Determining the Optimal Sampling Method to Estimate the Mean and Standard Deviation of Pig Body Weights Within a Population[1,2]

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Summary

The accuracy and precision of pig subsampling methods can determine the swine producer's ability to sell pigs at optimal market BW and reduce economic discounts. The first objective of this experiment was to determine the time required to weigh pigs for different sampling methods used to estimate the mean and SD of a population. The second objective was to define the optimal sampling method considering the time required to weigh pigs as well as the precision and accuracy of each sampling method. A total of 68 pens of pigs (359 × 1050, PIC, Hendersonville, TN; 169.8 lb BW) in 2 commercial finishing facilities with 20 to 35 pigs per pen were used. Pens of pigs were blocked by location within barn and randomly allotted to 1 of 4 treatments with 17 pens per treatment. The 4 treatments included (1) selecting and weighing the heaviest and lightest pig per pen; and (2), (3), and (4) weighing the first 5, 10, and 15 pigs out of the pen, respectively. The time required for 2 people to complete each treatment was recorded. To determine the total barn time required to conduct a specific sample, the time required to weigh the specific number of pigs per pen was multiplied by n pens. The accuracy and precision for estimating the mean BW and SD for each sampling method was determined by using datasets A and C reported in Paulk (2014[4]). The precision was determined by calculating a 95% confidence interval (CI) for the sample means and SD. The time taken to select and weigh the heaviest and lightest pigs in a pen (Treatment 1) did not differ from weighing 5 pigs per pen (Treatment 2). Increasing the number of pigs weighed per pen (Treatments 3 and 4) increased ($P < 0.05$) the amount of time to weigh a single pen. Based on these results, the number of pens for each treatment that can be weighed without influencing weighing time was determined to be 15 pens (30 pigs), 15 pens (75 pigs), 9 pens (90 pigs), and 6 pens (90 pigs) from Treatments 1, 2, 3, and 4, respectively. For dataset A, these 4 sampling methods had a similar CI range for estimating the mean BW and SD. For dataset C, Treatments 1 (30 pigs) and 2 (75 pigs) had a reduced CI range for estimating the mean BW compared with Treatments 3 (90 pigs) and 4 (90 pigs); however, Treatments 2 (75 pigs) and 3 (90 pigs) had a reduced CI range for estimating the SD compared with Treatments 1 (30 pigs) and 4 (90 pigs). Therefore, we conclude that swine producers should weigh 5 pigs from 15 pens to estimate the mean BW and SD within a barn.

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[4] Paulk, C.B. 2014. Predicting market pig weights and fat iodine value and effect of zinc on growth performance and immune function of finishing pigs. Ph.D. Thesis. Kansas State University, Manhattan, KS.

Key words: finishing pig, mean estimation, standard deviation estimation, sample size

Introduction

Because individual pig BW in a barn typically follows a normal distribution, subsampling methods to predict the mean and SD can be used to model distributions of BW. The accuracy and precision of these subsampling methods can determine the swine producer's ability to sell pigs at optimal market BW and reduce economic discounts. Paulk (2014[4]) determined the accuracy and precision of varying sampling methods used to estimate the mean and SD of pig BW within a population. Increasing the sample size of a random sample, regardless of pen arrangement, improved the precision for estimating the mean and SD of pig BW; however, a majority of the improvement occurred when the sample size was increased from 10 to 30 pigs. Increasing the sample size of a random sample requires additional labor and cost.

Because the greatest improvement in estimating the mean and SD was at 30 pigs, Paulk (2014) also evaluated methods to improve the estimates without increasing the sample size of 30 pigs. When the total sample size was held constant, increasing the number of pens sampled improved the precision. However, the precision of estimating the mean and SD could be further improved by selecting the heaviest and lightest pigs from 15 pens. In determining the optimum sampling method, swine producers should use both the time required to weigh the pigs and the precision and accuracy of each sampling method. Therefore, the first objective of this experiment was to determine the time required to weigh pigs for different sampling methods used to estimate the mean and SD of pig BW of a population. The second objective was to determine the optimal sampling method using the time required to weigh pigs and the precision and accuracy of each sampling method.

