

Understanding Current On-Farm Storage Systems and Safety Practices
of Ohio Cash Grain Operators

THESIS

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By

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Abstract

Hazards associated with agricultural confined spaces are a contributing factor to agricultural injuries, and are quickly becoming a significant problem for Ohio farmers. In order to make substantial improvements, we must first understand how the industry operates, the culture of the workers, and the current practices used to avert casualties. This research project was designed to bridge the gap between what is currently known about the risks that exist on Ohio's farms, specifically in the cash grain industry, and how safety and health information is conveyed to the workforce. Using a 4-part questionnaire, cash grain operators were surveyed to determine the type of storage and drying facilities used on Ohio's farms, the presence of moldy and out-of-condition grain, and the health and safety factors practiced around these facilities. Understanding the current situation on Ohio cash grain facilities will allow for a more targeted intervention plan to occur, both in regards to implementing better engineering controls as well as outreach education.

Dedication

This work is dedicated to my mother Wei Zhang and My father Changhuai Geng for their support, patience and encouragement.

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Without the support and guidance from the following people, this project and the report that describes my efforts would not have been possible.

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Chapter 1: Introduction

The grain industry is an essential field in the agricultural industry. It produces food, fodder, and raw materials and has connections with other industries such as food and chemical. The grain industry is a large business. For instance, in Ohio, soybeans produced 2.6 billion dollars in 2014 and corn produced 2.2 billion dollars (USDA-NASS, 2014b). In the grain industry, grain farmers play an essential role. They take part in the planting, harvesting, storing, and transporting the grain. Within every step of producing the grain, farmers are exposed to variety of risks. Hazards could trigger injuries or fatalities, and damage the equipment. Therefore, safety education and practice is important in agriculture. This research focuses on the risks and hazards farmers face in the grain storage facilities in Ohio.

Ohio Grain Agricultural Situation

The state of Ohio has a large grain agriculture presence. According to the 2012 Census State Profile of Ohio, there were 75,462 farm operators, owning a combined total of approximately fourteen million acres of land. Farming is the primary occupation with 43.9% of operators employed as the primary farm operator (n=33,140). The average age of these operators is 59.4 years old (USDA-NASS, 2014).

Corn and soybean plants cover more than half of the land in Ohio. In 2012, Ohio ranked eighth and ninth in the United States for the harvesting of corn and soybeans, respectively. In 2014, Ohio's farmland produced approximately 610 million bushels of corn and 254 million bushels of soybeans (USDA-NASS, 2014b). For management and economic reasons, many of these cash grain crops are stored on the farm until market deliveries are made.

Grain bins are one of the more popular types of storage facilities in Ohio. These structures range in size and can store thousands of bushels of grain. Smaller feed-style bins can be 12-15 feet tall, while larger bins can be upwards of 54 feet tall. It is common for all bins to have external ladders or stairs, with the medium to large bins having many more features such as fans, drying systems and monitoring devices.

Besides grain bins, there are two other types of facilities for cash grain storage, silos and flat storage. There are many different types of silos: cement storage silos, tower silos, concrete stave silos, low-oxygen tower silos, bunker silos, and silage bags. The size of these structures vary and could contain several thousand to several hundred thousand pounds of material.

Flat grain storage buildings look similar to large warehouses. They are built with all-steel rigid frames, concrete walls and have large roofs. Flat storage units can range in size depending on the needs of the farmer. Usually the slope of the building roof is from 1:12 to 7:12 and grain can be up to 20' deep against the buildings' sidewalls.

Safety Risk in Grain Storage Facilities

Farm operators are considered to be in a dangerous occupation. Data from 2009 to 2013 from the National Census of Fatal Occupational Injuries show that the fatal work injury rates of farmers, ranchers, and other agricultural managers were between 21.3 and 41.4 per 100,000 full-time equivalent respectively for those years. For comparison, the all-worker fatal injury rate in the United States was about 3.2 to 3.5 per 100,000 full-time equivalent, in this same time period. The fatal work injury rate of farmers is about 7 to 10 times the normal rate. Farmers, ranchers and other agricultural managers are located in the top 10 occupations with highest fatal work injury rates. These farm workers ranked 4th in 2009 and 2010, 7th in 2011, 9th in 2012 and 8th in 2013 high fatal work occupations (Bureau of Labor Statistics, 2010, 2011, 2012, 2013, 2014).

There are many risks in the agricultural workplace such as transportation, contact with objects and equipment, and exposure to harmful substances or environments (Smith & Program, 2002). Using NIOSH data from 1992 to 2005, tractors accounted for 37% of fatalities in farmers and farm workers. Agricultural machines, animals and falls were also common causes of death (NIOSH, 2006). According to the 2001, 2004, 2009, and 2012 surveys by Occupational Injury Surveillance of Production Agricultural (OISPA), contact with objects and equipment was consistently the top cause for agricultural injuries. Falls, bodily reaction and exertion and other events were also common causes for injuries (NIOSH, 2014).

Grain storage facilities are also hazardous. Both grain bins and silos can be classified as confined spaces. The definition of a confined space according to the

Occupational Safety and Health Administration (OSHA) is a space large enough and so configured that an employee can physically enter and perform assigned work; has limited or restricted means for entry or exit; and is not designed for continuous employee occupancy (OSHA 29 CFR 1910.146, 2015).

Agricultural confined spaces have a close relationship with work-related injuries and fatalities in agricultural production. According to data in Purdue's Agricultural Confined Spaces Database (1964 to 2010), there were 1,251 agricultural confined space related accidents. From these events, 887 (70.9%) cases happened in a grain storage facility such as grain bins and silos (NCERA-197, 2011). There are several different injuries that can occur within agricultural confined spaces. The most common injuries result from grain entrapment, suffocation, falls, heat stress, and explosions (Adejumo & Haruna, 2013; NCERA-197, 2011; NIOSH, 1994). In the "2012 Summary of Grain Entrapments in the United States," Matt Roberts et al. reported a total of 1,474 agricultural confined space incidents between the years 1964 and 2012. From these cases, 1,059 incidents were involved with grain storage. From this study, an increased incidence of grain entrapments were reported between the years of 2002 and 2012. The steady increase in these injuries is a huge threat, as grain entrapment incidents have a mortality rate of 48.1%; meaning if two people were to suffer a grain entrapment incident, one of these incidents would result in a fatality (Issa, Roberts, & Field, 2013).

Grain bin entrapment is a very serious problem for Ohio farmers. Similar to national data in 2013 there were three incidents in Ohio. These included both fatal and non-fatal injuries. The data of the total number from 1964 is 36. (Issa & Field, 2013).

Surveillance data from Ohio's Farm Fatality and Injury Database of Ohio revealed 11 fatalities directly connected with grain handling and storage from the years 2004 to 2013. These deaths accounted for 6.5% of all farm fatalities reported in Ohio. A closer look at these 11 cases revealed four farmers died from entanglements, two were killed by falls, and five died from suffocation (The Ohio State University, 2015).

Health Risks in Grain Storage Facilities

Farmers are also at risk for respiratory hazards from organic dust, inorganic dust and gases (Kirkhorn & Garry, 2000). Organic dust is the main health risk in grain storage environments. Organic dusts include grain, insect parts and microorganisms such as mold. These particles can cause asthma, asthma-like symptoms, organic dust toxicity syndrome (ODTS), chronic bronchitis, and hypersensitivity pneumonitis (Farmer's Lung) (Cathomas, Brüesch, Fehr, Reinhart, & Kuhn, 2002; Kirkhorn & Garry, 2000; Rylander, 1986). Atmospheric hazards are another type of respiratory risk in confined spaces. These areas may contain oxygen deficient environments along with the occasional presence of some toxic gases such as nitrogen dioxide (NIOSH, 1994).

Hearing loss is another major health hazard in the grain storage environment. Tractors and grain dryers are common pieces of equipment operated around grain storage facilities. Both of these machines can easily reach sound levels up to 105 decibels (dB). When sound levels measure over 85 dB, hearing protection is needed (OSHA 29 CFR 1910.95, 2015). Some studies show that farmers have different levels of hearing loss though different age groups (Plakke & Dare, 1992). The noise exposure standard is defined under OSHA 1910.95 (OSHA 29 CFR 1910.95, 2015). In this standard,

“Employers shall make hearing protectors available to all employees exposed to an 8-hour time-weighted average of 85 decibels or greater at no cost to the employees. Hearing protectors shall be replaced as necessary.”

Hazards of Out-of-Condition Grain

Out-of-condition grain refers to stored grain that has become wet, clumped or has spoiled (“Grain facility occupational exposure,” 2015). Out-of-condition grain is a common problem that arises during grain storage. Grain goes out-of-condition for many reasons including, heat, mold and inappropriate moisture (Maier, 1993).

The out-of-condition grain has links with both the safety risks and health risks in grain storage facilities. For instance, mold is one reason for the out-of-condition grain. Out-of-condition grain contributes to grain entrapment which is a safety risk, (Freeman, Kelley, Maier, & Field, 1998), and out-of-condition grain produced by mold have connections with organic dust, which is a health risk.

The Current Situation of the Problem with Grain Storage Facilities

There are many factors which influence farmers’ behavior and the injury incidents during their work. Farmers’ attitudes, safety consciousness and safety knowledge are three factors for preventative and protective safety measures (Bawden, Macadam, Packham, & Valentine, 1984; Elkind, 1993; Westaby & Lee, 2003). Different attitudes toward safety will yield different behaviors of farmers (Atkinson, 1957; Frederick X.Gibbons, 1995). The unsafe behaviors practiced by some farmers could heavily contribute to the occurrence of deadly accidents (McLain, 1995). Moreover, some

researchers pointed out that economic motivation is another important factor to effect the farmers' behavior in agricultural safety and health (Elkind, 2007; Kidd et al., 1998).

Safety training and education are essential methods used to promote change in farmers' behaviors and improve their knowledge and consciousness (McLain, 1995; Rubinsky & Smith, 1973). A more advanced knowledge of hazards and education about safe work practices could influence the attitude of the farmer (Elkind, 1993).

There are many organizations that provide standards and recommendations to farmers. The governmental rules and recommendations from OSHA and NIOSH, other education groups such as eXtension and universities' extension programs, emphasize that personal protective equipment (PPE) is an efficient method to protect farmers from the hazards of agricultural confined spaces. Wearing personal protective equipment such as ear plugs, respirators and fall protection equipment, could increase a farmer's chance of survival from the hazards in grain storage facilities (Haruna, 2013; NIOSH, 1994; Iowa University, 2015).

Besides their personal protection, there can also be training given for the operation of their storage structures. Understanding equipment controls and operating systems could be an important factor to protect farmers. Kingman et al (2004) pointed out that controlling the moisture in a grain bin is an effective method to avoid grain entrapments. Drying the grain to 14.5% is a good method to prevent unnecessary incidents (Kingman, Spaulding, & Field, 2004). In addition, using a drying system correctly could improve grain quality in long term storage (Jayas & White, 2003). Managing the grain storage facilities could decrease the incidence rate of the out-of-

condition grain. It could reduce the chance that farmers enter the facilities and decrease the time they are exposed to noise, organic dust, and other possible hazards.

Problem Statement

Hazards associated with agricultural confined spaces are a contributing factor to agricultural injuries, and are quickly becoming a significant problem for Ohio farmers. In order to make substantial improvements, we must first bridge a gap between what is currently known about the risks that exist on Ohio's farms, specifically in the cash grain industry, and how safety and health information is conveyed to the workforce.

Purpose and Objectives

The purpose of this study was to describe the current storage practices, as well as the safety and health conditions for Ohio cash grain operators, and the situation about the recent three year grain storage.

The objectives were to:

1. Describe Ohio's on-farm grain storage situation which includes farm area, workers' number and age distribution.
2. Describe farmers' safety knowledge and their behavior during their work.
3. Describe the past three years of corn and soybeans storage, such as the amount of the corn and soybeans harvested, how long grain is stored.
4. Explore the relationship between farmers' safety knowledge and their behaviors with grain storage and the problem with out-of-condition grain.

Definitions

The following definitions were used in this study

Agriculture- the industry which involves the production of crops and livestock (farming) plus agricultural services, forestry (excluding logging), and fishing (D. J. Murphy, 1992).

Cash Grain- or Cash Crop, is an agricultural crop grown to provide revenue from an off-farm source (EPA, 2015).

Confined Spaces- is a space large enough and so configured that an employee can physically enter and perform assigned work; has limited or restricted means for entry or exit; and is not designed for continuous employee occupancy (OSHA 29 CFR 1910.146, 2015).

Farm-a location or place where raw agricultural products such as livestock or crops are produced; also called a production agricultural operation (D. J. Murphy, 1992).

Farmer- Farmer (also called an agriculturist) is a person engaged in agriculture, raising living organisms for food or raw materials, the term usually applies to people who do some combination of raising field crops, orchards, vineyards, poultry, or other livestock. A farmer might own the farmed land or might work as a laborer on land owned by others, but in advanced economies, a farmer is usually a farm owner, while employees of the farm are known as farm workers, or farmhands (Dyer, 2007).

Grain entrapment-or grain engulfment, occurs when a person becomes submerged in grain and cannot get out without assistance. This more frequently occurs at storage facilities such as silos or grain elevators, but has been known to occur around any large quantity of grain, even freestanding piles outdoors (“Grain entrapment,” 2015).

Organic Dust-comes from hay, grain, fuel chips, straw, and livestock. Organic dust includes molds, pollens, bacteria, pesticides, chemicals, feed and bedding particles, and animal particles including hair, feathers, and droppings (OSHA, 2015b).

Out-of-Condition grain-Out-of-condition grain refers to stored grain that has become wet, clumped or has spoiled (“Grain facility occupational exposure,” 2015).

Personal protective equipment-commonly referred to as "PPE", is equipment worn to minimize exposure to a variety of hazards (OSHA, 2015a).

Respirator- is a protective device that covers the nose and mouth or the entire face or head to guard the wearer against hazardous atmospheres. Respirators may be:

1. Tight-fitting—that is, half masks, which cover the mouth and nose and full facepieces that cover the face from the hairline to below the chin; or
2. Loose-fitting, such as hoods or helmets that cover the head completely. In addition, there are two major classes of respirators:
3. Air-purifying, which remove contaminants from the air; and
4. Atmosphere-supplying, which provide clean, breathable air from an uncontaminated source. As a general rule, atmosphere-supplying respirators are used for more hazardous exposures(OSHA, 2002).

Assumptions

It was assumed in this thesis that:

1. Farmers have knowledge about their safety and healthy practices.

2. Farmers have clear recollection of their recent three years grain storage situation and knowledge of their grain storage facilities.
3. The participants finished all questions honestly, without pressure and obligation.

Limitation of study

Possible limitations within this study include:

1. This research uses convenience sampling for collection. Convenience sampling has high cost effectiveness, but it has selection bias, and the results are not generalizable.
2. This research depends on farmers recall about the recent three years grain storage situation and information about their grain storage facilities. Farmers may have unclear or unsure memory when they answer the question.
3. The survey required farmers use fifteen to twenty minutes to finish.

Conceptual Framework

A conceptual model was created to guide this study. Figure 1 depicts a conceptual model in the context of grain handling and storage facilities. This model goes one step further to highlight education and engineering areas where farmers have more control than the enforcement approach. Education and Engineering seen in the grey shadowed box represent what farmers have control over, and the Enforcement is in the box without a shadow, indicating that farmers have limited control in this part. The research presented in this paper is primarily focused on the aspects that farmers can control.

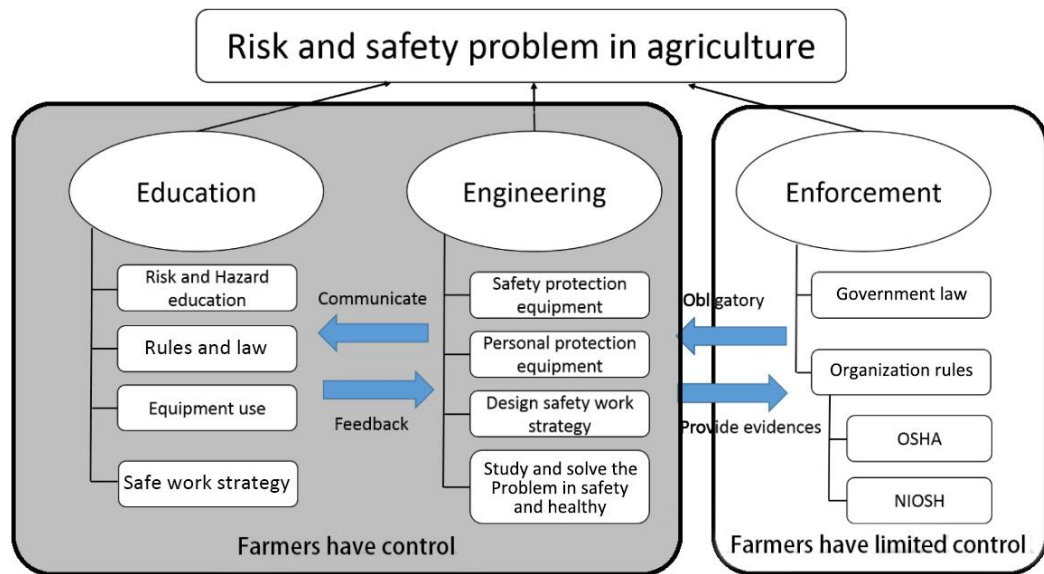


Figure 1. The Model of “Three E” in Grain Storage Facilities

Chapter 2: Literature review

The safety of grain storage facilities is very important to agricultural health and safety. This problem is complex and includes many different hazards that contain safety and health risks. In the state of Ohio, this has been a problem that has continuously perplexed farmers. This literature review will introduce the problem in two parts; the first section will describe the problem and how to deal it, and the second section will introduce the theory used in this thesis.

There are two categories of risks that are present in the grain storage facility that we will investigate: health risk and safety risk. Agricultural confined spaces, including grain storage facilities, have a close relationship with work-related injuries and fatalities in agricultural production. Lots of research exists on this topic, including the Developing a Research and Extension Agenda for Agricultural Confined Spaces North Central Education/Extension Research Activity Committee (NCERA-197) , a comprehensive report about the injures and accidents that occur within agricultural confined spaces (NCERA-197, 2011).

The researchers used seven different categories to describe the type of agricultural confined space: Grain and Feed Storage Facilities, Forage Storage Structures, Manure Storage Structures, Agricultural Transport Vehicles, Agricultural Equipment, Food Processing and Storage Equipment/Facilities, and Other, which includes grain driers,

greenhouses, and more. For my thesis project, I focused on Grain Storage Facilities, due to the amount of the hazards associated with them.

The Extension Research Activity Committee published eleven hazards associated with confined spaces, including:

1. Entrapment and engulfment in loose or free flowing agricultural products within storage structures or transport vehicles resulting in suffocation or injury.
2. Suffocation/asphyxiation within a confined space due to exposure to toxic gases or insufficient levels of oxygen.
3. Respiratory disease due to acute and chronic exposure to toxic dust, molds, and other airborne hazards.
4. Drowning in liquids present within the confined space.
5. Injuries associated with entanglement in energized components within the confined space.
6. Falls into confined spaces or from structures containing confined spaces.
7. Heat stress/exhaustion due to high temperatures within confined spaces.
8. Hypothermia due to extended engulfment/entrapment in chilled grain or environmentally controlled spaces.
9. Injuries caused by first responders during victim extrication from confined spaces.
10. Injuries to first responders attempting to conduct rescue operations in and around confined spaces.

