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Summary of Fatal Entrapments in On-Farm Grain Storage Bins, 1966-1998

Douglas M. Kingman, *Illinois State University*
Dirk E. Maier, *Purdue University*
William E. Field, *Purdue University*

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D. M. Kingman, W. E. Field, D. E. Maier

Abstract

For over 30 years, Purdue University has maintained a national database of agriculture–related entrapment cases that have occurred in loose agricultural material. At present, 391 documented fatal and non–fatal entrapments from the U.S. and Canada make up the Purdue University Agricultural Entrapment Database. In order to specifically study fatal cases of entrapments in grain bins located on farms, the database was reviewed, 181 cases were identified using specific criteria, and the results were summarized. Approximately five cases per year were identified between 1966 and 1998, representing 18 states and one Canadian province. Entrapments were generally reported more often in the top corn–producing states and during the months of November, December, January, March, and June. In 24% of the cases in which the victim's age was known, the victims were younger than 16. Children and adolescents younger than 16 were more often fatally entrapped in June than in any other month. For cases in which the product was known, corn was the agent of injury in 53% of the cases and was frequently found to be out–of–condition. At the time of entrapment, victims were involved with bin unloading activities in 76% of the cases in which the activity was identified. These findings are being used to design new injury prevention strategies, including educational materials and recommendations for engineering controls that focus on primary causative factors.

Keywords. **Engulfment, Suffocation, Grain hazard, Flowing grain safety, Grain bin, Farm fatalities.**

Researchers from Purdue University's Agricultural Safety and Health Program (PUASHP) have been collecting agricultural–related entrapment cases for over 30 years. The Purdue University Agricultural Entrapment Database (PUAED) was developed using reports of fatal and non–fatal agricultural work–related entrapments that were identified as having occurred in free–flowing or loose agricultural material between the years 1966 and 1998. Reports were derived from newspaper clippings, case studies submitted by agricultural safety professionals, state and federal reports, and death certificates. Database records included information on

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The authors are **Douglas M. Kingman,** ***ASAE Member,*** Assistant Professor, Department of Agriculture, Illinois State University, Normal, Illinois; and **William E. Field,** ***ASAE Member,*** Professor, and **Dirk E. Maier,** ***ASAE Member Engineer,*** Associate Professor, Department of Agricultural and Biological Engineering, Purdue University, West Lafayette, Indiana. **Corresponding author:** Douglas M. Kingman, 107A Turner Hall, Department of Agriculture, Illinois State University, Campus Box 5020, Normal, IL 61790–5020, phone: 309–438–2925; fax: 309–438–5653; e–mail: dkingma@ilstu.edu.

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entrapments that occurred primarily in on–farm and commercial storage structures and grain transport vehicles (GTVs), such as gravity flow wagons, semi–truck trailers, and railroad cars.

Using the PUAED, a study was conducted to: (a) provide more consistent and detailed information concerning the characteristics of the entrapment victims, (b) identify specific causal factors, and (c) determine common circumstances among documented cases. The study focused on fatalities that have occurred in farm grain bins because they represented a more comprehensive database since many non–fatal partial entrapments are never reported. It was believed that a study that subjected available cases to consistent criteria for selection would also provide a more reliable annual fatality rate. The information gathered from this study was considered essential to the design of effective intervention strategies and to support the development of voluntary engineering design standards that would increase the safety of persons working in or around on–farm grain storage bins.

Prior Research

In 1978, the Purdue University ASHP staff initiated a study to investigate on–farm entrapments and suffocations in flowing grain. Fifty–nine separate cases occurring between 1966 and 1979, involving 61 individuals and resulting in 38 fatalities, were documented during the initial study (Field and Bailey, 1979). This study summarized data from the cases identified, provided recommendations for specific design changes for grain bins and GTVs, and suggested information for use in safety educational material. Changes that occurred, at least partially as the result of the study, included improved hazard warning labels for grain bins, greater use of inside–bin ladders, and increased public awareness of the dangers of entrapment. Another result of the study was the development of protocols for victim extrication from grain bins under varying circumstances (Baker et al., 1982).

Schwab et al. (1985) examined the vertical pull applied to a subject during the static and dynamic engulfment of a mannequin in shelled corn and wheat. They indicated that the earlier work of Schmechta and Matz (1971) was the only identified attempt by researchers to account for the force needed to extract a subject entrapped in grain. Two mannequins and an experimental peg (equal in surface area to the adult mannequin) were used as test subjects in the entrapment experiments (table 1). Covered in denim to represent clothing, the mannequins were subjected to vertical pull tests during static, flowing, and transition conditions. Schwab et al. (1985) found no significant difference in vertical pull between flowing shelled corn and wheat. They also found that there was no significant difference between the pull required to extract a mannequin from flowing grain and the pull required to suspend the same mannequin in an inflow of grain. (The mannequin was located in the depression formed on the grain surface during the unloading of a grain bin). Schwab et al. (1985) provided little documentation concerning the magnitude of the suffocation problem, but their research efforts culminated in the development of a grain hazard awareness education display (“Tug–of–War with Grain,” Iowa State Extension Service, 1995) that demonstrated the effort required to pull an individual out of a grain mass.

