RESEARCH REPORT

NPB FINAL RESEARCH GRANT REPORT

Project Title and NPB project identification number: Evaluation of late finishing space allowance and marketing strategy and the strategic use of hyper-doses of phytase to improve production performance and profits - NPB #21-096

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Industry Summary
Available floor space allowance per unit of pig body weight is an important consideration to optimize growth performance, especially during the late-finishing stage, and when pigs are at heavy marketing weights. Our previous studies suggested that the supplementation of high levels of phytase positively impacted performance of pigs, most notably during the final finishing stages. We speculated that high levels of phytase (above super-dosing levels) could improve growth performance of late finishing pigs housed under crowded conditions and that this improvement could be related, in part, to the nearly complete destruction of the anti-nutrient phytate and the associated increase in inositol. This project was designed to evaluate the impacts that hyper-dosing levels of phytase (defined here as 4,500 to 5,000 FTU/kg of feed) on growth performance, carcass characteristics, and serum chemistry of late-finishing pigs housed under space restriction or marketed using two different marketing strategies. Three studies were conducted using 375, 2,200, and 17,862 finishing pigs for study 1, 2, and 3, respectively. Phytase supplementation at 4,500 to 5,000 FTU/kg compared to the standard of 2,250 to 2,500 FTU/kg did not improve growth performance or carcass quality, regardless of floor space allowance or marketing strategy. Reducing floor space allowance from 0.85 to 0.64 m^2 reduced final body weight, average daily gain, and feed intake, but did not impact feed efficiency. Considering that more pigs can be placed per pen at the reduced space allowance, there is a financial advantage for space restricted pigs, in spite of the reduction in body weight associated with reduced space. This advantage is less pronounced when feed cost is low and pig prices are high. Similarly, altering marketing strategy by holding the first marketing cut in the pens for a longer period of time was advantageous in a commercial research study in spite of prolonging the total time to market by an average of 3 days per pig. Collectively, these studies demonstrate that space allowance and marketing strategy are important determinants of net profit and that hyper-dosing of phytase did not have an impact on pig performance or carcass quality, regardless of marketing approach.

Key Findings:

- Restricted floor space allowance reduced body weight, growth rate, and feed intake of late finishing pigs and hyper-dosing of phytase at 5,000 FTU/kg of feed compared to super-dosing phytase at 2,500 FTU/kg was not an effective strategy in improving growth performance, regardless of space allowance.
- In two commercial studies (2,200 and 17,862 pigs, respectively), hyper-dosing of phytase at 4,500 FTU/kg compared to 2,250 FTU/kg was not an effective strategy in improving growth performance or carcass quality of late finishing pigs.
- Floor space restriction (0.85 vs. 0.64 m^2) reduced growth performance, but the ability to house more pigs in a pen is economically advantageous in most price scenarios,, except when pig prices are high and feed costs are low.
- Altering marketing strategy by delaying the first marketing cut in the pens for a longer period of time (22 days in our study) was economically advantageous in spite of prolonging the total time to market by an average of 3 days per pig.

Key Words: Finishing Pigs, Floor Space, Hyper-dosing, Phytase, Performance, Profit

Scientific Abstract:

This project was designed to determine the impacts of space allowance, marketing strategy, and the strategic application of hyper-doses of phytase (≥ 4,500 FTU/kg) on performance and carcass quality of late finishing pigs, and to further provide an analysis integrating the effects of space requirements and phytase application with feed costs, pig price, and pork produced per unit of space. In experiment 1, a total of 375 finishing pigs (94.63 ± 0.61 kg) were randomly assigned to 48 pens, with 7 to 8 pigs per pen equally balanced for gilts and barrows. Two phytase supplementation doses (control of 2,500 FTU/kg or hyper-dose of 5,000 FTU/kg) and two space allocation dimensions (adequate with 0.85 m^2/pig or restricted with 0.64 m^2/pig) were combined to create 4 treatments in a 2 x 2 factorial arrangement. No interactions ($P > 0.10$) were observed between floor space allowance and phytase supplementation. Pig body weight was determined weekly and was reduced ($P < 0.008$) by restriction of space. Body weight considering all pigs marketed (day 28 and day 42) was reduced ($P = 0.009$; 133.9 vs. 135.4) by space restriction. Average daily gain and average daily feed intake were reduced in space restricted pigs ($P < 0.05$), but gain:feed, back fat depth, and loin eye area were not impacted ($P > 0.08$). In experiment 2, the effects of hyper-dosing of phytase (control of 2,250 or hyper-dose of 4,500 FTU/kg) in late finishing pigs (2,200 pigs with 18 to 24 pigs per pen and 96 pens) on pig performance and carcass quality was evaluated when using a standard marketing program or a modified program. For the standard strategy the first marketing cut was made at 110 kg of body weight and for the modified strategy, the first cut was targeted for 130 kg of body weight, which was 22 days later. The second cut and the final marketing were the same for both marketing programs. No interactions were observed between marketing strategy and phytase supplementation and hyper-dosing of phytase did not impact any of the growth

parameters measured throughout the study. Overall, the average market weight of pigs using the modified marketing strategy was 2.15 kg higher ($P < 0.001$) than the market weight of pigs using the standard marketing strategy. When considering the number of pigs and days to market, no differences were observed for average daily gain ($P = 0.727$), average daily feed intake ($P = 0.486$), and gain:feed ($P = 0.807$). Body weight at harvest, hot carcass weight, and yield were greater ($P < 0.001$) for pigs in the modified marketing program. In Experiment 3, the impact of supplementing hyper-doses of phytase (4,500 FTU/kg) was evaluated compared to the standard super-dose of 2,250 FTU/kg using a total of 17,862 pigs distributed in 16 barns (8 barns per dietary treatment). Average body weight at marketing, number of days to market, total gain, average daily gain, average daily feed intake, gain:feed, carcass weight, percent lean, back fat thickness, loin depth, adjusted base price, and lean premium were not different ($P > 0.230$) between treatments. The results of these experiments suggest that there was no benefit in supplementing phytase above the standard level of 2,250 to 2,500 FTU/kg. Based on feed costs, carcass value, and the performance results in these experiments, housing more pigs per pen (ie, restricting space) or using a modified marketing program (ie. delaying the first marketing cut) is economically advantageous in spite of reductions in performance.