11. Explosions and fires associated with confined spaces where flammable liquids are stored or flammable dust or gases are present.

Similar hazards are also identified in a NIOSH report, *Worker Deaths in Confined Spaces, a Summary of NIOSH Surveillance and Investigative Findings* (NIOSH, 1994).

Background Information

According to Purdue's Agricultural Confined Space Database there were 1,251 accidents associated with agricultural confined spaces between 1964 and 2010. A total of 887 (70.9%) cases occurred in grain storage facilities, making it a major agent for accidents. The authors also reported the victims' age. Victims' age was also reported and the results suggest that there was no significant difference in incidents between age groups. There were accidents in every age group, but the majority of cases happened in age group 1-15 years. In most age groups, the majority of incidents are fatal. Over this time period, there was a steady increase in the number of incidents per year, indicating a growing problem.

In their report, the Extension Research Activity Committee reviewed the different education resources and activities available in each state. In the state of Ohio, farmers are provided a two-day training for ag rescue/bin training and a one day general ag rescue class. From their results, they found that there are some gaps between research and education, and farmers need to know more about the hazards in agricultural confined spaces to increase their safety at work.

One of the most common hazards in grain storage facilities is entrapment or engulfment. These are the main hazards seen in grain storage facilities. Purdue University

focused on this problem as a main topic of their research, including an annual report of grain entrapments in the United States. In the report “2012 Summary of Grain Entrapments in the United States”, there were 1,474 total agricultural confined space incidents between 1964 and 2012, and 1,059 (71.8%) of these incidents happened in a grain storage facility (Issa et al., 2013). In the “2013 Summary of U.S. Agricultural Confined Space-Related Injuries and Fatalities” there were 1,640 total cases between 1964 and 2013, and 1201 (73.2%) happened in a grain storage facility (Issa & Field, 2013). Both of these reports use the same database, NECERA-197. These three publications support the idea of a rising trend in the number of confined space incidents, especially in grain storage facilities (Issa & Field, 2013; Issa et al., 2013; NECERA-197, 2011).

In addition, Purdue’s annual report provided the geographic distribution of grain entrapment and identified especially problematic areas. The area with a higher frequency of grain entrapment cases is referred to as the Corn Belt Region (Issa & Field, 2013; Issa et al., 2013). This area consists of ten states, listed from largest to smallest case count: Indiana, Iowa, Illinois, Minnesota, Nebraska, Wisconsin, Kansas, Ohio, South Dakota, and Missouri. Both the 2012 and 2013 reports provided the same state rank. Ohio, while in the Corn Belt Region, is one of the lower ranked states within it, in terms of incident count. In the 2013 report, Ohio was recorded as having three incidents happen in just that year; the total amount of such cases since 1964 was 36. Compared to the rest of the Corn Belt Region, Ohio does not have as alarming numbers, but it is still a very serious safety problem.

Data provided from the Farm Fatality and Injury Database of Ohio, showed there were 11 fatalities associated with grain storage facilities between 2004 and 2013. These fatalities comprised 6.5% of all farmers' fatalities reported in Ohio. In these eleven cases, four farmers died from entanglements, two were killed by falls and five died from suffocation (Ohio State University, 2015). These incidents are similar to those hazards reported in NCERA-197.

In an attempt to deal with the hazards in the confined spaces, NIOSH published a guide in 1987 (NIOSH, 1987). In this handbook, NIOSH provided details about the behaviors and personal protective equipment that should be utilized in confined spaces. One of the more popular strategies to deal with hazards in grain storage facilities is to turn off and lock out the energy source. Another popular method to increase safety is to wear respirators that protect the worker from respiratory hazards, like dust and mold, in the environment. It is also recommended to work with a team when in confined space, at the very least have a standby person in case anything goes wrong. This person could be vital in dangerous situations by being able to react and control the lifeline. Workers in the grain storage facilities should wear both this lifeline and respiratory protection in order to best approach confined space hazards. These strategies are not unique to the NIOSH guidelines and have been observed in lots of other related research. (Adejumo & Haruna, 2013).

Safety and Health Risks

In NCERA-197, the researchers introduce eleven hazards within the agricultural confined spaces. In this research they focus on the grain and feed storage facilities, forage

storage structures, manure storage structure, agricultural transport vehicles and equipment, and food processing and storage equipment(NCERA-197, 2011). Not all of the hazards reported in NCERA-197 are plausible in grain storage facilities, such as sinking in liquids.

Grain Entrapment

Grain entrapment is a serious hazard that occurs in grain storage facilities. Those who are in fatal grain entrapment accidents usually die by suffocation. Researchers found four common situations where grain entrapments could be caused. There could be an entrapment of a worker by flowing grain, the collapse of a grain bridge, the avalanche of a grain wall, or the entrapment of a worker using a grain vacuum or grain transport vehicles (Alabama Cooperative Extension System, 2016; Extension, 2015; Penn State Extension, 2015; Purdue Extension, 2015; The Ohio State University, 2016). These four categories of grain entrapment are widely accepted by many universities and agricultural extension programs, such as Purdue University, the Ohio State University, and eXtension.

Flowing grain is a phenomenon that occurs when grain is moved by the auger from the bottom of grain bin, causing the grain to come to the center of bin. The process produces a funnel shape. When the auger keeps turning, the flowing grain acts much like quicksand. If a worker is inside the grain bin at this time, they will quickly sink down into the bin. Workers who are entrapped can usually sink six feet in only 25 seconds, and to be able to escape the flowing grain, one would need a lot of force to become free without others' assistance (Penn State Extension, 2015).

A collapsing grain bridge is another situation that can trigger entrapment, and is seen when grain goes out-of-condition. A grain bridge is mostly made of moldy grain and can occur on the surface or inside the grain bin. If it is on the surface, farmers may use the auger to unload their grain out of the bin while standing on the grain bridge. When they start to remove the grain, the grain under the grain bridge becomes flowing grain. When the grain bridge collapses, the farmer will fall into the flowing grain (Alabama Cooperative Extension System, 2016; Extension, 2015; Penn State Extension, 2015; Purdue Extension, 2015; The Ohio State University, 2016).

A grain wall avalanche is a special case of a collapsing grain bridge that occurs when moldy grain sticks to the walls of the bin. After removing the loose grain, the farmers may face a wall of grain. If the farmer breaks the grain wall, they could be buried by the grain (Alabama Cooperative Extension System, 2016; Extension, 2015; Penn State Extension, 2015; Purdue Extension, 2015; The Ohio State University, 2016).

Grain vacuums have a similar mechanism of entrapment as the auger. Both the vacuum and the auger can remove grain and can cause the grain to flow quickly. The main difference between the two is that the auger works from the bottom of the grain bin, and the grain vacuum works on the surface of the grain.

Usually entrapments will happen in grain storage facilities, but sometimes they could also happen when the grain is transported (Extension, 2015; Penn State Extension, 2015; Purdue Extension, 2015).

Grain dust explosions

Grain dust explosions are another serious incident that could happen in grain storage facilities. It could damage the equipment, reduce work time and lead to injury or death (eXtension, 2016). From OSHA statistics, there were 503 explosion accidents causing 677 injuries and 184 fatalities in the United States from 1976 to 2011. (OSHA, 2016d).

Four basic elements can trigger grain dust explosions:

Fuel: organic dust such as particles from corn, soybean and wheat and the density affect the dust's minimum explosive concentration (MEC).

Oxygen: normal oxygen levels and the oxygen for continuous fire and explosions.

Confinement: a confined space such as grain bin, silo, and grain transport equipment.

Ignition source: the source could trigger explosion, such as short circuits, static electricity, overheated bearings, welding devices, grinder sparks, lightning and so on (eXtension, 2016; Noyes, 1998; OSHA, 2016b).

Organic dust explosions have two phases: primary explosion and secondary explosion. The primary explosion could induce a secondary explosion. If the fuel and oxygen is in perfect condition, the primary explosion could cause one or more secondary explosions. Both explosions could damage the structure and cause injury or death (eXtension, 2016; OSHA, 2016b).

Most grain dust explosions happen at grain transfer points. During grain transfer, the working machine could release grain dust in high levels, causing an explosion. The dust could exceed their MEC level (eXtension, 2016).

Fall Hazards

The fall hazard is another important hazard that is prevalent in grain storage facilities. As time goes on, grain storage facilities become larger and larger. A grain bin could be 45 feet tall, and a silo can be even higher than a grain bin. Falling could be a hazard because the worker could fall in the grain storage facilities or fall from the grain storage facilities. This hazard is much more serious in silos than grain bins, since many silos do not have a good platform for farmers to work on (Adejumo & Haruna, 2013).

Both grain bins and silos have fixed ladders. To protect safety for employees, OSHA has standards about fixed ladders, for instance, "Landing platforms." When ladders are used to ascend to heights exceeding 20 feet (except on chimneys), landing platforms shall be provided for each 30 feet of height or fraction thereof, except that, where no cage, well, or ladder safety device is provided, landing platforms shall be provided for each 20 feet of height or fraction thereof (OSHA, 2016a); and "Ladder safety devices." Ladder safety devices may be used on tower, water tank, and chimney ladders over 20 feet in unbroken length in lieu of cage protection (OSHA, 2016b).

Respiratory Hazards

When farmers are working in the grain storage facilities they also risk the safety of their health. In the hazards list provided by NCERA-197, toxic gases or insufficient

oxygen could lead to suffocation or asphyxiation and toxic dust, molds and other airborne hazards trigger acute and chronic respiratory diseases (NCERA-197, 2011). Respiratory hazards are also published by Purdue Extension (Purdue Extension, 2015). In this program, they pointed out that the main respiratory hazard in the grain storage facility is caused by mold spores which are produced by moldy grain.

Mold spores are a type of organic dust. In 1986, a study by Rangnar Rylander pointed out that the organic dusts in a farm environment could cause a variety of lung diseases, including acute inflammation, chronic bronchitis, hypersensitivity pneumonitis, occupational asthma and toxin fever (Rylander, 1986).

Steven R. Kirkhorn et al. published a research article in 2000 on agricultural lung disease (Kirkhorn & Garry, 2000). In this research, Steven R. Kirkhorn et al. gave a lot of detail about the agricultural respiratory hazards and diseases, including its categories, sources, environments and conditions. The common respiratory hazards in agricultural environment are organic dusts, inorganic dusts, gases, pesticides, fertilizers, disinfectants, solvents, welding fumes, and zoonotic infections. According to their research, the respiratory hazards that are commonly seen in grain storage facilities are organic dusts and gases, this idea is also supported by NCERA-197. Organic dust can come from grain, hay, endotoxins, silage, cotton, animal feed, animal byproducts, cotton, and microorganisms. In the grain storage facilities, the organic dusts are often produced from grain and microorganisms, including mold spores (Purdue Extension, 2015). The organic dusts could cause asthma, asthma like syndrome, organic dust toxicity syndrome (ODTS)

and hypersensitivity pneumonitis (farmers' lung). Rangnar Rylander also found similar disease the associate with grain storage facilities (Rylander, 1986).

Gas is another respiratory hazard found in grain storage facilities. Gas has two especially pertinent hazards: one is toxic gas such as ammonia and nitrous oxides, and the other is insufficient oxygen. Both of these hazards are introduced in Developing a Research and Extension Agenda for Agricultural Confined Spaces North Central Education/Extension Research Activity Committee (NCERA-197, 2011) and Worker Deaths in Confined Spaces, a Summary of NIOSH Surveillance and Investigative Findings (NIOSH, 1994). The asphyxia by insufficient oxygen is more commonly seen as a hazard in grain storage facilities than toxic gas.

Another common health hazard in grain storage facilities is hearing loss. Agricultural extension programs emphasize the need for farmers to use hearing protection when they are working around the grain storage facilities (Iowa University, 2015; Penn State Extension, 2015). Hearing loss is not directly caused by the grain and grain storage facilities. It instead comes from the agricultural machines such as grain augers, grain dryers and grain vacuums. In Hearing Loss Among Farmers and Agricultural Workers, the sound level dB of these agricultural machines are 92 dB from grain augers, 105 dB from grain dryers, and 97 dB from grain vacuums (Iowa University, 2015). The OSHA standard 1910.95 requested that when sound levels measure over 85 dB, hearing protection is needed (OSHA, 2016e).

In 1992, Bruce L. Plakke et al. published research about occupational hearing loss in farmers. In this research, they designed an experiment to test the hearing sensitivity of

farmers and a survey to collect the farmers' thoughts about hearing. The results show that compared to the control group, the farmers have more hearing loss, and this problem becomes more serious with an increase in age (Plakke & Dare, 1992). This result is also support by William S. Beckett et al.'s research (Beckett, William S. Chamberlain, Diane Hallman et al., 2000). In this research, William S. Beckett et al used a similar experiment method as Bruce L. Plakke et al., and they designed a survey to research what factors, including kinds of work, gender, and education level, could lead to hearing loss. They also did noise measurements for the equipment of farmers. They found that serious hearing loss is connected with older age, male gender, lower educational level, chemical spraying, recreational hunting with firearms, and use of the grain dryer. These results support Bruce L. Plakke et al. and provide more detail of the hearing loss problem in farmers. In William S. Beckett et al.'s research, they pointed out that the grain dryer is significantly associated with hearing loss, but is an essential machine in grain storage.

Out-of-Condition Grain

Out-of-condition grain is a common problem during grain storage. Dirk E. Maier described this problem in the report "Why is stored corn deteriorating prematurely" (Maier, 1993). Dirk E. Maier pointed out the several causes of the out-of-condition grain: crusting by sprouting and molding, condensation and moisture reabsorption causing soggy wet surface corn, and temperature increases at the top of the pile. This is also written in the Official United States Standards for Grain. In this book, the factors which could make grain damaged, besides mold and heat damaged grain, are diseases, frost,

germ, insect, sprout, bad ground, bad weather, and other material damage (United States Department of Agriculture, 2016).

A major problem in grain storage facilities is out-of-condition grain. Out-of-condition grain can crust together at the top of grain facilities, this process could produce grain bridges which could trigger entrapment and grain avalanche (Penn State Extension, 2015; Purdue Extension, 2015). The out-of-condition grain also could be damaged by mold, which in itself is a respiratory hazard (Kirkhorn & Garry, 2000; Rylander, 1986).

Out-of-condition grain is not only an issue in storage but in food quality and consumer safety. Fungi could produce mycotoxin, a toxic secondary metabolite of fungi. Mycotoxin could cause mycotoxicoses (diseases) when humans eat the grain polluted by mycotoxin (Richard, 2007). In 2007, John L. Richard made an overview about the major mycotoxins and mycotoxicoses. In the overview, John L. Richard introduces seven types of mycotoxins: Aflatoxins, Deoxynivalenol, Fumonisin, Zearalenone, T-2 toxin, Ochratoxin, and Ergot. All these mycotoxins can be produced during grain storage. They could cause many diseases, including a softening of the white matter in the brains, swine lung edema, liver tumors, kidney tumors, esophageal tumors, and toxicity. In this review, John L. Richard also pointed out that keeping the moisture and temperature constant is a key to control mycotoxin. Moisture levels below 14%, and not over 20°C are recommended many times in the paper to control the mycotoxins (Richard, 2007). S. N. Chulze reported a similar result in the study, “Strategies to Reduce Mycotoxin Levels in Maize During Storage: a Review” (Chulze, 2010).

Keeping the grain in good quality may improve the safety in grain storage facilities (Mosher, Keren, Freeman, & Hurburgh, 2012). Further research on the farmers' behavior when they work with grain storage may provide insight on some factors connected with the injuries and incidents in grain storage facilities. This idea will be further addressed in this thesis. This assumption is first published by D. M. Kingman et al. (Kingman et al., 2004), in his 2004 report about an on-farm grain storage hazard assessment tool could be used in predicting the potential of engulfment. In the research, D. M. Kingman et al. designed a questionnaire to explore the behavior of farmers work within grain storage facilities and the information about their storage condition, such as how long they store them and what the percentage they chose to dry their grain. After they analyzed these results, they found eight survey questions that suggest a significant association with entrapment. These questions mainly concern working behaviors and grain management. The questions in my thesis survey were heavily influenced by D. M. Kingman's research. Moreover, his results are supported by the 14% moisture target level found for grain drying in the research by John L. Richard (Richard, 2007).

Therefore, by properly managing grain quality we could control many problems. Researchers have focused on grain quality control for many years. Now researchers accept that the temperature and humidity are two main conditions to control during grain storage (Christensen & Kaufmann, 1969; Gnadke, 2001; Iowa University, 1997; Richard, 2007; Shukla, 2014). In 1969, Clyde M. Christensen and Henry H. Kaufmann introduce a lot of detail about grain quality and how to control them in their book, *Grain Storage: The Role of Fungi in Quality Losses*. In their book, they focused on problems with fungi,

and they emphasize that temperature and humidity are the main reasons for fungi growth in the storage. The same ideas are pointed out by John T. Gnadke (Gnadke, 2001), in his book *QUALITY GRAIN CARE*. He systematically introduced the method to control the grain quality during storage. In his description, the use of a grain dryer is essential to the whole system. If farmers could use their grain dryers correctly, choose the right percentage to dry their grain and make sure they achieved the target percentage, then the grain will have some period for safety during storage. The length of the safety period depends on the moisture of the grain, the lower the moisture, the longer the safety period. John T. Gnadke also recommended using the fan when storing in grain bins. During storage, he recommended that farmers monitor their grain bins and regularly measure the moisture and temperature inside the grain bin. He also provided useful charts and tables to guide the work.

These strategies are not perfect. In 1993, Dirk E. Maier reported that in the previous year, many farmers and elevator managers reported that their stored corn went out-of-condition, even if they did a good job in drying and cooling (Maier, 1993). Another example is that in 1997, Iowa University recommended farmers to check their storage grain weekly beginning in March to protect the previous year's harvested corn (Iowa University, 1997). This only supports that grain storage is a complicated situation, especially because of the fungi activities during storage.

There is a lot of research focused on these fungi activities, including great work done by Magan et al. and Rossella Gregori et al. In 2003 "Post-harvest fungal ecology : Impact of fungal growth and mycotoxin accumulation in stored grain," Naresh Magan et

al. reported that the fungi activities in the post-harvest is a dynamic system. It will destroy the grain and be affected by both biotic and abiotic factors. Magan et al suggests the consideration of the storage system as a small ecosystem (Magan, Hope, Cairns, & Aldred, 2003). Then, in 2013 “Dynamics of fungi and related mycotoxins during cereal storage in silo bags”, Gregori et al. successfully finished an experiment in the real storage environment to support this theory (Gregori et al., 2013). Pereyra et al.’s research also support Magan and Gregori’s results. In their research they found the environment in the upper, middle, lower and borders of silo are different, and the mycotoxins test result are also different in each part, which mean fungi activities also vary by the place of the silo (Pereyra et al., 2008).