Procedures

Time required to weigh pigs for different sampling methods

A total of 68 pens of pigs (359 × 1050, PIC, Hendersonville, TN) in 2 commercial finishing facilities (Barns 1 and 2) in northern Iowa were used in the experiment. Pigs in Barn 1 and 2 were approximately 163.8 and 175.9 lb BW, respectively. Pigs were housed in curtain-sided finishing barns with 20 to 35 pigs per pen. Pens of pigs were blocked by location within barn and randomly allotted to 1 of 4 treatments with 9 replicate pens in Barn 1 and 8 replicate pens in Barn 2 for a total 17 pens per treatment.

The 4 treatments included: (1) selecting and weighing the heaviest and lightest pig per pen; and (2), (3), and (4) weighing the first 5, 10, and 15 pigs out of the pen, respectively. The time required to complete each treatment was recorded. All treatments were completed by 2 people using an individual pig scale with a digital weight indicator (SW600, Digi-Star, Ft. Atkinson, WI). The scale was made out of aluminum and had 2 wheels attached to the front, so it could be moved easily by 1 person. The scale contained 2 swinging gates at the front and back end. The back gate was opened and closed using a latch on top of the gate. The front gate was attached to an aluminum arm with a handle. The arm extended the length of the scale so the handle was located in close proximity to the back gate. The handle was lifted up and pushed forward to open the gate and lifted up and pulled back to close the gate, so 1 person was able to open and close both gates while standing in the same spot. The same 2 people completed the treatments on all 68 pens in the experiment. Treatments were conducted in Barn 1 on d 1 and Barn 2 on d 2. Person 1's first responsibility was to place the scale a pen's length away from the pen to be weighed. Once the scale was set in place, Person 1 and 2 met at the gate of the pen to be weighed. When both persons were ready, Person 1 recorded the time and retrieved the scale, placed it in position next to the current pen to be weighed, and zeroed the scale. For Treatment 1, Person 2 began searching for the heaviest and lightest pig in the pen while Person 1 set up the scale. After Person 1 zeroed the scale, he helped Person 2 decide which pigs were the heaviest and lightest by visual evaluation. Then, Person 2 marked those pigs with marking paint. Person 1 then opened the gate while Person 2 started sorting the heaviest and lightest pig toward the scale. For Treatments 2, 3, and 4, while Person 1 set up the scale, Person 2 opened the gate and was positioned in the pen ready to start assisting pigs onto the scale. For all treatments, while weighing pigs, Person 1's responsibilities were to open and close the scale gates and record pig BW, and Person 2's responsibility was to use a 30- × 36-in. sorting board to assist pigs onto the scale. For Treatment 1, after the first pig was weighed, Person 1 backed that pig off the scale back into the pen while Person 2 sorted the second pig to the scale. After the second pig was weighed, Person 1 backed that pig off the scale back into the pen, and Person 2 closed the pen gate when the pig was in the pen. After the pen gate was closed, Person 1 recorded the time. For Treatments 2, 3, and 4, after Person 1 recorded the BW of each pig, the gate at the front of the scale was opened and the pig was run into the aisle. After all pigs were weighed, Person 2 moved the scale to the other side of the open gate to allow Person 1 to move the pigs back into the pen. After all pigs were returned to the pen, the gate was shut and the time was recorded. The same person assumed the same responsibilities for completing treatments on all 68 pens. Treatments were conducted on assigned pens in order of location block; therefore, each of the 4 treatments was conducted on the designated pen within block before starting on the next block. When Person 1 and 2 took a break, it was taken between blocks.

