RESEARCH REPORT

ANIMAL WELFARE

Title: Depopulation methods in swine: what has been done and what are the knowledge gaps?
NPB #20-102

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Industry Summary:

Mass depopulation refers to the need of ending the life of large numbers of animals due to emergencies. This need could arise, for example, when we face disease epidemics (especially for pathogens that can transmit between humans and animals), and during natural disasters. A more recent application of depopulation was to reduce welfare issues associated with slaughter delays, which was observed in the United States in 2020 because of the Coronavirus disease (COVID-19) pandemic. In any case, depopulation should be conducted in a way that assures rapid and reliable unconsciousness followed by death.

The objective of this project was to summarize information on depopulation methods available to date specifically for swine, and to highlight gaps in knowledge to guide the focus of future research. To accomplish this objective, our research team searched several electronic databases to find peer-reviewed and non-peer reviewed papers on the topic. The timeline considered was from 1990 to 2020, and we included English publications from anywhere in the world.

We found 26 publications that were relevant to the topic of depopulation in swine. From those, the majority of research has been conducted with inhalable gaseous formulations (e.g., CO_2), and there was a lack of research in methods such as the use of captive bolts, electrocution, and oral formulations. Furthermore, our literature review showed a lack of research in the areas of worker safety, worker emotional health, and on validation of animal-based measures to be used for depopulation welfare assessments.

Our conclusion was that a safe and reliable manner to induce unconsciousness and death for large populations of swine is lacking and urgently needed for preparedness purposes.
If you have further questions or want to read the whole publication, please contact Dr Andreia Arruda at arruda.13@osu.edu.

Key Findings:

- Despite research over three-decades, a safe and reliable way to induce rapid unconsciousness and death in larger populations of swine is not available to the industry.

- There are very few studies on the topic of mass depopulation of swine, and available literature is inconsistent in regards to which details are provided
    - For the future, minimum requirements for depopulation-type studies should include sample size/ age of animals, animal welfare, death and insensibility assessment methods, ease of carcass disposal, human safety assessment, personnel skill; and equipment and facility requirements.

- Further research is needed in the effectiveness of alternative methods for swine depopulation such as the use of water-based foam, sodium nitrate, and ventilation shutdown plus.

Keywords:

swine euthanasia, swine depopulation, systematic literature review, emergency preparedness

Scientific Abstract:

Swine mass depopulation refers to the destruction of large numbers of pigs and may include not only animals affected with a disease but also healthy pigs in a facility or surrounding areas. Emerging applications of mass depopulation include reducing welfare issues associated with slaughter delays, which was observed in the United States in 2020 as a result of the Coronavirus disease (COVID-19) pandemic.

The objectives of this review were to summarize the available literature on swine depopulation methods and to highlight critical gaps in knowledge. Peer-reviewed articles were identified through a systematic search in electronic databases including Web of Science, MEDLINE, and PubMed.

A total of 68 publications were assessed. Gaseous carbon dioxide inhalation was the most commonly reported depopulation method for both small- and large-scale trials. Measurements of consciousness state, which serves to assess suffering and humaneness, appeared to be lacking in a high proportion of the studies. None of the published studies demonstrated an ideally reliable and safe way to induce rapid unconsciousness in large groups of pigs.

In conclusion, our systematic review showed that development of rapid mass depopulation methods applicable to large groups of pigs is necessary to provide industry partners with suitable and low-cost emergency preparedness procedures while adhering to personnel safety and animal welfare standards. Lastly, there is an urgent need to standardize comprehensive reporting guidelines for depopulation studies.

Introduction:

Mass depopulation involves euthanasia of very large numbers of pigs, and may include not only pigs infected with a disease, but also healthy pigs in a facility or surrounding areas.

The most common reasons for depopulation include immediate disease control, where euthanasia of swine on farm is necessary to minimize the risk of highly virulent pathogen spread, foreign diseases; response to natural or human-made disasters; and to protect public health in the case of potential zoonosis. Other emerging applications include euthanasia to reduce economic and welfare costs associated with slaughter delays result of decreased demand for meat or limitations in slaughterhouse processing capacity as observed during the COVID-19 pandemic.