Introduction

Providing the proper space allowance for finisher pigs is a balance between maintaining welfare, optimizing growth performance and facility use, and maximizing economic return. Gonyou et al. (2006) suggested expressing the space requirement of pigs per unit of body weight, rather than as space per pig. Using an allometric approach, they determined that the space requirement of pigs could be expressed as:

Space allowance (in m^2) = 0.0336 * (Body weight (in kg))$^{0.667}$

In which 0.0336 is the calculated constant space allowance coefficient (k) determined by broken-line analysis of average daily gain as a function of space allowance of grower-finisher pigs on fully slatted floors.

Thus, as pigs grow, the floor space available per pig mass decreases, resulting in reduced growth rates. This issue is especially harmful to the performance of pigs at heavier body weights. The commercial industry has approached this problem by split marketing wherein heavy pigs in the pen are marketed first, followed by additional marketing groups. This provides more space to the remaining pigs, which has been demonstrated to improve performance of the remaining pigs (e.g. DeDecker et al., 2005; Flohr et al., 2016; Carpenter, 2018). On the other hand, split marketing increases the cycle length, which decreases carcass gain per unit of space (O'Connell et al., 2005). Recently, Lerner et al. (2020) reported reduced feed intake and daily gain when the number of pigs per pen increased (increased stocking density) and that this occurred starting at 220 lbs and at a critical k value above 0.0336. They further demonstrated that increased stocking density maximized total weight gain per pen and that multiple marketing events allowed for acceptable performance (Lerner et al., 2020). Thus, marketing decisions are highly dynamic and need to consider many factors, including feed cost, pig price, and space availability. The final finishing phase is a period of increased stress and reduced growth performance. Especially in the absence of Paylean, identifying and confirming solutions to benefit the late finishing performance of pigs is becoming more critical.

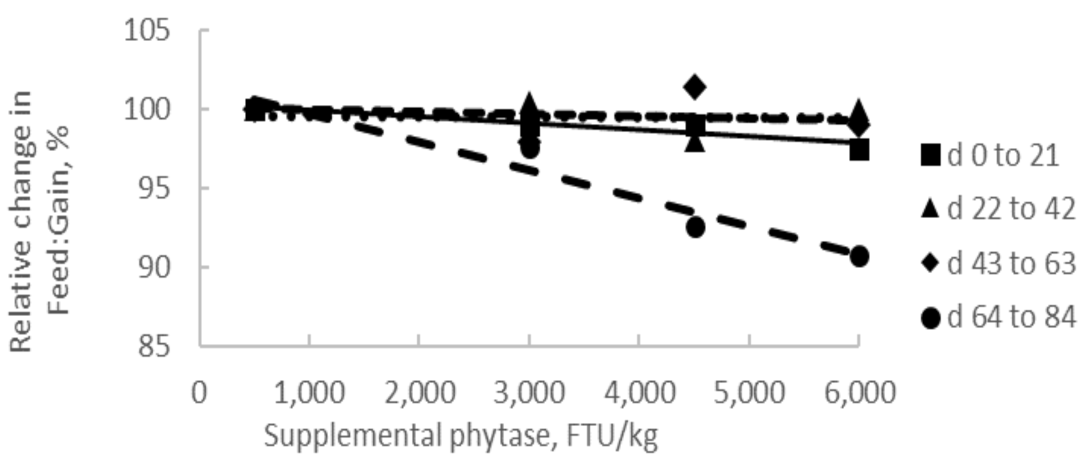
We propose to evaluate the use of hyper-doses of phytase in late finishing pigs housed under space-restricted and space adequate conditions and under different marketing strategies, using a combination of University and large-scale commercial studies. Numerous reviews and studies have validated the positive effects of using exogenous phytase in monogastric animals (Simons et al., 1990; Cromwell et al., 1993; Radcliffe et al., 1998; Selle et al., 2000; Sands et al., 2001; Omogbenigun et al., 2003; Selle and Ravindran, 2007, 2008; Chu et al., 2009; Adeola and Cowieson, 2011; Woyengo and Nyachoti, 2013). Supplementation of phytase to swine diets has traditionally been focused on improving the utilization of phytate-P (a potent anti-nutritional factor), thus increasing P availability and reducing P excretion in manure. However, in some cases, supplementation of phytase in P adequate diets has been demonstrated to improve performance of pigs and chickens, suggesting that improvements in growth performance are not completely explained by enhanced P availability (Selle and Ravindran, 2008). These extra-phosphoric effects of phytase may be related to (partial) destruction of phytic acid, thereby improving Ca, Zn, Fe, Mg and Na utilization, enhancing amino acid and energy utilization, improving activity of gastric enzymes (pepsin, trypsin, and chymotrypsin) and reducing endogenous losses (enzymes or mucin).

