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Refinement of water-based foam procedures for the depopulation of swine (22-066)

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Key Findings:

- During extraordinary circumstances, it may become necessary to depopulate large populations of swine as a disease containment measure. Depopulation methods currently recommended or recommended under constrained circumstances for swine by the AVMA present significant logistical challenges when scaled to large populations or performed in field conditions.
- In the United States, water-based foam is currently approved for poultry depopulation, and recent field studies demonstrated it can also be an effective depopulation alternative for swine.
- Our study investigated the effect of foam fill rate and foam fill depth on animal behavior, time to cessation of movement, and time of cardiac arrest, with the main goal of refining operating protocols for application of water-based foam under field conditions.
- Results from our trials showed that, when using a smooth-sided container, immersing animals in foam within 90 seconds and using a fill depth of at least 1.75x times the pig head height is recommended to reduced animal stress levels while ensuring a rapid destruction.
- It is important to note that only one type of foam concentrate and a custom-made container were used in this study, therefore industry-wide generalizations need to be made with caution.

Keywords:

Depopulation, swine, water-based foam, welfare assessment

Abstract

Modern swine production coupled with expanding global movement of people and animals increases the chance of introduction and spread of pathogens in US swine populations. Although the US swine herd is free of African Swine Fever (ASF), there is ongoing transmission throughout China, parts of Europe, and the Dominican Republic; and preparation of contingency plans remains a high priority for the US swine industry. These plans must include detailed steps for depopulation of large numbers of swine in a short timeframe. Several methods are recommended by the AVMA; but one solution does not fit all situations in the U.S. pork industry. Water-based foam may provide an additional solution for an emergency depopulation event; therefore, the main goal of our project is to add to the body of knowledge on water-based foam as a potential method for swine depopulation. Specific objectives of this project were to 1) assess the effect of fill rate of water-based foam on the welfare of finishing pigs; and 2) Determine the optimal depth of water-based foam for depopulation of finishing pigs.

A subset of pigs (N = 153) from a 4000-head wean-to-finish facility were enrolled in the study and were depopulated using a modified 64.5-m^3 (dimensions 12.2 × 2.36 × 2.24 m; length, width and height) rendering trailer. Foam was generated during using a Class A foam concentrate (1%), and delivered using medium expansion aspirated foam nozzles. For objective 1, 77 finisher pigs were divided into 3 treatments groups with 2 replicates each based on a pre-established fill rate (slow, medium, or fast). Pigs had subcutaneous data loggers that allowed for activity and electrocardiogram (ECG) data collection. For objective 2, 76 finisher pigs were assigned into 3 treatment groups with 2 replicates each based on a predetermined foam fill level (99 cm, 116 cm, or 132 cm) from the trailer floor. A trained welfare specialist observed and timed the entire depopulation process for both objectives.

Results from our study showed that time to cessation of movement was significantly longer in the slow foam rate treatment compared to the fast and medium foam rate treatments. Furthermore, the number of foam surface breaks were the highest for the slow fill rate treatment compared to the number seen in one of the fast fill rate replicates. The number of surface breaks was also higher for the 0.99m fill depth. No vocalizations were heard for any of the treatments. In conclusion, our trials showed that for WBF depopulation of swine in smooth-sided containers, immersing animals in foam within 90 seconds and using a fill depth of at least 1.75x times the pig head height is recommended to reduced animal stress levels while ensuring a rapid destruction.

Introduction:

Modern swine production coupled with expanding global movement of people and animals increases the chance of introduction and spread of pathogens in US swine populations. Disease outbreaks cause negative impacts on animal health and welfare, public health, and the environment, food supply, and the economy as a whole. To minimize such effects, disease control plans are needed. As an example, African Swine Fever (ASF) is a severe viral disease affecting domestic and feral pigs, for which currently there is no commercially available vaccine. Although the US swine herd is free of ASF, there is current and ongoing transmission throughout China, parts of Europe, and the Dominican Republic (OIE, 2020). Because the ASF virus can be transmitted by numerous modes of transmission, preparation of contingency plans remains a high priority for the US swine industry. These plans must include detailed steps for depopulation of large numbers of swine in a short timeframe.