Theoretical Background

“Three E” approach

The “Three E” strategy is a common approach to address agricultural safety and health problems, and it is also a common sense approach in this thesis (R. A. Murphy, Aherin, & Westaby, 1992). The “Three E” approach has three main parts: Engineering, Enforcement and Education. These three parts as described by Murphy focused on the different aspects of agricultural safety and health problems and support each other’s purpose.

Engineering Part

The aim of engineering is to eliminate the problem by designing new machines, safe working systems, safety protection equipment, such as a cage on the fixed ladder of grain bins, and personal protection equipment, such as fall protection equipment.

Enforcement Part

Enforcement of rules and regulations is in the hands of the government and similar organizations. It is up to these regulators and officials to make rules and requirements for individuals and companies to follow. An example of a regulation that requires enforcement in order to work as intended can be seen in OSHA 1910.272, standards of grain bin handling.

For general industry, OSHA established standards for the workplace including grain storage facilities. OSHA 1910.272 (OSHA 29 CFR 1910.272, 2015) enforces a rule that requires every employee to wear personal protective equipment (PPE) which could include a body harness, lifeline or a boatswain's chair. The rule 1910.272(g)(3) emphasizes that the worker who is working in the grain bin must have an observer. It is also stated in 1910.272(g)(4) that grain bins need to have equipment for rescue operation. The content of the rule 1910.272(g)(5) is that the employees must be trained of the hazards. While these standards are enforced at commercial grain facilities, they do not apply to family farms. A family farm is a farm that has no more than ten employees. This exemption means that there are employees on smaller farm operations who may not get similar education and training on safe work practices. In addition to OSHA's guidelines and recommendations, the National Institute for Occupational Safety and Health

(NIOSH) published guidelines for safety in confined spaces, such as testing the atmosphere, lockout the energy and wearing respirators. Their guidelines also point out that working in a team is a recommended method for safety (NIOSH, 1994).

Education Part

Education is an essential step to provide safety knowledge and training. The intended population of this education is to farmers, farm workers, and the children and adolescents who are at risk of agricultural hazards. Education can be delivered in a variety of ways. For instance, many land grant universities conduct non-formal courses regarding agricultural safety and health. Agricultural organizations and commodity groups also incorporate safety education into their annual meetings, field days and conferences. Safety DVDs, posters and the Internet are growing areas that can be utilized for resources of farm education.

These three approaches (engineering, education, enforcement) work in tandem to form a theoretical concept for effective injury prevention strategies. A multifaceted approach is stronger than a single approach. An applied example of this concept is given here: Engineering provides information about farm equipment. To operate farm equipment, one needs training and a certain level of knowledge provided by the education component. The enforcement aspect allows the farmers to be regulated by rules and standards set in place by the government and other organizations. Farmers need to follow these rules, and can be punished if not practicing according to regulations. Enforcement is heavily supported by the education component. Education of rules and regulations helps farmers to understand the standards that could be enforced onto them. Employees

and researchers can use aspects of education to help collect information from farmers in order to provide essential feedback to those concerned with engineering and enforcement. Education is a vital aspect of this system, as it is the bridge between farmers and other people and organizations involved in promoting and enforcing safety. Through education, farmers can be provided with valuable knowledge and training about agricultural safety. James D. Westaby et al. designed a structure to introduce the different factors that would influence farmers' thoughts (Bawden et al., 1984; Westaby & Lee, 2003). In their study they identified three factors that could influence the injury rates: safety knowledge, safety consciousness and dangerous risk taking. These three parts could be influenced by education. The authors also emphasize that reeducation is very important to keep the farmer informed and aware of current regulations, rules, and equipment options.

In the "Three E" approach, education plays a key role in this thesis. If we want to provide some knowledge and practice or give some recommendation, the first thing is to collect information from farmers, their thoughts about this problem, and their reaction. In 1984, Richard J. Bawden et al. did a study about the farmers thinking method and what could affect their behaviors, reported in *Systems Thinking and Practices in the Education of Agriculturalists* (Bawden et al., 1984). In the paper, they built a model of farming as a human activity system, which include farming system and environment in two parts. Farmers' behaviors are in the farming system part, which is influenced by environmental factors, such as natural perturbations, socio-economic perturbations, cultural forces and evolutionary forces. They also provided a model of the problem-solving/learning process that included four steps: concrete experiences, observation and reflections, formation of

abstract concepts and generalizations and testing implications of concepts in new situations. The research of Bawden et al. focused on the whole agricultural part. Pamela Dee Elkind's studies focus on the safety aspect of this problem. In correspondence between knowledge, attitudes, and behavior in farm health and safety practices, Pamela Dee Elkind found that just simple education and practice fail to change farmer's behavior, and many farm hazards had technological, political and economic reason. Therefore farmers' decisions and behaviors are complex problems and need more research (Elkind, 1993). The answer to this problem could be found in psychology. In 1957, John W. Atkinson found that when people decide to do something, they consider the motivation, expectancy, and incentive. These factors affected their risk-taking behavior. If they think the motive to achieve is very strong, they are more willing to take the risk. On the other hand, if they focus on safety and avoid the risk, they will prefer the easy and safe task (Atkinson, 1957). There is other research that supports Elkind's conclusion, that some risk behavior will be influenced by the sociality (Frederick X. Gibbons, 1995) and environment (McLain, 1995). In 2007, Pamela Dee Elkind published further research in safety behaviors in agriculture (Elkind, 2007). In this research, they found that information about stressors in occupational, political economy of farming, control the working environment are working together to influence the agricultural injuries and agricultural-related diseases.

James D. Westaby and Barbara C. Lee integrated the previous research and built a new safety model in agricultural health and safety. They published it in "Antecedents of injury among youth in agricultural settings: a longitudinal examination of safety

consciousness, dangerous risks taking, and safety knowledge” in 2003 (Westaby & Lee, 2003). In their new structure, the injury incidence is affected by safety constructs including safety knowledge, safety consciousness, and dangerous risk taking. They also published five factors that could influence safety constructs. The amount of time spent working influences safety knowledge. Participating in safety activities can change both safety knowledge and safety consciousness. Self-esteem may affect safety consciousness and dangerous risk taking. Leadership self-concept has a relationship with safety consciousness. Gender influences safety consciousness and dangerous risk taking. In their study they did two times experiment, and they found that dangerous risk-taking playing an important role in predicting future injuries in this result is supported by Atkinson’s study. The study by James D. Westaby and Barbara C. Lee also pointed out the need for education and reeducation in safety education.

This research helped to build the image about farmers’ safety consciousness and behavior. This thesis looks specifically at Ohio farmers’ behavior and knowledge about grain storage and find the factors that could influence their work. Research from past studies helped shape this study.

Summary

Grain storage facilities are complex environments. There are many hazards and risks in the grain storage facilities. For instance, grain entrapment, grain dust explosion, fall hazard, respiration hazards and hearing loss. On the other hand, grain storage is a necessary process in the grain industry. Grain farmers spend lots of time operating and managing their grain bins or silos. Therefore safety in the grain storage facilities is very

important. To control the hazards and protect farmers, researchers usually use the “three E” approach. In engineering, there are many PPE designed to protect farmers working in grain storage facilities, such as life lines and respirators. For enforcement, OSHA and NIOSH created rules to standardize farmers’ behaviors. Both the Engineering and Enforcement aspects of the “three E” strategy need support of Education. Many researchers focus on the education part. They study farmers’ thoughts and behaviors, and design teaching and practice programs for farmers. There are many problems that need to be discovered and solved, a main reason this thesis focuses on safety in grain storage facilities.

Chapter 3: Methodology

This quantitative study used survey research to collect information from Ohio farmers who use on-farm storage structures for corn and soybeans. The survey also collected information about farm workers, the current storage facilities used in Ohio, as well as the farmer's past three years of storage history.

Participants and Sampling Strategy

All participants in this study were Ohio farmers who stored grain and soybeans on their farms. Data was collected during different agricultural education meetings conducted around Ohio where attendees had an equal chance to take part in the survey. Farmers in attendance were from different Ohio counties. This survey uses two mechanisms for a convenience sample data collection, in person paper survey and online survey.

Paper convenience sample: an exhibit was on display during the education meeting to attract farmers to take part in this survey. Once they completed the survey, farmers were provided with a choice of personal protective equipment including an N95 respirator, gloves, earplugs, or safety glasses.

Online convenience sample: the survey also has an online version. The researchers invited Ohio agricultural educators who focus on grain field to help us send the link to the farmers. Farmers could finish it online.

The online survey had the same content as the paper version.

Instrumentation

A questionnaire was created for this study. The questionnaire included four sections to collect information about a farms' location, employee number, PPE used, storage facilities' type and grain management practices.

The first section examined "General Farm Information". Eleven questions were used in this section to collect demographic information including farms' geographic location, the number of employees, and the workers' age distribution.

The second part was labeled "Health and Safety Aspects of Your Grain Facility". This section contained seven questions about the farmers' knowledge in agricultural safety, their behaviors during work and their preferred method to receive safety education. This section was designed to study the farmers' behaviors and safety knowledge background.

The third section was labeled "Management Practices of your Stored Grain". This part investigated the current situation of out-of-condition grain on their farms in the past 3 years. The questions were focused on corn and soybean storage where the corn part contained eight questions and the soybean part contained nine questions. Technology questions were asked in this section. For instance, "What was your target percentage moisture when you dried your corn?" This part is used to discover the behavior of

farmers during the grain drying and storage process. Simultaneously, this section collects storage information and information about accidents concerning out-of-condition grain in the past 3 years,

The fourth section was “Information About Farmers’ Grain Storage Facilities”. In this section, farmers were asked questions about the type of facilities used to store grain: grain bins, silos, and flat storage. Each facility type had corresponding questions pertaining to that structure. This section collected the information of farmers’ grain storage facilities, and the behavior of their use and maintenance.

A cover letter accompanied the questionnaire. The cover letter included a brief introduction of this program. It also provided information about the researchers, the IRB process, and that participating in the survey was totally voluntary.

Validity

After a review of previous research and census questions that farmers were accustomed to completing, a questionnaire was designed for this study. A panel of two experts reviewed the instruments to establish content validity. The experts were scholars working in agricultural safety and experienced employees in grain storage and management fields. Their advice was used to modify the questionnaire. After content validity was established, six farmers were invited to test the instrument. Their role was to establish face validity.

The Ohio State University Behavioral and Social Science Institutional Review Board (IRB) approved the research and survey instrument. The issued IRB protocol number of the project is 2015E0056.

Data Analysis

SPSS 22 (statistical software) was used to analyze the data. Descriptive statistics were compared and reported. The mainly used is the describe statistic, Student T test.

Correlation analysis.

Chapter 4: Results

Data collection began on March, 2015 and ended on March, 2016. There were 223 farmers who took part in the survey, with 182 of these questionnaires deemed valid and included in the analysis.

Results of General Farm Information

This research was conducted state-wide. Data were collected from 88 counties, with 64 of Ohio's counties included with in the valid questionnaires. Figure 2 shows the location of these 64 counties. The list of the counties' name and the numbers of farmer participants from that county are reported in Table 1. Some farmers operated farmland in several counties. The total acres of farmland ranged from 15 acres to 6,000 acres with the average farm size being 1,171 acres. The distribution of the acres is shown in Figure 3, using acreage size labels similar to those used in the 2012 U.S. Census reports. The predominant farm size (ranging between 500 - 4,999 acres) comprises 72.0% of all surveyed farmers.

County	(n)	County	(n)	County	(n)	County	(n)
Adams	1	Fayette	5	Lucas	3	Preble	2
Allen	3	Franklin	4	Madison	7	Putnam	4
Ashland	2	Fulton	10	Mahoning	7	Richland	1
Ashtabula	2	Greene	1	Marion	4	Ross	16
Auglaize	4	Hancock	5	Medina	2	Scioto	1
Brown	1	Hardin	4	Mercer	4	Seneca	1
Carroll	3	Harrison	2	Miami	2	Shelby	1
Champaign	5	Henry	9	Montgomery	1	Stark	3
Clinton	5	Hocking	2	Morgan	1	Trumbull	4
Columbiana	6	Holmes	2	Morrow	1	Tuscarawas	7
Coshocton	2	Huron	3	Muskingum	1	Union	4
Crawford	2	Jefferson	1	Paulding	1	Van Wert	3
Darke	2	Knox	2	Perry	2	Wayne	3
Defiance	4	Licking	3	Pickaway	35	Williams	4
Delaware	1	Logan	3	Pike	3	Wood	4
Fairfield	21	Lorain	2	Portage	1	Wyandot	4
Adams	1	Fayette	5	Lucas	3	Preble	2
Allen	3	Franklin	4	Madison	7	Putnam	4

Table 1. List of the Counties and the Numbers of Farmers Participants



One or more surveys received in this county.
 No surveys received in this county.

Figure 2. Geographic Location by County

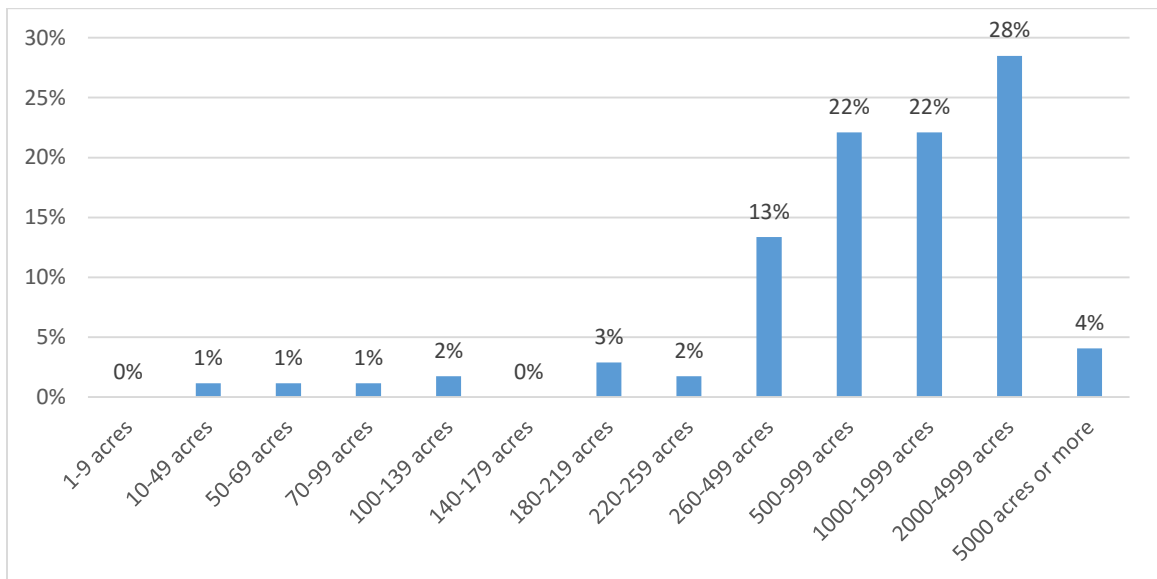


Figure 3. Distribution of Acres on Ohio Farms

Workers' Situation

These farms reported a total of 710 workers having grain-handling responsibilities. The number of workers per farm ranged from 1-12 employees, with an average number of four workers (Figure 4). The age distribution of the 720 total workers were divided into four broad categories: seven workers were 13 years old or under (1.0%), 72 workers were aged 14 – 19 years old (10.0%), 553 workers were 20 – 64 years old (76.8%), and 88 workers were 65 years and older (12.2%). The difference of the total amount of workers, (710 versus 720) can be attributed to farmer response errors.

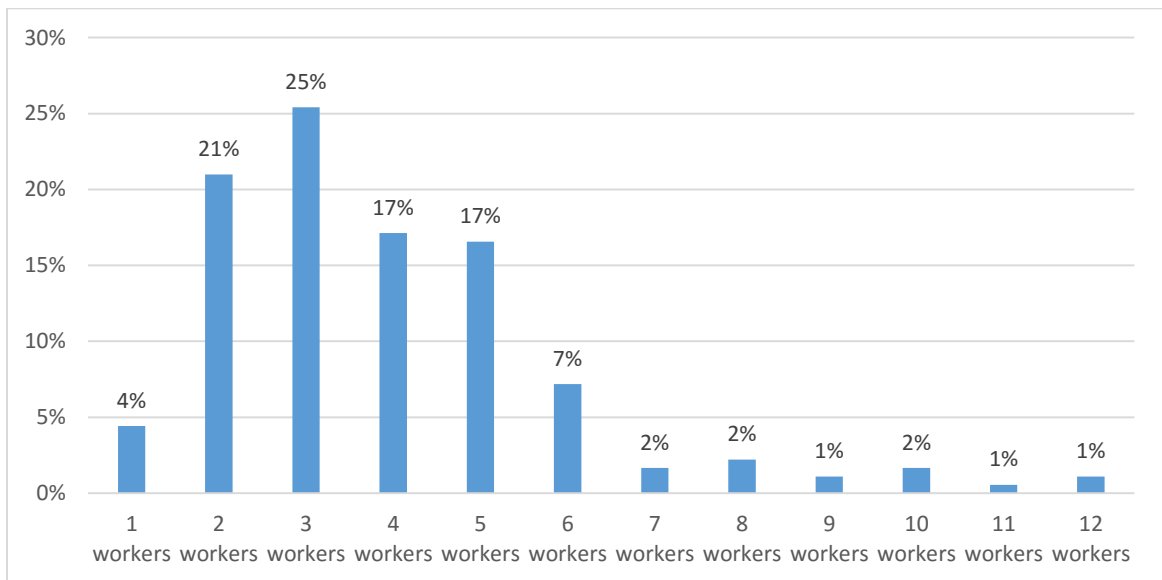


Figure 4. Distribution of Number of Workers on Each Farm

The types of work performed by the farm workers is reported in Table 2. Farmers were asked to classify their work activities as: grain harvest tasks, grain transport responsibilities, grain storage-related duties, and grain facility cleaning tasks.

Two workers in the 13 years and under age group were responsible for cleaning the grain facility, the other five workers' held jobs that were not identified or not applicable to grain harvest. The 51 workers in the 14 – 19 year old age group were reported to also clean the facilities (70.8%), as well as grain transport (31.9%). Thirty-four of the teen workers had tasks associated in the grain storage area (47.2%), and forty-one youth helped with harvest activities (56.9%). Twelve of the teen workers were reported to perform all four types of work.

Age Group of Workers	Grain Harvest	Grain Transport	Grain Storage-Related	Grain Facility Cleaning	Not Applicable
13 and under (n=7)	0	0	0	2	5
14-19 (n=72)	41	23	34	51	2
20-64 (n=553)	539	505	525	483	0
65 and over (n=88)	70	64	58	42	1

Table 2. Worker Responsibilities by Age Group

The majority (81.6%) of workers aged 20 – 64 years old were reported to perform all four types of work. Nearly all (97.5%) worked with grain harvesting activities, and

94.9% worked with storage-related activities, and 87.3% cleaning the facilities. There were 91.3% of the workers who transported grain to market.