More recently, there has been interest in supplementing phytase at levels that exceed commercial levels aimed at releasing P (1500-2500 FTU/kg) to take advantage of the afore-mentioned extra-phosphoric effects of phytase (super-dosing). These relatively extreme levels of phytase aim to degrade at least 85% of insoluble anti-nutritional phytate esters and generate myo-inositol, which presumably plays an important role in facilitating transport of fats and fat-soluble nutrients (Cowieson et al., 2011). The effect of super-dosing phytase and generation of myo-inositol have been studied primarily in poultry (Cowieson et al., 2013, 2015; Walk et al., 2014) with Wilcock et al. (2014) and Holloway et al. (2016) showing benefits in finisher pigs. We recently demonstrated that the improvement in the efficiency of growth in nursery pigs when applying super-dosing phytase could be linked, in part, to complete dephosphorylation of phytate and liberation of myo-inositol, and that myo-inositol had a greater metabolic impact in piglets immediately after weaning (Moran et al., 2019). Inositol has been shown to have insulin-like effects in mammals, increasing serotonin and dopamine, reducing stress levels, and increasing feed intake (Huber, 2016). Several studies in pigs have demonstrated improved pig performance with high levels of phytase in nursery, grower, and finisher pigs (Braña et al., 2006; Cowieson et al., 2006; Kies et al., 2006; Walk et al., 2013; Holloway et al, 2016; Miller et al., 2016).

Most studies included super-doses of phytase at 1,500 to 2,500 FTU/kg. However, there is evidence that phytase continues to improve performance, bone characteristics, and Ca and P digestibility at doses up to 10,000 (Augspurger and Baker, 2004), 12,000, (Shirley and Edwards, 2003), 15,000 (Kies et al., 2006) and 20,000 FTU/kg (Zeng et al., 2014). Given the decreasing costs associated with phytase inclusion in practical diets and rising feed ingredient costs, higher levels of supplemental phytase above those typically used in super-dosing studies (2,500 to 3,000 FTU/kg) may be justified. In our most recent study (funded by the National Pork Board), we evaluated supplementation of ultra-high doses of phytase on growth performance of finishing pigs. In that study, a total of 2,150 pigs were supplemented with either 500 (control), 3,000, 4,500, or 6,000 FTU of phytase from 69.3 lbs of body weight to market weight. Phytase linearly improved daily gain and feed efficiency when considering the overall growth period until the first marketing cut. The improvement in feed efficiency was most dramatic during the late finishing phase (from 210 to 255 lbs of body weight; from day 64 to 84 of the study; see figure below), improving feed efficiency from 3.76 to 3.41; a 9.3% improvement in feed efficiency. This would result in an estimated feed savings of 8 tons per 1,000 pigs for this period alone.

The late finishing phase represents a period of increased stress related to decreasing floor space per unit of pig body weight, resulting in a relatively profound reduction in pig performance. Results of this previous study suggest that a targeted application of hyper-doses of phytase during the final stages of production would provide a more cost-effective opportunity to improve growth performance and may allow for more flexible marketing plans as well as partly help recover the loss of performance in late finishing, especially with the removal of Paylean.

We propose that specifically targeting the latter portion of the growth phase of finishing pigs (from approximately 210 lbs of body weight) with the supplementation of hyper-doses of phytase (5,000 FTU/kg) will improve growth and feed efficiency of pigs and will be economically attractive. The impact of phytase when it is supplied during the targeted growth period immediately prior to marketing needs to be considered to take advantage of potential extra gain that can be accomplished and the economic benefits associated with reduced days to market, reduced feed costs per pig, and increased income per pig space.



Objectives

The goal of this project was to determine the impacts of space allowance, marketing strategy, and the strategic application of hyper-doses of phytase (≥ 4,500 FTU/kg) on performance of late finishing pigs and to further provide an analysis integrating the effects of space requirements and phytase application with feed costs, pig price, and pork produced per unit of space. We hypothesize that supplementation of hyper-doses of phytase will result in the near complete destruction of the anti-nutrient phytate, maximize inositol production in the small intestine, and through insulin-like effects of inositol, increase serotonin and dopamine, reducing stress and increasing feed intake. Thus, the application of hyper-doses of phytase in late finishing pigs pre- and post- the first marketing cut is expected to be beneficial in maintaining growth performance of pigs with inadequate floor space prior to marketing. Specifically, our objectives were to:

1) Determine the impacts of hyper-dose levels of phytase from 95 kg of body weight and late finishing stocking density on growth rate, feed intake, feed efficiency, carcass characteristics, plasma inositol, serum chemistry, and postprandial serum glucose concentrations in late finishing pigs.
2) Evaluate the effects of hyper-dosing of phytase (compared to a standard super-dose) fed from 95 kg of body weight in a commercial production facility on pig performance, carcass characteristics, and carcass weight produced per unit of space when using a standard industry marketing program or a modified version with different level of marketing.
3) Evaluate the impact of a hyper-dose level compared to standard super-dosing of phytase during the late finisher phase on performance, carcass characteristics, and carcass weight produced per unit of space using a large multi-barn commercial production flow and a common marketing approach.
4) Conduct a comprehensive economic analysis considering feed costs, pig price, weight produced, facility costs, and opportunity costs using a dynamic financial calculator.

Materials & Methods

Experiment 1. A total of 375 finishing pigs (Smithfield Premium Genetics; 94.63 ± 0.61 kg) were randomly assigned to 48 pens, with 7 to 8 pigs per pen, equally balanced for gilts and barrows. Two phytase supplementation doses (control of 2,500 FTU/kg or hyper-dose defined as 5,000 FTU/kg) and two space allocation dimensions (adequate with 0.85 m^2/pig or restricted with 0.64 m^2/pig) were combined to create 4 treatments in a 2 x 2 factorial arrangement. Pigs were fed a finishing diet primarily based on corn and soybean meal formulated to contain 0.68% standardized ileal digestible (SID) lysine, 0.55% Ca, and 0.24% available P (**Table 1**). Phytase was given equal matrix values for Ca, P, SID amino acids, and net energy for both supplementation levels. The 3 heaviest pigs per pen (2 barrows and 1 gilt) were marketed on day 28 and the remaining pigs were marketed on day 42. Pig body weight was determined weekly throughout the study. Feed provided to pigs was recorded and the feed remaining in the feeders was determined weekly, at the same time pigs were weighed. On day 28, ultrasound measurements were conducted for all pigs to determine loin eye area and back fat thickness. Blood samples were obtained from one low- and one high- body weight pig in each pen on day 0 (for base line) and day 28 of the study. Plasma was obtained and samples were analyzed for myo-inositol concentration by HPLC using a Dionex DX600 HPLC system as described by Laird (2016). In addition, serum glucose concentrations were measured in blood samples collected from pigs 45 minutes after they were fed a restricted meal that was provided after an overnight fast of the pigs that were in the first marketing cut on day 28.

