Removing Out-of-Condition Grain: An Exploration and Documentation of Existing Strategies

Salah F. Issa[1,*], Daniel Gaither[1], Mian Muhammad Sajid Raza[1], John Lee[2], William E. Field[3]

[1] Agricultural & Biological Engineering, University of Illinois at Urbana Champaign, Urbana, USA.
[2] Grain Feed Association of Illinois, USA.
[3] Agricultural & Biological Engineering, Purdue University, West Lafayette, Indiana, USA.
[*] Correspondence: salah01@illinois.edu, salahfuadissa@hotmail.com

HIGHLIGHTS

- Different approaches used to handle out-of-condition grain can be split into three broad categories: outfitting, outside, and inside the bin.
- A total of 21 strategies to handle out-of-condition grain are documented in this article.
- Outside the bin strategies are split into four categories: grain handling solutions, rodding, force-based solutions, and alternate grain extraction methods.

ABSTRACT. *Grain entrapments remain a major concern in the grain storage and handling industry. Even with the adoption of safer technology, enhanced enforcement of OSHA regulations, and considerable investment in training and outreach efforts, grain entrapments continue to occur in significant numbers. The most significant contributing factor to grain entrapment is the presence of out-of-condition grain. A better understanding of existing strategies employed to remove out-of-condition grain from storage is important to provide evidence-based solutions to reduce the perceived need to enter grain storage structures and the grain entrapment associated with this activity. A review of existing strategies for handling out-of-condition grain used previously by farmers and workers with experience in grain storage facilities was conducted. Training programs, extension resources, and published research were reviewed to document existing strategies to remove out-of-condition grain. These strategies were split into three broad categories: outfitting the bin, outside of the bin, and inside the bin. A total of 21 strategies were documented. Each of the strategies was defined and, where possible, the risks and benefits were discussed. The study highlights the importance of researching the safety and effectiveness of each of these strategies in various out-of-condition grain situations and the lack of available knowledge of the effectiveness of each strategy.*

Keywords. *Engulfment, Entrapment, Inside the bin strategies, Outfitting the bin strategies, Out-of-condition grains, Outside the bin strategies, Spoiled grains, Storage.*

Submitted for review on 2 October 2021 as manuscript number JASH 14897; approved for publication as a Review Article by Associate Editor Dr. S. Dee Jepsen and Community Editor Dr. Michael Pate of the Ergonomics, Safety, & Health Community of ASABE on 13 July 2022.

The grain handling and storage industry, including both on-farm and commercial sites, is well known as a highly hazardous industry with multiple types of serious and life threatening dangers (Kingman et al., 2003; Issa et al., 2016; OSHA, 2020). Workers are exposed to hazards such as grain dust explosions, grain entrapments, falls, exposure to toxic gases, and entanglements involving grain handling equipment (Issa et al., 2016; OSHA, 2020). Of these dangers, grain entrapments (in which the victim is unable to self-extricate) represent about half of all documented incidents (Issa et al., 2016). On average, 33 grain entrapment incidents have been documented each year since 2007 (fig. 1; Roberts and Field, 2010; Cheng et al., 2021). This trend has continued unabated, even as the industry has invested in enhancing the safety of their facilities, introduced new engineering standards, enhanced OSHA regulatory enforcement, and over $4.7 million dollars of support since 2008 from OSHA has been made available for developing training programs that target the grain industry and related industries (ASABE, 2018; OSHA, 2021). Even though there have been considerable efforts to understand the physical aspects of grain entrapments (Issa et al., 2017) and provide training and outreach to farmers, there remains a lack of a good understanding of safe and cost-effective strategies for removing out-of-condition grain. The objective of this paper is to summarize existing strategies reported to be used by farmers and grain industry workers to remove out-of-condition grain, including solidified grain, from storage spaces and to assess the potential risks associated with each.

Overview of Grain Entrapments and Out-of-condition Grain

There are seven potential causes of grain entrapment: entrapment in a flowing column of grain (flowing-grain), collapse of a crusted surface (bridging), collapse of a vertically crusted grain surface (avalanche), entrapment in a free-standing grain pile, structural failure entrapment, covered by grain (grain is poured on top of the individual), and grain vacuum machine entrapment (Issa et al., 2018). Of these, flowing-grain, avalanche, bridging, and vacuum conveyor related entrapments are directly linked with out-of-condition grain. The most common type of grain entrapment is being caught in a flowing column of grain which occurs when a worker enters from the top of a grain bin while the unload auger is running to breakup clumps of grains in the grain sump or well by prodding. When the grain sump clears out, allowing grain to flow again, there is potential for the worker to be drawn