Even though there are guidelines developed by the American Veterinary Medical Association (AVMA) on swine depopulation and euthanasia (AVMA 2019, AVMA 2020), applying recommended measures to large populations of swine under field conditions while assuring rapid, humane destruction of animals and the provision of safe and mental health efficacious protocols for humans remains a challenge. As recommended by the AVMA, developing and testing a plan before an incident occurs becomes imperative. The goal of best practice depopulation systems is to minimize or eliminate animal anxiety, pain, and distress before the loss of consciousness. Thus, when evaluating depopulation systems, both the induction of unconsciousness and handling/ restraint processes must be considered (AVMA 2019). Current preferred depopulation methods include physical methods (non-penetrating captive bolt, penetrating captive bolt, electrocution, manual blunt force trauma, and movement to slaughter) and inhaled methods (carbon dioxide and anesthetic overdose). However, most of these methods are not good candidates for mass depopulation because they are either time consuming (delivered at the individual level), and/or would represent a high risk of disease dissemination to other swine (e.g. movement to slaughter).

Rapid depopulation of infected and exposed animals will help maintain continuity of business for non-infected animals and non-contaminated animal products. As we know, one solution does not fit all situations in the U.S. pork industry. Thus, is it important to assess risks and available options to ensure that good balance between rapid destruction and minimized suffering is upheld (Sawyer and Huertas, 2018). Previously cited work by our research group has shown that water-based foam (WBF) may provide an additional solution for an emergency depopulation event and could be a suitable depopulation candidate for swine, but additional refinement of methodology and assessment of the animal behavior implications of the procedure is warranted. This proposed study aimed to investigate the effect of foam fill rate and foam fill depth on animal behavior, time to cessation of movement, and time of cardiac arrest, with the main goal of refining operating protocols for application of water-based foam under field conditions.

Objectives:

Objective 1: Assess the effect of fill rate of water-based foam on the welfare of finishing pigs.

Objective 2: Determine the optimal depth of water-based foam for depopulation of finishing pigs.

Materials & Methods:

Animals

A subset of pigs (N = 153) from a 4000-head wean-to-finish facility were enrolled in the study as they had accidental access to rodent bait, and therefore needed to be removed from the food chain. This event allowed for the depopulation trial and associated data collection to take place during field conditions.

Depopulation trailer

A modified 64.5-m^3 (dimensions 12.2 × 2.36 × 2.24 m; length, width and height) rendering trailer was used for depopulation in this study. The rendering trailer was customized with a hydraulic lift system and a hinged gate at the back of the trailer to enable additional loading access via a ramp and to facilitate easy carcass unloading post-depopulation. A cut gate was located at mid-length, allowing for added compartmentalization within the trailer during loading and foaming to accommodate smaller or larger groups of animals. An elastomeric polyurethane coating was added to the trailer floor for increased traction and to reduce potential animal slipping during the foaming procedure. The trailer walls consisted of smooth steel without any protruding seems, bolts, hinges or other hardware to reduce animal injuries during pig escape attempts or movements during foaming. All pigs were directly loaded from the holding pens into the modified rendering trailer using a single file loading ramp.

Foam generation

Foam was generated during using a PHOS-CHEK WD881 Class A foam concentrate (Perimeter Solutions, Rancho Cucamonga, CA, USA) added to freshwater vessels (1,892 L) creating a 1% foam-water solution. The foam-water solution was pumped from the foam-solution holding vessel by gasoline-powered water pumps (AMT Pump Company 2MP13HR, Royersford, PA, USA) via a 5.08-cm diameter suction hose connected to the pump inlet. The foam-water solution was delivered out of the pump in a 3.81 cm diameter firehose (15 m in length) to a medium expansion aspirated foam nozzle (KR-M4, ANSUL, Marinette, WI, USA). This setup enabled a 40-50:1 foam to water expansion ratio to be pumped into the modified rendering trailer at a rate equivalent to 18.1 to 22.6 m^3 of foam per minute per pump. Personnel involved in the operation wore personal protective equipment including hats, gloves, glasses, boots and appropriate waterproof clothing at all times. Two research team members were assigned to each foaming unit, operating one pump and one aspirated nozzle, respectively. To prevent falling accidents off or into the trailer during the foaming procedure, staff wore fall protection harnesses equipped with snap hook lanyards attached to a guide wire on top of the trailer.