Data were analyzed using the mixed models procedure of SAS (SAS Institute, Cary, NC) as a completely randomized design with factorial arrangement of treatments. The model included main effects of space restriction (adequate or reduced), phytase supplementation (2,500 or 5,000 FTU/kg), and their interaction. Initial body weight was used as a covariate for the analysis of growth performance and body weight on day 28 was used as a covariate for the analysis of carcass characteristics. Differences between treatments were evaluated, when appropriate, using the LSD procedure.

Experiment 2. A total of 2,200 finishing pigs (89.64 ± 0.31 kg of body weight) were randomly allocated within each section of the rooms and weight block to 96 pens in two commercial barns with 18 to 24 pigs in each pen. Two phytase supplementation doses (control of 2,250 FTU/kg or hyper-dose of 4,500 FTU/kg) and two marketing strategies were combined to create 4 treatments in a 2 x 2 factorial arrangement. Marketing strategies consisted of a standard marketing strategy in which the first cut was made at 110 kg of body weight or a modified marketing strategy in which the first cut was targeted for 130 kg of body weight. To achieve target weights, the first cut of pigs in the standard marketing group was made 22 days after the start of the study, whereas the first cut for the modified program was made after 44 days. The second cut was made 50 days after the start of the study and the final marketing was done after 62 days, which were the same for both marketing programs. The target number of pigs to market in the first cut was set to 1 to 5 of the heaviest pigs with the number of pigs being the same between the two phytase treatments. Treatment diets were fed in 2 phases with the first phase being fed from the start of the study with a feed budget of 58.5 kg per pig, followed by the second phase fed until the last pigs were marketed. Diets were formulated to meet or exceed nutrient recommendations suggested by the NRC (2012). Both diets were given equal nutrient credit for supplemental phytase such that the only difference in the diets was the level of supplemental phytase. All pens within the two barns were weighed and the number of pigs in the pen were counted at the start of trial, prior to the first cut, prior to the second cut, and prior to the final load of pigs. Feeding was conducted by using a computerized feeding system (Big Dutchman) that recorded the amount of feed delivered to each feeder. Feed remaining in the feeder was measured at the same time pigs were weighed to calculate feed consumption. Any pig removed from the test was weighed and its RFID tag number was recorded with removal reason, and date. Any pigs that died, were removed from pens, or were euthanized due to health issues, were weighed and their location and the date of the event were recorded. At marketing, pigs were harvested at Triumph Foods and data were collected on individual pigs using RFID tags for identification. Information recorded included number of pigs delivered, treatments, RFID tag identification, pig body weight at harvest, hot carcass weight, and ultrasonic pig carcass grading (AutoFom).

Data were analyzed using the mixed models procedure of SAS (SAS Institute, Cary, NC) as a completely randomized design with factorial arrangement of treatments. The model included main effects of marketing strategy (standard or modified), phytase supplementation (2,250 or 4,500 FTU/kg), and their interaction. Differences between treatments were evaluated, when appropriate, using the LSD procedure.

Experiment 3. A total of 17,862 finishing pigs were randomly allocated to a total of 16 barns at two finishing sites. Two dietary treatments (control of 2,250 FTU/kg or hyper-dose of 4,500 FTU/kg of phytase) were assigned to barns on each site with 4 barns receiving the control diet and 4 barns receiving the hyper-dose of phytase on each site for a total of 8 barns per dietary treatment. The study started when the average weight of the barn reached 94.6 kg of body weight. Pigs received finisher 4 diets containing dietary treatments for 4 weeks (feed budget of 76 kg) followed by finisher 5 treatment diets until marketing. Diets were corn, soybean meal, and wheat midds based with inclusion of synthetic amino acids. The first marketing cut was made 3 weeks after the start of finisher 5 diets, followed by the second cut 1 week later, the third cut after 1 more week and the final marketing after another 3 weeks. At the start of the study, data were collected for the number of gilts and barrows by pen by barn and the date pigs started consuming the finisher 4 diets. Additional data collected during the study included the dates the barns switched diet phases (from finisher 4 to finisher 5), the number of pigs that were removed, died, or were euthanized, including the reason and gender, pen inventory, and any treatments that were given (injectable medications and water medication or supplements). During marketing, dates for each marketing event at each barn, number of pigs marketed and remaining in each pen, carcass weight by market load at each event, dead and euthanized pigs by reason and gender, cull or light pigs by reason (light, rupture, boar, wound, etc.) and gender at the end of the marketing at each barn were recorded. The amount of feed remaining in bins (tons) was estimated after dumping barns. The amount of feed left in feeders after the final marketing was estimated. Data for every market load were extracted from the Triumph packing plant, including dead scale weight, hot carcass weight, percent lean, fat cover, loin depth, and gender.

Data were analyzed using the mixed models procedure of SAS (SAS Institute, Cary, NC) as a completely randomized design. The model included main effects finishing site and dietary phytase supplementation (2,250 or 4,500 FTU/kg). Barn was used as the experimental unit (n = 8 per dietary treatment). Differences between treatments were evaluated, when appropriate, using the LSD procedure.