Of the 88 workers in the 65 years and older group, approximately 80% worked in grain harvest, 73% worked grain transport and 66% worked on grain storage. Over 47% of the farmers in this age group cleaned grain facilities and 41% took part in all types of work.

From these preliminary results there were no farms surveyed having more than 12 workers. Three farms (1.7%) had 11 or more employees. According to the U.S. Department of Labor, farms with 10 or fewer employees fall under the small farm exemption and would not be required to follow OSHA standards.

Results of Health and Safety Aspects of Farmers

In this section, information about safety knowledge and behavior of farmers was collected. Table 3 shows the farmers' knowledge about the health effects of out-of-condition grain and the risks of entering a bin with grain in this condition. For the most part, 82% of farmers had knowledge about the health effects of out-of-condition grain. Nearly 84% of these farmers also reported knowledge of the safety risks of entering a bin that contained out-of-condition grain.

For analysis, the researchers designed the score from "know nothing" to "know everything," represented by a numerical scale of 0 to 100. Farmers' average score in the health effects of out-of-condition grain was 53.8. Their average score in the safety risks of entering a bin with out-of-condition grain was 59.2. A *t*-test was performed and these results suggested that the two average scores had a significant difference ($p=0.016$).

Therefore, farmers know more information about safety risk than the health effects of out-of-condition grain.

Reported knowledge level (n=183)	Know nothing (0)	Know a little (25)	Know somewhat (50)	Know a lot (75)	Know everything (100)	Have some reported knowledge *
The health effects of out-of-condition grain	7	26	82	66	2	150
The safety risks of entering a bin with out-of-condition grain	7	22	53	96	5	154

* Column represents data combined from three cells: Knows somewhat, Knows a lot, and Knows everything.

Table 3. Farmers' Self-Reported Knowledge of Out-of-condition Grain

Information about PPE worn by the farmers and where farmers purchase their PPE are presented in Figures 5 and 6. The top five PPE items worn by farmers were dust masks, gloves, hearing protection, N95 respirators and safety glasses. The least worn PPE included life line, full mask respirator and a hard hat. Seven farmers indicated they used a towel or cloth to cover their nose and mouth, and six farmers reported no PPE use at all when working around grain storage facilities. A total of 91.8% farmers reported wearing some combination of respiratory protection while working. These items included: a dust mask, an N95 mask, or a full mask respirator. Farmers preferred to buy their PPE from

local farm stores (50.3%), hardware stores (32.2%) safety companies (29.5%) and the Internet (20.2%).

Safe work related behaviors are reported in Figure 7. The top three practices were: wear PPE (72.1%), work in a group (63.4%), and turn off power (58.5%).

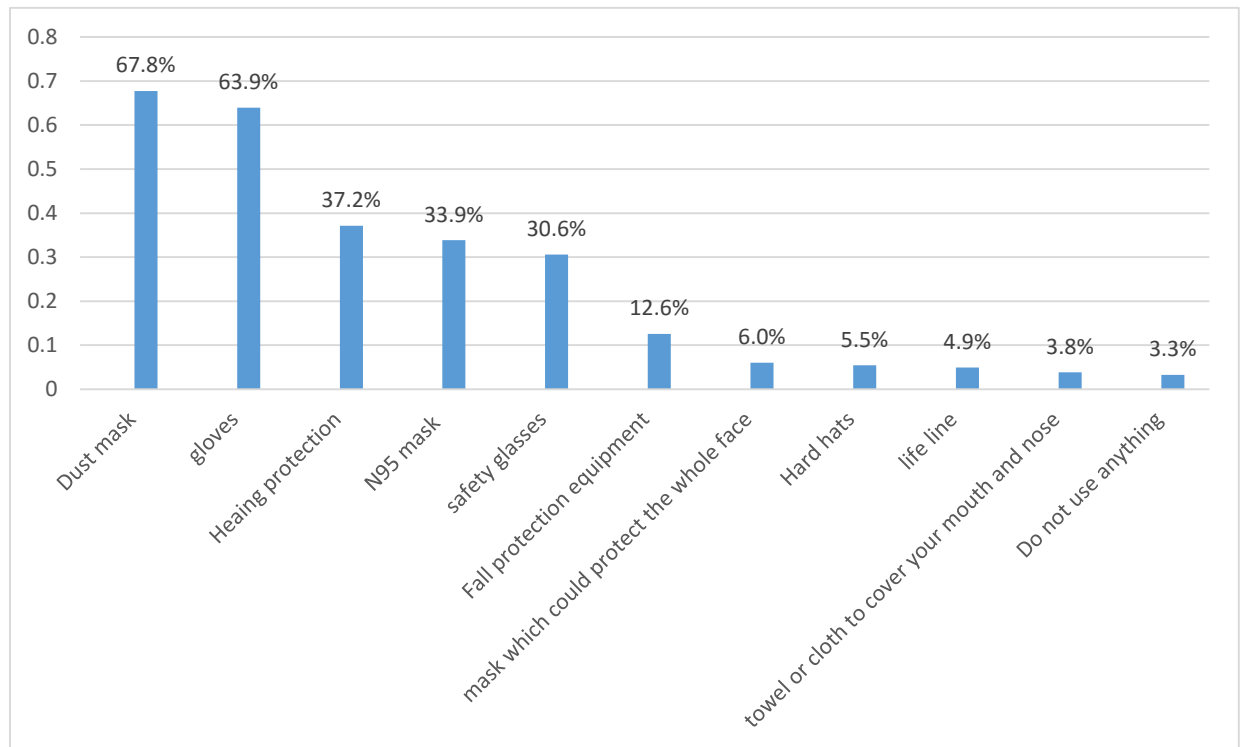


Figure 5. PPE Worn by Farmers

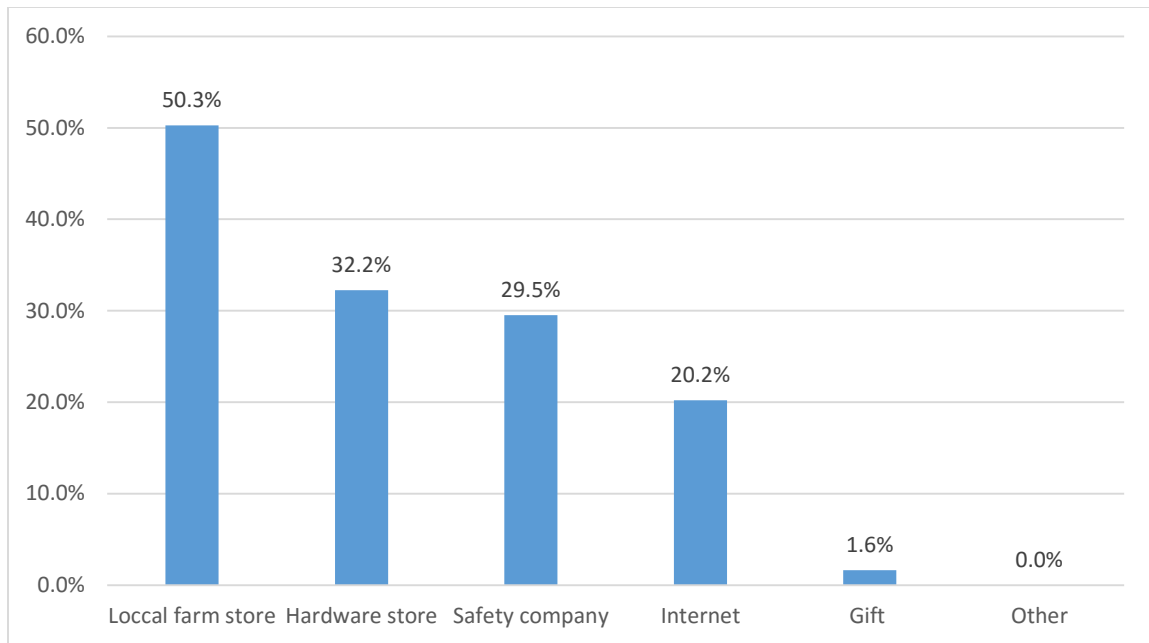


Figure 6. Where Farmers Get Their PPE

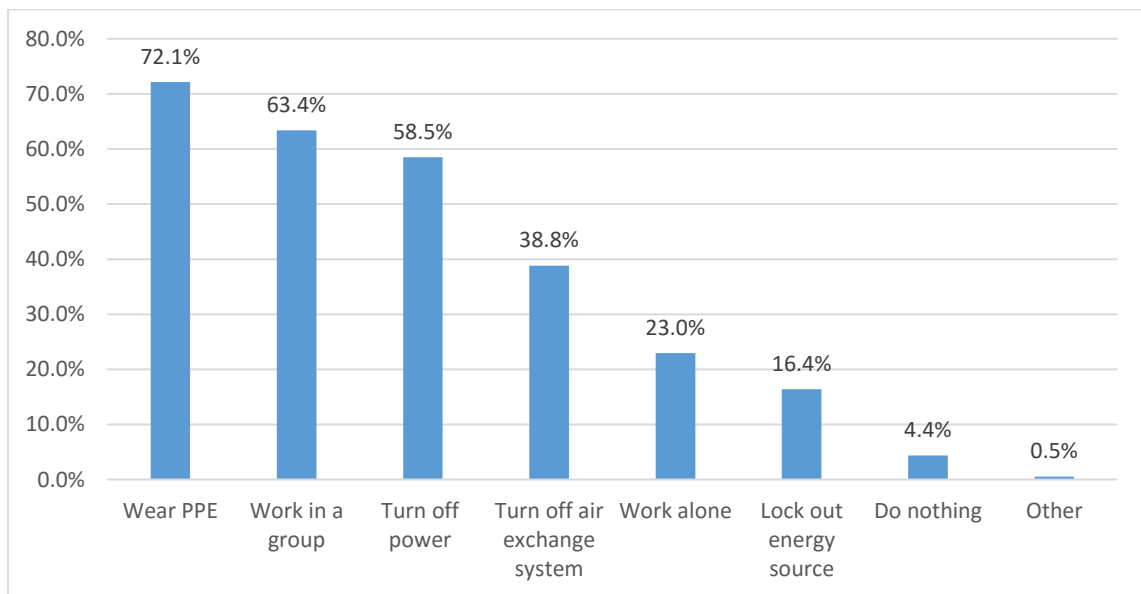


Figure 7. Safety Behaviors When Working around Grain Storage Facilities

An analysis of the correlation was performed to investigate the relationship of farmers' knowledge in safety and health risk of out-of-condition grain with the PPE they chose for work, and their safety behavior. The results are presented in Appendix B: Correlation Matrix. From the correlation analysis, the highest positive correlation (0.792) is between the knowledge of health risk and safety risk of out-of-condition grain. This indicates farmers who have good knowledge in health risk of out-of-condition grain also know the safety risks when they enter a grain bin with poor quality grain.

Focusing on the knowledge of health risk and the PPE chosen, fall protection equipment had the highest positive correlation (0.245) with farmers' health risk knowledge. Negative correlations appeared when compared with the towel or cloth to cover mouth method (-0.005) and when farmers self-reported they did not use anything method of protection (-0.143). The other kinds of PPE had positive correlations with the health risk knowledge such as an N95 mask (0.191), safety glasses (0.153), gloves (0.161), and hard hats (0.128). The correlation of dust mask, hearing protection, and full mask respirator were positive, but less than 0.1. This is interpreted to mean that health risk knowledge enables farmers to know what PPE to wear. The specific PPE includes: fall protection equipment, N95 masks, safety glasses, gloves and hard hats. However the knowledge did not determine what kinds PPE should be used. Moreover, 91.8% farmers wore respirators, even though they did not have high level of knowledge of health risks. Dust masks had a negative correlation (-0.566) with the N95 mask, meaning farmers usually chose one of them.

For farmers' safety behavior, wearing PPE had highest positive correlation (0.356) with safety risk knowledge. Working in a group had a correlation of 0.192 when compared to safety risk knowledge. A negative correlation was detected with the variables of: working alone (-0.182) and doing nothing about safety (-0.338). This suggests the farmers' knowledge about the safety risk of out-of-condition reflected on their PPE using behaviors and decisions to work in a team. All correlation matrix tables can be found in Appendix B.

Figure 8 represents the different methods in which farmers obtain safety knowledge. The top three ways farmers reported how they received information was from a magazine/periodical (60.1%), a course or seminar (50.8%), or an equipment operation handbook (43.2%). Farmers also reported their preferred education methods. These included: taking a course or seminar (53.6%), reading a magazine/periodical (38.8%), and the Internet (38.3%). Figure 9 compares the information between these two questions. The results show that a course or seminar and magazine/periodical were widely used and preferred educational methods. An interesting note to highlight from this data is that while the Internet was the 8th most used education method, it was ranked 3rd for farmer preference in how they would like to learn.

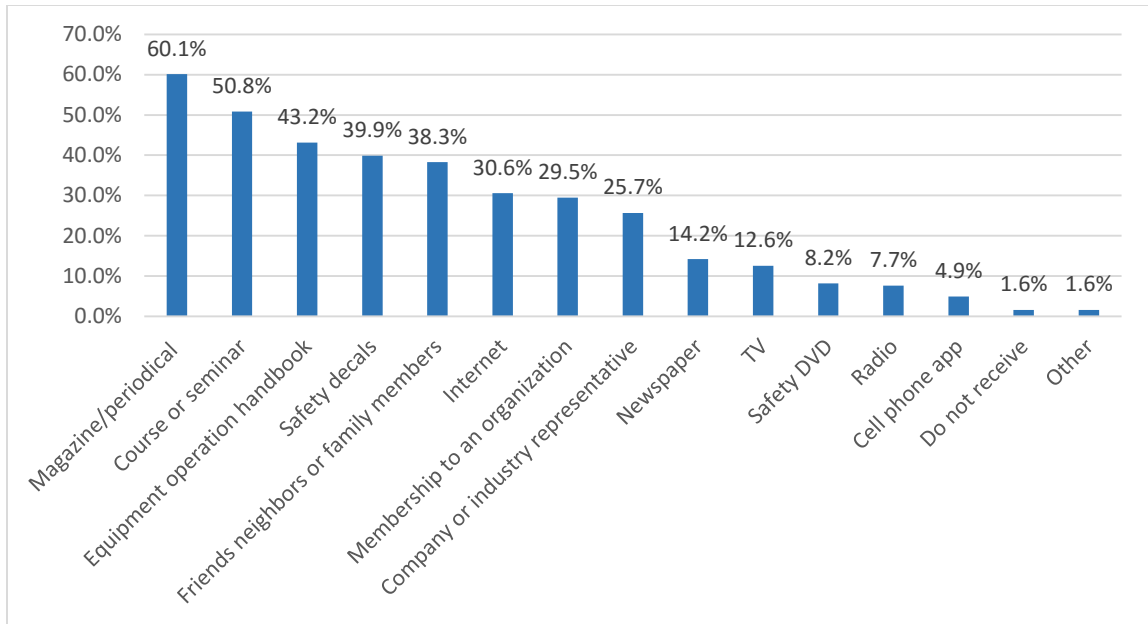


Figure 8. Where Farmers Get Their Safety Information

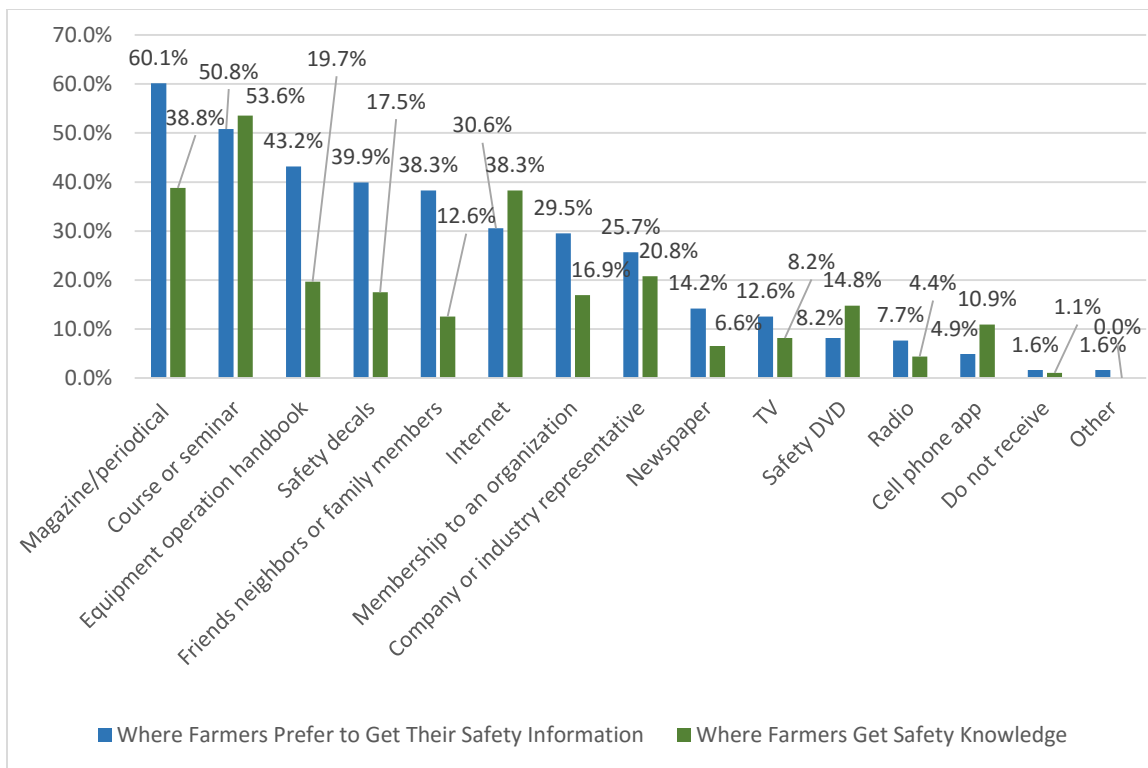


Figure 9. Where Farmers Prefer to Get Their Safety Information

Results of Management Practices of Stored Grain

This section contains self-reported data about farmers' grain storage practices during the years 2012 – 2015. From the 182 valid surveys, it was found that 155 farmers reported storing corn, 108 farmers stored soybeans, and 104 of these farmers stored both corn and soybeans on their farm.

Corn

The questionnaire collected information about farmers' on-farm storage practices for a three-year period of 2012 – 2014 or 2013 – 2015, depending on the time of year participants received the survey. It was important to maintain a three-year time period for reporting purposes, even though some farmers were reporting for different years. Table 4 combines this data for the reporting range of the 2012 to 2015. Regardless of the year, more than 60% of farmers start storing their corn in October, and the average storage period is six months. Collectively from this cohort of survey participants, farmers stored more than 7,000 bushels (bu) of corn on their farms. The most popular storage facilities used by farmers was the grain bin. About 98% of farmers reported using grain bins for on-farm storage of their corn, leaving 2% using other storage types (silos and flat storage). There were 80% who reported only using grain bins as their on-farm storage system.

Before placing corn in storage, the farmers need to dry down their grain for quality management purposes. The average target moisture content selected by the farmers was 14.8%, with the mode target being 15% moisture content. More than 70% of farmers reported confidence on their drying process.