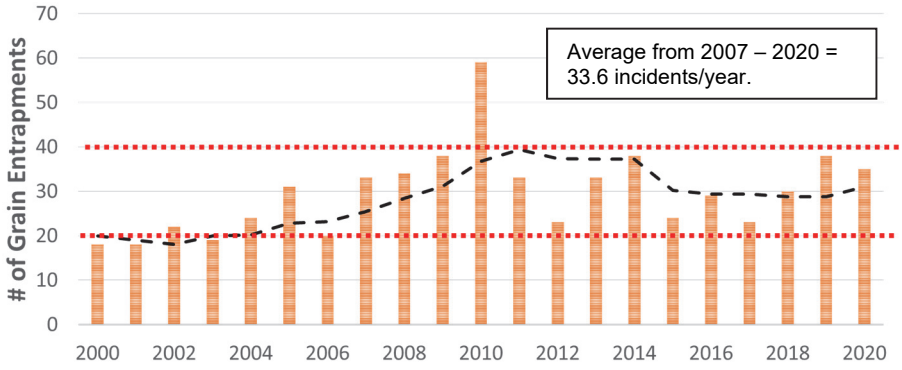

Figure 1. Number of grain entrapments over time. Black dashed line represents five-year average. Red dashed lines highlight 20 to 40 incidents occurring most years since 2000 (Roberts and Field, 2010; Cheng et al., 2021).

into the flow and become entrapped. Another similar scenario is workers entering a grain storage structure with a running auger to walk down the grain and break up crust before it reaches the grain sump. Approximately 70% of all documented grain entrapment cases relate to flowing grain entrapments, of which 63% are fatal (Issa et al., 2018).

Avalanche entrapment is another leading cause in which spoiled grain forms a rigid but unstable tower as the surrounding grain is removed. When a worker enters the storage space and attempts to dislodge the crusted material at the base of the tower, it can collapse and avalanche over the worker. Figure 2 shows a grain tower formed inside a bin. These towers have been documented as tall as twenty-one meters (70 feet) high. They usually form either over the center sump or against the bin wall where the grain goes out-of-condition first (Decker, 2019). These conditions are caused by a variety of factors, including storage at too high of a moisture content (>14%), foreign material or broken grain that settles in the center of a pile and/or the presence of moisture due to structure leakage. Approximately 10% of reported cases are related to avalanche entrapments, of which 61% are fatal (Issa et al., 2018).

Bridging is the third major type of grain entrapment and accounts for about 7% of all reported entrapment incidents due to out-of-condition grain. A bridging entrapment is caused when a thick layer of crust forms on the surface of the grain mass (usually due to improper drying or structural leakage). As workers empty the grain bin, the crusted grain layer maintains its shape and conceals a cavity as grain below is removed from the bottom of the bin. When a worker enters the bin and steps on the crust (either to break the crust or being unaware of the crust and cavity), the crust can suddenly collapse, and the worker falls into the cavity, being engulfed or entrapped by surrounding grain. About 70% of bridging entrapments are fatal (Issa et al., 2018).

Lastly, entrapments while using grain vacuum machines represent about 3% of all grain entrapments and occur when the bin sump is clogged, or a worker enters a bin to remove residual grain with a grain vacuum system as an alternative method to empty the grain bin.

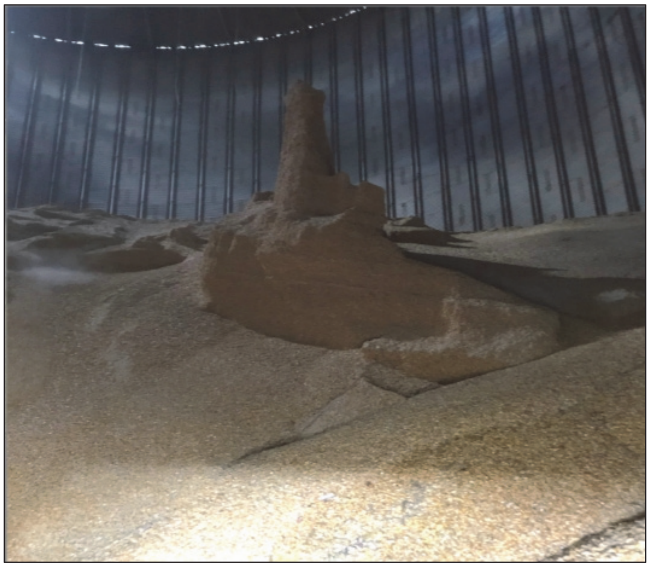

Figure 2. Example of grain tower (approx. 70 feet tall) composed of out-of-condition grain. (Lee, 2021).