It is important to note that, even though euthanasia and humane slaughter methods can be used for the purposes of depopulation, not all depopulation methods are considered to be euthanasia by the American Veterinary Medical Association (AVMA) when the focus is ending the life of an individual animal in a way that minimizes pain and distress.

The AVMA classifies various either pharmacological, physical, and electrical techniques, including injectable and gaseous agents, mechanical trauma, and electric shock; as 'preferred' or 'preferred under constrained circumstances' for depopulation of animals (1). According to the AVMA, methods considered 'preferred' "are given the highest priority and should be utilized preferentially when emergency response plans are developed and when circumstances allow reasonable implementation during emergencies" (1). In contrast, methods considered 'permitted in constrained circumstances' refer to methods permitted "only when the circumstances of the emergency are deemed to constrain the ability to reasonably implement a preferred method" (1). In any case, once applied, the methods used should be able to result in the death of a complete population of animals in a quick and effective manner.

The selection of a depopulation method varies based on the specific purpose of the method, age and number of pigs, available personnel, and availability of equipment and resources. Pilot and small-scale experimental studies have been conducted in the past to identify suitable swine depopulation methods concerning equipment design, cost, and efficiency of attaining desirable outcomes including speed of unconsciousness or insensibility without raising animal welfare issues. However, there is a need to compile outcomes and characteristics of various methods for evidence-based decision-making during specific field circumstances. Given the potential application of these methods for large-scale depopulation, the scientific community needs to explore improvements in mass depopulation methods applied under field conditions.

Objectives:

The objectives of this project were to summarize available literature on swine depopulation methods and to highlight critical gaps in knowledge pertaining to swine depopulation methods classified by the AVMA as 'preferred' and 'permitted under constrained circumstances'.

Materials & Methods:

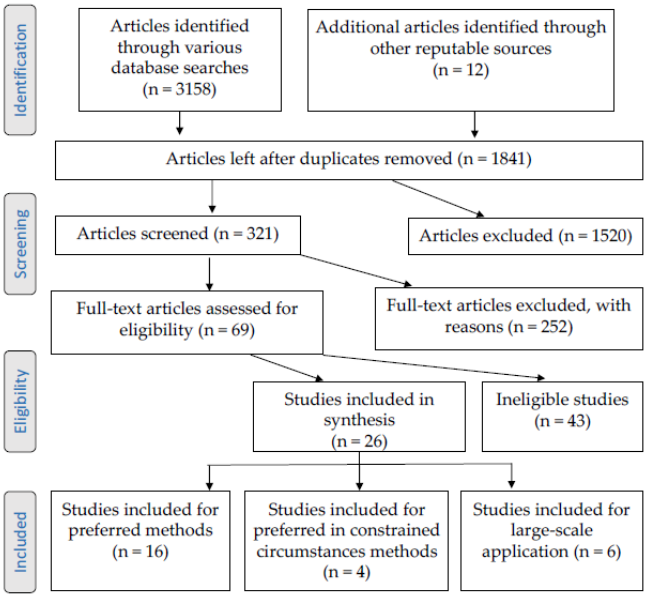
Relevant peer reviewed articles from pilot, small-scale and large-scale studies were identified through a systematic search in electronic databases of PubMed, Cab Abstract/Web of Science and MEDLINE using key words and themes. Eligible studies were screened according to the schematic framework of Preferred Reporting Items for Systematic reviews guidelines (2).

The databases search included the following search title/abstract/keywords: (swine OR porcine* OR sow* OR pig* OR hog* OR boar) AND (depopulation OR stunning OR euthan*) addressing themes of swine euthanasia, mass depopulation, and stunning methods.

For each eligible article, a record was made in a Microsoft Excel spreadsheet (available from authors upon request) describing: the geographical location where the study was conducted; the objective(s) of the study; a summary of the study; the method used for depopulation; the number and age of pigs included in the study; the method of measurement for unconsciousness; the insensibility and death confirmation methods; other (included carcass disposal method, human safety assessment, personnel skill, equipment, and facilities requirements).

