INCIDENCE AND SPREAD OF INSECTS FROM BUCKET ELEVATOR LEG BOOTS

by

DENNIS RAY TILLEY

B. S., Kansas State University, 1987
B. S., Kansas State University, 1993
M. S., Kansas State University, 2005

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Grain Science
College of Agriculture

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Manhattan, Kansas

2013

Abstract

In commercial grain elevators and feed mills, the boot and pit areas contribute to commingling of insects with grain that moves through the elevator leg. A pilot-scale bucket elevator leg with a modified removable boot, or slip-boot, was used to measure the magnitude of commingling as a function of stored-product insect density and boot holding time in tests with wheat and corn. Pilot-scale tests showed that clean grain transferred over infested boots was infested with about 1 insect/kg when transferred immediately after the boot was infested; this increased to 2 insects/kg after incubating the boot for 8 wk. Larger numbers of kernels with internal infestations were picked up by clean grain during transfer compared with externally infesting insects, because the mobility of the latter enabled them to move away from buckets during transfer. Monthly surveys over two years at elevators and feed mills revealed several stored-product insects in grain residues from the boot and pit areas and bulk load-out samples. Insect densities in the boot and pit areas were impacted by seasonal temperatures and facility sanitation practices. Recommended sanitation guidelines for the boot and pit areas include: (1) boot residual grain clean-out every 30 d, (2) removal of grain spillage and floor sweepings from the pit area, and (3) proper disposal of boot and pit residual grain. Facilities following these sanitation guidelines could avoid costly grain discounts, increase income of the business operation and minimize or prevent cross contamination of clean grain by infested grain in the boot and pit areas.

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Approved by:

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In commercial grain elevators and feed mills, the boot and pit areas contribute to commingling of insects with grain that moves through the elevator leg. A pilot-scale bucket elevator leg with a modified removable boot, or slip-boot, was used to measure the magnitude of commingling as a function of stored-product insect density and boot holding time in tests with wheat and corn. Pilot-scale tests showed that clean grain transferred over infested boots was infested with about 1 insect/kg when transferred immediately after the boot was infested; this increased to 2 insects/kg after incubating the boot for 8 wk. Larger numbers of kernels with internal infestations were picked up by clean grain during transfer compared with externally infesting insects, because the mobility of the latter enabled them to move away from buckets during transfer. Monthly surveys over two years at elevators and feed mills revealed several stored-product insects in grain residues from the boot and pit areas and bulk load-out samples. Insect densities in the boot and pit areas were impacted by seasonal temperatures and facility sanitation practices. Recommended sanitation guidelines for the boot and pit areas include: (1) boot residual grain clean-out every 30 d, (2) removal of grain spillage and floor sweepings from the pit area, and (3) proper disposal of boot and pit residual grain. Facilities following these sanitation guidelines could avoid costly grain discounts, increase income of the business operation and minimize or prevent cross contamination of clean grain by infested grain in the boot and pit areas.

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Dedication

This dissertation is dedicated to my mom (Faye Tilley) for her unconditional love and support throughout my life.

Chapter 1 - Literature review

1.1 Introduction.

Commercial grain elevator facilities can quickly become infested with stored-product insect pests (Reed et al. 2003; Arthur et al. 2006). The likely source of insect pests that infest newly harvested grain stored in commercial elevators is previously infested grain carried over from the previous year. Ingemansen et al. (1986) found that the percentage of insect infested bins and the average insect densities in stored oats correlated with the previous year's peak insect densities inside that same bin. Recorded data suggested insect pest infestation was carried over from one year until the next. Likely sources of elevator areas being infested are grain residues in empty bins, discharge spouts, dump pits, head houses, spills, and residual grain in handling equipment (Dowdy and McGaughey 1998; Reed et al. 2003; Arthur et al. 2006). There are many areas of the grain elevator that provide harborage for pest insects and contribute to insect pest carry over from one year to the next. However, the dynamics of insect infestation in grain-handling equipment at elevators is not fully characterized or understood.