Results:

Experiment 1. Analyzed phytase concentrations were 2,970 and 6,650 FTU/kg of complete feed for the 2,500 and 5,000 FTU/kg diets. Although higher than the target concentrations, the levels were distinctly different allowing us to make valid comparisons between diets. No interactions were observed between floor space allowance and phytase supplementation (P > 0.10). Hyper-dosing with phytase did not impact body weight on day 28 (P = 0.36; 124.80 vs. 124.20 for pigs fed 2,500 and 5,000 FTU of phytase, respectively), body weights for the 2 marketing cuts, or average body weight of all pigs marketed (P = 0.19; 134.83 vs. 133.83 kg). Overall ADG (P = 0.57; 1.097 vs. 1.087 kg/day), ADFI (P = 0.91; 3.456 vs. 3.461 kg/day), gain:feed (P = 0.41; 0.318 vs. 0.314) and carcass characteristics were not impacted by hyper-dosing of phytase. Pig body weight was reduced (P = 0.007) by space restriction when all pigs were weighed after 28 days on test (**Table 2**). Pig body weight tended to be reduced (P = 0.119) for the first marketing group (3 pigs per pen were marketed on day 28) and the final marketing group, representing the remaining pigs marketed on day 42 (P = 0.078) by restriction of space. Overall, body weight was reduced (P = 0.009) by 2.07 kg by space restriction when considering all pigs marketed (day 28 and 42 combined). Space restriction reduced (P ≤ 0.001) average daily gain by 6.35% and 5.43% during the 28 day period and the overall marketing period, respectively. Average daily feed intake was reduced in space restricted pigs by 6.33% and 6.19% for the 28 day period and the overall marketing period, respectively (P < 0.001). Gain:feed was not impacted by space restriction (P = 0.62), suggesting that the reduction in weight gain in space-restricted pigs was driven by reduced feed intake. Carcass characteristics measured for all pigs on day 28 and analyzed using body weight on day 28 as a covariate (**Table 2**) was not impacted by space restriction (P > 0.18).

Space restriction significantly increased serum total protein concentration and decreased urea N (P < 0.05). Hyper-dosing phytase decreased aspartate transaminase (P < 0.05). Plasma concentration of inositol measured before the initiation of dietary treatments (day 0) was 44.24 µM and initial inositol concentration was used as a covariate in the analysis of inositol concentration on day 28 of the study. No interactions between space, diet, and body weight (light vs. heavy pigs) were observed for plasma inositol concentrations. Hyperdosing of phytase increased (P = 0.003) plasma inositol concentrations (**Table 3; Figure 1**) by 22.6% compared to the 2,500 FTU/kg phytase level. Light-weight pigs had greater concentrations of inositol compared to heavy-weight pigs (P = 0.014; 51.0 vs. 43.1 µM). Glucose concentrations were determined in pigs exactly 45 minutes after feeding following an overnight fast. Pigs did not consume all of their feed prior to the collection of blood samples; therefore the amount of feed consumed prior to bleeding was used in the analysis of serum glucose concentrations. Space restriction and supplementation of phytase above super-dosing levels did not impact serum glucose concentrations (P > 0.79) and their interactive effects were not significant (P = 0.15) (**Table 3**).

Experiment 2. Two different marketing strategies were evaluated in this study and the potential impact of high levels of phytase (in addition to super-dosing) was determined within each marketing strategy.

No interactions were observed between marketing strategy and phytase supplementation. Hyper-dosing of phytase did not impact any of the growth parameters measured throughout the study. The marketing strategies primarily differed in the timing of the first cut of pigs which was 22 days earlier for the standard marketing strategy compared to the modified strategy. An average of 2.96 pigs were marketed as the first cut at an average weight of 123.3 kg for the standard marketing, whereas an average of 3.00 pigs were marketed at an average weight of 145.3 kg for the modified marketing strategy. The number of pigs marketed in this first cut represented an average of 13.2% of the pigs in the pen. The second marketing cut was made at the same time for both marketing strategies with an average of 2.96 pigs at a bodyweight of 147.3 kg for the standard and 3.00 pigs at a body weight of 144.8 kg for the modified marketing. The second cut represented an average of 15.4% of the remaining pigs in the pen. Overall, the average market weight of pigs using the modified marketing strategy was 2.15 kg higher ($P < 0.001$) than the market weight of pigs using the standard marketing strategy (**Table 4**). This advantage is directly related to the marketing strategy used, considering that an average of 3 pigs per pen within the modified marketing strategy remained in the pen for an additional 22 days, gaining additional weight, compared to the standard marketing strategy. When considering the number of pigs and days to market to calculate average daily gain, no differences ($P = 0.727$) were observed in average daily gain between marketing strategies. Similarly, average daily feed intake ($P = 0.486$) and gain:feed ($P = 0.807$) were not different between marketing strategies (**Table 4**). Body weight at harvest, hot carcass weight, and yield were greater ($P < 0.001$) for pigs in the modified marketing program (**Table 5**). Percent carcass lean ($P = 0.008$) was lower and fat cover was higher ($P = 0.044$) for pigs in the modified marketing program. All primal cuts (boneless and bone-in ham and loin, spareribs, belly, picnic, and butt were heavier for pigs in the modified marketing program. These observations are consistent with the heavier final body weight of these pigs. However, when using body weight at harvest as a covariate to adjust for body weight differences, significant responses were still observed for hot carcass weight, yield, and the weights of all primal cuts, with the exception of boneless loin.