Results:

We assessed 3,158 articles to identify 26 that met our criteria. This review included 26 studies assessing AVMA preferred swine depopulation methods (n = 16), permitted in constrained circumstances swine depopulation methods (n = 4), or large-scale application of swine depopulation methods (n = 6). Out of the six large-scale studies, five used CO_2 and one study used argon.



Source: Arruda et al., 2020 (3), Table 1

The 26 selected studies were revised and reported in details – please refer to the table below for a summary. A full description of the studies are available on the publication (Arruda et al., 2020- (3)).

Number	Category	Study authors	Country	Study title	Method (s) used	Study objective (s)	Number of pigs	Age (or weight) category	Overall metrics used	Loss of conciousness method (s)	Death confirmation method (s)
1	**Preferred method**	**Raj and Gregory 1995**	**New Zealand**	Welfare implication of the gas stunning of pigs 1. Determination of aversion to the initial inhalation of CO2 or Argon	**CO2 and Argon**	To determine if different concentrations of CO2, Ar and combinations causes the pigs to show signs of aversion	Two groups in separate trials (6 and 10 each)	Adults; 55-72kg	Behavioral reluctance- time to withdrawal of the pigs' heads after the first entry and total time spent in the box	n/a	n/a
2	**Preferred method**	**Raj and Gregory 1996**	**New Zealand**	Welfare implications of the gas stunning of pigs 2. stress of induction of anesthesia	**CO2 and Argon**	To evaluate the severity of respiratory distress prior to loss of posture during exposure to various concentrations of CO2 and Ar/ O2	95 pigs: two experiments (trial one: 5-6 pigs per group)	Adults; 15-31kg	Loss of posture, respiration score (time to onset of audible breathing)	Time to loss of posture	Not mentioned
3	**Preferred method**	**Velarde et al., 2007**	**Spain**	Aversion to carbon dioxide stunning in pigs: effect of carbon dioxide concentration and halothane genotype (NN/ Nn)	**CO2**	Assess the aversiveness of the exposure to CO2 concentration levels in a stunning system	18 NN and 14 Nn pigs (2 trials, 8 NN and 8 Nn pigs exposed to 70% CO2 and 2nd trial- 10 NN and 6 Nn pigs, exposed to 90% CO2)	Adults	Aversion learning measurements (retreat attempts , gasp, escape attempts)	Time to loss of posture	Not mentioned
4	**Preferred method**	**Verhoeven et al., 2016**	**Netherlands**	Time to loss of consciousness and its relation to behavior in slaughter pigs during stunning with 80 or 95% carbon Dioxide	**CO2**	To assess timing of unconsciousness in pigs during exposure to high concentrations of CO2	48 cross breed (Pietrain × Large White × Landrace)	Adults	electroencephalogram (EEG) activity and the relation with the behaviors: sniffing, retreat and escape attempts, lateral head movements, jumping, muscular contractions, loss of posture, and gasping	Visual assessment of changes in the amplitude and frequency of EEG traces (high amplitude, low frequency)	Not specified (respiratory arrest?)
5	**Preferred method**	**Kells et al., 2018**	**New Zealand**	Evaluation of Different Gases and Gas Combinations for On-Farm Euthanasia of Pre-Weaned Pigs	**CO2 100% Argon 100% Ar/CO2 [60%:40%]**	To evaluate the effects of various concentrations of CO2 and argon combinations in piglet welfare during euthanasia	Study 1: 15 male piglets split into 3 treatment groups of n=5 Study 2: 15 male piglets split into 3 treatment groups of n=5	Pre-weaned piglets	Physiological (cortisol and epinephrine concentrations, Raw EEG, ECG and respiration dataectroencephalograph (EEG)), behavioural response to gas exposure	Loss of posture	Determined by isoelectric EEG and the cessation of cardiac contractile activity
6	**Preferred method**	**Sadler et al., 2014**	**US- Iowa**	Effects of flow rate and gas mixture on the welfare of weaned and neonate pigs during gas euthanasia	**CO2 and Argon**	To evaluate (1) efficacy of CO2 versus CO2:Ar mixture at 4 different flow rates, and (2) effects on welfare in neonatal and weaned pigs	340 pigs (weaned pigs (90 female-male pairs), Neonates (80 female-male pairs)	Young-weaned (16-24d) and neonate (1.4d)	Corneal reflex response, pupillary reflex, nose prick ^^The above methods were used as part of the death confirmation process specifically	Loss of posture and last movement	Absence of heartbeat, corneal reflex/pupillary reflex/nose prick and heartbeat
7	**Preferred method**	**Smith et al., 2018**	**USA- Texas**	A Two-Step Process of Nitrous Oxide before Carbon Dioxide for Humanely Euthanizing Piglets: On-Farm Trials	**CO2 and N2O**	To evaluate if a two-step method using N2O then CO2 would reduce behavioral distress in newborn piglets.	2 experiments (18 groups in each)	Newborn piglets	Behavioral response and reflexes	Loss of posture, righting responses	Last movement