The elevator boot is the enclosed base of an elevator leg casing, where static grain, referred to as residual grain, accumulates after the first loading of material. The elevator boot is usually located in the basement or in a sub-basement pit area. The boot pit area is often damp and the temperature is moderated by the subterranean location, providing an ideal habitat for insect population growth and development. The elevator boot area can be an important source of insect pest infestation, especially if grain is allowed to accumulate inside the elevator boot and surrounding area. Infestations originating in the boot pit could spread to other locations as the grain is moved from this area to other locations by elevator buckets and spouts. Residual grain often remains in the boot because manual clean-out of the elevator boot is not done on a regular basis in most grain elevator and feed mill facilities. Grain residue accumulations in the boot pit area can result from clean-out operations or spills from worn spouting. Good (1937) recommended cleaning this area on a frequent basis to manage insect pests in flour mills prior to fumigation. Residual grain accumulation in the elevator boot likely contributes to commingling or mixing of insects with grain that moves through the elevator leg.

1.1.1 ELEVATOR FACILITY DESCRIPTION AND INSECT PEST SURVEYS

In the United States, an elevator is a facility used for receiving and storing large volumes of grain. The name “elevator” comes from the bucket elevators that are used to elevate grain from an underground receiving pit to the top of the facility where the grain is weighed and distributed to different storage bins. Bucket elevators are enclosed vertical belts with a series of buckets attached that pick up grain in the bottom boot area, elevate it to the top, and discharge it at the head area. Elevators are used to store grain but may also sort, clean, size, dry, and fumigate grain (Hagstrum and Subramanyam 2006). Thus, elevators provide a constant food resource for stored-product insect populations throughout the calendar year. Wright (1991) and Reed et al. (2003) conducted studies to determine the extent of insect infestations in empty grain bins and wheat stored in upright concrete bins. At grain elevator facilities, insect populations outside of grain bins (i.e., discharge spouts, dump pits, spills, and residual grain in handling equipment) have been assessed by Dowdy and McGaughey (1998) and Arthur et al. (2006). Insect densities in grain residues, both inside empty bins and outside of bins, were higher (>10 fold) than those in the bulk grain mass stored in bins. This difference is likely a result of the total volume of grain stored in bins being much higher when compared with grain residues in empty facilities or spills.

Wright (1991) surveyed a decommissioned terminal elevator site in Sydney, Australia, by trapping residual insect infestations in 80 empty concrete silo bins. The author reported only the proportional occurrence of adult insect species trap catches in bins using different food bait attractants (whole wheat grain, whole wheat flour, whole wheat flour/carob powder mixture, wheat germ oil, *Tribolium castaneum* (Herbst) pheromone lure). Psocids (Psocoptera: *Liposcelis entomophilus* (Enderlein)) were the most abundant insect species trapped, occurring in about 85% of all insect trap captures. Adults of the insect species broad-horned flour beetle, *Gnatocerus cornutus* (F.), and sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) comprised about 40% and 50%, respectively, of all insect trap captures, using flour as a food-bait. Other insect species occurring occasionally in traps were the cigarette *Lasioderma serricorne* (F.) and lesser grain borer, *Rhyzopertha dominica* (F.).

Dowdy and McGaughey (1998) surveyed four commercial grain elevator facilities in north central Kansas to determine insect activity over a two-year period. Insect activity was monitored using a delta sticky traps and corrugated cardboard traps inside and outside each concrete elevator facility. Delta traps are a triangular shaped trap with open ends, allowing for insects to fly into the trap and are caught on a surface treated with a non-drying sticky glue. Delta traps (unbaited) and corrugated cardboard traps (baited with flour) were used to monitor insect activity in different areas of each facility. Monitoring areas at each facility included the pit and the elevator leg base, with other large areas grouped by similar facility structure design (i e., top of elevator head house and silo head space above the grain mass.). Adults of *O. surinamensis* were the most common insect pest species found in cardboard and delta traps at all elevators. Other insect pest species trapped in cardboard traps were several unidentified dermestid species, the hairy fungus beetle, *Typhaea stercorea* (L.), foreign grain beetle, *Ahasverus advena* (Waltl), cadelle, *Tenebrioides mauritanicus* (L.), yellowmeal worm, *Tenebrio malitor* (L.), and *Cryptolestes* spp. The delta traps captured many of the same species found in the cardboard traps. However, many of the delta traps captured *Plodia interpunctella* (Hübner) in head space areas of elevators. The degree of cleanliness of facilities was inversely related to insect numbers captured in traps.