Treatments were initially analyzed using 2 response criteria: (1) time to complete each treatment per pen; and (2) time to conduct each treatment on a total of 30 pigs. To obtain the time required to conduct a sample size of 30 pigs, the time required to conduct each treatment (select and weigh the heaviest and lightest pig per pen or weigh the first 5, 10, and 15 pigs out of the pen) was multiplied by a factor of 15, 6, 3, and 2, respectively. After preliminary analysis, it was determined that to achieve a total sample size of 30 pigs, selecting and weighing the heaviest and lightest pigs (Treatment 1) from 15 pens required more time than weighing the first 5, 10, or 15 pigs from 6, 3, or 2 pens, respectively. Therefore, the time required to weigh a total of 30 pigs by selecting and weighing the heaviest and lightest pigs (Treatment 1) from 15 pens was compared with the time required to weigh a total of 60, 75, and 90 pigs by weighing the first 5, 10, or 15 pigs (Treatments 2, 3, and 4) from the required number of pens. This was completed to determine the number of total pigs that could be weighed in an amount of time similar to that required to select the heaviest and lightest pigs (Treatment 1) in 15 pens (30 pigs). This led to 3 additional response criteria: (3) time to conduct Treatments, 2, 3, and 4 so that the total pigs weighed equaled 60; (4) time to conduct Treatments 2 and 4 so that the total pigs weighed equaled 75; and (5) time to conduct Treatments 2, 3, and 4 so that the total pigs weighed equaled 90. Regression analysis was also completed to predict the time required to weigh 5 to 15 pigs per pen. The slope of the line from the regression analysis represents the additional time required to weigh each additional pig per pen.

The time analysis did not account for the time required to change clothes for biosecurity measures and set up the barn. This was not included because it was considered to be consistent across all treatments. Changing clothes and setting up the scale and preparing the barn took approximately 27 min in both barns.

Data were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC) with pen as the experimental unit. Treatment was included as the fixed effect and location block as a random effect. Differences between treatments were determined using the PDIFF option of SAS. Sampling methods were analyzed using 4 response criteria: (1) time to complete each method per a pen; (2) time to conduct each sample method so that the total pigs weighed equaled 30; (3) time to conduct Treatment 1 so that the total pigs weighed equaled 30 and time to conduct Treatments 2, 3, and 4 so that the total pigs weighed equaled 60; (4) time to conduct Treatment 1 so that the total pigs weighed equaled 30 and time to conduct Treatments 2 and 4 so that the total pigs weighed equaled 75; and (5) time to conduct Treatment 1 so that the total pigs weighed equaled 30 and time to conduct Treatments 2, 3, and 4 so that the total pigs weighed equaled 90. Significant differences were declared at $P < 0.05$ and trend at $P < 0.10$. In addition, the REG procedure of SAS was used to develop a regression equation to predict the time required to weigh 5 to 15 pigs per pen.

Precision for estimating the mean and SD

For a sample size of 30 pigs, the heaviest and lightest pigs in 15 pens can be selected and weighed to achieve a confidence interval (CI) range of 14.8 to 15.2 lb when estimating the mean and 11.9 to 16.8 lb when estimating the SD (Paulk, 2014). However, preliminary analysis determined that when weighing the first 5, 10, or 15 pigs per pen, a larger sample size can be conducted in the same amount of time as selecting and weighing the heaviest and lightest pigs in 15 pens. Therefore, datasets A and C from Paulk (2014) were used herein to determine CI range for a total sample size of 60, 75, and 90 pigs. These sample sizes were achieved by taking random samples of 5 pigs within 12, 15, or 18 pens; 10 pigs within 6 or 9 pens; and 15 pigs within 4, 5, or 6 pens. Datasets A and C were used because they had similar pen arrangements to the 2 barns used in the experiment conducted herein (i.e., approximately 20 to 35 pigs per pen). These sampling methods were evaluated using a simulation model developed using R (Paulk, 2014; R Foundation for Statistical Computing, Vienna, Austria). Each sample size was conducted 10,000 times, generating 10,000 estimated means and SD. These were used to determine the accuracy and precision for each sample method. The accuracy was determined by comparing the mean of the 10,000 sample means and associated SD to the actual population mean and SD pig BW, respectively. The precision was determined by calculating a 95% CI for the 10,000 sample means and SD. The distances between the upper and lower confidence limits represent the estimated means and SD CI range. When the heaviest and lightest pigs were selected from 15 pens, the mean was estimated using the following equation: Estimated mean, lb = 0.77 × sample mean, lb + 0.25 × sample median, lb, and the SD was estimated by subtracting the sample's lightest pig BW from the heaviest pig BW and dividing the difference by 6 (Paulk 2014).