Skromme (1987) developed a summary of agricultural fatality cases from 1986 and 1987 media reports and farm injury summaries from 25 states. Skromme identified 20 suffocation deaths but did not distinguish whether the deaths occurred in grain bins, silos, or by other means.

Table 1. Test mannequins for entrapment experiments performed by Schwab et al. (1985).

	Length	Mass
50th percentile articulated adult	1.75 m (69 in)	75 kg (165.35 lb)
50th percentile articulated child	1.17 m (46 in)	24 kg (52.91 lb)
Experimental peg	1.75 m (69 in.)	73 kg (160.94 lb)

Snyder et al. (1992) summarized available National Traumatic Occupational Fatality surveillance system data and reported that 20% of the deaths involved in grain and silage handling activities were suffocation cases. Snyder and colleagues did not specifically identify the suffocation deaths as occurring in grain bins, silos, or other types of structures, or whether the incidents occurred on farms or at commercial facilities.

Fatal childhood injury data from Indiana and Wisconsin involving cases that occurred between 1970 and 1990 were reviewed by Sheldon (1992). He identified 33 fatalities due to asphyxiation or suffocation, of which 27 involved grain, feed, or other loose material. Seven percent of all deaths over the 21–year period were identified as suffocation in loose, free–flowing material.

A Purdue study was initiated in 1993 to assess the scope and frequency of incidents involving grain transport vehicles (GTVs), primarily gravity–flow wagons. As part of this research, Kelley and Field (1996) catalogued data from 235 fatal and non–fatal farm work–related entrapments identified as having occurred in free–flowing agricultural materials between the years 1966 and 1994 in 23 states and one Canadian province. (Even though entrapment data has been gathered from 23 states, only 18 states had cases involving on–farm storage.) They identified 39 of the 235 cases as being related to GTVs. Victims under the age of 15 accounted for 59% of the cases examined, with males accounting for 94% of the total for which age and gender were known.

Freeman et al. (1998) completed a follow–up summary of 71 fatal and non–fatal entrapments at commercial grain storage facilities that had been identified by Kelley and Field (1996). These cases were investigated separately due to the important differences that existed between commercial and on–farm grain storage operations. Freeman et al. (1998) found that 92% of victims fully engulfed by loose agricultural material did not survive regardless of the type of rescue efforts carried out. They also reported that 80% of the cases that were described as partial entrapments at the time the rescue began resulted in fatalities. The work of Freeman et al. (1998) contributed to the development of the safety education material, *Don't Go With The Flow*, designed specifically for commercial grain handlers and emergency personnel (NGFA, 1998).

Research Methodology

Fatal and non–fatal entrapment cases were combined from the efforts of Kelley and Field (1996) and Freeman et al. (1998) and resulted in the formation of the Purdue University Entrapment Database (PUAED, 1998). In order to manage the cases, the PUAED records were entered into an electronic database. This database was utilized to facilitate the adding, updating, querying, analyzing, and long–term storage of the case information. For instance, the fatal farm–related engulfments in grain bins summarized in this report were separated from other PUAED cases by programming the database with selection criteria, which are identified later in this article.

Fatality Case Identification

In an effort to expand the PUAED and ensure more comprehensive flowing grain engulfment data, personal contacts were made with agricultural safety and health professionals at each land grant university in each of the major grain–producing states to solicit summary data for farm–related fatalities. In addition, a letter was sent to 175 agricultural safety contacts that had been established during previous attempts to collect fatality data (Kelley and Field, 1996). This network of agricultural safety specialists, agricultural engineers, safety educators, and farm organization representatives formed an informal group that was willing to share fatality data and injury investigation material. The letter requested their assistance in identifying cases of entrapment and suffocation in flowing grain and other agricultural materials. In response to the calls and the letter, reports of fatalities, including newspaper clippings, state summary reports, and other incident descriptions, were received. Previously unidentified cases were added to the PUAED from Idaho, Iowa, Kansas, Michigan, Minnesota, Mississippi, Nebraska, North Carolina, North Dakota, Ohio, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, and Wisconsin.

All identified fatal and non–fatal incidents involving possible entrapment or suffocation were considered for this study regardless of classification or agent of injury (table 2). Case selection criteria were not applied to reduce the number of cases during case acquisition activities so that misreported or incompletely reported cases would not be overlooked.