8	**Preferred method**	**Sutherland et al., 2017**	**USA-Indiana**	The effect of age and method of gas delivery on carbon dioxide euthanasia of pigs	**CO2**	To evaluate the effect of age and delivering method during carbon dioxide (CO2) euthanasia on the welfare of pigs (Sus scrofa).	Experiment 1 included 30 female pigs, 5 per age group, 1-6 wk old) and experiment 2 included 5 female pigs, 3 - wks old)	Young	Plasma cortisol concentrations, behavioral measurements	Behaviors indicative of stress and insensibility were recorded continuously during gas exposure; including panting, open-mouth breathing, righting response, escape attempts, loss of posture, muscular excitation and respiratory arrest.	Absence of cardiac activity was confirmed by palpation
9	**Preferred method**	**Llonc et al., 2013**	**Spain**	Assessment of unconsciousness in pigs during exposure to nitrogen and carbon dioxide mixtures.	**CO2 and N2- 70% nitrogen: 30% CO2, 80% nitrogen: 20% CO2, 85% nitrogen: 15% CO2, and 90% CO2 in air; all with O2 below 2%.**	To assess unconsciousness in pigs during and after the exposure to CO2 and N2 gas mixtures	24 in 4 groups of 6	Adults; females 93kg	EEG and behavior measurements- Index of Consciousness (IoC) and the electroencephalography suppression rate (ESR)	Loss of balance, vocalization, gagging	Responsiveness to pain stimulus, absence of rhythmic breathing and corneal reflex, IcV values close to zero and absence on all three reflexes were used to consider an animal dead
10	**Preferred method**	**Becerril-Herrera et al., 2009**	**Mexico**	CO2 stunning may compromise swine welfare compared to electrical stunning	**CO2, Electric stunning**	To evaluate effects of two different stunning methods on critical blood values	658 pigs (cross Yorkshire-Landrace mother and a Pietrain sire)	Adults	None-Energetic profile, acid imbalance and blood gas levels	n/a	Bleeding of animals was carried out right after stunning, this study was done in a federally inspected slaughterhouse
11	**Preferred method**	**Casey-Trot et al., 2013**	**Canada**	Effectiveness of a nonpenetrating captive bolt for euthanasia of piglets less than 3 d of age	**Nonpenetrating captive bolt**	To determine the effectiveness of a nonpenetrating captive bolt (NPCB), the Zephyr-Euthanasia (Zephyr-E), for euthanasia of neonatal piglets < 72 h	100	Neonatal piglets	Cardiac arrest	4/100 the piglets required a secondary step (exsanguination) due to the presence of a faint, irregular heartbeat at the 15-min endpoint, and the other 2 piglets required anesthetic overdose as an alternative euthanasia method due to sustained,	Brainstem reflexes, convulsions, and heartbeat were used to assess insensibility, time of brain death, and cardiac arrest