Results

Time required to weigh pigs for different sampling methods

The time taken to select and weigh the heaviest and lightest pigs in a pen (Treatment 1) did not differ from weighing 5 pigs per pen (Treatment 2; Table 1). Increasing the number of pigs weighed per pen (Treatments 2, 3, and 4) increased ($P < 0.05$) the amount of time required to weigh a single pen. For conducting a sample size of 30 pigs, selecting and weighing the heaviest and lightest pigs in 15 pens (Treatment 1) increased ($P < 0.05$) the time required compared with weighing the first 5, 10, or 15 pigs (Treatments 2, 3, and 4), from 6, 3, or 2 pens, respectively. Weighing 5 pigs (Treatment 2) from 6 pens tended to increase ($P < 0.10$) time required compared with weighing 15 pigs (Treatment 4) from 2 pens, with the time needed to weigh 10 pigs (Treatment 3) from 3 pens being intermediate. For conducting a sample size of 60 pigs, selecting and weighing the heaviest and lightest pigs in 15 pens (Treatment 1) increased ($P < 0.05$) the time required compared with weighing the first 5 pigs (Treatment 2) from 12 pens. Both of these treatments increased ($P < 0.05$) the time required compared with weighing 10 or 15 pigs (Treatments 3 and 4) from 6 or 4 pens, respectively. For conducting a random sample of 75 pigs, the time required for selecting and weighing the heaviest and lightest pigs in 15 pens (Treatment 1) did not differ from weighing the first 5 pigs (Treatment 2) from 15 pens; however, both of these treatments required more ($P < 0.05$) time than to weigh the first 15 pigs (Treatment 4) from 5 pens. For conducting a random sample of 90 pigs, the time taken to select and weigh the heaviest and lightest pigs in 15 pens (Treatment 1), weigh the first 10 pigs (Treatment 3) from 9 pens, and weigh the first 15 pigs (Treatment 4) in 6 pens did not differ, but all took less ($P < 0.05$) time than weighing the first 5 pigs (Treatment 2) from 18 pens.

The following regression equation ($R^2 = 0.74$; SE = 2.53) was developed to predict the time needed to weigh 5 to 15 pigs per pen:

$$y = 30.23x + 64.18$$

where y = time (s) required to weigh x number of pigs and x = the number of pigs per pen to be weighed. The predicted time needed to weigh 5 to 15 pigs per pen can then be multiplied by the number of pens to determine the time needed to conduct the total sample.

Precision for estimating the mean and SD

For dataset A, selecting and weighing the heaviest and lightest pigs (Treatment 1) in 15 pens and weighing 5 or 10 pigs per pen (Treatments 2 and 3, respectively) to equal a total of 75 or 90 pigs had a similar (within 1.3 lb) CI range for estimating the mean and SD of BW (Table 2). For dataset C, selecting and weighing the heaviest and lightest pigs (Treatment 1) in 15 pens and weighing 5 pigs per pen (Treatment 2) to equal a total of 75 or 90 pigs had a similar (within 2.4 lb) CI range for estimating the mean BW. Selecting and weighing the heaviest and lightest pigs (Treatment 1) in 15 pens and weighing 5, 10, or 15 pigs per pen (Treatments 2, 3, and 4, respectively) to equal a total of 75 or 90 pigs had a CI range within 5.5 lb of each method for estimating the SD, with Treatment 1 having the highest CI range and Treatment 2 having the lowest.

Discussion

In a finishing pig barn, pigs are typically housed with 25 to 60 pigs per pen and 19 to 48 pens per barn depending on the design of the barn. For weighing a set number of pigs, the precision for estimating the mean and SD BW is improved by increasing the number of pens sampled (Paulk, 2014). However, weighing pigs from multiple pens requires more resources and time, including opening gates and entering pens and moving the scale throughout the barn. The intercept and slope of the developed regression equation represent the estimated time required to set up the scale for each pen and the time to weigh each pig, respectively. Therefore, it took approximately 64 sec to move the scale 1 pen's length, zero the scale, and open the gate before weighing any pigs and 30 sec for each pig weighed per pen.