Experiment 3. The impact of supplementing hyper-doses of phytase (4,500 FTU/kg) was evaluated compared to the standard super-dose of 2,250 FTU/kg used at this multi-barn facility. A total of 17,862 pigs representing 8,998 and 8,864 pigs for the control (2,250 FTU/kg of phytase) and hyper-dose (4,500 FTU/kg of phytase) treatments, respectively, were placed on test. At the packing plant, a total of 17,351 pigs were received (8762 and 8589 for the control (2,250 FTU/kg of phytase) and hyper-dose (4,500 FTU/kg of phytase) treatments, respectively), and these pigs were considered as full value pigs that successfully completed the study and were marketed. The difference between the number of pigs marketed and the number of pigs placed was due to death losses and removals, but there were some discrepancies between inventories and some removals apparently were not reported. Average body weight at marketing, number of days to market, total gain, average daily gain, average daily feed intake, and gain:feed were not different ($P > 0.230$) between treatments (**Table 6**). In addition, days from placement to slaughter, carcass weight, percent lean, backfat thickness, loin depth, adjusted base price, and lean premium were not different ($P > 0.509$) between treatments (**Table 7**). The results of this experiment suggest that there was no benefit in supplementing phytase above the standard level of 2,250 FTU/kg.

Economic analysis. Phytase supplementation above super-dosing (4,500 to 5,000 FTU/kg compared to 2,250 to 2,500 FTU/kg) did not improve growth performance or carcass characteristics in the 3 experiments reported herein. Thus, there was no economic advantage to include phytase at higher levels than currently used. Managing space allocation was evaluated in Experiment 1 and 2. In experiment 1, pigs were given either 0.64 or 0.85 m^2 of space per pig by varying the space of the pen while keeping the number of pigs within each pen the same. If we assume that a commercial finishing pig pen provides a total pen area of 15.1 m^2, then the total number of pigs that can be placed in a commercial sized pen using the space allocation in the present study is 22.8 and 17.2 pigs for the 0.64 or 0.85 m^2 space allocation, respectively. Pigs housed in adequate space gained 2.07 kg more than space restricted pigs during the final finishing stage of this experiment and they consumed 8.12 kg more feed. Considering that more pigs can be housed in restricted space and extrapolating to 22.8 pigs in this restricted space, a total of 883 kg of weight was produced within the restricted space compared to 701 kg in the adequate space. Despite lower feed consumption per pig, the greater number of pigs of pigs that can be housed in the restricted space would consume more total feed per pen (2809 kg) than pigs housed in adequate space (2254 kg) during the final finishing phase. Assuming a feed cost of $0.40 per kg and a pig price of $1.32 per kg, the net value per pig can be calculated as $2.35 for the restricted pigs and $1.87 for the adequate pigs. In most price scenarios, housing more pigs per pen (restricted in the present study to 0.64 vs. 0.85 m^2) is economically advantageous, except when pig prices are high and feed costs are low.

In the second study, two marketing strategies were used, defined here at standard or modified. In the modified scenario, an average of 3 pigs were marketed in the first cut 22 days later compared to the standard marketing strategy in which the 3 pigs were marketed earlier. Thus, pigs within the modified marketing strategy were more crowded during those extra 22 days, and produced on average heavier total market weights. Pigs marketed using the modified strategy reached market weight in an average of 59.7 days, while pigs marketed using the standard strategy reached market in 56.8 days. Considering average daily feed intake and days to market, pigs within the modified strategy consumed 181.2 kg of feed compared to 173.5 kg for the standard marketing during the test period, costing $57.91 and $55.47 in feed cost (using $290/ton of feed), respectively. Total costs, including the cost of pigs at the start of the study ($1.21 per kg), feed cost, and facility cost ($0.11 per day) were $172.91 and 170.22 per pig for the modified and standard marketing, respectively. Income from pigs sold using carcass weight at a value of $0.167 per kg was $173.73 and $169.73 per pig, resulting in a net revenue per pig of $0.82 and -$0.49 for the modified and standard marketing strategies. Based on the feed costs, carcass value, and the performance results in this experiment, the modified marketing strategy was economically beneficial compared to the standard marketing strategy.

Discussion

Super-dosing phytase and the associated generation of myo-inositol has shown benefits in finisher pigs (Wilcock et al., 2014; Holloway et al., 2016). Moran et al. (2019) demonstrated an improvement in the efficiency of growth in nursery pigs when applying super-dosing phytase levels and this could be linked, in part, to complete dephosphorylation of phytate and liberation of myo-inositol. Inositol has been shown to have insulin-like effects in mammals, increasing serotonin and dopamine, reducing stress levels, and increasing feed intake (Huber, 2016). Several studies in pigs have demonstrated improved pig performance with high levels of phytase in nursery, grower, and finisher pigs (Braña et al., 2006; Cowieson et al., 2006; Kies et al., 2006; Walk et al., 2013; Holloway et al, 2016; Miller et al., 2016). There is evidence that phytase continues to improve performance, bone characteristics, and Ca and P digestibility at doses up to 10,000 (Augspurger and Baker, 2004), 12,000, (Shirley and Edwards, 2003), 15,000 (Kies et al., 2006) and 20,000 FTU/kg (Zeng et al., 2014). In a recent commercial study, we showed linearly improved daily gain and feed efficiency, especially in the late finishing phase, when pigs were supplemented with either 500 (control), 3,000, 4,500, or 6,000 FTU of phytase. In the present project, no beneficial effects of phytase supplementation at hyper-dosing levels (4,500 to 5,000 FTU/kg of phytase) compared to super-dosing (2,250 to 2,500 FTU/kg) were observed in the 3 experiments, regardless of space restriction and the associated crowding stress. Hyper-dosing increased serum inositol concentrations, suggesting that additional phytase was still effective in breaking down phytic acid and its derivatives. Nonetheless, no improvements in pig performance were evident and based on the results of the current experiment, hyper-dosing of phytase was not an effective and economically advantageous strategy to improve growth performance of space restricted late finishing pigs.

