visits, and diurnal patterns of feeder visits, but they had similar growth performance, such as ADFI, ADG, and feed efficiency. These results suggest that pigs may be able to adapt their eating behavior to feeder occupancy rate and maintain growth performance when there are not many pigs for each feeder space. However, the number of pigs per feeder space may have been limited in the previous study[20] and larger numbers of pigs per feeder space may subject pigs to more limitations that restrict their adaptability to increased feeder occupancy. In other words, with a large number of pigs sharing a single feeding space, not all pigs may gain access to the feeder or achieve desired feed intake. That might be why a dramatic decrease in ADG was observed in pigs fed other diets, but not a DM diet. Regardless of the interaction between feed form and water availability in the feeder, pigs tended to perform better when feeder occupancy rate was maintained lower than 100%. In addition, in the current study, across all combinations of feed form and water availability in the feeder, total eating time tended to decrease when feeder occupancy rate reached above 80%, indicating that pigs were not given enough time to eat. These results suggest that pigs have limited ability to adapt their eating behavior to high occupancy rates of the feeder in order to maintain feed intake and growth. This is further supported by the eating-rate data from the current study. As feeder occupancy rate increased, increases in eating rate were not significant, regardless of feed form or water availability in the feeder. Collectively, results of the current study suggest that an 80% feeder occupancy rate should be recommended to maintain both growth performance and welfare of pigs, regardless of the size of pigs, feed form, or feeder design.

Implications

- Under the conditions of this study, when testing levels of feeder space allowance and identifying the optimum, the designated number of pigs per feeder space should be determined according to the eating behavior of the pigs and the feeder occupancy rate under different production settings.
- Both feed form and water availability within the feeder affect eating behavior, and consequently, affect feeder occupancy rate.
- To maintain growth performance and allow enough time for pigs to eat their desired amount of feed, 80% feeder occupancy rate is recommended for pigs during both growing and finishing phases.

Conflict of interest

None reported.

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