Reed et al. (2003) surveyed seven grain elevator facilities in central Kansas by sampling intermittently for stored-product insect pests over a period of two and half years. Grain samples were collected from the upper half of the grain mass with a power vacuum sampler, from the grain residue of discharge spouts at the base of bins, and from grain residue remaining in empty bins. *Cryptolestes* spp. were the dominant insect pest found in all samples, constituting >60% of all insects found in most of the discharge spout samples and >40% of all insects found in most of the power vacuum grain samples. Other common insect pest species found in grain residue samples were *R. dominica* (9.0% of total samples), *Oryzaephilus* spp. (3.0%), *Sitophilus* spp. (32.4%), and *Tribolium* spp. (10.6%). Most of the grain residue samples (~80%) collected from empty silos were infested with insect pests. The authors concluded that cleaning empty bins resulted in a reduced insect population density in the discharge spouts.

Arthur et al. (2006) surveyed nine grain elevator facilities in Kansas monthly for stored-product insect pests over a two-year period. Grain residue samples were collected from the following locations: elevator boot pit, tunnel, truck dump, rail line, and ground-level areas. The most abundant insect pest species recorded in all grain residue samples were *Sitophilus* spp. and *Cryptolestes* spp., which comprised about 80% of all insect pests collected. However, most grain residue samples contained no stored-product insects. Grain residue samples obtained from the boot pit and tunnel areas comprised the highest insect densities, with *Sitophilus* spp. found in over 70% of samples collected from the boot pit area. The density of other non-dominant insect pest species of *T. stercorea*, *R. dominica*, *A. advena*, and *Oryzaephilus* spp., comprised <2 insects per kg in grain residue samples for each month. The density of *Sitophilus* spp. was >5 insects/kg in grain residue samples for each month except December, and numbers peaked in early fall. The combined densities of all insect species from grain residue samples fluctuated between 16 and 66 insects/kg and peaked during the early spring months.

1.1.2 FEED MILL FACILITY DESCRIPTION AND INSECT PEST SURVEYS

In the United States feed mill facilities are divided into various cost centers including: receiving, material processing, mixing, pelleting, packaging, warehousing, and loading (Rempe 1994). Feed mill design and construction is highly variable, primarily due to differences in the type and quantities of feed produced and the process flow (Larson 2008). Feed mill material components are of major and minor ingredients (Schoeff 1994). The formulation of feed is largely from cereal based grains, with minor ingredients of vitamins, minerals, amino acids, fat, molasses, flavor enhancers, and antibiotics (Mills 1992, Larson et al. 2008). Stored-product insect populations are found in commercial feed mill facilities throughout the year (Mills and White, 1993). Commercial feed mill facilities are conducive to insect pest populations because of warm temperatures in production areas, the accessibility of cereal grain products in raw and processed form and complex sanitation requirements (Mills 1992).

Rilett and Weigel (1956) sampled insects in eight feed mills, two flour mills, and one flour and feed mill during a six-month period in Buffalo, New York. They reported insect pest activity found in grain residue and grain dust samples from various mill areas. Insect counts and mill location areas were not recorded separately, only the incidence of insect pest species at each facility location. The most commonly collected insect pest species, in order of abundance, were the confused flour beetle, *Tribolium confusum* (Jacquelin du Val), ; black carpet beetle, *Attagenus piceus* (Oliv.); *G. cornutus*; rice weevil, *Sitophilus oryzae* (L.); and *T. castaneum*. Most feed mill facilities had at least four insect pest species, with a few facilities had eight to nine species. However, one mill facility recorded very few insect pest species, primarily due to increased frequency of sanitation and cleaning practices. This mill was cleaned every two weeks of residual grain and dust material. The authors concluded that insect control must be continued throughout the entire year, even during the cold winter months when insect numbers may be low, because residual breeding stocks carried over in favorable environments within the mill facility may account for increased insect pest activity during the warm summer months.

Triplehorn (1965) surveyed 118 grain elevator and feed mill facilities in all parts of Ohio. He collected samples of dust and grain residue material from various mill and elevator facility locations (i.e., around machinery, behind switch boxes, etc.). Adult insect species were extracted and recorded from the samples. However, the insect species were not recorded separately for the mill and elevator facility without any reference to a particular location. Additionally, the magnitude of infestation by the various species was not evaluated. For example, a single specimen was sufficient for recording that species as present in a given facility. Insect species were only reported, either in the spring or fall, as a percentage of facilities out of the total 118 facilities sampled. The most abundant insect pest species collected for each sampling period was *A. piceus*. Other commonly trapped insect pest species in mills and elevators included *Cryptolestes* spp., *O. surinamensis*, *Sitophilus spp.*, *T. mauritanicus*, and *T. molitor.*