For a sample size of 30 pigs, the precision for estimating the mean and SD of pig BW can be further improved by selecting the heaviest and lightest pigs from 15 pens vs. weighing n random pigs from n random pens to equal a total sample size of 30 pigs (Paulk, 2014). Although this improved the precision without increasing the number of pigs weighed, selecting and weighing pigs from 15 pens includes additional time to select and sort pigs and weigh multiple pens as previously discussed. Personnel weighing pigs altered the workload and time required by backing each pig off of the scale; however, selecting pigs and sorting them to the scale took additional time. It took the same amount of time to select and weigh the heaviest and lightest pig per pen as it did to weigh the first 5 pigs per pen. In addition, for a total sample size of 30 pigs, selecting and weighing the heaviest and lightest pigs in 15 pens took 2.5, 3.0, and 3.1x longer to complete compared with weighing 5 pigs from 6 pens, 10 pigs from 3 pens, and 15 pigs from 2 pens, respectively. Therefore, the comparison of sampling methods needed to be reevaluated based upon the time required to conduct the sample instead of the number of pigs weighed.

A similar amount of time was necessary, approximately 52 to 54 min, to conduct the following sampling methods: selecting and weighing the heaviest and lightest pig in 15 pens (30 pigs), weighing 5 pigs from 15 pens (75 pigs), 10 pigs from 9 pens (90 pigs), and 15 pigs from 6 pens (90 pigs). Based on the CI range, an optimal sampling method was not clearly defined for estimating both the mean and SD. However, for datasets A and C, weighing 5 pigs from 15 pens had a CI range similar to or reduced compared with the other 3 methods when estimating the mean and SD of BW. Also, weighing 10 pigs from 9 pens (90 pigs), and 15 pigs from 6 pens (90 pigs) increased the CI range when estimating the mean for dataset C. Weighing 5 pigs from 15 pens increased the CI range by 1.1 to 2.4 lb for estimating the mean but reduced the CI range by 0.2 and 5.5 lb for estimating the SD compared with selecting and weighing the heaviest and lightest pig in 15 random pens.

In addition to improvements in the CI range, weighing 5 vs. 10 or 15 pigs per pen may have caused less stress when moving pigs back to the pen after being weighed. Although stress levels were not measured in this experiment, Lewis and McGlone (2006[5]) observed elevated heart rates of pigs moved in groups larger than 5 or 6 pigs. Also, when the heaviest and lightest pigs were selected and weighed, each pig was backed off the

[5] Lewis, C.R.G., and J.J. McGlone. 2007. Moving finishing pigs in different group sizes: Cardiovascular responses, time, and ease of handling. Livest. Sci. 107:86–90.

scale into the pen instead of let into the aisle. Therefore, moving pigs back to their pens was not a concern, but stress-related measurements of backing each pig off the scale were not determined.

Determining whether to select and weigh the heaviest and lightest pigs in 15 random pens or weigh the first 5 pigs in 15 random pens may also depend on personnel skill. The time required to select the heaviest and lightest pigs can depend on the person's ability to assess the BW of pigs within a pen and make the decision. The accuracy and precision for estimating the mean and SD can also depend on their ability to accurately select the heaviest and lightest pigs. Personnel not experienced at selecting pigs may prefer to weigh 5 pigs per pen because it can be done by randomly selecting pens and weighing the first 5 pigs in each of those pens.

In conclusion, based on time required to conduct the sample and the precision and accuracy of the sampling method, weighing the first 5 pigs in 15 pens is the recommended sampling method. In addition, weighing the first 5 pigs per pen does not include the assumption that personnel can select the correct pigs and reduces the possibility of bias occurring. It is expected to take 2 employees approximately 55 min to weigh the first 5 pigs from 15 pens, not including time to prepare and clean up.