Depending on the quality of the grain and placement of the hose, it can quickly remove the grain surrounding and beneath the worker and entrap/engulf the worker. About 85% of these cases are fatal (Field et al., 2014; Issa et al., 2018).

Over the years, farmers and commercial grain storage operators have developed a variety of strategies to remove non-free-flowing grain from storage structures. Based upon the data presented, some of these methods have placed workers at a great risk of grain entrapment. The link between removing out-of-condition grain and the continued incidents of death and injuries is well established. Each of these methods is explored in detail.

Methods

The literature review was conducted using the American Society of Agricultural and Biological Engineers (ASABE) Technical Library, Google Scholar, Extension pages from both Purdue University and the University of Minnesota, and a review of grain safety webinars conducted by industry experts. The list of keywords applied in accessing these sources included aeration, bin whips, compressed air, explosions, fans, flowing grain, grain entrapment, grain engulfment, grain vacuums, out-of-condition grain, plugged sumps, rescue, rotting grain, and any term that might be useful in understanding grain entrapment and engulfment. Several published individual case studies on grain entrapments and engulfment were reviewed as well. Grain safety trainers and industry experts were consulted, who provided valuable insight on additional strategies they were aware of (e.g., using guns or explosives). All strategies documented through the literature review and consultations were documented with the aim of developing a list of strategies as comprehensive as possible without regard to efficacy or safety. The strategies were split according to the location of the worker implementing the strategy (outside vs. inside bin) and whether the strategy was implemented during or before the need to remove out-of-condition grain occurred. Lastly, the strategies were further categorized by the type of device used to break up grain clumps.

The discovery process included a meeting of eight experts from the grain industry, grain safety, and farm operators, organized using an expert panel approach. The various strategies were reviewed, and panel comments were gathered.

Results and Discussion

Existing strategies for handling out-of-condition grain were split into three broad categories: a) outfitting the bin; b) outside the bin; and c) inside the bin. Outfitting the bin strategies refer to solutions implemented in advance to prevent and breakup out-of-condition clumps. These solutions tended to be modifications to the storage structure. However, since not all strategies were permanent modifications, the term “outfitting” was deemed a more suitable fit. Outside the bin refers to any strategy that does not require the worker or producer to enter the grain bin. Inside the bin is any strategy that involves a worker or producer entering the bin to dislodge grain. Outside and inside the bin strategies are responses to the problem of out-of-condition grain, while outfitting strategies are responses that recognize that out-of-condition grain can occur and should be prepared for. Note that many of the same strategies that can be implemented outside of the bin are also implemented inside of the bin.

Outfitting the Bin

While there have been considerable improvements in grain storage structures designed to handle out-of-condition grain, this section will only focus on solutions that can be used with or implemented on existing structures. Existing solutions can be placed into three broad categories: stirators, rodding devices, and sump alterations.

Auger Stirators

Auger stirators are any devices that are designed to preserve grain quality by stirring the grain. The idea behind this is that by constantly stirring the grain these devices can maintain uniform moisture content, prevent clumping of out-of-condition grain and break up any clumps that do form. There are three types of stirators: vertical stirators, plug busters, and robotics.

Vertical Stirators

Vertical stirators are auger devices that are placed upright in the grain bin (perpendicular to the grain bin floor) on a frame suspended from the bin roof that move grain locally from the bottom to the top of the bed. As the frame rotates around the bin, the vertical augers rotate as well, helping to stir and distribute the grain evenly across the grain bin. It can prevent and break up any grain clumps that might form.

Plug Busters

Plug busters are designed to be attached and powered by the sweep auger system already in the bin. It is composed of a beater that breaks up grain clumps above the floor sump. In such a system, the sweep auger is left in the bin when it is being filled with grain. A plug buster is designed to handle and operate under the pressure of the grain. See Lyseng (2020) for an example of a plug buster.

Robotics

Robotics is a recent development in handling grain with little published research. One of the pioneers of this strategy is the Grain Weevil. These robots use an auger-based propulsion system (think short horizontal segments of augers as wheels) to move across the surface of the grain. As the unit moves across the surface of the grain, it breaks up any crusting and levels the grain after multiple passes. According to the manufacturer, using robotics as a preventative strategy helps maintain grain quality by increasing aeration efficiency, increasing inspection frequency, and breaking up crusted grain. In addition, the Grain Weevil can also be an outside of the bin strategy when used in situations to breakup crusted or bridged grain. In the case of bridged grain, breaking and falling through the grain bridge does not harm the robot, as the robot can dig itself out of an engulfment due to its unique auger propulsion system.