										sporadic convulsions.	
12	**Preferred method**	**Widowski et al., 2008**	**Canada**	Assessing the effectiveness of a non-penetrating captive bolt for euthanasia of newborn piglets	**Nonpenetrating captive bolt**	To evaluate the effectiveness of a non-penetrating captive bolt device (Zephyr ZE, BOCK Industries) in comparison to traditional methods for on-farm euthanasia of low viability neonatal pigs when performed by different stock people.	175 (99 low viability piglets using the Zephyr (ZE), 76 piglets using traditional manual blunt trauma (BT))	piglets requiring euthanasia (all less than 24 hours old)	Palpating the cornea for a blinking reflex, presence of a fixed central eye position and the absence of jaw tone	Palpating the cornea for a blinking reflex, presence of a fixed central eye position and the absence of jaw tone	Presence of respiration and duration of limb reflex movements by visual inspection and heartbeat by palpation and stethoscope.
13	**Preferred method**	**Grist et al., 2018**	**United Kingdom**	The Use of a Non-Penetrating Captive Bolt for the Euthanasia of Neonate Piglets	**Nonpenetrating captive bolt**	To evaluate a mechanical non-penetrating captive bolt (the Accles and Shelvoke CASH small animal tool, Birmingham, UK) to produce an immediate stun/kill with neonate piglets	202 piglets total (55 with 1.25-grain cartridge; 147 with 1-grain cartridge); Discussion section erroneously lists 57 piglets as being euthanized by the 1.25-grain method	Neonatal piglets	Semi-quantitative scoring systems to assess post-stun clonic movement and intracerebral tissue damage; comparison of cranial bone displacement (measured in mm)	Discussion section suggests presence of clonic movements as indicator of loss of consciousness; LOC was not directly examined if taking the report verbatim (as written by authors), though in reality the onset of clonic movement in piglets here suggests instantaneous loss of consciousness	lack of occurrence of rhythmic breathing/ recovery, loss of movement, trauma to the brain which would be inconsistent with normal cortical function
14	**Preferred method**	**Blackmore et al., 1995**	**New Zealand**	The use of a shotgun for the emergency slaughter or euthanasia of large mature pigs	**Gunshot**	To evaluate the use of a shotgun for the emergency slaughter or euthanasia of large mature pigs	9	Adults (heads; one live sow)	Immediate recumbence, pupillary dilation	Immediate recumbence and pupillary dilation	The animal was ensanguined 30s after shooting
15	**Preferred method**	**Zhang, 2017 (Proceedings)**	**Canada**	Euthanasia of pig using nitrogen gas and decompression	**N2**	Assess if N2 and decompression are acceptable humane methods for on-farm euthanasia of pigs	somewhat unclear ("groups of 1, 3, 10 and 29"- therefore, total of 43 for the N2 experiment (?); "groups of 1 and 3"- therefore, total of 4 pigs for the decompression experiment (?))	30kg and smaller	Distress (measured by "falling over"), last movement, vocalization, seizures, animal behavior and public perception / "aesthetics" were assessed by an expert panel (5 people: 3 veterinarians, 1 animal welfare specialist, 1 engineer)	Loss of righting reflex	Not clearly defined; last movement was recorded
16	**Preferred method**	**Meyer et al., 2013**	**USA- North Carolina**	Effect of physical and inhaled euthanasia methods on hormonal measures of stress in pigs	**Electrocution, captive bolt, 70% N2/ 30% CO2 and 100% CO2 at different displacement**	Determine the effect of different euthanasia methods on plasma levels of hormonal stress indicators	39 pigs for the physical methods, 62 pigs for captive bolt, 16 pigs for N2/ CO2 mix (4 pigs per	Mean body weight was 7kg for electrocution group, 12.3kg for captive bolt	Open-mouthed breathing, righting reflex, mean latency to onset of open-mouth breathing	Loss of righting reflex	Time to loss of heart beat was determined by palpation of the thorax