Farmers reported reasons for adjusting their target moisture content. Figure 10 depicts the reasons farmers changed their drying target percent. These reasons included: amount of time pressures (45.1%) and market values (23.0%). In the “other” category, three farmers reported that they did not consider changing the moisture levels; one farmer said that target moisture should not change. Yet another farmer said that it depended on the harvest moisture. A livestock farmer said it depended on quality of livestock feed he was mixing. Although these farmers reported drying their grain to 13% or under, they still encountered out-of-condition grain.

	2012 corn storage	2013 corn storage	2014 corn storage	2015 corn storage
Start month				
Sep	26.2%	19.9%	21.4%	29.2%
Oct	61.5%	68.9%	67.5%	67.4%
Nov	12.3%	11.3%	10.4%	3.4%
Dec			0.6%	
Average months of storage	5.51 month	5.98 month	6.17 month	6.58 month
Amount of corn stored	72106 bu	84664 bu	82635 bu	78617 bu
Storage method				
Grain bin	96.7%	98%	98%	98.9%
Grain bin only	80.3%	84.5%	83.3%	91.0%
Silo	8.2%	6.8%	8.7%	3.3%
Silo only	3.3%	2.1%	2.0%	1.1%
Flat storage	4.9%	4.1%	2.7%	3.3%
Target moisture percentage				
Mean	14.8%	14.8%	14.8%	14.8%
Mode	15%	15%	15%	15%
Farmer's confidence to reach target moisture percent				
No confidence	1.6%	1.4%	0.7%	1.1%
Somewhat confident	23.0%	28.4%	28.2%	24.4%
Very confident	75.4%	70.3%	71.1%	74.4%

Table 4. Storage Situation of Corn from 2012 to 2015

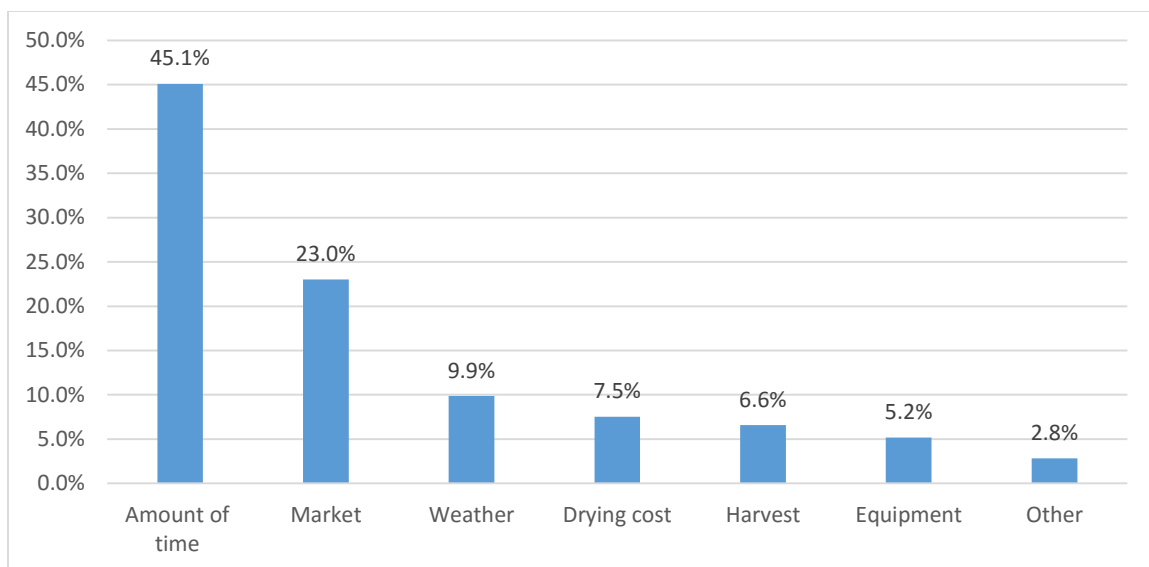


Figure 10. The Reason Farmers Change Their Target Moisture Content of Corn

The incidences of out-of-condition grain are shown in Figure 11. In 2015, the percentage of “no incidents” was 91%, but the data collection stopped in March 2016 with a large amount of corn remaining in storage. The majority of bins (70%) reported no problems with out-of-condition grain in 2012 to 2014.

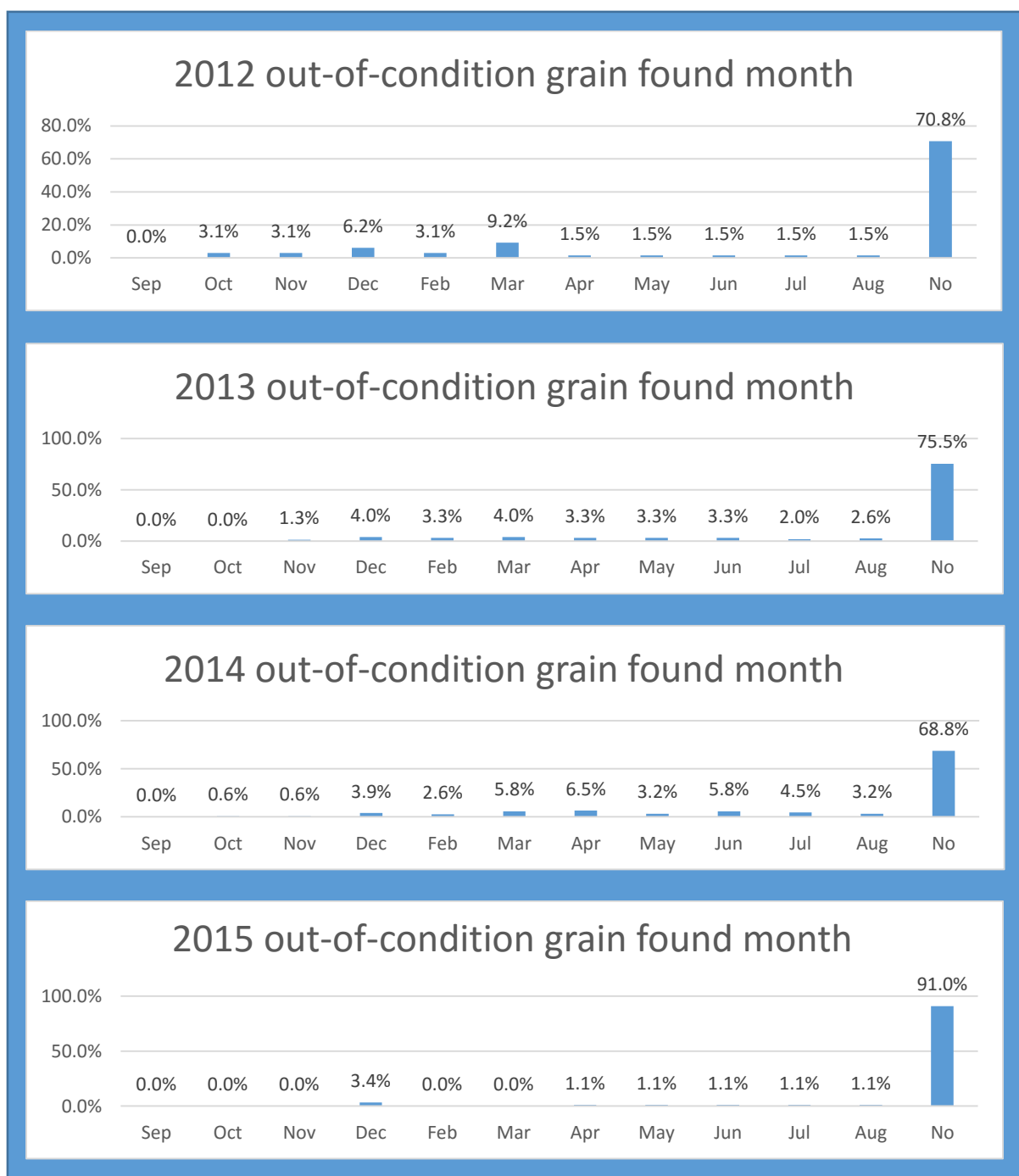


Figure 11. The Incidence of Out-of-Condition Grain, Found by Month, from 2012 to 2015 in Corn Storage

Soybeans

As with the corn, survey questions inquired of on-farm storage of soybeans from 2012 to 2015. Table 5 reports the farmers' three-year storage history of soybeans.

Farmers began to store their soybeans in the months of September and October, and reported storing the beans for approximately 6.5 months. Grain bins were the preferred on-farm storage system used by farmers, with 93% using grain bins exclusively for soybean storage. There were 97% of the farmers reporting a combination of grain bin, silo, and flat storage systems, whereby the percentage that used silos were less than 10%, and flat storages less than 5%. The average drying percentage of soybeans was reported at 13.2% with the mode response of 13.0%. Nearly all farmers had confidence of their drying process.

	2012 soybean storage	2013 soybean storage	2014 soybean storage	2015 soybean storage
Start month				
Sep	50.0%	53.8%	47.7%	79.7%
Oct	45.0%	42.3%	43.9%	20.3%
Nov	5.0%	2.9%	2.8%	
Dec				
Average months of storage	6.2 month	6.5 month	6.5 month	6.8 month
Amount of corn stored	31530 bu	27562 bu	29022 bu	25653 bu
Storage method				
Grain bin	97.3%	97.0%	98.0%	96.9%
Grain bin only	91.9%	93.0%	93.0%	93.8%
Silo	8.1%	7.0%	6.0%	3.1%
Silo only	2.7%	3.0%	2.0%	3.1%
Flat storage	2.7%	2.0%	2.0%	3.1%
Target moisture percentage				
Mean	13.42%	13.19%	13.19%	13.0%
Mode	13%	13%	13%	13%
Farmer's confidence to reach target moisture percent				
No confidence	2.4%	0.0%	0.0%	0.0%
Somewhat confident	48.8%	33.3%	64.0%	25.4%
Very confident	48.8%	66.7%	36.0%	74.6%

Table 5. Storage Situation of Soybeans from 2012 to 2015

Figure 12 depicts the reason farmers' changed the soybeans' target moisture content. The weather and time pressures were the top two reasons farmers cited as reasons to change their moisture content. In the "other" category, farmers responded: never considered changing their target moisture content of soybeans, and target moisture content depended on harvest moisture content of the grain.

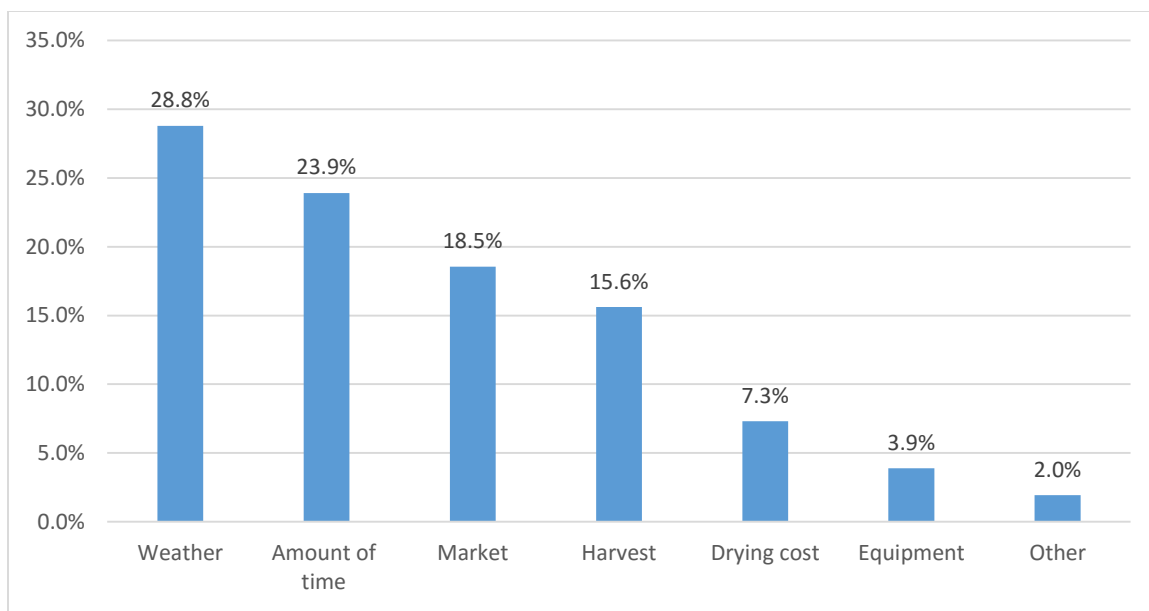


Figure 12. The Reason that Farmers Change Target Moisture of Soybeans

Figure 13 shows the incidence of out-of-condition grain occurring to soybeans in storage. For the most part, farmers did not report grain quality problems for soybeans, reporting less than 10% of their bins having out-of-condition grain in any given year. The months of September and October did not have any occurrences of poor quality grain detected.

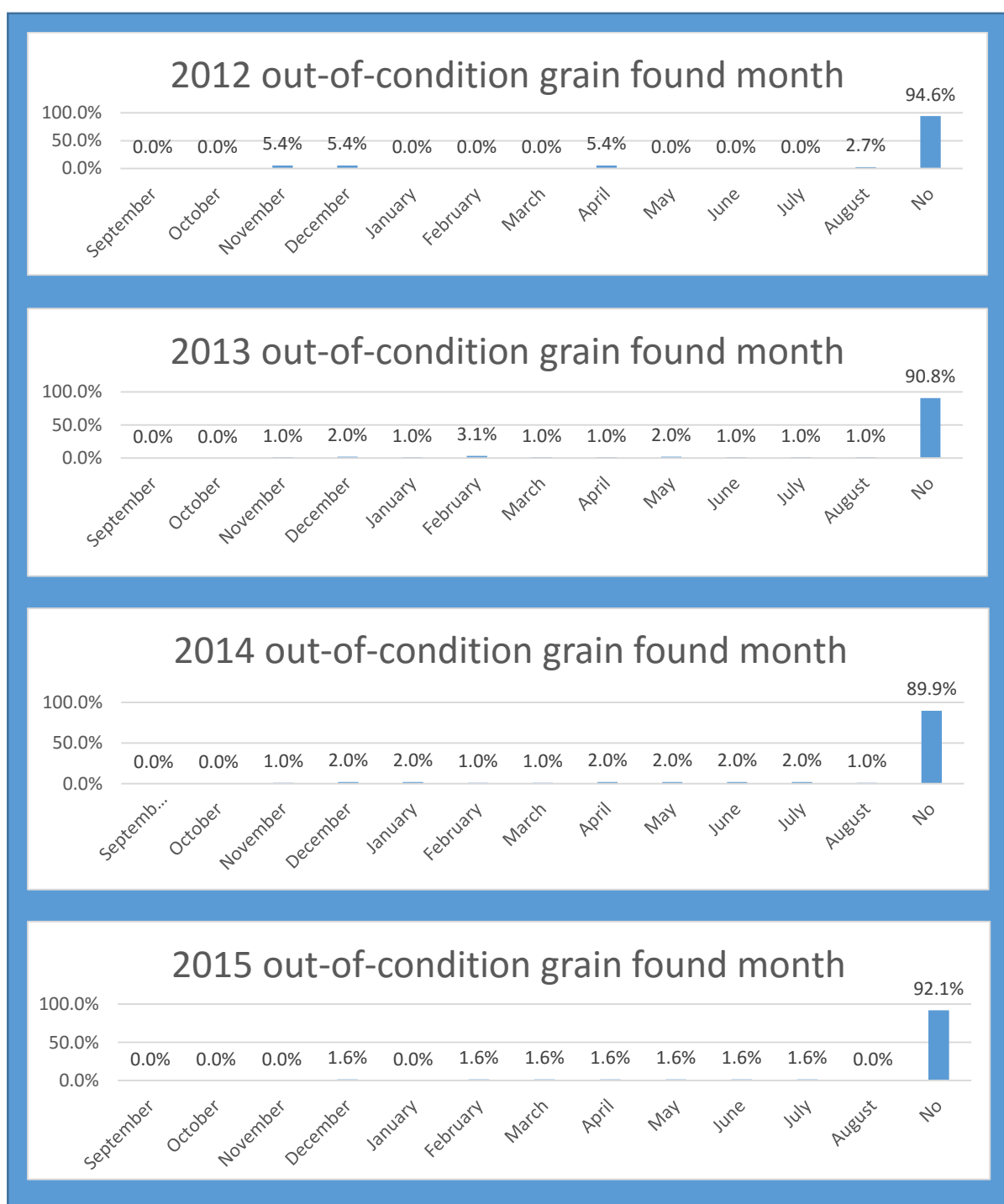


Figure 13. The Incidence of Out-of-Condition Grain, Found by Month, from 2012 to 2015 in Soybeans Storage

Comparing Corn and Soybeans Storage Situations

Farmers usually store corn beginning in October, and soybeans storage begins in September and October. The storage period of both grains are approximately six months. Corn is stored on the farm nearly two times more than that of soybeans being stored on the farm. The preferred on-farm grain storage facility for both crops is the grain bin. Farmers typically dry their corn to about 15% moisture and soybeans to 13% moisture content. Farmers reported a stronger confidence level for drying corn than drying soybeans. The primary reasons for farmers to change the target moisture content in both crops were based on the market, weather forecast conditions, and the burden of time pressures. The results also showed that corn storage encountered more out-of-condition grain reports than soybeans.

The data were analyzed by Student *t*-tests and correlation analysis. Because corn and soybeans harvested in 2015 were still in storage, the analysis was only calculated for the years 2012 to 2014. The results of the Student *t*-test was that the average target moisture chosen by farmers and the probability of encountering no out-of-condition grain had significant differences. The target moisture of corn was significantly higher than soybeans ($p=0.002$), and the probability of encountering no out-of-condition corn was significantly lower than soybeans ($p=0.002$). This can be interpreted that corn is more likely to go out-of-condition than soybeans during their storage time period. The results of the correlation analysis showed a correlation between the average target moisture level and the probability of encountering no out-of-condition grain was -0.953.

Result of Information about Grain Storage Facilities

Grain storage facilities are integral components of the grain industry. In this research, researchers focused on three kinds of facilities: grain bins, silos and flat storages. Data collected from 182 farmer participants found 156 farmers provided grain bin information, sixteen farmers reported they had silos on their farms, and seven farmers used flat storage areas. Having an understanding of the types of facilities and their associated drying systems may be important towards the overall safety and health practices of farmers.

Grain Bin

Of those 156 farmers who utilized grain bins, information was provided on a collective number of 1,071 bins. With reference to Figure 14, farmers typically operated no more than eight grain bins with the average age being 27 years old. The average capacity was reported as 49,000 bushels. In these grain bins, 75.2% were storage bins, and 23.5% were drying bins. The remaining 1.4% were included as “other kinds” which were predominately classified as wet bins. Grain bins had a fan system to control the environmental condition in the structure. Most bins (77.5%) had an up draft fan, and 5.6% grain bins were equipped with a draw draft fan. Farmers reported 16.9% of their bins had an in-bin dryer.