Information from the National Institute of Occupational Safety and Health (NIOSH), National Safety Council (NSC), and Bureau of Labor Statistics (BLS) was reviewed for additional case identification. Existing fatality reports, like those that have been summarized by Snyder et al. (1992) and the NSC Accident Facts (NSC, 1996), did not provide sufficient information to distinguish grain bin entrapments from other types of engulfments or suffocations that occur on farms or at commercial facilities. As with previous attempts by Kelley and Field (1996) to obtain case–specific fatal injury surveillance data from government agencies, data confidentiality issues precluded NIOSH and BLS from providing the raw data necessary for case–by–case

Table 2. Classification and agent of injury for entrapment cases for the years 1966–1998 (PUAED, 1998).

Classification	Agent of Injury	Fatal	Non–Fatal
On–farm cases	Grain bin	181	44
	GTV	33	15
	Silo	11	0
	Truck bed/semi–trailer	7	5
	Feed bin	2	0
	Barn/livestock building	2	0
	Grain dryer	1	0
	Other	8	1
	Unknown farm cases	18	2
Non–farm cases	Grain bin	25	4
	Silo	12	4
	Barn	1	2
	Truck bed/semi–trailer	3	1
	Auger	1	0
	Other	8	0
Total		313	78

matching with the PUAED. Therefore, neither the National Traumatic Occupational Fatalities surveillance system, which is maintained by NIOSH, nor the Census of Fatal Occupational Injuries surveillance system, maintained by BLS, could be used to identify additional grain bin entrapment cases.

NIOSH has collected detailed information about selected fatal injury events from selected states through its Fatality Assessment and Control Evaluation (FACE) program. NIOSH provided the total number of cases involving grain–related fatalities that had been identified in states that participate in the program (table 3). The authors then contacted participating states to gain additional information on documented cases. The Minnesota Department of Health (Wahl, 1999) provided case–specific information with personal identifiers removed. The Minnesota reports provided a detailed description of the fatal injury event and offered recommendations for preventing similar fatalities in the future. A sample of a typical state summary report for all types of suffocation is shown in table 4. These cases were acquired from the South Dakota Department of Health (Campbell, 1998). These data provided few details. They were used only for comparative purposes and to establish that fatalities by suffocation have occurred on a regular basis.

Case Selection for Study

The following case selection criteria were used to identify cases that have occurred in on–farm grain bins and to safeguard against the redundant use of cases.

Table 3. NIOSH–documented grain suffocation fatalities, 1990–1998[a].

State	Year	Number of Reported NIOSH Suffocation Fatalities
Indiana	1994	1
	1996	1
	1997	2
Iowa	1995	2
	1996	2
	1997	1
	1998	2
Minnesota	1992	5
	1993	2
	1994	3
	1995	2
	1996	6
Missouri	1992	1
	1995	1
	1998	1
Mississippi	1997	1
Nebraska	1994	2
	1995	1
Wisconsin	1992	1
	1993	3
	1996	1
	1997	1
Wyoming	1995	1
Colorado	1990	1
Total		44

[a] Unpublished NIOSH FACE data for grain suffocation fatalities, 1990–1998 (Pratt, 1998).

Table 4. South Dakota suffocation fatalities, 1985–1997[a].

Year	Number of Fatalities by Suffocation
1985	1
1986	1
1989	3
1990	1
1991	1
1993	1
1994	2
1997	1
Total	11

[a] Unpublished data for South Dakota grain suffocation fatalities, 1985–1997 (Campbell, 1998).

- Did the engulfment result in a fatality?
- Was the victim located in a grain bin that was located on a farm? (A grain bin is a round, bottom–unloading, stationary, metal, storage structure that stores or conditions grain or feed, and is not a concrete or metal silo or other oxygen–limiting structure typically used for the storage of silage and like materials.)
- Was the product involved some type of loose or free–flowing agricultural product?
- Were the date, location, or time of the incident available?
- Was the victim's name or age established?

Each case was reviewed and additional information was sought until a clear determination of the nature of the incident and selection criteria for this study had been satisfied. Local fire, rescue, and law enforcement squad members and extension educators were contacted when additional information was necessary to satisfy case selection criteria.

Several incidents identified in the case selection process involving deaths in grain bins or other storage structures were determined not to meet the case selection criteria. These cases included victims who were not involved with engulfment but rather suffered incidents such as auger entanglements, falls from grain bins, and suffocation by other agricultural materials such as sawdust and silage. These cases were not included in this study.

Findings

From the PUAED cases, 181 fatality cases were determined to be relevant to this study based on meeting the selection criteria. In order to summarize the cases, they were analyzed by annual frequency, geographic distribution, monthly distribution, age and gender of the victims, product involved, grain movement at the time of entrapment, grain condition at time of entrapment, and whether or not safety equipment was used by the victim. The data represented 18 states (not all states represented in the database reported entrapments in on–farm bins) and 1 Canadian province and reflects a "best picture" of a problem that is unquestionably underestimated due to the lack of comprehensive reporting and accurate classification of agriculture–related fatalities.