Loschiavo and Okumura (1979) surveyed four feed mill facilities in Hawaii at weekly, biweekly or monthly intervals, and they reported the frequency of occurrence of insect pest species from samples in light traps and bait bags. The locations where traps and bait bags were placed was not mentioned in the paper. Four insect pest species (the lesser mealworm, *Alphitobius diaperinus* (Panzer); *R. dominica*, *S. oryzae*, and *T. castaneum*) were frequently and consistently found in all facilities. Other insect pest species (*Attagenus* spp.; the drug store beetle, *Stegobium paniceum*; and *T. stercorea*) were found in three of the four feed mill facilities sampled. The most frequently collected insect pest species were *T. castaneum* and *R. dominica.*

Pellitteri and Boush (1983) surveyed twenty feed mill facilities in southern Wisconsin at biweekly intervals during June through August in 1975 and 1976. They collected insects from traps which were not described, extracted insects from grain and feed residue samples, and hand-collected visible insects during mill visits. Mill facility conditions of sanitation, infestation problems, insecticide treatments and pertinent comments obtained in conversations with the mill managers were recorded. *Cryptolestes* spp. was the most common and abundant insect pest species recorded. The granary weevil, *Sitophilus granarius* (L.) was abundant and widely distributed in all samples from feed mill facilities. However, *S. oryzae* was not collected in any of the feed mills sampled. Other economically important stored-product insect pests recorded in mill facilities included: *T. mauritanicus, S. paniceum, R. dominica*. Secondary feeders, *T. castaneum* and *T. confusum*, were widely distributed and in some cases abundant. *Tribolium* spp. populations were largest in heated mill facility manufacturing areas. Constant populations of *O. surinamensis* were present in 95% of the sampled sites throughout the warm summer months. Sanitation conditions varied greatly among mills sampled, and mill managers reported that little time was invested in cleaning when business picked-up during the spring and fall months. Consequently, the authors reported insect infestation levels were directly proportional to the amount of grain residue found on the floor of a given mill facility.

Larson et al. (2008) surveyed eight feed mill facilities in five Midwestern states between January and November, 2003; visiting each mill facility either two or four times. Feed mill facilities were sampled for stored-product insect pests by using commercial food- and pheromone-bated traps. A total of 30 different insect species (27 species of beetles and three species of moths) were captured in traps from all of the mills sampled but only five species occurred in every mill. These species were *A. advena*, *T. stercorea*, *T. castaneum*, the warehouse beetle, *Trogoderma variable* (Ballion); Indianmeal moth, *Plodia interpunctella* (Hübner) The most abundant insect pest species captured inside of all mill facilities was *T. castaneum*; the most abundant species captured outside the mill was *T. variabile*. Additionally, the most abundant moth species captured inside the mill was *P. interpunctella*. All mill facilities recorded high diversity of insect species captured in traps. The authors note the lack of similarity among mills in species composition could be due to geographical location of mill facilities, type of feed produced, and degree of sanitation and pest management practices.

The above literature reviews of insect pest surveys in feed mill and grain elevator facilities indicate high species diversity between mill locations. Insect species diversity between mill and elevator facilities could be attributed to differences in sampling methods used by various researchers (insect trapping, residual grain accumulations, or finished product), environmental conditions (temperature, resource availability, moisture, trap locations and design), and biological factors (age, sex, mobility, and feeding status of insects) (Phillips et al. 2000). Thus it is critical for feed mill and grain elevator managers to understand the diversity of insect species present and their management (Pedersen 1994), with improved facility sanitation guidelines and establishment of good manufacturing practices (Gill 1994).

Insects commonly found in commercial grain elevator and feed mill boot, pit and load-out areas include *T. castaneum, R. dominica*, *C. ferrugineus*, *S. oryzae*, *O. surinamensis*, *P. interpunctella*. A general characteristic description of each species is given below in section 1.1.3, with a brief focus on the biology, economic importance, and ecology.