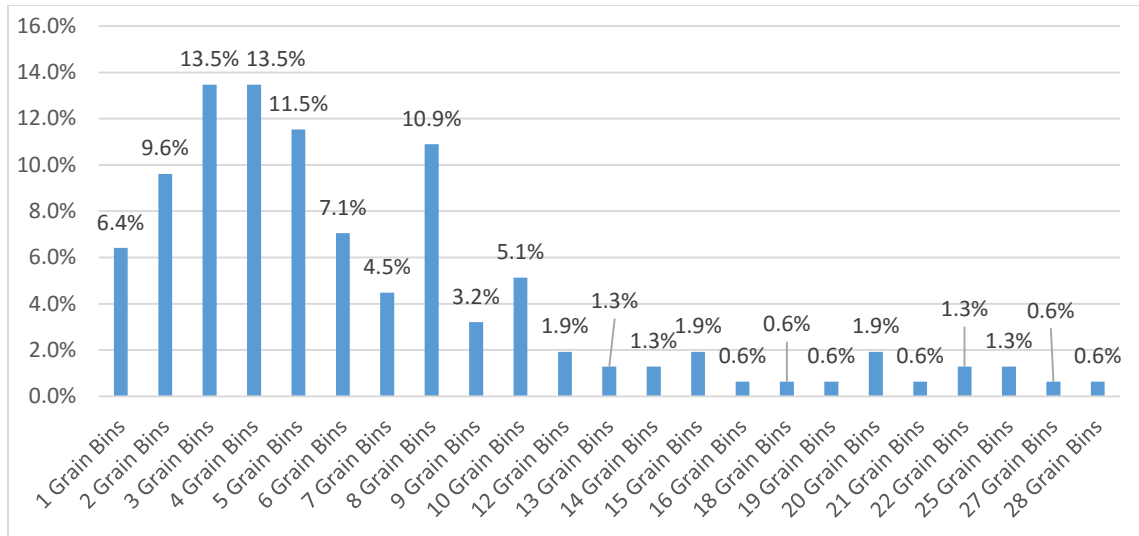


Figure 14. The Distribution of Grain Bins Managed by Farmers

The survey questionnaire inquired about how farmers managed the drying systems of their grain bins. Figure 15 represents how farmers used their aeration systems within their bins. Most (84.6%) of farmers used their fan system depending on the external weather. Another 26.9% farmers used their fan based on weather conditions as well as with a systematic approach. A group of 5.8% of the farmers reported running their fans continuously; while 3.2% did not know how and when to use their fan system or reported they did not use it at all.

When asked about their bin cleaning practices, 87.2% of the farmers preferred to clean their grain bins at least once a year (Figure 16). The method used for cleaning the bins is reported in Figure 17, and includes using a sweep auger (82.7%) and a hand shovel (80.8%). In the “other” kind of cleaning method, farmers reported they use shop vacuums, leaf blowers, and brooms. One farmer reported his/her grain bins were in use the entire season and there was no time to clean these bins.

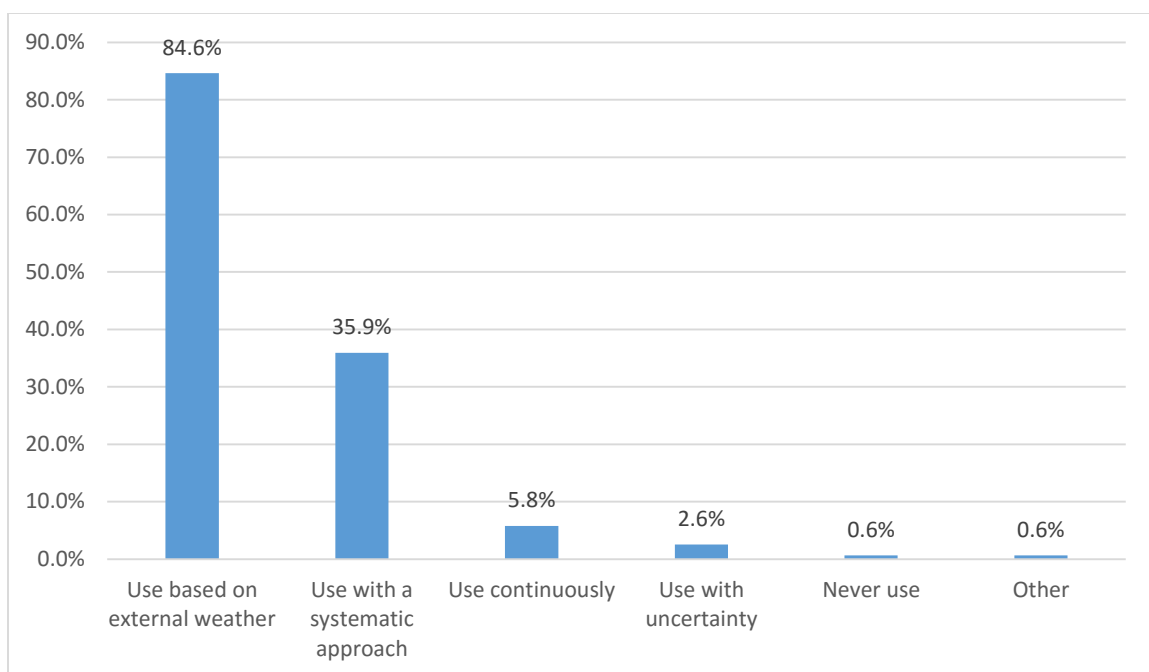


Figure 15. How Farmers Used Their Fan Systems

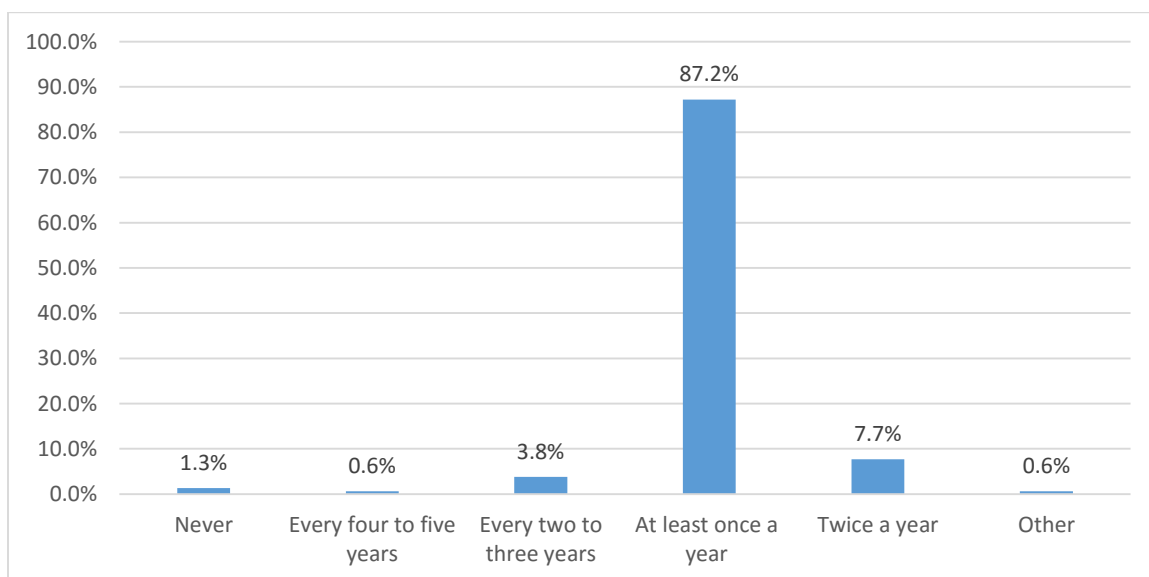


Figure 16. The Frequency Farmers Cleaned Their Grain Bins

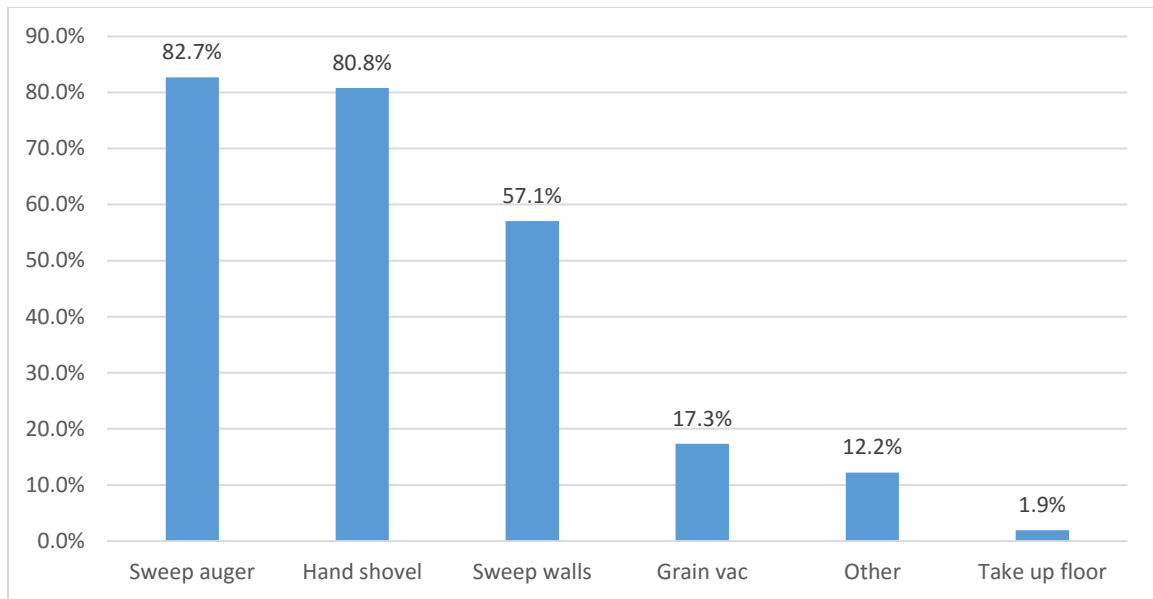


Figure 17. The Method Farmers Used to Clean Their Grain Bins

Figure 18 shows the distribution of occurrences when farmers found out-of-condition grain in the grain bins' history of use. About half (48.7%) of farmers in this research encountered out-of-condition grain. Except for during the harvest and early storage months of September, October, and November, these incidents happened in every month of the year, at a rate of 10%. In this research 76 (48.7%) of farmers reported incidences in the history of the grain bin with out-of-condition grain. Of these farmers, 36 reported just a one-time problem with the grain quality for 62 bins. The average age of these bins was 18 years old, with a capacity of 21,000 bushels. Thirty-one farmers reported that out-of-condition grain occurred more than one time in 96 different grain bins. The average age of these bins was 27 years old, with a capacity of 18,000 bushels. An additional fifteen farmers reported having various combinations of out-of-condition grain occurring in one time to several times within their bins' history.

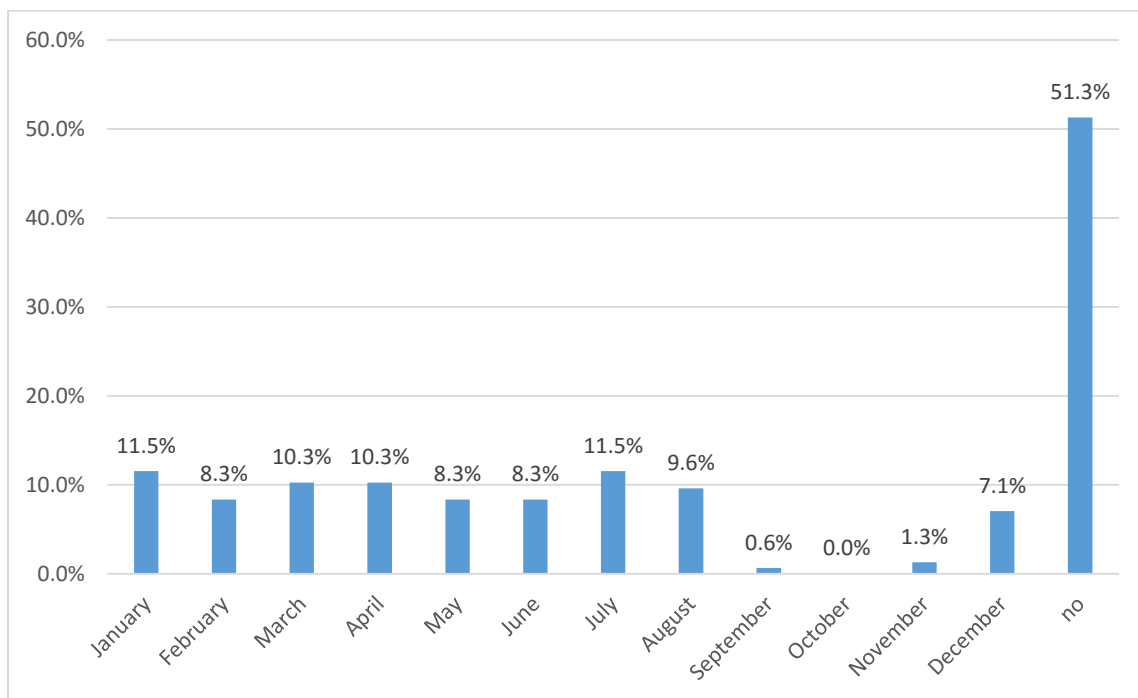


Figure 18. The Incidence of Out-of-Condition Grain Occurring in the Grain Bins' History

Silos

In the results, sixteen farmers utilized a total of 37 silos for grain storage. The average age of the silos was 34 years old and their average capacity was 20,000 bushels. These 37 silos were reported as: harvest silos (55.3%), stave silos (28.9%), and concrete silos (15.8%). Thirteen of the sixteen farmers (81.3%) reported cleaning their silos at least once a year. One farmer cleaned his/her silos twice a year, and there were two farmers who did not clean their silos at all. When they did clean the silos, 37.2% of farmers took up the floor to clean them. Farmers also used hand shovels, grain vacuums, brooms, and sweep augers; they also swept the silo walls (Figure 19).

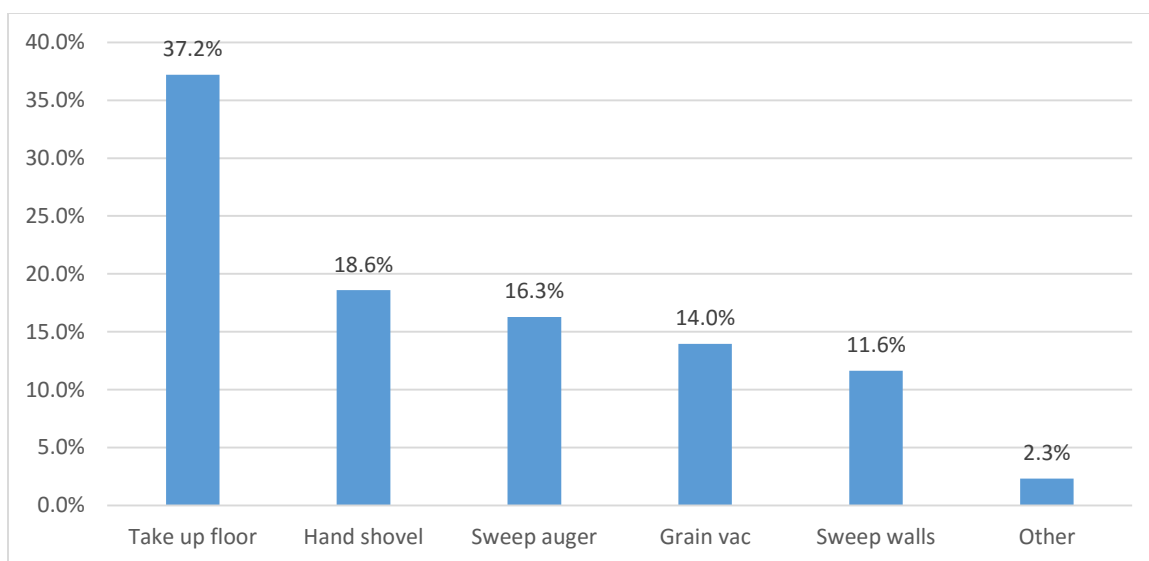


Figure 19. The Method Farmers Use to Clean Their Silos

Silos also had the problem of out-of-condition grain. Two farmers reported that five of their silos had out-of-condition grain at one time in the history of using the silo. Another farmer reported that one of the silos had out-of-condition grain more than one time. The majority of silos (66.7%) had no reported incidents of out-of-condition grain.

Flat Storage

Of the 182 valid questionnaires, only seven farmers used flat storage areas as on-farm grain storage systems. They collectively reported on 21 flat storage areas with the average age of 35 years old, and having the capacity of 9,000 bushels. Farmers reported cleaning their flat storages one or twice a year. The methods commonly used to clean these areas are shown in Figure 20. Only one farmer reported out-of-condition grain in a flat storage area. These areas reported no occurrences of out-of-condition grain in 71.4% of the time.

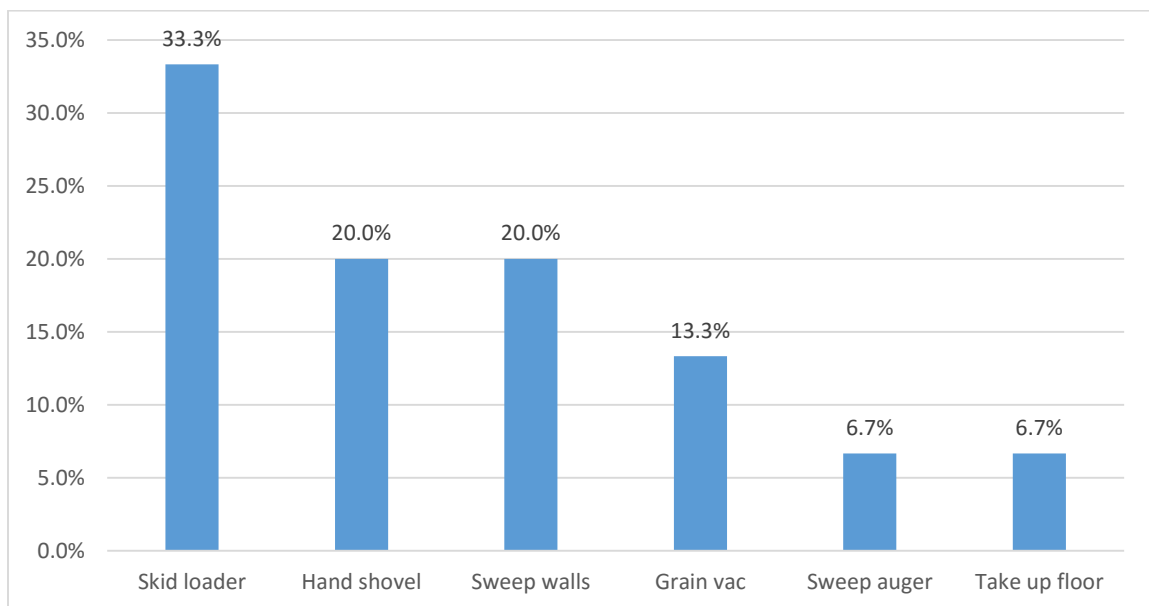


Figure 20. The Method Used to Clean Flat Storages

Chapter 5: Conclusion and Discussion

General Farm Information

This thesis is a state wide research project. The data was collected over the course of one year when farmers participated in selected safety educational events conducted by OSU Extension educators. Using this convenient sample, farmers in 64 of Ohio's 88 counties were represented. In this sample, farmland size was reported from fifteen (15) acres to several thousand (6,000) acres. The average size farm in this sample was 1,171 acres, with nearly 76% of the farms being larger than 500 acres.