Fatality rates, such as the deaths per 100,000 workers or deaths occurring over a given exposure period, were not determined due to the lack of data concerning the total number of persons exposed to flowing grain situations and the duration of their exposure. Using total numbers published for farms, farm workers, or farm residents in attempting to develop comparative rates leads to errors due to the large numbers

of farmers that do not maintain grain storage facilities and the variability in the levels of exposure. Rates based upon the number of storage structures were also determined to be problematic due to the substantial variability found in the level of mechanization, size of structures, and grain handling practices.

Frequency

Figure 1 shows the distribution by year of identified fatalities from 1966 to 1998 in the U.S. and one Canadian province. Over this time interval, the annual morbidity rate was approximately five cases per year. Though substantial efforts have been made over the past 20 years to identify entrapment cases, it appeared that the number of identified cases during certain periods may have related to periods when more intensive data gathering efforts occurred, such as 1978 (Field and Bailey, 1979), 1986 (Skromme, 1987), and 1992–1993 (Kelley and Field, 1996). However, using all sources, only two fatalities meeting the selection criteria were identified in 1998. While anecdotal data indicated that engulfments in ear corn occurred before 1966, on–farm flowing grain hazards were minimal until post–harvest storage and processing technologies were widely implemented in the mid–1960s. These technologies included the field shelling of corn, high–volume grain handling systems, and artificial drying of grain (Brooker et al., 1992). By 1970, these technologies were prevalent in the U.S., and the volume of grain produced and stored on the farm increased substantially; therefore, the exposure of workers and their families to the hazards of flowing grain increased.

Another explanation for peaks in annual fatality numbers may include the effects caused by precipitation, humidity, temperature, field–drying conditions, harvest moisture content, and delayed harvest on the condition of the stored grain. A review of these factors for the production years of 1985 and 1992 indicated contradictory findings. The deaths in 1993 may have been linked to a late and wet harvest of corn in much of the Corn Belt in the fall of 1992, leading to a considerable amount of out–of–condition corn in storage (Kelley and Field, 1996). However, when attempting to draw the same conclusion for the deaths in 1986, it was found that favorable field–drying conditions occurred throughout the region in 1985.

The 1992 moisture content of harvested corn throughout the Corn Belt was also much higher than the five–year average of harvest moisture content of corn for the years of 1990 to 1994 during the months of October and November (USDA, 1997).

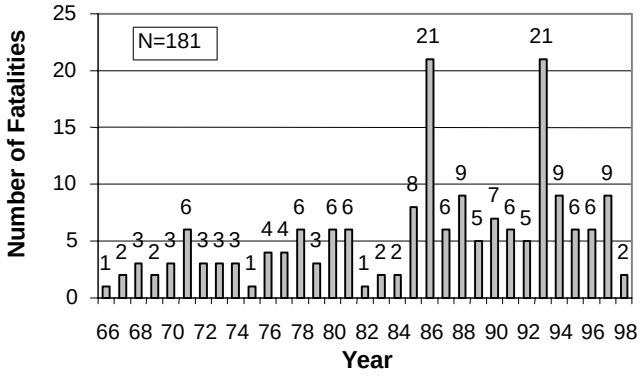
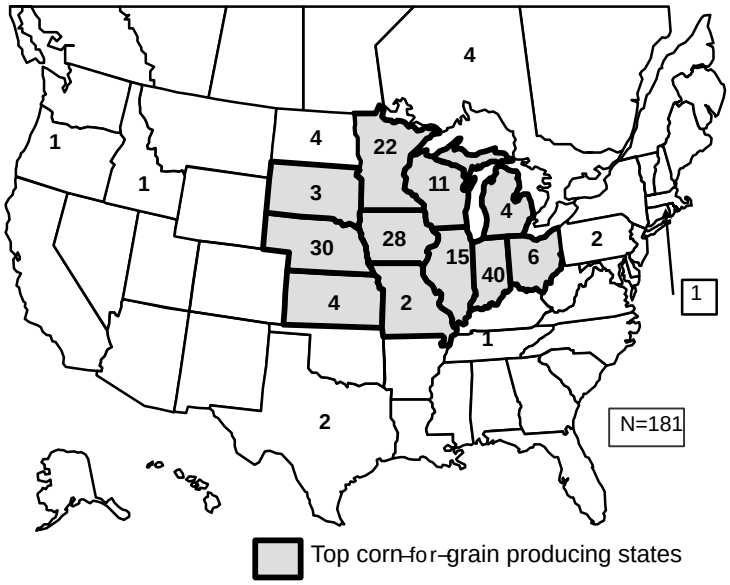


Figure 1. Entrapment fatalities per year (PUAED, 1998).

A late and wet corn harvest has typically resulted in on–farm drying capacity problems and subsequently higher moisture contents during storage. In some cases, excessive moisture contents at harvest and during storage have led to grain spoilage and the formation of crusted or clumps of grain, which can result in the plugging of unloading equipment during grain removal from bins. Out–of–condition corn was found to be an important causative factor. Victims who were attempting to unclog plugged unloading auger inlets were at greater risk of entrapment due to the practice of entering the storage bin to break up clumps of out–of–condition grain. This was also noted in the summary of commercial entrapments, where out–of–condition grain was involved in 81% of the commercial entrapments (Freeman et al., 1998).