Rodding Devices

Rodding devices can come in many designs, but the basic premise is a mechanical device that can knock or break up any grain clumps that are blocking the grain sump. Some of the most common solutions are a bar on the sump gates or a rod over the sump.

Bar on Sump Gates

Before any grain is placed in the bin, rods can be directly inserted into the sump gate (fig. 3). When grain clumps up and stops flowing, a worker can then open and close the sump gate while outside the bin to move this rod back and forth. The rod will then break up any grain that is directly above (and blocking) the sump. This approach has been used

Figure 3. Slide gates with attached bar. Workers open and close sump gates to move rod and break up grain.

in both commercial and farm settings and provides the agricultural worker a good option that doesn't require tunnels with rodding ports under the bins.

Rod over Sump

The rod over sump solution is very similar to the bar on sump gate solution. This solution requires a worker to drill a small hole at the base of the grain bin and insert a long rod that reaches the center sump. At the end of the rod, a 90-degree elbow is installed to allow the worker to break up grain clumps (fig. 4). The rod is controlled from outside the bin and the bar can be rotated so that it does not protrude when not in use (Lee, 2021). The benefits of this solution are that it allows workers to lower the rod when not in use and does not impact grain flow. The worker also can move the grain rod up and down and side to side giving them one more degree of freedom than installing rods on the sump gate. However, if the rod is accidently left across the gate opening, the rod itself could cause clumps or

Figure 4. Rod over sump. An individual can move rod back, forth, and sideways to break up grain clumps.

plugs to form. This method is potentially more effective in smaller bins than larger storage bins.

Sump Alterations

Sump alterations are any strategy that involve modifying a sump access point and can be split into two broad categories: enlarged sumps and sump guards.

Enlarged Sumps

Enlarged sumps are a strategy where the size of the sump is enlarged as a means of increasing unload capacity and allowing larger chunks of crusted or out-of-condition grain to enter the in-floor unload auger to be broken up.

Sump Guards

Sump guards can come in many shapes or forms, but in general, they are a formed and welded steel grate that is placed above the center sump (fig. 5). The grate can break up grain clumps or push to the side clumps that will not break. Workers will have to install these guards before filling the structure with grain. Furthermore, they will interfere with sweep auger operations because they stand above the floor level. This method is potentially effective in handling low to medium amounts of crusted grain. However, it might not be capable of addressing severe crusting issues and towers. This solution is relatively inexpensive and easy to install.

Outside the Bin Strategies

There are currently a wide variety of strategies for dealing with out-of-condition grain from outside the bin. These range from generally inexpensive (using a rod) to expensive (using a BinWhip). The wide variety of solutions is not surprising given the different positions that out-of-condition grain can be in and different structural configurations. These strategies can be split into four categories: (1) grain handling solutions, (2) rodding, (3) force-based solutions, and (4) alternate grain extraction methods.

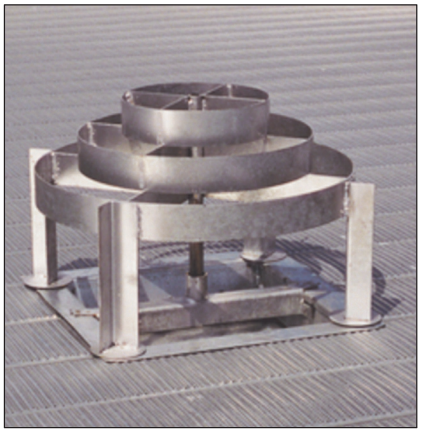

Figure 5. Example of sump guard. Image used with permission from Brock (2022).

Grain Handling Solutions

Grain handling solutions refer to solutions that use existing grain storage and handling tools to break up clumps and towers of out-of-condition grain. There are two primary ways that this can be done: turning on aeration fans or adding grain to the bin.