Most of the farms were family farms with an average workforces of four workers. Only 1.7% farms had more than ten employees. Per Department of Labor statute, family farms are not supervised by OSHA, nor are they required to follow OSHA standards. However OSHA's safety training and standards could be useful recommendations for the family farm. It is the belief of the researchers that family farms could take part in OSHA's training, and follow their standards to ensure safe working conditions for all persons employed and part of the family.

The main workforce age ranged between the ages of 20 - 64 years old. These workers performed all types of work, all requiring different work-related technology skills, experience, and knowledge. There were teen workers and senior workers also

reported on these farms. Seven children, ages thirteen years or under, were also reported to do work on the farm. Two of these children cleaned the grain facilities and five performed duties that were not applicable to grain storage or handling. It is important for researchers and outreach educators to note this fact so they can help focus training programs on different target audience groups, as well as specific tasks for each job description. The literature base acknowledges work around grain storage facilities provide for many risks. It is heavily discouraged that children be permitted to work in these areas.

In agricultural safety and health, children are a special group in that they may live and work on farms. In 2012, an estimated 995,000 youth (under 20 years old) resided on the farm and about half of them (472,000) worked on the farm (NIOSH, 2016b). In 2009, a total of 15,876 youth encountered injuries on the farm, and the rate of these injuries was 7.5 per every 1,000 household youth (Hard, Allen & Robison, 2011). From 1995 to 2002, 113 youth under 20 years old died annually from farm-related injuries, and 66% of these incidences happened to youth under 16 years old (NIOSH, 2016b).

Dennis Murphy's 2006 publication "Children and Safety on the Farm" reported that farmers should maintain safety zones around farm structures that are especially dangerous for children, such as silos and grain bins. And for the youth in the age group of 14 to 18 years old, Murphy recommends training and education before the teens operate tractors and augers (which are usually connected with grain storage chores). Murphy goes on to say, these students should have constant supervision. Therefore, allowing children to work in or around grain storage facilities is very dangerous and should be discouraged.

Health and Safety Aspects of Farmers

A reported 82% of farmers said they knew about health effects of out-of-condition grain. When they were asked about the safety risks of entering a bin with out-of-condition grain, 84% reported knowledge of the risks. The farmers slightly reported more knowledge in understanding the safety risks than in those associated with health risks. And these two kinds of knowledge showed a strong positive correlation with each other, meaning the better their safety risk knowledge, the better their knowledge for health risks. Results also showed that unsafe behaviors, such as not using any PPE, working alone, and doing nothing in safety had a negative correlation with farmers' knowledge. Fall protection equipment, N95 masks, and working in a group had higher positive correlations than any other PPE type or working behaviors, although not a significantly strong association.

When farmers used PPE, the two most common items selected were dust masks and gloves. And of the 91.8% of farmers who reported using respirator protection, the items they selected included dust masks, N95 masks, or full mask respirators. The negative correlation between N95 masks and dust masks (-0.566) suggests that farmers will just choose one of these protective measures. While this may represent a possible reporting error in what farmers report using, it may also be highlighting the fact that farmers do not distinguish between dust masks and N95 masks. Many extension programs recommend that farmers working in the grain storage facilities need to wear a N95 mask for the best protection from grain dust (eXtension, 2016; Penn State Extension, 2016). And the N95 masks choice showed a 0.191 correlation with farmers' health risk

knowledge. It is possible that including additional education opportunities for farmers to know the difference in protection values of these masks would lead to more selection of the N95.

The difference between N95 mask and a single strapped dust mask is essential to note. “A dust mask or a filtering facepiece is a negative pressure particulate respirator with a filter as an integral part of the facepiece or with the entire facepiece composed of the filtering medium” (OSHA, 2016a). “An N95 respirator is an air-purifying negative pressure respirator equipped with an N95 filter. If the filter is an integral part of the facepiece, or the entire facepiece composed of the filtering medium, the respirator is also considered a filtering facepiece respirator” (OSHA, 2016f). An N95 mask could be considered as a kind of dust mask that is also considered a particulate respirators (OSHA, 2016c). An N95 mask is under NIOSH standard 42 CFR part 84. NIOSH certifies three classes of filters, N-, R-, and P-series, with three levels of filter efficiency, 95%, 99%, and 99.97%, in each class. All filter tests employ the most penetrating aerosol size, 0.3 μm aerodynamic mass median diameter. The N-series has been tested against a mildly degrading aerosol of sodium chloride (NaCl). The R- and P-series filters have been tested against a highly degrading aerosol of dioctylphthalate (DOP). N95, N97 and N100 have 200 mg filter loading (NIOSH, 2016a).

Therefore when farmers choose respirators to protect themselves, they should choose at least N95 mask, noting that the N99 and N100 are even better choices. It is important for farmers to note the 200 mg filter loading capacity of the N- series mask, and change

their PPE when it is overloaded. However, it is not stated the length of time it takes for an N series mask to reach its maximum load capacity. More research is needed in this area.

With regards to the dust mask, NIOSH does not recommend its use in high organic dust environments. Grain dust is predominately organic material, and has potential to cause great harm to the human respiratory system. Therefore, dust masks without the minimum N95 rating are not to be used in agricultural settings.

In the safety behaviors, the highest safety behavior accepted by farmers is wearing PPE, which is supported by OSHA and NIOSH (NIOSH, 1987; OSHA, 2016h). In wearing PPE, OSHA standard states “Whenever an employee enters a grain storage structure from a level at or above the level of the stored grain or grain products, or whenever an employee walks or stands on or in stored grain of a depth which poses an engulfment hazard, the employer shall equip the employee with a body harness with lifeline, or a boatswain's chair that meets the requirements of subpart D of this part” (OSHA, 2016h) However, the lifeline is not widely used by farmers.

Besides PPE, other safeguards are suggested by OSHA. Working in a team and turning off the power are two common injury prevention practices. When turning off the power, OSHA also required lock-out. In this thesis, not many farmers reported using lock-out techniques. The OSHA standard states “All mechanical, electrical, hydraulic, and pneumatic equipment which presents a danger to employees inside grain storage structures shall be de-energized and shall be disconnected, locked-out and tagged, blocked-off, or otherwise prevented from operating by other equally effective means or methods”(OSHA, 2016h).

This research also sought information about how farmers acquired their knowledge. The top four ways farmers currently receive safety information were from a magazine/periodical, a course or seminar, an equipment operation handbook, and safety decals. The top methods farmers preferred to receive safety method were taking a course or seminar, reading a magazine/periodical, and the Internet. Compared to the traditional education method, the Internet had a large increase as the farmers' preferred method. Therefore online learning may become a new popular approach in agricultural safety education. On the other hand, magazine/periodical, an equipment operation handbook, and safety decals had a large decrease in the farmers' preferred educational method. In the future, the course or seminar preference may be an important method to continue for in injury prevention education methods.

Management Practices of Stored Grain

Recent trends in Ohio harvesting practices incorporate on-farm grain drying and storage systems. Farmers report soybean storage begins in the months of September and October, while corn storage begins in October. These crops remain in storage for approximately 6.5 and 6.0 months respectively. The amount of the corn in storage is more than two times that of soybeans.

The common preference of grain storage facilities was to use grain bins. About 97% of farmers use grain bins as the main storage method, and more than 80% of farmers only use grain bins. A smaller percentage of farmers used silos and flat storage as auxiliary storage methods. Only 3% of farmers reported using silos as their only storage method.

Grain drying is a critical process before storage. A higher moisture content makes grain more likely to go out-of-condition during the storage period. This conclusion is supported by grain management resources (Gnadke, 2001). In this thesis, farmers reported a lower target moisture content for their soybeans than their corn. Also soybeans were reportedly easier to maintain in quality condition during the storage period. When drying soybeans the predominate factors affecting the target moisture content included weather conditions and amount of time pressures on the farmer. Likewise, when drying corn, the factors effecting the target moisture choice, were the amount of time pressures on the farmer and the price offered at the market.

When choosing the drying moisture target, farmers prefer 15% in corn and 13% in soybeans. Farmers reported more confidence for the drying result in corn. John T. Gnadke pointed out that there is allowable storage time for shelled corn (Gnadke, 2001). This idea was first calculated by Carl J. Bern et al. (Bern, Steele, & Morey, 2002). However in their research they mainly tested a 16% moisture content, and only for corn. Based on their results, other tables were calculated. This analysis used a table made by Karl VanDevender (Vandevender, 2016). In this table Karl VanDevender used the name 'maximum storage time', replacing a previous term 'allowable storage time'.

In this thesis, farmers reported a six-month time period where they stored their grain, beginning in October. This places the typical ending month to be between March and April. The climate data from the National Oceanic and Atmospheric Administration (NOAA) annual report during this period shows that the temperature in Ohio would be no more than 60 °F. Supposing that the temperature during storage is 60 °F, in Karl

VanDevender's table, 15% corn could be stored at a maximum of 9.2 month, and 13% soybeans reflected the same data (Vandevender, 2016). These 9.2 months are longer than Ohio farmers' average storage time, meaning there are adequate months of storage time, where external temperatures would remain in the 60°F range. However, 30% of the farmers in this sample reported out-of-condition corn, and 10% reported out-of-condition soybeans. Additional data are needed on farms with out-of-condition grain to determine if target moisture content was actually achieved, if grain was continuously monitored, or if other factors influenced the overall quality of the stored grain. Ideally, there should be no incidents of out-of-condition grain, but the opposite was true; these incidents still happened in this population of farmers. Focused on these data, some farmers encountered out-of-condition grain in the maximum storage time at the target moisture they chose. Some farmers had a safe storage period longer than the maximum storage under their target moisture. Therefore, the maximum storage time is a theoretical concept, and there are likely more factors that influence out-of-condition grain. However, when lower target moisture was reported by farmers, they also reported fewer observations of out-of-conditioned grain. Therefore, farmers should choose the lower target drying moisture level, and avoid the pressures of other variables to adjust this rate, when possible.

Information about Grain Storage Facilities

Grain bins were the main storage facility used by Ohio grain farmers for their on-farm storage systems. Farmers reported operating no more than eight grain bins with the average age of 27 years old. The majority (77.5%) of grain bins had an up-draft fan system to control the grain's condition during storage, and more than 84.6% of farmers

reported use of their fan system depending on the external weather. However, external weather should not be the only criteria for making fan use decisions. The recommended method is to use a fan system in a systematic approach, and also consider the weather effect. In this thesis, only 26.9% of the farmers reported both methods. The drying and fan system usage should depend on the amount of grain in storage, the kind of system in place, and the environmental factors, such as temperature and humidity (Backer et al., 1987; Gnadke, 2001; Vandevender, 2016). Therefore, farmers should use the instructions provided by the manufacturers to maximize fan systems' efficiency and effectiveness.

Cleaning frequency of on-farm grain storage systems was a reported area of this thesis' survey research. Farmers reported cleaning their grain bins at least once a year (87.2%). They used hand shovels, vacuums, brooms and sweep augers, as well as additional methods to sweep the walls. Farmers reported cleaning their silos at least once a year (81.3%), however, some silos were not cleaned on an annual basis. Flat storage areas were cleaned approximately every two years. When farmers clean the silos they take up the silo's floor, and they used a skid loader to clean flat storages.

The out-of-condition grain was reported in every month of the year except for October during the year. A storage facility that had previously encountered out-of-condition grain was more likely to have repeated experiences (40%). Therefore farmers are recommended to pay particular attention to these structures when storing grain in future years.

Summary

Ohio farms are ranked 8th in corn production and 9th in soybean production. The majority (98%) of Ohio farms are family farms, with an average of four employees. While all ages were reported to participate in grain harvest and storage activities, several farms utilized children, teen and senior workers. Additional training is needed for these age groups when they are involved in grain handling and storage tasks. Because the risks of these activities are very dangerous, young children and teen workers without supervision, are not recommended to be in these areas of the farm.

The Ohio farmers participating in this research reported knowledge of the health effects and safety risks associated with out-of-condition grain. They identified PPE as protective measures to protect themselves from common safety injuries. More than 90% of the sampled farmers utilized a respirator during their grain handling work. About 64% of the farmers wore gloves and 37.2% farmers used hearing protection. On the other hand, there were 3.3% farmers who reported no PPE usage during their work. Other safety behaviors, such as working in a team (63.4%) and turning off the power when working in the grain storage facilities (58.5%) were reported as practices used by Ohio farmers. However, 23% farmers chose to work alone, and 16.4% farmers reported locking out potential energy sources as their workplace practices. Some farmers in the sample (3.3%) did nothing about safety.

Farmers reported acquiring safety knowledge from a magazine or periodical, a course or seminar, an equipment operation handbook, and safety decals. They preferred

to study safety information through a course or seminar, by reading a magazine or periodical, or from the Internet.

Ohio farmers identified grain bins as their preferred on-farm storage system. They reported managing a number of grain bins, from one up to twenty-eight structures, with the average age of 27 years and capacity of 49,000 bushels. The storage period of corn was 6 months, and the storage period for soybeans was 6.5 months. Farmers preferred to dry their corn to 15% moisture content and soybeans to 13% moisture.

The incidence of out-of-condition grain happened in both corn and soybean crops. These occurrences were found throughout the year, except for the month of October, when crops were just beginning their storage period. The probability of no encounter with out-of-condition grain did not show big differences between grain bins, silos and flat storages. However there was an association between the target moisture level a farmer chose to dry their grain and the occurrence of out-of-conditioned grain. Lower target moisture contents of the grain when placed into storage can reduce the incidence of grain going out of condition in future storage months. Likewise, on-farm structures that had a history of grain going out-of-condition, had a 40% reoccurrence rate of future crops going out-of-condition.

Future Work

This research was conducted to establish a baseline of knowledge about Ohio's grain practices for on-farm storage. The results were descriptive in nature and will be used to improve education programs for different audience groups, and in a method acceptable for their learning preference. Understanding farmers' storage types, age of

structures, cleaning practices, types of drying systems, and the target moisture content are important variables that impact grain quality. It is through a combination of these engineering controls and educational resources that farmers can work in a safe environments.

Reference

- Adejumo, B. A., Haruna, S. A. (2013). Workers Health and Safety in Bulk Handling Of Grains for Storage in Metallic Silos, 2(9), 78–83.
- Aherin, R. A., Murphy, D. J., & Westaby, J. D. (1992). *Reducing Farm Injuries: Issues and Methods*. St. Joseph, MI : American Society of Agricultural Engineers, c1992.
- Alabama Cooperative Extension System (2016). Grain Bin Hazards and Safety Considerations. <http://www.aces.edu/pubs/docs/A/ANR-1332/ANR-1332.pdf>
- Atkinson, J. W. (1957). Motivational determinants of risk-taking behavior. *Psychological Review*, 64, Part 1(6), 359–372. <http://doi.org/10.1037/h0043445>
- Backer, L. F., Brook, R. C., Cloud, H. A., Hellevang, K. J., McKenzie, B. A., Peterson, W. H., Van Fossen, L. D. (1987). *Grain Drying, Handling and Storage Handbook*.
- Bawden, R. J., Macadam, R. D., Packham, R. J., & Valentine, I. (1984). Systems thinking and practices in the education of agriculturalists. *Agricultural Systems*, 13(4), 205–225. [http://doi.org/10.1016/0308-521X\(84\)90074-X](http://doi.org/10.1016/0308-521X(84)90074-X)
- Beckett, William S. Chamberlain, Diane Hallman, E., May, J. M., Hwang, S.-A., Gomez, M., Eberly, S., Cox, C., & Stark, A. (2000). Hearing Conservation for Farmers: Source Apportionment of Occupational and Environmental Factors Contributing to Hearing Loss. *Journal of Occupational and Environmental Medicine*, Volume 42(8), August 2000, pp 806-813.

- Bern, C. J., Steele, J. L., & Morey, R. V. (2002). Shelled Corn CO₂ Evolution and Storage Time for 0.5% Dry Matter Loss.
- Bureau of Labor Statistics (2010). National Census of Fatal Occupational Injuries in 2009 (Preliminary Results), (202), 1–13.
http://www.bls.gov/news.release/archives/cfoi_08192010.pdf
- Bureau of Labor Statistics (2011). National Census of Fatal Occupational Injuries in 2010 (Preliminary Results), (202), 1–13.
http://www.bls.gov/news.release/archives/cfoi_08252011.pdf
- Bureau of Labor Statistics (2012). National Census of Fatal Occupational Injuries in 2011 (Preliminary Results), 13. Retrieved from
<http://www.bls.gov/news.release/pdf/cfoi.pdf>
- Bureau of Labor Statistics (2013). National Census of Fatal Occupational Injuries in 2012 (Preliminary Results), (202), 1–14. <http://www.bls.gov/news.release/pdf/cfoi.pdf>
- Bureau of Labor Statistics (2014). National Census of Fatal Occupational Injuries in 2013 (Preliminary Results), (202), 1–14.
- Cathomas, R. L., Brüesch, H., Fehr, R., Reinhart, W. H., & Kuhn, M. (2002). Organic dust exposure in dairy farmers in an alpine region. *Swiss Medical Weekly*, 132, 174–178. <http://doi.org/2002/13/smw-09892>
- Christensen, C. M., & Kaufmann, H. H. (1969). *Grain Storage*. Minnesota archive editions.
- Chulze, S. N. (2010). Strategies to reduce mycotoxin levels in maize during storage: A review. *Food Additives & Contaminants. Part A, Chemistry, Analysis, Control*,

- Exposure & Risk Assessment*, 27(January 2015), 651–657.
<http://doi.org/10.1080/19440040903573032>
- Dyer, C. (2007). A Suffolk Farmer in the Fifteenth Century. *The Agricultural History Review*, 55, 1–22.
- Elkind, P. D. (1993). Correspondence between knowledge, attitudes, and behavior in farm health and safety practices. *Journal of Safety Research*, 24(3), 171–179.
[http://doi.org/10.1016/0022-4375\(93\)90028-L](http://doi.org/10.1016/0022-4375(93)90028-L)
- Elkind, P. D. (2007). Perceptions of risk, stressors, and locus of control influence intentions to practice safety behaviors in agriculture. *Journal of Agromedicine*, 12(January 2015), 7–25. <http://doi.org/10.1080/10599240801985167>
- Environmental Protection Agency (2015). Ag 101 Crop Glossary.
- eXtension (2015). Entrapment Risk due to Flowing Grain.
<http://articles.extension.org/pages/63151/entrapment-risk-due-to-flowing-grain>
- eXtension (2016). Asthma and Agriculture. Retrieved from
<http://articles.extension.org/pages/66326/asthma-and-agriculture>
- eXtension (2016). Grain Dust Explosions.
<http://articles.extension.org/pages/63142/grain-dust-explosions>
- Frederick X. Gibbons, M. G. (1995). Predicting young adults' health risk behavior. *Journal of Personality and Social*. Retrieved from
<http://www.psychology.iastate.edu/~fgibbons/pdfs/Gibbons1995predicting.pdf>

Freeman, S. A.S, Kelley, K. W., Maier, D. E., & Field, W. E. (1998). Review of Entrapments in Bulk Agricultural Materials at Commercial Grain Facilities. *Journal of Safety Research*, 29(2), 123–134. [http://doi.org/10.1016/S0022-4375\(98\)00008-5](http://doi.org/10.1016/S0022-4375(98)00008-5)

Gnadke, J. T. (2001). Quality Grain Care. AGS Inc; 3rd edition (2001).