Geographic Distribution

Figure 2 indicates the geographic distribution of the 181 documented engulfments and the states with the historically highest production of corn–for–grain (NASS, 1985–1997). The number of fatalities for each state was found to relate somewhat to the amount of corn produced in that state. However, this fact was difficult to ascertain in every state because higher fatality numbers, especially in Indiana, Iowa, Nebraska, and Minnesota, probably reflected higher production levels and better surveillance efforts rather than solely higher grain production. For example, if everything else were equal, Illinois would be expected to report more cases than Indiana or Minnesota, considering the larger amount of grain produced and the higher number of on–farm storage structures found in the state. Illinois, however, reported fewer on–farm fatal entrapments than most Corn Belt states and more commercial entrapments during the years 1988 to 1995 than any other state (Freeman et al., 1998). During that same time frame, Illinois ranked second to Iowa in corn production and first in off–farm storage sites (Freeman et al., 1998). The amount of corn stored in off–farm facilities may have been an influencing factor.



State	Fatalities
IN	40
NE	30
IA	28
MN	22
IL	15
WI	11
OH	6
KS	4
MI	4
ND	4
SD	3
MO	2
PA	2
TX	2
CT	1
ID	1
OR	1
TN	1
Ontario	4

Figure 2. On–farm fatalities occurring in grain bins by state (PUAED, 1998).

The geographic location of the fatalities appeared to have also been associated with crop type. Small grains such as wheat, oats, and barley were reported to have been involved in fewer cases of entrapment than corn. These grains tend to be grown in larger quantities in states with lower precipitation and humidity levels, resulting in less storage problems and consequently fewer reported cases of entrapment.

Seasonal Distribution

The months in which the fatalities occurred were identified in 173 of the cases. The months of June, December, November, January, and March were higher in fatalities, with June and December being the highest (fig. 3). October was not found to be a major month for deaths in grain bins, as was previously reported for GTV entrapments (Kelley and Field, 1996; Field and Bailey, 1979). A review of data concerning the months in which field crops were typically sold revealed that some of the most substantial periods for grain sales and movement (November, December, and January) coincided with the months for adult entrapment in grain bins. During these times, there was clearly an increased exposure to flowing grain hazards. The peak month of June reflected a disproportionate number of children under the age of 16 who died during that month. The relationship between age and month will be addressed later.

Age Distribution

The victim's age was known in 176 of the 181 cases studied and ranged from 3 to 86 years (fig. 4). There were seven and six fatalities of 13 and 14 year old children, respectively. Forty–two (24%) of the victims were under the age of 16, while 56 (32%) were over age 55 (fig. 5). This age breakdown was based on the fact that there are presently no restrictions on those over 16 to participate in farm work that is recognized as hazardous by the U.S. Department of Labor (USDOL, 1999).

Relationships Between Age and Season

A comparison was made on a monthly basis between suffocations involving children who were 15 or younger and victims who were 16 to 35 (fig. 6). These data were available for 79 cases. This analysis revealed that there were differences in the months

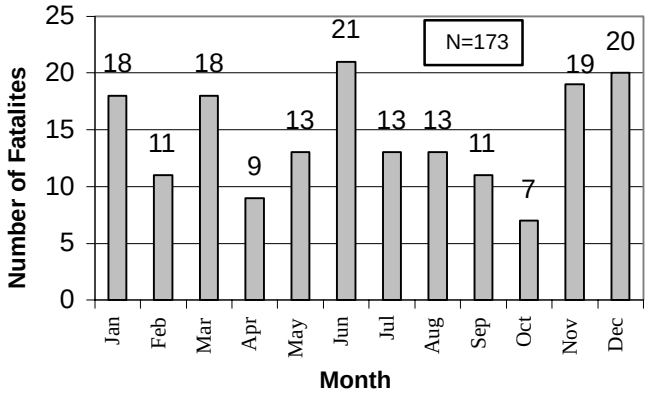


Figure 3. Monthly distribution of fatalities (PUAED, 1998).