Turning on Aeration Fans

This strategy has been reported as one of the most effective in handling out-of-condition grain. The concept behind this strategy is that grain towers and clumps continue to hold a lot of moisture, and by running the fans and removing that moisture, they will dry up and slowly break apart. This is a safe and effective way to break up stubborn clumps and towers located anywhere in the bin (Lee, 2021). The only cost is the electricity necessary to run the fans, which is relatively low compared to other methods. The main concern with this issue is drying time. Aeration can take up to three weeks to break up the clumps, and even then, it is not a guaranteed solution (Lee, 2021). If the farm or elevator has sold the grain for delivery and has a deadline to meet, this may not be an appealing or even feasible option. To avoid "rewetting" the grain, aeration fans should only be used on low humidity days.

Adding Grain to the Bin

This strategy can be used to break up out-of-condition grain towers or surfaces that form over the center sump. In this solution, the worker will run grain from one bin and into the bin with crusted out-of-condition grain. By pouring new grain over the crusted grain, workers take advantage of the weight of grain (about 60 pounds per bushel) and the abrasive force of grain can break up clumps and cause the tower to fall over. This can be a safe and effective method of breaking up towers that are located over the center sump. The cost is also low and only involves conveyor operation, but this solution is limited to grain crusted in the center of the bin. If the tower is not in the center of the bin, the grain being loaded into the bin will likely not hit the crusted grain directly. Additionally, if the grain sump is already clogged, this might not be an effective solution and might worsen the situation. Operating the unload auger while adding grain can prevent the build-up of additional grain and alert the operator if the grain sump gets clogged.

Rodding

Rodding refers to using a large pipe, rod, or stick in order to break up clumps and allow the grain to flow again. Rodding can occur either inside or outside the bin. From outside the bin, there are three existing strategies to rod the grain: opening/closing sump gates, using an extendable pole, or using a grain/bin tunnel.

Opening/Closing Sump Gates

The sump gate is the piece of metal that acts as a door to the reclaim auger or belt. These gates are closed during storage and then opened when one wants grain to flow out of the bin. Most of the grain flows out of the center sump (Lee, 2021). When grain chunks formed by out-of-condition grain flow down, they block the grain sump and stop the flow of grain. If at least part of the grain clump is within the grain sump, a worker could break up the clumps simply by opening and closing the sump gate. This method is the first strategy that a worker should attempt. However, this is also a limited strategy because if the clump is resting completely above the gate opening, then opening and closing the gate will not strike and break up the clump. Thus, some form of external action, such as rodding, becomes necessary.

Extendable Pole

A telescoping pole or pipe may allow an individual to be in a safe location while rodding the bin (fig. 6). The worker simply pushes or pokes the pipe into the grain tower or clump to break it up from a safe place like the roof hatch (Decker, 2019). This can be an effective method to break up stubborn clumps and towers that are found in smaller bins, especially those without tunnels that provide below-floor access to the structure. The process can usually be done by a single individual and is relatively inexpensive to implement. A limitation of this method is that, as the storage structure gets larger, the needed pole must become longer as well, making it harder to control and yield. Another limitation is that as the worker has limited access ports to insert a pole, if accessed on top of the grain bin, this could introduce additional hazards as well, such as falls and electrocution if the pipe comes into contact with power lines (Lee, 2021).

Grain/Bin Tunnel

Many commercial grain storage structures have access tunnels below the grain bins and concrete silos that can be accessible to workers. In these tunnels, inspection panels or rodding ports can be setup to allow the workers to safely rod the grain bin unload spout without exposure to hazards inside the grain bin. To rod the grain, a worker opens the access point and the rodding device is pushed and pulled to break up the grain clumps from over the sump hole until they fall into the reclaim auger. Rodding from a tunnel is a safe and effective way to break up stubborn clumps that are located over the center sump. No one has to enter the bin, and the process can be done by a single individual with minimal cost. The only concern is that tunnels must be designed into the original design of the structure and therefore found only at commercial facilities. Country elevators and most farms do not have below-floor access to their grain storage structures.

Force-based Solutions

Compressed Air

This method uses high-pressure compressed air as an air cannon to knock down towers as well as break up clumps that have sumps plugged. To clear out grain sumps, a worker would have to remove the bin unload auger. The worker then pushes a pipe with an elbow

Figure 6. Extendable pole in action. Pole is used to break grain clumps blocking sump.