1.1.3 CHARACTERISTICS OF INSECT PEST SPECIES COMMONLY ASSOCIATED WITH FEED MILL AND ELEVATOR FACILITIES:

1.1.3.1 Characteristics of T. castaneum:

T. castaneum is one of the most common stored-product insect pest species associated with stored grain and processed food commodities in elevators, mills, and warehouse facilities throughout the world. The species is often considered a secondary pest of stored grain, feeding primarily on broken kernels, germ, grain dust or other cereal products (Trematerra 2000). However, the economic importance of this pest species is enormous in terms of the number of stored products attacked, climate adaptability, flying ability, omnivorous feeding behavior, and rate of reproduction capacity (Sinha and Watters 1985).

This species is a cosmopolitan pest and likely originated in the Indo-Australian region and has been recorded during the time period of the Pharaohs in Egypt (2500 B.C.) (Rees 2004). Adults are reddish brown to black in color, with an elongated and relatively flat body measuring 2.3-4.5 mm in length. The species is climatically well-adapted and has unusual tolerance for low humidity (minimum relative humidity 1%) (Sinha and Watters 1985). Adults and larvae are omnivorous and cannibalistic. Cannibalistic behavior occurs in crowded and over populated areas, where they feed on eggs and pupa (occasionally larvae) of their own species.

Adult *T. castaneum* can live for many months to several years under favorable conditions. However, they may survive moderately cold winters in unheated buildings. The female lays 2-10 eggs each day and may produce 1000 eggs during a life time. Total development from egg to adult can be very rapid, with a life cycle completed in about 21 days under optimal conditions of 35°C and 75% RH, but this period can vary, depending on availability of food resources, temperature, and relative humidity. Howe (1956, 1962) investigated the effect of temperature and humidity on *T. castaneum* life cycle developmental stages, with oviposition possible between 22 and 40°C. Oviposition was highest at about 32.5°C.

1.1.3.2 Characteristics of *R. dominica*:

R. dominica is a devastating cosmopolitan pest, occurring in all areas of the world where grain is produced and stored (Potter 1935). The species is 3 mm long, and reddish-brown to black-brown beetle. The body is an oval shape, slim, cylindrical, and with the head concealed from above. *R. dominica* is a strong flier and uses wind currents to travel long distances. It commonly infests stored grain in elevators and on-farm bins (Dowdy and McGaughey 1994, 1998). This species is a major pest of a wide variety of foods, mostly cereal grains of all kinds, and has been reported from 115 different types of commodities and materials (i.e., wood, and many other materials) (Arbogast 1991, Hagstrum and Subramanyam 2009). *R. dominica* is thought to have originated as a wood borer, prior to becoming a pest of stored-grains (Potter 1935).

R. dominica is a major pest of stored grains because it feeds on whole grain in both the larval and adult life stages, reducing grain biomass (Brower and Tilton 1973, Swaminathan1977) and produces insect damage kernels (IDK). IDK’s are used as a quality parameter assessment in grain contracts and a grading factor used in grain standards, determining grain quality (i.e., 32 IDK or more in wheat is considered sample grade and must not enter the human food supply) (GIPSA 1993). Additionally, *R. dominica* reduces grain quality through contamination of the grain mass with insect fragments and uric acid (Swaminathan 1977, Wehling et al. 1984, Jood and Kapoor 1992). Heavily infested stored grain is distinguished by a sweetish, musty odor, a result of the male-produced aggregation pheromone (Sanches-Marifenez et al. 1997). These reduced quality factors can change dough properties of wheat and reduce final bread quality through offensive odors and low loaf volume.

The eggs are laid outside of grain kernels, larvae enters kernels and develops within, molting four to five times (Arbogast 1991). Females are capable of laying up to 500 eggs in their lifetime (Birch and Snowball 1945, Howe, 1950). The first instars can bore into intact grain kernels and complete development within. The adults have powerful mandibles, and are capable of creating large irregular holes in grain kernels and powerful enough to bore into wood (Arbogast 1991). The majority of the life cycle of *R. dominica* is in the larvae developmental stage (27 to 31 days at 28°C). *R. dominica* is a long-lived species, and one of the most difficult to manage with chemicals, because of their ability to develop resistance (Arthur 1992, Lorini and Galley 1996, Huang and Subramanyam 2005).

Grain kernels infested by internal feeders such as *R. dominica* may show no indication on their exterior but could contain hidden larvae or pupae (Storey et al. 1982). Grain is inspected at elevator and mill facilities for insect infestations during shipping and receiving operations. Detection of internal live infestations using radiographic technique or novel technique proposed by Pearson and Brabec (2007) would likely benefit elevator and feed mill facility operations, minimizing fumigation of grain and reduce facility costs. Pearson and Brabec (2007) evaluated a modified roller mill system to measure and analyze the electrical conductance of wheat to detect internal insect infestations. The instrument was most successful detecting fourth instar and pupae *R. dominica*, with average detection of 8.3 out of 10 infested kernels per 100 g of wheat.