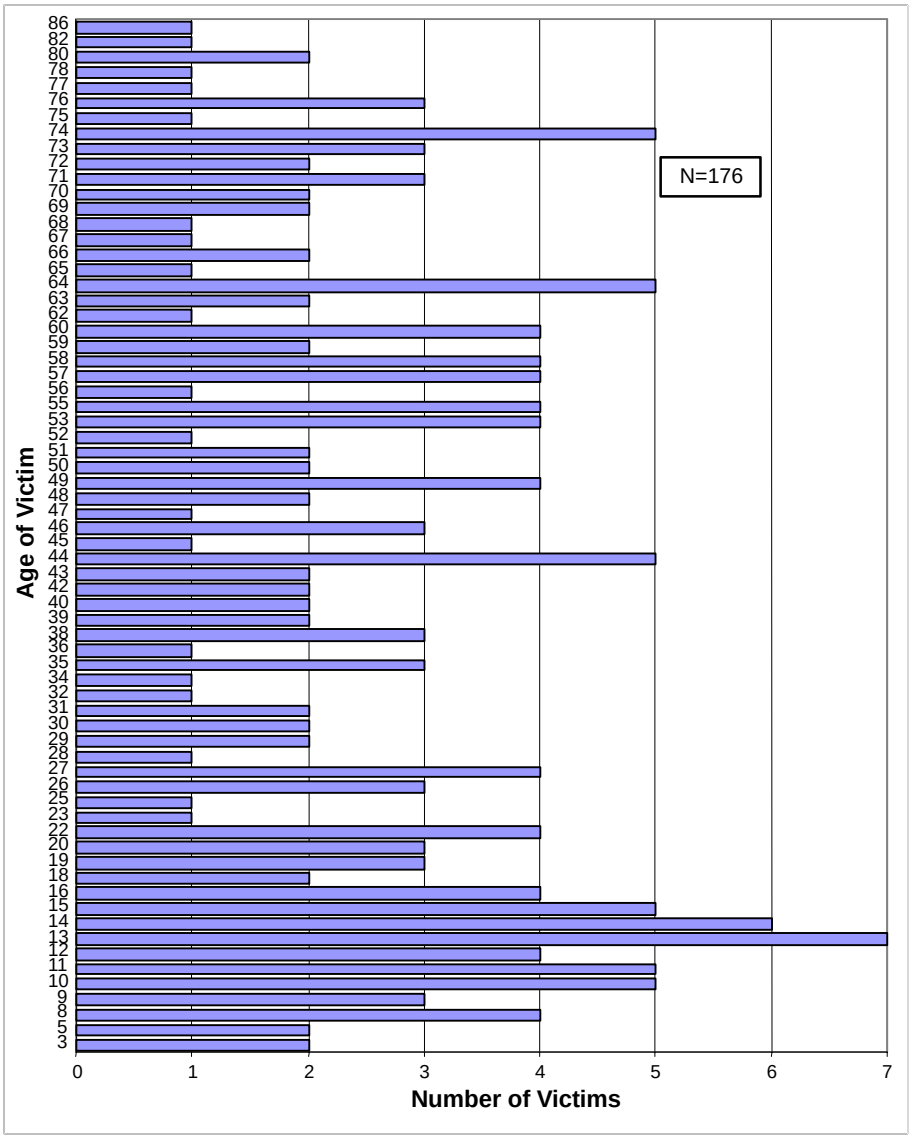


Figure 4. Ages of victims (PUAED, 1998).

during which each group experienced the highest incidence of suffocation. Eleven victims between the ages of 16 and 35, but none younger than 16, suffocated during the month of January. The data also indicated a disproportionate number of June fatalities (nine) for children under the age of 16 versus four fatalities in the 16 to 35 age category. The June fatalities were associated with the ending of the spring semester for many public schools and increased numbers of vacationing families, including children, visiting grandparents on their farms. (Though not analyzed for all cases, several of the cases were reported to have involved a grandson on his grandfather's farm.)

Figure 5. Ages of victims by group (PUAED, 1998).

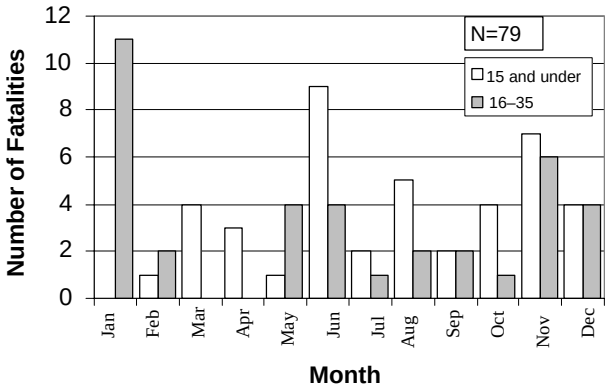


Figure 6. Younger victims by month (PUAED, 1998).

With respect to victims between the ages of 36 and 55, it was noted that suffocation occurred more often during the months of November, December, February, and March, corresponding to peak periods of grain handling (fig. 7). The highest months for fatalities of victims between 56 and 75 were July, June, May, and March. It was also noted that this age classification was the only group with one or more reported fatalities in each month.

Gender

Of the 178 cases for which gender was known, 171 (96%) of the victims were identified as males. Only seven victims (4%) were known to have been female. The ages of the female victims were 5, 10, 12, 22, 47, and two were 74 years of age. The high proportion of cases for which the gender of the victims was known was a reflection of newspaper reporting practices, in which the victim's name, age, and gender were usually published.