Providing proper space for finisher pigs is a balance between maintaining welfare, optimizing growth performance and facility use, and maximizing economic return. The space requirement of pigs is best expressed per unit of body weight, rather than as space per pig (Gonyou et al., 2006), which implies that available space per pig decreases as pigs grow. Applying marketing cuts to remove the heaviest pigs for harvest provides more space to the remaining pigs, which improves performance of the remaining pigs (e.g. DeDecker et al., 2005; Flohr et al., 2016; Carpenter, 2018), but it also increases days to market (O'Connell et al., 2005). Marketing decisions are highly dynamic and need to consider many factors, including feed cost, pig price, and space availability. In the present series of studies, we selected two ways to impact space allocation. In the first experiment, we managed the amount of space per pig from adequate to restricted by decreasing the pen dimensions while maintaining the same number of pigs in the pen. Restricting space had clear negative impacts on growth performance as expected because we restricted space to below the requirement suggested by Gonyou et al. (2006). In the second experiment, we delayed the marketing of the first cut by 22 days (modified marketing) compared to the standard marketing. The total weight of pigs marketed and the weight of primal cuts was increased for the modified marketing strategy, which was related to the fact that pigs remained in the pens for an average of 3 days per pig longer than the pigs using the standard marketing strategy. In both cases, more weight was produced per pen and when considering feed consumption, cost of feed, days to market, facility cost and total revenue from pigs, the net profit was increased when pigs were space restricted (and more pigs could be housed per pen) and by using a modified marketing strategy with delayed marketing of the first cut of pigs.

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Table 1. Composition of the experimental diets for Experiment 1 (as-fed basis).

Ingredient	2,500 FTU/kg phytase	5,000 FTU/kg phytase
Corn, yellow dent	86.70	86.67
Soybean meal, 46.5% CP	10.20	10.20
Poultry fat	1.000	1.000
L-lysine HCl	0.290	0.290
DL-methionine	0.001	0.001
L-threonine	0.064	0.064
L-tryptophan	0.018	0.018
Monocalcium phosphate 21%	0.191	0.191
Limestone	0.852	0.852
Salt	0.400	0.400
Finisher trace mineral premix	0.150	0.150
Finisher vitamin premix	0.050	0.050
Phytase[1]	0.025	0.050
Xylanase[1]	0.010	0.010
Colorant[2]	0.050	0.050
Calculated Composition		
ME - kcal/lb.	1545	1545
NE - kcal/lb.	1181	1181
Crude Protein %	12.23	12.23
Total Lysine %	0.77	0.77
Calcium %	0.551	0.551
Total P	0.335	0.335
Avail. P	0.240	0.240
Digest. P	0.267	0.267
SID Amino Acids		
Lys %	0.680	0.680
Thr %	0.449	0.449
Met %	0.198	0.198
Met+Cys%	0.408	0.408
Trp %	0.129	0.129
Ile %	0.425	0.425
Val %	0.502	0.502

[1] Provided by ABVista

[2] To color code diets for easy identification

Table 2. Growth performance and carcass characteristics of late-finishing pigs provided with adequate (0.85 m^2/pig) or restricted (0.66 m^2/pig) floor space (Experiment 1).

	Space allowance			
Variable	**Adequate**	**Restricted**	**SEM**	**P value**
Body weight, kg				
Day 0	94.59	94.59	*	NA
Day 28	125.44	123.56	0.481	0.007
Marketing cut 1	135.58	133.70	0.873	0.119
Marketing cut 2	135.31	132.98	0.954	0.078
All pigs marketed	135.36	133.29	0.559	0.009
Average daily gain, kg/d				
Day 0 to 28	1.103	1.033	0.014	< 0.001
All pigs marketed	1.123	1.062	0.013	0.001
Average daily feed intake, kg/d				
Day 0 to 28	3.506	3.284	0.030	< 0.001
All pigs marketed	3.569	3.348	0.034	< 0.001
Gain:feed, kg/kg				
Day 0 to 28	0.315	0.315	0.004	0.966
All pigs marketed	0.315	0.317	0.003	0.622
Carcass characteristics[1]				
Back fat thickness, mm	2.82	2.74	0.044	0.188
Loin eye area, cm^2	66.3	67.0	0.50	0.308

* Initial body weight was used as a covariate in the analysis of growth performance data.

[1]Carcass characteristics were measured by ultrasound on day 28 for all pigs. Body weight on day 28 was used as a covariate in the analysis of carcass data.

Table 3. Serum concentrations of inositol and glucose in late-finishing pigs provided with adequate (0.85 m^2/pig) or restricted (0.66 m^2/pig) floor space and supplemented with dietary phytase (Experiment 1).

	Space allowance				Phytase added			
Variable	**Adequate**	**Restricted**	**SEM**	**P value**	**2,500**	**5,000**	**SEM**	**P value**
Inositol, µM[1]	48.1	46.1	2.2	0.678	42.3	51.9	2.2	0.002
Glucose, mg/dL	108.0	109.4	3.8	0.800	108.1	109.3	3.8	0.813

[1] Serum inositol concentrations were determined in 1 heavy- and 1 light-weight pig per pen on day 28 of the study

[2] Serum concentrations of glucose were determined 45 minutes after feeding following an overnight fast

Table 4. Growth performance and carcass characteristics of late-finishing pigs using two different marketing strategies (Experiment 2).