1.1.3.3 Characteristics of C. ferrugineus:

C. ferrugineus is a cosmopolitan insect pest of 69 different commodities, mostly of unprocessed cereals and oilseeds (Hagstrum and Subramanyam 2009). The species is one of the most abundant pests of farm-stored wheat in the US (Flinn and Hagstrum 1995). Adult *C. ferrugineus* are dorso-ventrally flattened, rectangular, reddish brown beetle, about 1.5-2 mm long, and have a filiform antennae. Being highly flattened they are able to enter very small cracks and crevices of grains and they generally feed exclusively on the germ. Larval and pupal development usually occurs inside burrows of the wheat germ and by the time larvae reach pupal stage the entire germ is consumed.

C. ferrugineus females lay about 200 eggs which are deposited on or in the crevices of grain kernels or in grain dust material. The life cycle of this species ranges between 17-103 days at temperatures from 21-38°C and 75% RH. However, under optimal conditions (33°C, 70% RH) the life cycle is completed in 23 days (Rees 1996). C. *ferrugineus* has an unusual ability to acclimate to low temperature and relative humidity climates (Sinha and Waters 1985). The species can survive exposure to winter conditions in temperate climates (Rees 1996), with low temperature of -12°C and low humidity of 10% (Sinha and Waters 1985).

Economic losses from infestations of *C. ferrugineus* cause grain kernel damage to the germ and can be recognized by the presence of a distinct burrowing hole in the germ area. Sinha and Waters (1985) report widespread grain infestation and outbreaks occur under certain conditions. Shortly after harvest, grain stored at high temperatures will likely become infested. *C. ferrugineus* can build up large populations and become a major cause of grain heating and spoilage. Insect-induced ”hot spots” are likely to cause economic losses and decrease grain quality attributes, such as mold and musty odor, change the free fatty acid levels, grain sprouting, loss in germination, and reduced milling and baking quality.

1.1.3.4 Characteristics of *S. oryzae:*

S. oryzae is a cosmopolitan insect pest but is especially abundant in warm temperate to tropical climate regions. The adult species measures between 2.5 and 4 mm, is a reddish to dark brown in color, with a long narrow snout that contains strong mandibles for chewing, and the species has an eight-segmented, elbowed and club-shaped, antennae. The species is regarded as one of the most destructive primary pests of stored rice, wheat, barley, and corn, among other commodities. Sinha and Waters (1985) report that *S. oryzae* feeding of whole grains, by both adult and larvae life developmental stages, cause kernel weight loss, fungal growth, increase in free fatty acids and moisture (Sinha 1984).

The adult female burrows a hole into a single grain kernel, deposits a single egg and seals the opening with a gelatinous plug. A female lays two to three eggs per day and between 300-576 eggs in its lifetime (Sinha and Watters 1985). Larvae feed and develop, through four instars, and pupate inside the grain kernel. Rarely will more than one adult emerge from a single kernel, primarily due to the cannibalistic behavior of the species. Following hatching, the adult chews its way out of the grain kernel, emerging through an irregular shaped hole about 1.5 mm in diameter. Complete development, under optimal conditions (27°C, 70% RH), takes 35 days; development is possible at temperatures between about 15 and 35°C (Rees 1996). The species is moderately cold-hardy but requires relatively high relative humidity to survive and complete development.

1.1.3.5 Characteristics of *O. surinamensis*:

O. surinamensis has a worldwide geographical distribution and is commonly found in areas of the world that have temperate to warmer climates. This species is a common pest of stored grain and processed cereals in Canada, US, Britain, Australia, Asia, Africa, and North and South America (Sinha and Watters 1985). Adult *O. surinamensis* are slender, flattened, parallel-sided dark-brown beetles 2.5-3.5 mm long and the prothorax has six toothlike projections along each side (Rees, 1996). O. surinamensis is cold tolerant (Howe 1956) and can survive short periods at temperatures below 0°C (Rees, 1996).