(to push the air upwards) through the bottom of the sump. After running the air compressor for a few minutes, the worker closes the sump gate, clears out the auger port using compressed air, and places the auger back to test the grain flow. The worker might repeat this process a few times until the grain flow is consistent. To break up grain towers, the individual uses a pipe-like extendable pole and shoots the air from the door or top hatch directed at the towers (Lee, 2021). Another approach to this strategy is drilling a hole in the structure, inserting a pipe with the high-pressure air hose inside it until it reaches the center of the bin, and then operating the air compressor. For this strategy to work, a commercial grade air compressor that produces up to 250 cfm is needed to produce enough force to break up the crusted grain. Most farm-owned compressors only run around 50 cfm, so farmers might have to rent a compressor with more capacity. The advantages of this method are that it can be used in almost all types of storage and can handle both clogged sumps and grain towers without individuals having to enter a bin. Also, air compressors are relatively affordable to rent (about $150/day), making this an economical strategy. The downside to this strategy is that it can be extremely dangerous if the correct equipment is not used. Everything from the hose to the ball valve must be rated to handle the required flow rate to be successful. Proper PPE (personal protective equipment) is needed in order to use this method safely. Air compressors are extremely loud, so ear protection is a must, along with eye protection from possible flying debris. Also, the air wand has so much air at high pressure passing through it that it will get very hot and gloves will be required to handle it. Another potential concern is the large amounts of grain dust that gets suspended in the air, including toxic mold spores.

The 'BinWhip'

The BinWhip is a powered device used for cleaning the internal surfaces of silos and bins. A pneumatic or hydraulically driven 'Whip-Head' is inserted in the bin, suspended by a supply hose and located at the end of a manually operated wire rope controlled by an overhead boom, which spins a chain/rope that flails against the grain clumps (Decker, 2019). It works very similar to a drain snake. BinWhip machines tend to be very expensive and are usually rented from a grain salvage service provider. By using trained operators, the BinWhip machine enables the cleaning of a silo or bin's internal surfaces without the need for bin entry and the associated hazards. Due to the cost associated with BinWhips, they tend to be a last resort for farmers and commercial facilities. See Pneumat Systems (2022) for an example of the BinWhip machine.

Explosives and Guns

PVC pipe with accelerant, fireworks, dynamite, and shotguns are various methods used by workers to breakup towers and crusted grain (Lee, 2021). There is no evidence that explosive devices are an effective method of breaking up grain towers. However, this method can cause grain bin fires and dust explosions. In the case of guns, pellets and/or bullets can ricochet and cause injury or damage to the individual or the grain bin. The spark coming from the muzzle of the gun can also cause a grain dust explosion or flash fire. For these reasons, this method is not recommended. Note that there is an alternative strategy of using bullets shaped from ice instead of pellets and propelled by compressed air.

Alternate Grain Extraction Strategies

Inserting Auger Above the Floor/Foundation

This method provides an alternate strategy for emptying a grain bin if the sumps are plugged. It works by inserting an auger into the bin through a hole cut just above the flooring. The auger has about 3 to 5 feet of exposed flighting at the end. The auger can be powered by a tractor or loader and needs to go in as far as possible. Then, the bin can be unloaded from this auger instead of the sumps. This provides another option to unload the bin if the sumps are plugged without workers having to enter the bin (Decker, 2019). One major concern about this method is that if the auger is not pushed far enough into the bin, the pressure of unloading off-center will cause stress on the outside of the bin. This can compromise the integrity of the structure and potentially cause the grain bin to collapse. Another concern is the potential exposure to exposed augers and drive lines during the insertion process.

Grain Vacuum

A grain vacuum can be used to either break up towers or remove grain in bins with clogged sumps. Most grain vacuums come with both solid and flexible piping that can be extended to reach the out-of-condition grain. To break up towers, a worker inserts the vacuum conveyor with a rigid hose on its end. The worker then pushes the grain vacuum as deep as possible into the grain mass at the base of the tower while outside the bin. By vacuuming the loose grain at the base of the tower, the stability of the tower is undermined and it can potentially fall over and break up (Lee, 2021). The grain vacuum is also used to empty a grain bin with a clogged sump. This method is considered a safe option as long as no one has to enter the bin. Most commercial grain elevator companies have a grain vacuum, which makes this option less expensive for them than for a farmer who would have to rent the machine. One concern with using grain vacuums is that they tend to be heavy and are difficult to maneuver. They are physically demanding to use, with the potential to cause ergonomic injuries and are loud, requiring hearing protection.

Inside the Grain Bin

Almost any strategy used to break up out-of-condition grain outside the bin can also be used inside the bin. Any method used inside the bin is considered unsafe and a potential entrapment hazard. The list below is to give the reader a comprehensive list of methods documented as being used by workers in grain storage and handling facilities. Entering the grain bin to dislodge out-of-condition grain or to “walk down” the grain is extremely dangerous and prohibited by OSHA 1910.272, the grain handling standard.