Objective 1: Fill rate

Seventy-seven finisher pigs were divided by convenience into 3 treatments groups with 2 replicates each based on a pre-established fill rate (slow, medium, or fast) equivalent to 1, 2, or 3 pumping units used in tandem, respectively. Prior to pigs being loaded into the trailer, all pigs had subcutaneous data loggers (DST-Centi-HRT ACT, Star-Oddi, Gardabaer, Iceland) implanted caudally to the left or right triceps. The subcutaneous data logger allowed for activity and electrocardiogram (ECG) data collection and calculation of the time when cessation of movement (COM) and death occurred. The ECG tracings were reviewed using Mercury v5.99 and Pattern Finder software. This software combination enabled the interpretation and determination of the presence and time stamp of fatal arrhythmias such as asystole, third-degree atrioventricular block (AVB), atrial standstill or ventricular fibrillation (VF). Persistent or pulseless electrical activity (PEA) or electromechanical dissociation was defined as presence of any rhythm at the time of physical confirmation of death (i.e., clinical asystole).

Pigs were placed in the front half of the trailer and this time foam was applied until foam was overflowing the top of the trailer. After a dwell-time of 7.5 min, the trailer was hydraulically lifted, pigs and foam were removed, and a team of trained investigators evaluated individual pigs for signs of consciousness. Immediate euthanasia was applied if signs consistent with regained signs of consciousness were observed. Data loggers were recovered from the subcutaneous space and after confirmed death, carcasses were disposed by rendering, arranged by the producer.

A trained welfare specialist observed and timed the entire depopulation process for each replicate. Pig demeanor on entry to the trailer, reactions to foam initiation, time to foam reaching shoulder height, head height (full immersion), and final fill height were tallied for signs of adverse response (struggle, climbing, swimming, and/or vocalizing) with time at each point recorded. Assessment continued until all observable signs of pig movements ceased (including subjective signs such as sudden foam irregularities or disruptions caused by pig movement beneath the foam), at which time a final time was recorded. Data was descriptively analyzed.

Objective 2: Fill depth

Seventy-six finisher pigs were assigned into 3 treatment groups with 2 replicates each based on a predetermined foam fill level (99 cm, 116 cm, or 132 cm) from the trailer floor. The foam fill level was based on 1.5X, 1.75X or 2.0X the average finisher pigs' lateral head position (66 cm above ground) to ensure full foam immersion while standing on four legs but simultaneously investigate if any resurfacing occurred, which may prolong time spent conscious. Pigs were placed in the compartmentalized front half of the trailer and foam was applied from the top through the open canopy using three pumping units in tandem. For each treatment and replicate, foam was pumped into the trailer until it reached treatment specific fill heights demarcated by uniquely color-coded tape on the inside of the trailer wall. Similar to Objective 1, pigs were left immersed in the foam for 7.5 minutes before the trailer was hydraulically lifted, pigs were removed and assessed for signs of consciousness. If any signs of consciousness were observed, an immediate secondary euthanasia method using penetrating captive bolt was available. After confirmed death, carcasses were disposed by rendering, arranged by the producer. Animal behavior assessments were conducted as described for Objective 1, by the same welfare specialist.

Results:

Objective 1: Fill rate + welfare measures

Fill times for each treatment and replicate can be found in Table 1. The average time to immerse pigs in foam (fill to head) was 90.4 ± 87.5 s, but below 25 s for both fast and medium fill rate treatments. The overall high average immersion time was highly driven by the slow fill rate treatment which took significantly longer due to complications with the pumping unit (Table 1). The average time to fill the compartmentalized front half of the modified rendering trailer was 00:43 ±

00:05, 01:19 ± 00:10, and 03:58 ± 00:26 min for fast, medium, and slow foam rate groups, respectively. The average response time to the foam across treatments was 62.7 ± 50.0 s post-foam initiation; and was also largely driven by the slower fill rate treatment. Time to full immersion was below 25 s for the fast and medium fill rate treatments but significantly longer for the slow fill rate treatment (2:45-3:45 min:s).

In regards to animal behavior observations, the number of surface breaks were the highest (>35) for the slow fill rate treatment while 5 were seen in one of the fast fill rate replicates. In contrast, no escape attempts were observed during the slow fill rate treatment while 5 and 6 escape attempts were recorded in the medium and fast fill rate treatments, respectively. The average time to the last subjectively recorded pig response was 160.8 ± 82.5 s (2:40 ± 1:23 min:s). No vocalizations were heard for any of the treatments.