					rates		treatment group)	group, and ~2kg for inhaled method groups)			
17	**Preferred in constrained circumstances**	**Snow et al., 2012**	**USA- Texas**	Development of toxic bait to control invasive wild pigs and reduce damage	**ingestion of sodium nitrate**	Evaluate palatability, lethality and stability of a bait (HOGGONE, Animal Control Technologies Australia) on groups of captive invasive wild pigs	84 total, 56 treatment animals and 28 control animals (3 trials of 7 wild animals each; 4 replicates lasting 8 nights each)	Feral swine, body weight between 20-113kg	Amount of consumed food, number of mortalities, recording of feeding events for some replicates (feeding bouts)	Not specified	Not specified ("camera evidence")
18	**Preferred in constrained circumstances**	**Foster et al., 2014 (Proceedings)**	**USA- Texas**	Optimization of formulations for the lethal control of feral pigs	**ingestion of sodium nitrate**	Evaluate 3 different formulations of sodium nitrate loaded in a bait matrix on mortality and acceptance in the context of US registry requirements	70 feral pigs (30 males, 40 females) were challenged in 3 trials	Feral swine, 20-85kg	Mortality and consumption (camera/ photography)	Not specified	Not specified (recorded evidence)
19	**Preferred in constrained circumstances**	**Shapiro et al., 2016**	**New Zealand**	Efficacy of encapsulated sodium nitrate as a new tool for feral pig management	**ingestion of sodium nitrate**	Examine the effectiveness of encapsulated $NaNO_2$ for the management of feral pigs	9 pigs (large white breed, five females and four males for the pen trial) and 12 (5 males and 7 females) for the field trial	Feral swine, age unclear	Amount of bait consumed, clinical signs and welfare assessment observed by a veterinarian for the pen trial, cameras used for the field trial	Not specified	Deaths are reported as involving some or all of: pale nose and extremities, blue tongues, vomiting, lethargy, ataxia, tremors, collapse.
20	**Preferred in constrained circumstances**	**Lapidge et al., 2012 (Proceedings)**	**USA and Australia**	Development of a feral swine toxic bait (Hog-Gone) and bait hopper (Hog-Hopper) in Australia and the USA	**ingestion of sodium nitrate**	This paper reviews the last 2 years of work conducted in several states of the US (AL, FL, MS, MO, OK, TX) and Australia in pilot and field studies on baiting of feral swine using sodium nitrate	N/A (this report is a compilation of several studies seeking approval for the compound)	Feral swine, age unclear	These studies mostly appeared to rely on observation of clinical signs, usually camera-recorded, and count of mortalities.	N/A. Authors mention that the compilation of studies show that use of sodium nitrate provoques 20-30 minutes of mild symptoms followed by unconsciousness	N/A. Authors mention that the compilation of studies show that use of sodium nitrate provoques 20-30 minutes of mild symptoms (ataxia, labored breathing, unconsciousness and death), which they consider to be humane
21	**Large-scale application**	**Kinsey et al., 2016**	**USA -Texas**	Development of a Self-Contained Carbon Dioxide Euthanasia Trailer for Large-Scale Euthanasia of Feral Swine	**CO_2**	To assess whether CO_2 delivered through trailers would result in acceptable euthanasia of feral swine.	3 trials of 5 swine	Adults	Clinical signs of stress, anesthesia assessments	Lateral recumbence, Loss of righting reflex and cessation of movement	Observers confirmed mortality- no methods mentioned
22	**Large-scale application**	**Meyer and Morrow, 2005**	**USA -Texas**	Carbon dioxide for emergency on-farm euthanasia of swine	**CO_2**	Evaluate on-site mass depopulation using a modified roll-off solid waste dumpsters for containment of adult pigs and smaller temporary corrals constructed for containment of weaning and nursery pigs	30 pigs (trial 1) and 14 pigs (trial 2)	Adults	Animal motion, authors mention issues with CO_2 fog produced	Unclear- authors mention lack of a rhythmic breathing pattern (?)	Unclear- authors mention lack of return to a breathing pattern; and mention "time to death" being