Rodding from Inside the Bin

This option is similar to rodding from outside the bin. The worker enters the bin and pushes a rod through the sump to unclog it. This is a high-risk solution as most grain entrapments recorded are due to this method (Issa et al., 2018). The most common mistakes that workers make are not turning off and locking out unloading equipment motor switches or working beneath free-standing grain that can avalanche towards the center of the bin when the sump becomes unplugged. Other mistakes include not wearing a proper harness and not having an observer (Issa et al., 2018). Even done correctly, bin entry can still be extremely dangerous.

Breaking Up Towers from Inside the Bin

This process is similar to rodding grain from inside the bin and is also extremely dangerous. Attempting to break towers from the base of the tower is highly dangerous and can lead to crushing injuries, followed by entrapments. One method to reduce the risk of breaking up towers from inside the grain bin is by refilling the bin so that only about 1 meter (3 to 4 feet) of the peak of the tower is exposed (fig. 7). Workers break up the exposed tower safely, leave the bin, and the grain level is further lowered by about 1 meter, re-exposing the tower. This process continues until workers reach the bottom of the bin and/or tower. To maintain the safety of this strategy, it is essential to follow all grain bin entry procedures, including locking out and tagging all unloading equipment, wearing a full-body/climbing harness with a properly rigged and anchored lifeline system, and having a trained observer present when entering the bin to break up the tower (Lee, 2021). This strategy is not recommended but may be the only option in larger bins (105 to 135 feet in diameter with a tower in the center). One concern about this strategy is that workers tend to underestimate the height of towers and fail to take adequate steps to protect themselves, resulting in avalanche entrapment (Issa et al., 2018).

Power Tools

A video of a young man attempting to break up grain inside of a bin using a gas-powered string trimmer with a tiller attachment was recently posted and circulated on social media. In the video, three employees were at the top of the bin, standing on what appeared to be a bridged grain surface that was clearly out-of-condition with a large cavity below (Lee, 2021). Gas-powered equipment should not be used in bins because it creates an ignition source and emits carbon monoxide in a confined space. Additionally, it would be impossible to have good footing while standing in grain, possibly resulting in the power tools making contact with the individual using them (or other individuals nearby), resulting in injury (Lee, 2021). This approach is also in violation of OSHA 1910.272, the grain handling standard.

Grain Vacuum

This strategy has already been discussed in detail in the outside of the grain bin section. However, due to the hazards associated with using this solution inside the bin, it is important to emphasize again. When a worker is using a grain vacuum, the flow of grain into the vacuum is so fast that it could remove material beneath the worker's feet, pull the

Figure 7. Example of worker breaking up towers from inside bin.

Figure 8. Unsafe example of worker emptying grain bin using grain vacuum while inside bin.

worker down, and cause entrapment beyond the point of self-extrication within fifteen seconds (fig. 8; Field et al., 2014). Between the years of 1987 and 2012, 27 engulfment incidents related to grain vacuum systems were reported, and 78% of these cases were fatal (Field et al., 2014; Issa et al., 2018). Manufacturers of grain vacuum systems clearly warn operators not to use these machines while standing on the surface of the grain.

Conclusions

This article reviewed twenty-one strategies that were documented as being used on farms and commercial grain facilities to remove out-of-condition grain (table 1). While the authors believe that they have located the most frequently used methods, it is possible there may be others. The twenty-one methods were then classified into three categories, (1) outfitting the bin, (2) outside the bin, and (3) inside the bin. In general, outfitting strategies are considered the safest methods, followed by outside strategies and inside strategies, which are considered the riskiest methods. Note that the effectiveness and safety of these methods were not investigated in this article. It must be noted that grain storage facilities have the option to contract with a grain salvage company that will come in with a trained team and appropriate equipment to remove out-of-condition grain with no risk to their workers.

While a wide variety of solutions exist that farmers and workers can implement outside of the bin, the continued reports of grain entrapments in recent years indicate that farmers and workers are still entering grain bins in most cases to deal with out-of-condition grain. This could be due to a lack of time, financial constraints, lack of training, lack of knowledge, or failure to implement outside of the bin solutions. Due to a lack of research, the frequency that each strategy is used or implemented by workers is unknown, and the perceived risk of each strategy is also unknown. There is also a dearth of investigative

Table 1. List of all strategies to remove out-of-condition grain by category.