Table 1. Fill time (min:s) and number of pig responses (surfacing or vocalizations) of wean to finish pigs during a medium-expansion water-based foam during three different container fill depth levels[1] (0.99 m, 1.16 m, and 1.32 m) and foam fill rates[2] (slow, medium and fast).

					Fill time[3]			Time to pig response and number of responses (as observed in the field by welfare specialist)					
Trial	**Test group**	**Replicate**	**Fill level above head**	**N (pigs)**	**Shoulder**	**Head**	**Fill completed**	**First response**	**Last response**	**Surface breaks**	**Vocalizations**	**Escape attempts**	**Total responses**
Fill depth (m)	0.99	1	0.33	13	0:12	0:23	1:18	0:25	1:58	0	0	2	2
	0.99	2	0.33	13	0:15	0:24	1:18	0:20	2:31	16	0	0	16
	1.16	1	0.5	13	0:15	0:20	0:43	0:28	2:10	0	0	3	3
	1.16	2	0.5	11	0:13	0:22	0:50	0:00	1:42	0	0	1	1
	1.32	1	0.66	13	0:11	0:18	0:50	0:23	1:34	0	0	2	2
	1.32	2	0.6	13	0:14	0:23	0:57	0:22	1:40	0	0	1	1
Fill rate	Slow[4]	1	0.5	13	2:00	2:45	3:34	1:36	4:10	>20	0	0	>20
	Slow[4]	2	0.5	13	3:15	3:45	4:19	2:40	5:00	15	0	0	15
	Medium	1	0.5	13	n/a	n/a	0:57	0:32	1:58	0	0	1	1
	Medium	2	0.5	13	0:17	0:21	1:30	0:34	1:36	0	0	4	4
	Fast	1	0.5	12	0:12	0:22	0:42	0:35	1:50	5	0	0	5
	Fast	2	0.5	13	0:12	0:19	0:46	0:19	1:31	0	0	6	6

[1]Fill depth levels were based on 1.5x, 1.75x and 2.0x of the average pig's head height above ground (0.66 m) when standing on all 4 legs.
[2]Foam fill rate was based on using one (slow), two (medium) or three (fast) foam producing unit(s) simultaneously. The fill rate per pump was variable between 18.1 to 22.6 m^3 of foam per minute.
[3]Time to foam reaching above pig's shoulder height, head or container rim (overflow).
[4]The slower than expected fill rate was due to technical difficulties with the pumping unit.

The average time to cessation of movement (COM) post-foam initiation estimated from subcutaneous accelerometers were 05:22 ± 00:21, 03:32 ± 00:14, and 03:11 ± 00:13, min for slow, medium, and fast foam rate treatments, respectively. The time to COM was significantly longer in the slow foam rate treatment compared to the fast and medium foam rate treatments ($p < 0.001$) (Table 2). Furthermore, the time of COM in the medium foam rate treatment was significantly different ($p < 0.001$) compared to the fast foam rate treatment.