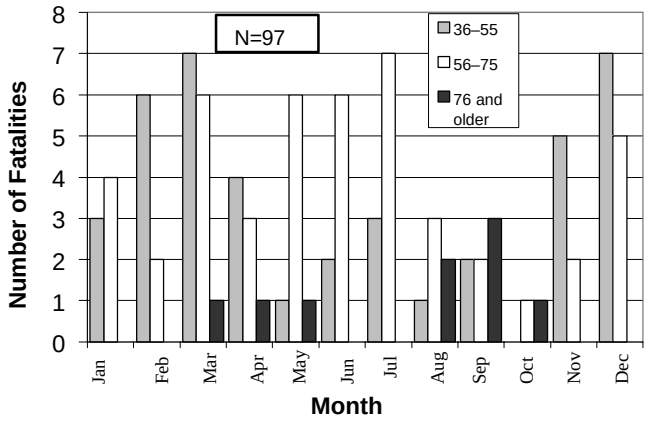


Figure 7. Older victims by month (PUAED, 1998).

Product

A noteworthy finding was that 96 (53%) of the 181 suffocation cases were known to have occurred in shelled corn (table 5). Other products that were reported included feed grain, mixed feed, grass seed, oats, screenings, and sunflower seeds. These findings are consistent with Freeman et al. (1998), who reported that corn was involved in 43% of the commercial entrapments for which the product was known.

Grain Movement

Grain movement at the time of engulfment was documented in 123 (68%) of the cases. Ninety–three (76%) of these victims were involved with unloading grain from the storage structure prior to the time of the entrapment (table 6).

Table 5. Product involved in fatality (PUAED, 1998).

Product	Fatalities	Percentage
Corn	96	53
Soybeans	6	3
Wheat	6	3
Milo	4	2
Feed	3	2
Other	6	3
Unknown	60	34
Total	181	100

Table 6. Grain movement at time of engulfment (PUAED, 1998).

Grain Movement	Fatalities	Percentage
Unloading	93	76
Loading	3	2
Other activity	27	22
Total	123	100

Safety Equipment

Only three victims were reported to have been using some type of safety equipment when their entrapments occurred. Safety equipment, such as body harnesses, lifelines, or lockout devices, while used in the commercial grain industry to prevent entrapment, is generally not found on most farms, and if present, has been found in some instances to be inadequate to protect the user or was being used incorrectly. In one case, a safety line was attached to the victim, but the line had not been securely fastened to an adequate anchor point. At present, most on–farm grain storage structures are not designed to accommodate confined–space entry procedures generally used in most other industries.

Work Status

An attempt was made to establish the work status of the victim in each case, that is, whether the victims worked full–time on a farm regardless of whether they were employed by the farm owner or self–employed. Of the 181 cases, 27 victims were documented to have full–time work status, while five were identified as working or farming part–time. The status of the bulk of the victims could not be ascertained.

It was determined in several of the cases involving children that they were visitors to the farm, rather than residents or workers at the time of entrapment. However, in 11% of the cases that involved children under the age of 16, the victim was reported to have been working at the time of entrapment. Under federal law (U.S. Department of Labor: Hazardous Occupations for Youth Under 16, in the Code of Federal Regulations, Title 29, Chapter V, Part 570, Subpart E–1), employed children under the age of 16 are restricted from entering grain bin storage facilities for work purposes. After the age of 16, there are no restrictions for participating in farm work. In other words, in at least 11% of the cases for which the victim's age and employment status were known, children were participating in an activity that would be classified as illegal employment. This number actually may have been much higher because the activity of the children during entrapment was rarely reported.

Rescue Procedures Used

During interviews with survivors and rescue personnel, it was clearly recognized that rescue attempts are complicated; they require a substantial amount of time, personnel, equipment; and they are rarely successful. In addition, the lack of the awareness of flowing grain hazards can lead to poor decision–making and contribute to the death or injury of partially entrapped victims and rescue personnel. It was found that partially entrapped victims are typically removed by constructing a makeshift cofferdam and then digging out around the victim. In one instance involving a mechanical leverage device to extract a victim engulfed past his knees, the effort failed, and the victim was paralyzed when the vertebrae in his back were stretched. Although several commercial facilities were found to have incorporated homemade rescue tubes into their confined–space entry rescue plans, there was no documentation regarding the efficacy of these devices during actual rescues or their compatibility with farm grain bins. The rescue tube concept was intended to be used as a cofferdam to facilitate the extrication of a partially engulfed victim (Carpenter and Bean, 1992). However, the recorded dimensions of the tube sections of some units were found to be larger than typical farm grain bin roof access ports and therefore unusable without modifications to the bin roof.

Fully engulfed victims were generally accessible only after removal of grain from the bin to the level of the victim. The most common procedure for unloading the grain involved cutting holes in the walls of the bin and allowing the grain to flow out. Once the grain level was lowered, the victim became accessible to the rescue workers for final extraction. In some cases, this was reportedly achieved in 45 minutes or less, but in other cases, 4 or 5 hours were required to reach the victim.