Category	Strategy
Outfitting the Bin	Vertical Stirators
	Plug Busters
	Robotics – Grain Weevil
	Bar on sump gates
	Rod over sump
	Enlarged sumps
	Sump guard
Outside the Bin	Aeration fans
	Adding grain
	Sump gates
	Extendable pole
	Bin Tunnel
	Compressed air
	BinWhip
	Explosives and Guns
	Inserting auger above floor
	Grain Vacuum
Inside the Bin	Rodding
	Breaking up towers (*fill until only 3 ft tower remain, breakup, repeat*)
	Power tools
	Grain vacuum

articles on the actual risks of each method, which might have contributed to a lack of extension recommendations on how to safely remove out-of-condition grain. This review points out that there remains a significant amount of required research to test and develop best practices for removing out-of-condition grain and to understand the reasons why workers choose to enter grain bins to remove out-of-condition grain.

Acknowledgments

This work is supported by the Critical Agricultural Research and Extension program [grant no. 2021-68008-34107 / project accession no. 1025155] from the USDA National Institute of Food and Agriculture. Figures 2 to 4 and 6 to 8 were provided courtesy of John Lee.

References

ASABE. (2018). ASABE News Detail: ASABE publishes grain bin access standard. Retrieved from https://www.asabe.org/News-Detail/asabe-publishes-grain-bin-standard

Brock. (2022). Brock ® well-gard ® discharge guards. Retrieved February 14, 2022, from https://www.brockgrain.com/products.php?product_id=265

Cheng, Y.-H., Nour, M., Field, W. E., Ambrose, K., & Sheldon, E. (2021). 2020 summary of U.S. agricultural confined space-related injuries and fatalities: Agricultural confined spaces - injury/fatality summary report. Purdue University. Retrieved from https://extension.entm.purdue.edu/grainsafety/pdf/2020_Confined_Space_Summary.pdf

Decker, J. D. (2019). Safe practices for entrapment/engulfment prevention. Webinar. Decker Consulting & Investigations, Inc. Retrieved from http://s3-us-west-2.amazonaws.com/grainnet-com/uploads/pdf/GHSC_Webinar_Slides_1.pdf

Field, W. E., Heber, D. J., Riedel, S. M., Wettschurack, S. W., Roberts, M. J., & Grafft, L. J. (2014). Worker hazards associated with the use of grain vacuum systems. *J. Agric. Saf. Health, 20*(3), 147-163. https://doi.org/10.13031/jash.20.9989

Issa, S. F., Cheng, Y.-H., & Field, W. (2016). Summary of agricultural confined-space related cases: 1964-2013. *J. Agric. Saf. Health, 22*(1), 33-45. https://doi.org/10.13031/jash.22.10955

Issa, S. F., Field, W. E., Schwab, C. V., Issa, F. S., & Nauman, E. A. (2017). Contributing causes of injury or death in grain entrapment, engulfment, and extrication. *J. Agromed., 22*(2), 159-169. https://doi.org/10.1080/1059924X.2017.1283277

Issa, S. F., Nour, M. M., & Field, W. E. (2018). Utilization and effectiveness of harnesses and lifelines in grain entrapment incidents: Preliminary analysis. *J. Agric. Saf. Health, 24*(2), 59-72. https://doi.org/10.13031/jash.12170

Kingman, D. M., Deboy, G. R., & Field, W. E. (2003). Contributing factors to engulfments in on-farm grain storage bins. *J. Agromed., 9*(1), 39-63. https://doi.org/10.1300/J096v09n01_06

Lee, J. (2021) How to deal with bad grain: Hazard recognition and safe work practices. Webinar. Retrieved from https://www.youtube.com/watch?v=-D8sgV2z9b0&t=4150s

Lyseng, R. (2020). Plug buster arrests 'killer grain bins'. The Western Producer. Retrieved from https://www.producer.com/crops/plug-buster-arrests-killer-grain-bins/

OSHA. (2020). Grain handling. Occupational Safety and Health Administration. Retrieved from https://www.osha.gov/grain-handling

OSHA. (2021). Susan Harwood training grant program: Funding opportunities and award announcements. United States Department of Labor, Occupational Safety and Health Administration. Retrieved from https://www.osha.gov/harwoodgrants/awards#tab2

Pneumat Systems. (2022). Bin & silo cleaning system. BinWhip. Retrieved from https://pneumat.com/es/productos/binwhip/

Roberts, M., & Field, B. (2010). 2009 summary of grain entrapments in the United States: Agricultural confined spaces - injury/fatality summary report. Purdue University. Retrieved from https://extension.entm.purdue.edu/grainsafety/pdf/09grainEntrapment.pdf