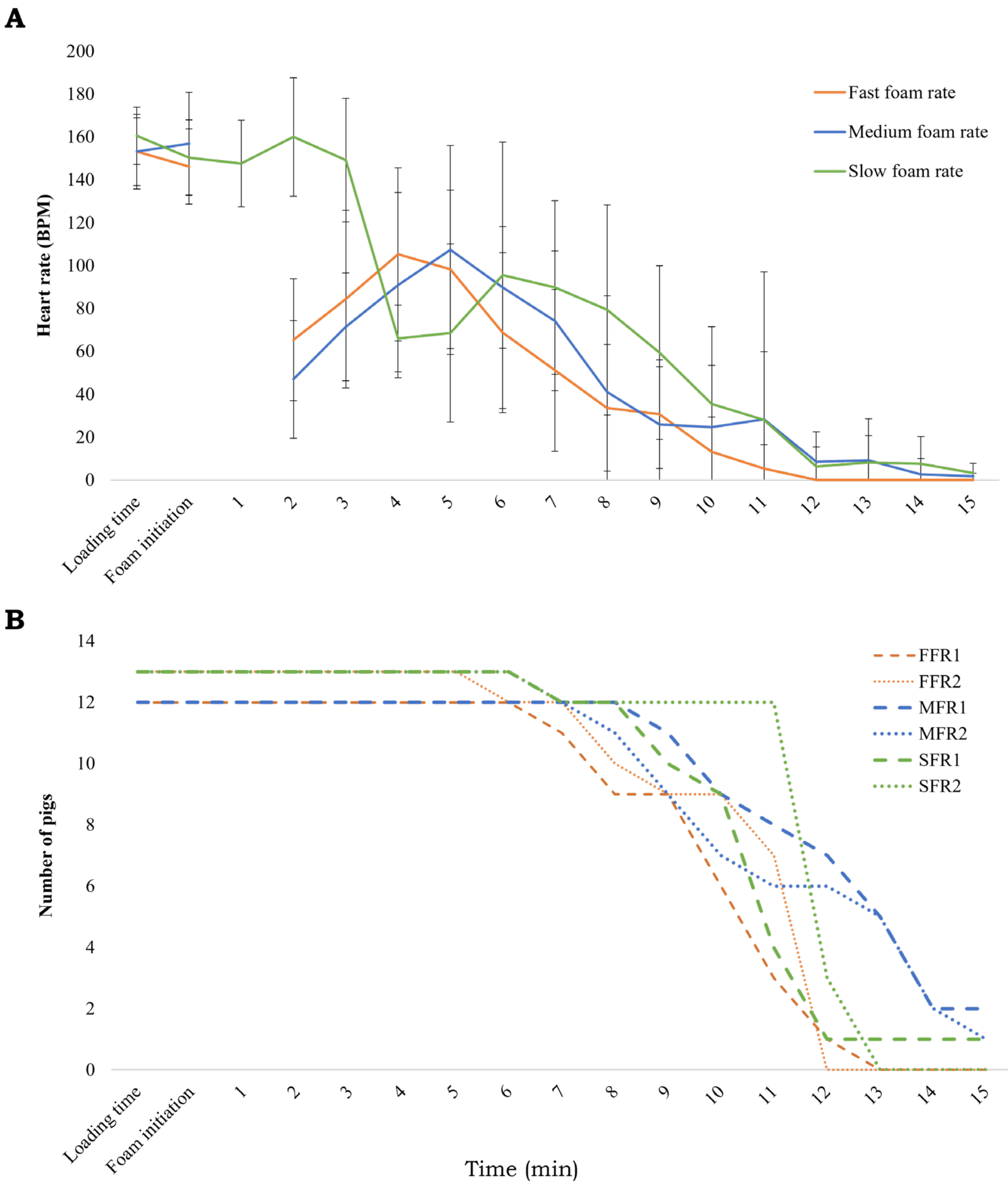
Table 2. Fill time (min:s) of medium-expansion water-based foam and the time to cessation of movement (COM) for wean to finish pigs during three different foam fill rates[1].

Foam rate group[1]	**Replicate**	**Time to fill trailer with WBF (mm:ss)**	**N (pigs)**	**Time to COM[2] (mm:ss ± standard deviation)**
Slow	1	03:39	13	04:30 ± 00:24
	2	04:16	13	06:17 ± 01:12
Medium	1	01:26	13	03:30 ± 01:02
	2	01:12	13	03:36 ± 01:52
Fast	1	00:42	12	03:00 ± 01:09
	2	00:46	13	03:24 ± 01:15

[1]Foam fill rate was based on using one (slow), two (medium) or three (fast) foam producing unit(s) simultaneously. The fill rate per pump was variable between 18.1 to 22.6 m^3 of foam per minute.
[2]The duration between the time of foaming start and the time of cessation of movement.

The average heart rate during the WBF procedure for each fill rate treatment is visualized in Figures 1A-B. Due to reading errors by the subcutaneous biologger during the first minute post foam initiation for the fast and medium fill rate treatments, no heart rate data was recorded for those time stamps. However, based on the slow fill rate treatment data and heart rate data starting at 2 minutes post-fill initiation, a significant decrease in heart rate (beats per minute, BMP) can be observed for both the fast (65.4 ± 28.4, 153.2 ± 15.8, and 146.2 ± 17.6 BPM, respectively, $p < 0.001$) and medium fill treatment (48.9 ± 26.3, 153.6 ± 17.6, and 156.9 ± 23.9 BPM, respectively, $p < 0.001$). For all treatments, after the initial drop, heart rates increased during the next 3-4 subsequent minutes after which they all continued to drop as pigs became unconscious and cardiac failures started to occur (Figure 1A).