											~14 min 35 sec, but they do not provide details on how this was confirmed
23	**Large-scale application**	**Meyer, et al., 2014**	**USA - North Carolina**	Evaluation of carbon dioxide administration for on-site mass depopulation of swine in response to animal health emergencies	**CO2**	Investigate the use of modified solid waste dumpsters for on-site depopulation purposes	212 pigs in 8 groups	Adults; 22-46kg	Time to loss of righting reflex, escape behaviors- captured by video images	Time to loss of righting reflex	Unclear - authors did not specify what was used in this particular study (even though they mentioned what should be considered)
24	**Large-scale application**	**Fiedler et al., et al., 2016**	**USA-Iowa**	Effects of stocking rate on measures of efficacy and welfare during argon gas euthanasia of weaned pigs	**Argon**	Evaluate the effects of chamber stocking rate on facets of animal welfare and efficacy during euthanasia of weaned pigs with argon gas	233 pigs, group sizes of 1, 2 or 6 pigs	Weaned pigs (3-10 weeks of age, ~8kg)	Neuromuscular excitation, last movement, righting attempts (distress), pacing, time to loss of posture, behavioral observations were video-recorded	Onset of neuromuscular excitation and convulsive activity, loss of posture/ balance, corneal reflex, nose and leg pinch, pupillary light reflex	Cessation of breathing and auscultation with a stethoscope for at least 20 seconds
25	**Large-scale application**	**Stikeleather et al., 2013**	**USA**	Evaluation of CO2 application requirements for on-farm mass depopulation of swine in a disease emergency	**CO2**	Describe CO2 distribution requirements for on-farm euthanasia of pigs using computational fluid dynamics.	No animals involved	n/a	n/a	n/a	n/a
26	**Large-scale application**	**Rice et al., 2014**	**USA**	Carbon dioxide system for on farm euthanasia of pigs in small groups	**CO2**	Adapt a CO2 system for euthanizing small groups of pigs	No animals involved	n/a	Tank pressure, CO2 concentration, and O2 concentrations over time	n/a	n/a

Discussion:

The major findings of this systematic review are that there are few studies on the topic of mass depopulation of swine, available reports are inconsistent in describing main characteristics of depopulation methods, and most assume a scalable process based on small sample sizes.

Injectable, physical, and ingestion/oral methods studied have been applied at the individual or small group levels. They would most likely not be good candidates for mass depopulation in swine because they would be time-consuming and/or unsafe for animals as well as operator personnel. They may also be minimally suitable considering animal welfare and potentially negative emotional impacts on personnel. Inhalation-based depopulation using gaseous CO_2 was the most commonly investigated method in the literature. It is important to consider, however, that although highly controlled environments for CO_2 application achieved in research experiments may be difficult to accomplish under on-farm scenarios. In addition, distress, aversion, and escape behaviors in response to the presence of a high concentration (greater than 50%) of CO_2 in the air indicates that CO_2 can compromise pig welfare, which should be taken into consideration.

The lack of standardization of several unconsciousness and death determination-related metrics, combined with the variety of possible method combinations examined in a single study from the ones examined reduced the number of direct comparisons among studies that could have been done. Future studies would ideally include, as a minimum: the number and age of pigs included in the studies, measures of unconsciousness, time to loss of consciousness, death and insensibility confirmation methods, ease of carcass disposal, human safety risk assessment, animal welfare assessment and issues, personnel skill and labor requirements, and equipment and facilities requirements.

Despite limitations inherent to each method previously reported, none of the published studies demonstrated an ideally safe and reliable way to induce rapid unconsciousness in large groups of pigs. Besides a few CO_2 trials, effectiveness studies under field conditions and in groups with large numbers of swine were largely lacking in the literature. Future studies are needed to support large-scale emergencies requiring multiple animals to be euthanized in a short window of time (24 h or less).

Euthanasia of individual animals or mass depopulation may be inevitable and necessary. One important point when discussing mass depopulation on swine or any animal species is the recent rise in public awareness about livestock mass depopulation conditions, which has become a subject for great discussion among animal rights groups, veterinary communities, and the overall public. Transparency and public education in regards to this issue will likely need to be considered in cases where swine depopulation is necessary, and appropriately communicating with different audiences on the subject will be an important piece of the process.

Our findings suggest that for successful emergency preparedness, further development of rapid mass depopulation methods for use in large groups of pigs is necessary to provide industry partners with suitable and low cost emergency preparedness procedures adhering to personnel safety and animal welfare standards.

References- these are references used directly in this report. For a full list of references for all papers included in this review, please refer to reference 3 below (Arruda et al., 2020).

1. American Veterinary Medical Association (AVMA) Guidelines for the Depopulation of Animals: 2019 Edition. Available online: https://www.avma.org/sites/default/files/resources/AVMA-Guidelines-for-the-Depopulation-of-Animals.pdf (accessed on 10 December 2020).
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