Important concerns were identified with the practice of cutting open large storage structures due to pressures on the bin sidewalls. The potential for bin failure during these rescue attempts is probable cause for exploring alternative techniques. Uneven unloading of bins has led to bin wall failures, in more than one of which the bin has collapsed. Victims engulfed while the auger was operating generally were located at the bottom center of the bin, directly above the unloading auger inlet. Several victims came into contact with the exposed flighting of the unloading auger and suffered injuries to the foot or leg, resulting in blood loss.

Conclusions

Since 1966, 181 cases of suffocation in flowing or loose grain were documented in the U.S. and Canada in on–farm grain storage bins. This equated to approximately five cases per year. It can be assumed that there were additional flowing grain–related fatalities that were not identified during the study, and that the summary presented in this article is a best–case scenario. These fatalities were identified throughout the U.S. but primarily in major grain, specifically corn, producing states, and in the Canadian province of Ontario. Many more close calls and near misses were documented, and like agricultural injuries in general, most are not recorded by any standard surveillance mechanism. Higher numbers of reported deaths may be associated with periods of extensive data collection efforts and with late harvesting activity due to undesirable weather conditions that affect the field–drying of grain, thus resulting in the development of out–of–condition grain during the storage period. Considering that exposure levels are low and appear to be primarily related to relatively short periods of time during unloading operations, the risk level appears to be higher than for other high–exposure activities engaged in by farmers, such as operating tractors or handling livestock.

In cases for which the victim's age was known, approximately 24% of the victims were between 3 and 15 years old. Victims younger than 16 suffocated primarily in June, while older victims suffocated during the months of November, December, January, February, and March. The high number of children who have died in on–farm storage bins raises several concerns, including the role of children in grain handling operations and ease of access to grain storage facilities.

Although grain handling activities were only reported in 123 of the cases, in 76% of these cases the victims were unloading grain at the time of the engulfment. Corn was involved in over 53% of the fatalities for which the agent of injury was known. In cases for which the victim's gender was identified, 96% of the victims were male. These consistent patterns suggest that prevention efforts could be highly targeted to reach those at greatest risk of suffocation.

Recommendations

It is anticipated that the results of this study can be used to design intervention strategies for reducing or eliminating entrapments in farm grain bins. The deaths of farm workers, especially children, in farm grain bins are significant because all of them are preventable. The following recommendations address a broad approach to the problem and will require varying levels of resources and cooperation to implement. It is not assumed that any one recommendation will lead to a complete solution:

1. The identification, selection, and addition of farm entrapment cases to the PUAED should continue, including fatal and non–fatal entrapments occurring in the U.S., Canada, and other major grain–producing countries where grain is stored in on–farm bins.

2. Utilizing the voluntary standards development process, an industry standard that addresses on–farm grain storage structures should be developed. The standard should incorporate components designed to increase the safety of individuals exposed to farm grain bins, including children and workers, by addressing the following issues:

- Hazard warning label location(s) and message content
- Lockout/tagout accommodations
- Location of auger controls
- Anchorage points for confined space rescue
- Ladders inside grain bins.

3. The opportunity afforded at farm shows to increase and reinforce grain hazard awareness should be explored by grain bin manufacturers. Fatality statistics, safety promotional literature, safety device acknowledgement, and interactive awareness displays could increase the knowledge base of farm workers, children, and infrequent farm visitors who may be completely unaware of or misinformed about the dangers associated with the storage and handling of grain.

4. Available teaching materials should be identified, or produced if not available, that target the most likely victims of engulfment in on–farm grain bins identified in this summary. Specifically, the teaching materials should target adult male farm workers and include the following topics:

- Fatality summary statistics including victim activity and profile
- Hazards of flowing grain
- Flow characteristics of grain during the unloading of a grain bin
- Categories of entrapment scenarios
- Bystander first–response steps
- Rescue procedures and techniques for partial and complete engulfment situations.

5. A seasonally influenced media effort should be designed and implemented to distribute information on the hazards of flowing grain and to promote awareness based on research findings on causative factors. This effort should specifically include:

- A spring campaign targeted at children who might be exposed to the farm grain handling system during summer months
- A November through February campaign targeting farmers and farm workers involved with on–farm bin unloading operations.

6. A study should be designed and implemented to gather information on the activities of farmers prior to entrapment, their attitudes toward flowing grain hazards, and effective methods of disseminating hazard awareness educational material to the target groups.

7. Additional research should be conducted on the relationship between out–of–condition grain and the frequency of grain engulfment. In addition, management practices should be identified or developed that could be implemented to reduce the likelihood of out–of–condition grain.

8. Rescue devices that could be used by farmers and local emergency response personnel to rescue engulfed victims should be developed, evaluated, and where found effective, incorporated into the grain handling system.

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