Figure 1. Average heart rate (HR) (solid line, beats per minute, BPM, mean ± SD) and number of pigs showing cardiac activity (CA) (dotted lines) over time for wean to finish pigs (n=77) implanted with a subcutaneous bio-logger using three fill rates of medium-expansion water-based foam in a modified depopulation trailer. Panel A, represent foam fill rates was based on using one (slow), two (medium) or three (fast) foam producing unit(s) simultaneously. Loading time heart rate represents the average heart rate during a 5-min period prior to foam initiation. For the medium and fast trial, heart rate data was corrupted during the first minute post foam initiation and omitted in the graphs. All pigs for each were removed after a 7.5-min dwell time. Panel B shows pig mortality over time with colors corresponding to slow (S-FR), medium (M-FR) and fast (F-FR) fill rate trials and replicates, respectively.



Objective 2: Fill depth + welfare measures

Fill times for each treatment and replicate can be found in Table 1. The average time to immerse pigs in foam was 21.7 ± 2.1 s with a complete fill time of 78.0, 46.5 and 53.5 s, for the 0.99 m, 1.16

m and 1.32 m fill depth treatments, respectively. The average response time to the foam across the treatment groups was 19.7 ± 9.1 s post-foam initiation. Sixteen surface breaks were recorded for replicate 2 of the 0.99 m fill depth treatment while the number of escape attempts were evenly distributed across treatments and replicates as long as pigs remained observable. The average time to the last recorded pig response was 116 ± 19.8 s (1:56 min:s ± 19.8 s) post-foam initiation. No vocalizations were heard for any of the treatments.

Discussion:

In the United States, water-based foam is currently approved for poultry depopulation, and recent field studies by our research team demonstrated water-based foam can be an effective depopulation alternative for swine. Main advantages of WBF is the depopulation of large groups of animals of different ages at once; and the cost and availability of necessary materials. However, even though depopulation methodologies aim to provide rapid destruction of animals, any risk of animals experiencing unpleasant emotional states, discomfort or temporary suffering should be minimized when possible (Duncan 2005, Anthony and De Paula Viera, 2022). As the AVMA considers water-based foam for the depopulation of pigs, the main goal of this study was to generate additional information to develop best practices for use of this method under field settings.

Assessing swine welfare during the WBF depopulation process is challenging due to the properties of the foam, which obscures animal behavior observations. The inability to conduct traditional behavioral assessments when pigs are immersed in foam requires some adjustments and use of precision technology such as accelerometers and electrocardiograms. In addition, it is paramount to ensure that the practical logistics of the WBF foaming protocol is rapid and consistent enough to not unnecessarily prolong the conscious animal stage of the depopulation procedure.

In the current study, we utilized a combination of animal behavior assessments taken by an animal welfare specialist along with direct measurements of cardiac activity and animal movement measures from bio-loggers (as indicators of unconsciousness and death) to understand the effects of varying foam fill rate and foam depth in animal behavior during depopulation. Results from our trials showed that a slow foam fill rate (< 1.5 min) and/ or a foam fill depth of less than 1.75 times the average pig head height 1appeared to cause more stress to the animals, as observed by a higher number of foam surface breaks and escape attempts. Time for cessation of movement was between 3 and 3.5 minutes for both medium and fast foam fill rates; which is consistent with previous work published using WBF (Arruda et al., 2022; Kieffer et al., 2022); with death following 6-15 minutes post-foam initiation (Figure 1B).

One of the main strengths of our project is that we were able to leverage accidental rodent bait ingestion to apply the experiment under field conditions, simulating the conditions of a disease outbreak and using a large number of market-age animals (robust sample size). Secondly, objective measurements of animal movement and cardiac death were taken using previously validated bio-loggers. Lastly, the process was assessed and evaluated through animal behavior assessments by a Welfare Board-Certified professional that had not been previously involved in this specific research, which helps with providing an external party evaluation of the process as a whole. Limitations of our study include the relatively small number of replicates, the fact that bio-logger devices were not available for use for both objectives, and the fact that only one foam concentrate and a specifically custom-made container was used, which may impact (and reduce) generalizability of results. Further research on other potential containers, foam concentrate, and set-up variations is warranted to make industry-wide recommendations.

In conclusion, results from our trials showed that for WBF depopulation of swine in smooth-sided containers, immersing animals in foam within 90 seconds and using a fill depth of at least 1.75x times the pig head height is recommended to reduced animal stress levels while ensuring a rapid destruction.