Grain entrapment (2015). In Wikipedia (p. https://en.wikipedia.org/wiki/Grain_entrapment).

Grain facility occupational exposure (2015). In Wikipedia (p. https://en.wikipedia.org/wiki/Grain_facility_occup).

Gregori, R., Meriggi, P., Pietri, A., Formenti, S., Baccarini, G., & Battilani, P. (2013). Dynamics of fungi and related mycotoxins during cereal storage in silo bags. *Food Control*, 30(1), 280–287. <http://doi.org/10.1016/j.foodcont.2012.06.033>

Hard, David L., Allen, W. Robison (2011). A Quindecennial of Progress. <http://www.cdc.gov/niosh/docs/2014-121/pdfs/2014-121.pdf>

Iowa University (1997). Have you checked your grain bin?, (March), 37–42. <https://www.extension.iastate.edu/grain/files/Migrated/SP46.pdf>

Iowa University (2015). Hearing Loss Among Farmers and Agricultural Workers. *Great Plains Center for Agricultural Health*, <http://www.public-health.uiowa.edu/gpcah/resources/hearing-loss.html>

Issa, S., Roberts, M., & Field, B. (2013). 2012 Summary of Grain Entrapments in the United States, 1–10. <https://extension.entm.purdue.edu/grainlab/content/pdf/2012GrainEntrapments.pdf>

- Issa, S., & Field, B. (2013). 2013 Summary of U.S. Agricultural Confined Space-Related Injuries and Fatalities Overview of Documented Agricultural Confined Space - Related Cases, 1–14.
<https://extension.entm.purdue.edu/grainlab/content/pdf/2013SummaryFinal.pdf>
- Jayas, D. S., & White, N. D. G. (2003). Storage and drying of grain in Canada: Low cost approaches. *Food Control*, 14, 255–261. [http://doi.org/10.1016/S0956-7135\(03\)00014-8](http://doi.org/10.1016/S0956-7135(03)00014-8)
- Kidd, P. S., Isaacs, S. G., Cole, H. P., Parshall, M., Scharf, T., & Struttman, T. (1998). An Economic Motivator for Safe Farming : Changing Perceptions Through Learning, (1), 205–212.
- Kingman, D. M., Spaulding, A. D., & Field, W. E. (2004). Predicting the potential of engulfment using an on-farm grain storage hazard assessment tool. *Journal of Agricultural Safety and Health*, 10(4), 237–245.
- Kirkhorn, S. R., & Garry, V. F. (2000). Agricultural Lung Diseases. Environmental Health Perspectives Supplements. Aug2000 Supplement 4; Vol. 108; p705. 8p. 1 Diagram; 2 Charts.
- Magan, N., Hope, R., Cairns, V., & Aldred, D. (2003). Post-harvest fungal ecology : Impact of fungal growth and mycotoxin accumulation in stored grain, 723–730.
- Maier, D. E. (1993). Grain Quality: Why is Stored Corn Deteriorating Prematurely?, 1–4.
- McLain, D. L. (1995). Responses To Health and Safety Risk in the Work Environment. *Academy of Management Journal*, 38(6), 1726–1743. <http://doi.org/10.2307/256852>

- Mosher, G. A., Keren, N., Freeman, S. A., & Hurburgh, C. R. (2012). Management of Safety and Quality and the Relationship with Employee Decisions in Country Grain Elevators, *18*(3), 195–215.
- Murphy, D. (2006). Children and Safety on the Farm.
<http://extension.psu.edu/business/ag-safety/youth-safety/children-and-safety-on-the-farm>
- Murphy, D. J. (1992). *Safety and Health for Production Agriculture*. Amer Society of Agricultural; 1st edition (September 1992).
- NCERA-197. (2011). Developing a Research and Extension Agenda for Agricultural Confined Spaces North Central Education/Extension Research Activity Committee Draft copy. Washington, D.C.:USDA Committee on Agricultural Saety and Health Reaearch and Extension (NECRA-197).
- NIOSH. (1987). A Guide for Safety in Confined Spaces. DHHS (NIOSH) PUBLICATION NO. 87-113. <http://www.cdc.gov/niosh/docs/87-113/pdfs/87-113.pdf>
- NIOSH (1994). Worker Deaths in Confined Spaces. DHHS (NIOSH) Number 94-103.
<http://www.cdc.gov/niosh/docs/94-103/pdfs/94-103.pdf>
- NIOSH (2006). NIOSH Agriculture, Forestry, and Fishing Program National Academies Review. *Cincinnati OH: NIOSH*.<http://www.cdc.gov/niosh/nas/agforfish/>.
- NIOSH (2014). Occupational Injury Surveillance of Production Agriculture (OISPA) Survey. <Http://www.cdc.gov/niosh/topics/aginjury/oispa/injtables.html>.

NIOSH. (2016a). 42 CFR Part 84 Respiratory Protective Devices. Retrieved from

<http://www.cdc.gov/niosh/npptl/topics/respirators/pt84abs2.html>

NIOSH. (2016b). AGRICULTURAL SAFETY. Retrieved from

<http://www.cdc.gov/niosh/topics/aginjury/>

Noyes, R. T. (1998). Preventing Grain Dust Explosions, 5–8.

OSHA. (2002). Respiratory Protection. *29 CFR 1910.134, 2002*.

OSHA. (2015a). Personal Protective Equipment.

<https://www.osha.gov/Publications/osa3151.pdf>

OSHA (2015b). Youth in Agriculture.

<https://www.osha.gov/dsg/topics/agriculturaloperations/youngworkers.html>

OSHA (2016a). OSHA 29 CFR 1910.134. Retrieved from

[https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARD
S&p_id=12716](https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARD&p_id=12716)

OSHA (2016b). Combustible Dust in Industry: Preventing and Mitigating the Effects of
Fire and Explosions.

OSHA (2016c). General Respiratory Protection Guidance for Respiratory.

<https://www.osha.gov/Publications/osa3151.pdf>

OSHA (2016d). Grain Handling.

<https://www.osha.gov/SLTC/grainhandling/>

OSHA (2016e). OSHA 29 CFR 1910.95

[https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARD
S&p_id=9735](https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARD&p_id=9735)

OSHA (2016f). Numerous questions on filtering facepiece/dusk mask respirators.

Retrieved from

https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=28565

OSHA (2016g). OSHA 29 CFR 1910.146

https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9797

OSHA (2016h). OSHA 29 CFR 1910.272. Retrieved from

https://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=INTERPRETATIONS&p_toc_level=3&p_keyvalue=1910.272&p_status=CURRENT

Ohio State University (2015). OHIO'S FARM FATALITY STATISTICS. *Agricultural*

Safety & Health Program Ohio State University Extension,

<http://agsafety.osu.edu/statistics>

Ohio State University (2016). Training Module: Grain Bin Entrapment.

<https://www.bwc.ohio.gov/downloads/blankpdf/congress10/113grain.pdf>

Penn State Extension (2015). Hazards of Flowing Grain.

<http://extension.psu.edu/business/ag-safety/confined-spaces/flowing-grain/e43>

Penn State Extension (2016). Farm Respiratory Hazards. Retrieved from

<http://extension.psu.edu/business/ag-safety/health/e26>

Pereyra, M. L. G., Alonso, V. A., Sager, R., Morlaco, M. B., Magnoli, C. E., Astoreca, a.

L., Cavaglieri, L. R. (2008). Fungi and selected mycotoxins from pre- and

- postfermented corn silage. *Journal of Applied Microbiology*, 104, 1034–1041.
<http://doi.org/10.1111/j.1365-2672.2007.03634.x>
- Plakke, B. L., & Dare, E. (1992). Occupational hearing loss in farmers. *Public Health Reports*, 107(5), 188–192.
- Purdue Extension. (2015). Beware of Flowing Grain Dangers.
<https://www.extension.purdue.edu/extmedia/ABE/S-77.pdf>
- Richard, J. L. (2007). Some major mycotoxins and their mycotoxicoses-An overview.
International Journal of Food Microbiology, 119(1-2), 3–10.
<http://doi.org/10.1016/j.ijfoodmicro.2007.07.019>
- Rubinsky, S., & Smith, N. (1973). Safety training by accident stimulation. *The Journal of Applied Psychology*, 57(1), 68–73.
- Rylander, R. (1986). Lung diseases caused by organic dusts in the farm environment.
American Journal of Industrial Medicine, 10, 221–227.
- Shukla, A. K. (2014). Occurrence of Mycotoxins in Storage Fungi. *Internatinal Journal of Science and Research (IJSR)*, 3(11), 1747–1750.
- Smith, D. W., & Program, E. S. (2002). US Agriculture Fatality Statistics, (808).
<http://agsafety.tamu.edu/files/2011/06/US-AGRICULTURE-FATALITY-STATISTICS1.pdf>
- United States Department of Agriculture. (2016). Official Untied States Standrads for Grain. <https://www.gipsa.usda.gov/fgis/usstandards.aspx>

USDA-NASS. (2014a). 2012 Census of Agriculture.

[http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level/Ohio/, 1\(May\).](http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level/Ohio/,1(May).)

USDA-NASS. (2014b). 2014 State Agriculture Overview.

http://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=OHIO.

Vandevender, K. (2016). Grain Drying Concepts and Options.

<http://www.uaex.edu/publications/pdf/FSA-1072.pdf>

Westaby, J. D., & Lee, B. C. (2003). Antecedents of injury among youth in agricultural settings: A longitudinal examination of safety consciousness, dangerous risk taking, and safety knowledge. *Journal of Safety Research*, 34, 227–240.

[http://doi.org/10.1016/S0022-4375\(03\)00030-6](http://doi.org/10.1016/S0022-4375(03)00030-6)

Appendices

Appendix A: Panel of Experts and the letter

1. Dr. Dee Jepsen, Agricultural Health and Safety, The Ohio State University

My advisor, focus on agricultural safety for many years

2. Andy Bauer, Heritage Cooperative, retired grain elevator manager. Agricultural Health and Safety Awareness, and have much experience in grain storage and manage

Dear Dr. _____:

Greetings. My name is Yang Geng. I am a graduate student at the Ohio State University pursuing a master degree in Agricultural Safety. I am currently conducting research for my independent study under Dr. S. D. Jepsen entitled Current Storage and Safety Conditions for Ohio's On-Farm Grain Facilities, that will seek to determine the situation about grain storage and moldy grain in Ohio, and the safety consciousness and working culture of farmers.

Due to your extensive knowledge and expertise in the field of agricultural safety, I have selected you to serve as one of the members of my panel of experts. I am formally

requesting your assistance in determining my instrument's content validity. I realize that this is a very busy time of year for you; however, I hope that you will be able to assist me with this matter.

Attached is a formal letter requesting your assistance, and the study's purpose and objectives. In addition, you will also receive an e-mail link to the questionnaire. I can be reached via e-mail at geng.83@osu.edu or by phone at (614)-886-5695. I would appreciate any feedback you can provide by Friday, March 27th, 2015 or as soon as possible. I realize this is a tight timeline, and if you are unable to help me, I understand. However, your help will be greatly appreciated.

Thanks in advance for your help with this review. Hopefully with your feedback and the feedback from others, this instrument will be a new method to study the agricultural safety problem for grain storage systems.

Sincerely,

Yang Geng

Graduate Student

Phone: (614)-886-5695

E-mail: geng.83@osu.edu

Appendix B: Correlation Matrix

Correlation Matrix					
		Health risk knowledge	Safe risk knowledge	Dust mask	Hearing protection
Correlation	Health risk knowledge	1.000	.792	.050	.050
	Safe risk knowledge	.792	1.000	.048	.140
	Dust mask	.050	.048	1.000	-.100
	Hearing protection	.050	.140	-.100	1.000
	N95 mask	.191	.173	-.566	.030
	Safety glasses	.153	.113	.027	.305
	Full mask respirator	.005	.022	-.074	.040
	Gloves	.161	.174	.010	.318
	Towel or cloth to cover mouth and nose	-.005	-.021	.135	.139
	Hard hats	.128	.144	-.043	.111
	Fall protection equipment	.245	.213	-.025	.181
	Do not use anything	-.143	-.115	-.269	-.143
	Life line	.047	.075	-.008	.084
	Turn off air exchange system	.021	.101	.042	.098
	Work alone	-.159	-.182	.072	-.139
	Turn off power	.086	.082	-.042	.144
	Work in a group	.205	.192	-.137	.248
	Lock out energy source	.073	.061	-.079	.204
	Do nothing	-.271	-.338	-.141	-.056
	Wear PPE	.317	.356	.012	.190
	Other	-.015	-.032	.050	.095

Continue

Table 6. Correlation Matrix

Table 6. Continued

Correlation Matrix					
		N95 mask	Safety glasses	Full mask respirator	Gloves
Correlation	Health risk knowledge	.191	.153	.005	.161
	Safe risk knowledge	.173	.113	.022	.174
	Dust mask	-.566	.027	-.074	.010
	Hearing protection	.030	.305	.040	.318
	N95 mask	1.000	.009	.059	.009
	Safety glasses	.009	1.000	.177	.203
	Full mask respirator	.059	.177	1.000	-.004
	Gloves	.009	.203	-.004	1.000
	Towel or cloth to cover mouth and nose	-.145	.173	.069	.029
	Hard hats	.028	.306	.141	.078
	Fall protection equipment	.211	.172	.182	.006
	Do not use anything	-.133	-.124	-.047	-.248
	Life line	.048	.011	.049	.063
	Turn off air exchange system	-.010	.046	.034	.052
	Work alone	-.130	-.094	-.086	-.020
	Turn off power	.066	.129	.024	.148
	Work in a group	.297	.080	.044	.141
	Lock out energy source	.145	.244	.074	.020
	Do nothing	-.155	-.086	-.054	-.121
	Wear PPE	.256	.167	.153	.247
	Other	-.054	.110	-.019	-.100

Continue

Table 6. Continued

Correlation Matrix				
		Towel or cloth to cover mouth and nose	Hard hats	Fall protection equipment
Correlation	Health risk knowledge	-.005	.128	.245
	Safe risk knowledge	-.021	.144	.213
	Dust mask	.135	-.043	-.025
	Hearing protection	.139	.111	.181
	N95 mask	-.145	.028	.211
	Safety glasses	.173	.306	.172
	Full mask respirator	.069	.141	.182
	Gloves	.029	.078	.006
	Towel or cloth to cover mouth and nose	1.000	-.048	.010
	Hard hats	-.048	1.000	.199
	Fall protection equipment	.010	.199	1.000
	Do not use anything	-.037	-.044	-.070
	Life line	-.045	.057	.371
	Turn off air exchange system	.017	.104	.036
	Work alone	-.043	-.077	-.132
	Turn off power	.108	.054	.014
	Work in a group	-.090	.028	.109
	Lock out energy source	-.088	.153	.366
	Do nothing	.097	-.051	-.081
	Wear PPE	-.072	.145	.229
	Other	-.015	-.018	-.028

Continue

Table 6. Continued

Correlation Matrix					
		Do not use anything	Life line	Turn off air exchange system	Work alone
Correlation	Health risk knowledge	-.143	.047	.021	-.159
	Safe risk knowledge	-.115	.075	.101	-.182
	Dust mask	-.269	-.008	.042	.072
	Hearing protection	-.143	.084	.098	-.139
	N95 mask	-.133	.048	-.010	-.130
	Safety glasses	-.124	.011	.046	-.094
	Full mask respirator	-.047	.049	.034	-.086
	Gloves	-.248	.063	.052	-.020
	Towel or cloth to cover mouth and nose	-.037	-.045	.017	-.043
	Hard hats	-.044	.057	.104	-.077
	Fall protection equipment	-.070	.371	.036	-.132
	Do not use anything	1.000	-.042	-.021	.043
	Life line	-.042	1.000	-.025	.053
	Turn off air exchange system	-.021	-.025	1.000	.035
	Work alone	.043	.053	.035	1.000
	Turn off power	-.034	-.016	.116	-.089
	Work in a group	-.056	.116	.075	-.343
	Lock out energy source	-.082	.104	-.019	-.071
	Do nothing	.261	-.049	-.170	.008
	Wear PPE	-.235	.138	.177	-.014
	Other	-.014	-.017	-.059	-.041

Continue

Table 6. Continued

Correlation Matrix				
		Turn off power	Work in a group	Lock out energy source
Correlation	Health risk knowledge	.086	.205	.073
	Safe risk knowledge	.082	.192	.061
	Dust mask	-.042	-.137	-.079
	Hearing protection	.144	.248	.204
	N95 mask	.066	.297	.145
	Safety glasses	.129	.080	.244
	Full mask respirator	.024	.044	.074
	Gloves	.148	.141	.020
	Towel or cloth to cover mouth and nose	.108	-.090	-.088
	Hard hats	.054	.028	.153
	Fall protection equipment	.014	.109	.366
	Do not use anything	-.034	-.056	-.082
	Life line	-.016	.116	.104
	Turn off air exchange system	.116	.075	-.019
	Work alone	-.089	-.343	-.071
	Turn off power	1.000	.008	.309
	Work in a group	.008	1.000	.113
	Lock out energy source	.309	.113	1.000
	Do nothing	-.257	-.288	-.095
	Wear PPE	.073	.247	.068
	Other	-.089	-.100	-.033

Continue

Table 6. Continued

Correlation Matrix				
		Do nothing	Ware PPE	Other
Correlation	Health risk knowledge	-.271	.317	-.015
	Safe risk knowledge	-.338	.356	-.032
	Dust mask	-.141	.012	.050
	Hearing protection	-.056	.190	.095
	N95 mask	-.155	.256	-.054
	Safety glasses	-.086	.167	.110
	Full mask respirator	-.054	.153	-.019
	Gloves	-.121	.247	-.100
	Towel or cloth to cover mouth and nose	.097	-.072	-.015
	Hard hats	-.051	.145	-.018
	Fall protection equipment	-.081	.229	-.028
	Do not use anything	.261	-.235	-.014
	Life line	-.049	.138	-.017
	Turn off air exchange system	-.170	.177	-.059
	Work alone	.008	-.014	-.041
	Turn off power	-.257	.073	-.089
	Work in a group	-.288	.247	-.100
	Lock out energy source	-.095	.068	-.033
	Do nothing	1.000	-.354	-.016
	Ware PPE	-.354	1.000	-.123
	Other	-.016	-.123	1.000