Table 1. Time required to select and weigh pigs for designated sampling methods[1]

	Treatment[2]					
Total sample	HL	5 pigs	10 pigs	15 pigs	SEM	*P* <
Time per pen,[3] min	3.6[a]	3.6[a]	6.0[b]	8.7[c]	0.3	0.001
Time required for weighing,[4] min						
30 pigs	53.4[a]	21.6[b]	17.9[b]	17.4[b]	2.4	0.001
60 pigs[5]	53.4[a]	43.2[b]	35.9[c]	34.8[c]	2.1	0.001
75 pigs[5]	53.4[a]	54.0[a]	---	43.5[b]	3.5	0.009
90 pigs[5]	53.4[a]	64.8[b]	53.9[a]	52.3[a]	3.5	0.003

[1] A total of 68 pens in 2 barns with 25 to 30 pigs per pen were used to conduct sampling methods.
[2] Treatments included: (HL) selecting weighing the heaviest and lightest pig per pen and weighing the first 5, 10, and 15 pigs out of the pen.
[3] Time required to conduct sampling method on a single pen.
[4] The time observed for selecting and weighing the heaviest and lightest pig per pen and weighing the first 5, 10, and 15 pigs out of the pen was multiplied a factor of n to equal the total sample size.
[5] The time observed for selecting and weighing the heaviest and lightest pig per pen was kept constant at a total sample size of 30 pigs.
[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

Table 2. The confidence interval (CI) range (lb) when a varying number of pigs and pens are sampled to estimate the mean and SD BW of the population[1]

	Treatment[2]			
Total sample	HL[3]	5 pigs	10 pigs	15 pigs
Dataset A[4]				
Mean				
30 pigs,[5]	14.8	26.0	28.9	32.0
60 pigs,[6]	---	17.6	20.5	22.0
75 pigs,[7]	---	15.9	---	19.6
90 pigs,[8]	---	13.9	16.1	18.1
SD				
30 pigs,[5]	11.9	19.0	19.6	19.8
60 pigs,[6]	---	13.9	13.4	13.9
75 pigs,[7]	---	12.3	---	11.7
90 pigs,[8]	---	11.7	11.2	11.0
Dataset C[9]				
Mean				
30 pigs,[5]	15.2	30.0	40.3	47.8
60 pigs,[6]	---	21.8	27.3	33.3
75 pigs,[7]	---	17.6	---	28.7
90 pigs,[8]	---	15.9	21.4	26.5
SD				
30 pigs,[5]	16.8	20.9	23.6	25.1
60 pigs,[6]	---	15.0	16.3	18.5
75 pigs,[7]	---	12.3	---	16.8
90 pigs,[8]	---	11.2	13.4	15.0

[1] Samples were simulated using datasets from Paulk et al., 2014 (see footnote 4 in main text). Samples were completed 10,000 times for each sampling method. The CI range was calculated for the 10,000 sample means and SD of each sampling method.

[2] Treatments included: (HL) selecting weighing the heaviest and lightest pig per pen and weighing the first 5, 10, and 15 pigs out of the pen.

[3] The mean was estimated using following equation: Estimated mean, lb = 0.77 × sample mean, lb + 0.25 × sample median, lb, and the SD was estimated by subtracting the sample's lightest pig BW from the heaviest pig BW and dividing the difference by 6.

[4] A total of 1,260 pigs (mean = 253.1 lb, median = 254.0 lb, SD = 32.8 lb, and CV = 13.0%) with 23 to 28 pigs per pen and a total of 48 pens.

[5] Samples included selecting the heaviest and lightest pig from 15 pens, 5 random pigs from 6 pens, 10 random pigs from 3 pens, and 15 random pigs from 2 pens for Treatments 1, 2, 3, and 4, respectively.

[6] Samples included selecting the heaviest and lightest pig from 15 pens, 5 random pigs from 12 pens, 10 random pigs from 6 pens, and 15 random pigs from 4 pens for Treatments 1, 2, 3, and 4, respectively.

[7] Samples included 5 random pigs from 15 pens and 15 random pigs from 5 pens for Treatments 2 and 4, respectively.

[8] Samples included 5 random pigs from 18 pens, 10 random pigs from 9 pens, and 15 random pigs from 6 pens for Treatments 2, 3, and 4, respectively.

[9] A total of 1,069 pigs were weighed (population mean = 222.4 lb, median = 224.0 lb, SD = 32.0 lb, and CV = 14.4%) with 40 pens and 20 to 35 pigs per pen.