	Marketing Strategy[1]			
Variable	**Modified**	**Standard**	**SEM**	**P value**
Body weight, kg				
Day 0	89.62	89.67	0.329	0.903
All pigs marketed	143.83	141.68	0.415	< 0.001
Average daily gain, kg/d				
All pigs marketed	0.895	0.900	0.009	0.727
Average daily feed intake, kg/d				
All pigs marketed	3.036	3.054	0.018	0.486
Gain:feed, kg/kg				
All pigs marketed	0.295	0.294	0.003	0.807

[1]In the modified marketing strategy marketing of the first cut of the pigs was delayed by 22 days compared to the standard marketing strategy.

Table 5. Carcass characteristics of late-finishing pigs supplemented with high levels of phytase and using two different marketing strategies (Experiment 2).

	Modified[1]		Standard[1]			P values		
	2,250	**4,500**	**2,250**	**4,500**	**SEM**	**Strategy**	**Diet**	**S * D**
Body weight at harvest	132.64	133.50	130.41	130.56	0.62	< 0.001	0.418	0.574
Hot carcass weight	103.40	104.25	101.46	101.41	0.48	< 0.001	0.401	0.354
Yield, %	78.07	78.19	77.72	77.66	0.10	< 0.001	0.932	0.439
Lean, %	54.30	53.99	54.32	54.38	0.08	0.008	0.094	0.018
Fat cover, mm	14.94	15.46	14.93	14.90	0.14	0.044	0.080	0.054
Loin depth, mm	64.16	63.63	63.36	63.56	0.25	0.092	0.516	0.157
Marbling	1.94	2.01	1.95	1.93	0.03	0.201	0.334	0.065
Primal cuts, kg								
Ham, bone-in	26.02	26.15	25.56	25.55	0.107	< 0.001	0.576	0.519
Ham, boneless	12.54	12.54	12.30	12.30	0.051	< 0.001	0.914	0.983
Loin, bone-in	23.93	24.06	23.51	23.51	0.100	< 0.001	0.516	0.519
Loin, boneless	8.78	8.80	8.61	8.61	0.042	< 0.001	0.795	0.907
Spareribs	4.28	4.30	4.21	4.21	0.017	< 0.001	0.605	0.491
Belly	13.87	14.03	13.62	13.61	0.064	< 0.001	0.261	0.186
Picnic	10.58	10.64	10.39	10.38	0.043	< 0.001	0.530	0.386
Butt	10.46	10.55	10.27	10.26	0.050	< 0.001	0.361	0.304
Primal cuts, total	89.14	89.74	87.56	87.52	0.38	< 0.001	0.458	0.396
Primal cuts, %	86.25	86.12	86.37	86.37	0.04	< 0.001	0.137	0.124

[1]In the modified marketing strategy marketing of the first cut of the pigs was delayed by 22 days compared to the standard marketing strategy.

Table 6. Growth performance of late-finishing pigs supplemented with either 2,250 or 4,500 FTU/kg of phytase (Experiment 3).

	Phytase supplementation			
	2,250	**4,500**	**SEM**	**P-value**
Body weight at placement, kg	28.46	28.58	0.62	0.899
Body weight at market, kg	139.93	138.86	1.59	0.639
Days to market	130.13	132.25	2.04	0.474
Total gain, kg	111.47	110.28	1.48	0.578
Average daily gain, kg	0.857	0.836	0.012	0.231
Average daily feed intake, kg	2.670	2.634	0.041	0.549
Gain:feed	0.321	0.318	0.005	0.616

Table 7. Carcass characteristics of late-finishing pigs supplemented with either 2,250 or 4,500 FTU/kg of phytase (Experiment 3).

	Phytase supplementation			
	2,250	**4,500**	**SEM**	**P-value**
Placement to slaughter, days	127.5	127.9	0.80	0.704
Carcass weight, kg	105.20	104.76	0.66	0.646
Lean, %	53.35	53.30	0.07	0.667
Backfat, mm	16.82	16.95	0.14	0.510
Loin depth, mm	62.75	62.59	0.16	0.509
Adjusted base price	106.02	105.96	0.88	0.964
Lean premium	1.61	1.34	0.51	0.714

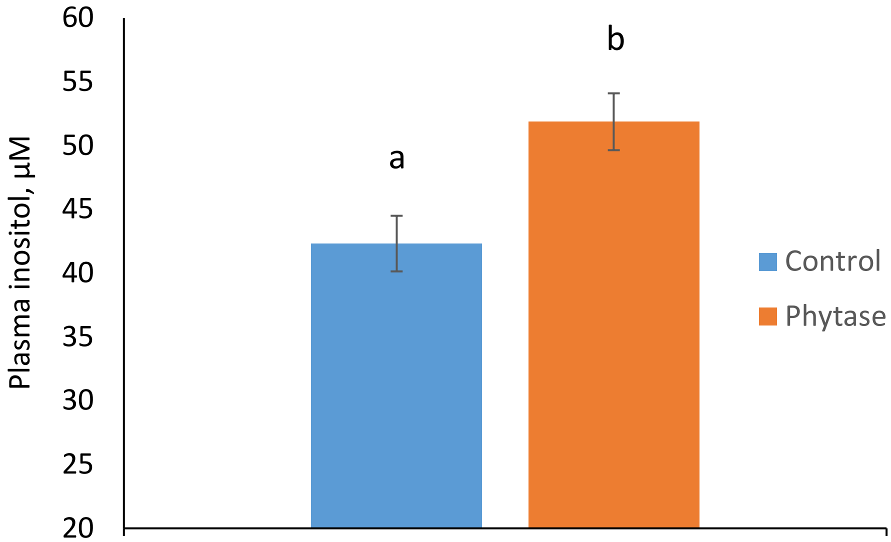

Figure 1. Plasma inositol concentrations (µM) in pigs supplemented with either 2,500 (Control) or 5,000 (Phytase) FTU/kg of phytase.