O. surinamensis is frequently associated with cereal grains and cereal products but can feed on other foodstuffs. However, *O. surinamensis* is unable to feed on sound grain but can attack grain with small lesions in the bran or germ area, completing development on the endosperm (Arbogast 1991). Eggs are laid singly or in small clusters of grain and usually deposited in crevices. The average total fecundity is about 280 eggs per female. There are typically three larvae instars, with development of larvae to pupae stage taking 12 days at 30°C and 70% rh. The optimum temperature for development is between 30-35°C. Low humidity does not prevent development of *O. surinamensis*. However, the rate of development increases with humidity, with the mean developmental period (egg to adult) ranging from 19 days at 74% rh to 24 days at 12% rh. Average adult lifespan of *O. surinamensis* ranges from 4 wks at 12% rh to 19 wks at 74% rh (Arbogast 1991).

1.1.3.6 Characteristics of *P. interpunctella*:

P. interpunctella is a cosmopolitan insect pest of stored-products and processed food commodities (Mohandass et al. 2006, Hagstrum and Subramanyam 2009). The species is likely the most economically important insect pest of processed food. Hamilin et al. (1931) reports that

P. interpunctella is the most destructive pest attacking dried fruits in storage and packing facilities in California. The species infests over 177 different commodities and has been recorded in 22 different types of facilities (i.e., processing, retail stores, warehouses, and mills) (Hagstrum and Subramanyam 2009). Infestations of stored grain are confined to the top 50-60 cm of the upper grain surface. The larvae are capable of feeding on wheat bran, germ, and endosperm (Madrid and Sinha 1982). Aitken (1943) reported that milled flour from wheat degermed by *P. interpunctella* larvae was lower in thiamine content than from normal sound wheat grain, and that the degermed wheat produced a bread loaf with an inferior loaf in volume, crumb texture, and crumb color.

P. interpunctella is an external feeder. The adults are short lived (5-7 days), with mating occurring soon after emergence. Females lay an average of 150-200 eggs but are highly variable, depending upon temperature, available food resources, and moisture content (Sedlacek et al. 1996). Eggs are typically laid on food or food packages. Larvae undergo five to seven molts, and under favorable conditions (28-32°C) require about four to five weeks to complete their development.

The last larval instar has the ability to diapause (a period of slowed or suspended growth or dormancy). Diapause can be initiated in response to environmental factors such as cold temperatures and short photoperiods. Bell and Walker (1973) reported that at temperatures below 25^{n}C and light periods below 13 h and 15 min induced larval diapauses. *P. interpunctella* larvae continuously spin a silken web both inside and on top of the food surface. Larval feeding takes place within the web, often causing particles of dry food to clump and become matted. The webbing, which often contains frass, cast skins, and can contaminate food and bind equipment (i.e., motors and augers). Thus contamination of food and equipment failure from *P. interpunctella* webbing material may be considered a direct economic loss to producers.

Hamlin (1931) reported economic impact levels of *P. interpunctella* and describes the ‘nature-of-damage’ to the California dried-fruit industry. The insect species causes significant losses to the industry each year. The economic impact is not from the quantity eaten by the insect but from the lowering of quality due to contamination of living worms, excrement, cast skins, webbing, dead insects, and the cocoons of parasites. These reduced quality factors directly increase processing costs before the product can be marketed and are considered an economic loss to the business. Additionally, the business will likely have increased production costs by the need of fumigation, extra handling of the product, rejection or seizure of shipments (which may include recall expenses), and consumer complaints (i.e., loss of consumer confidence in product brand, resulting in decreased sales).

1.2 Objectives:

The elevator boot and pit area are important sources for insect pest infestation in a commercial elevator. Knowledge of insect pest densities and commingling of insects in grain causing spread of an infestation from an elevator boot and pit area would be vital for a commercial elevator insect pest management program. The objectives of my study are to:

(a) Survey stored-grain insect pest populations in the boot area and in grain stored in silos of commercial elevators and feed mills in Kansas monthly for a two year time period and to correlate numbers found between boot area and storage bins determining the potential spread of insects from the boot/pit area to other locations.

(b) Measure the commingling levels of stored-grain insect populations in wheat and corn from pilot-scale bucket elevator boots, identify the dynamics that lead to the spread of infestations from this area to other sections of a facility, and examine the impact of a residual insecticide application to boot-pit on commingling insect densities.

(c) Compare costs associated with an elevator sanitation program with a risk-analysis study of insect commingling effects in grain elevator and feed mill storage facilities to identify the most effective and most economical pest management practices.

(d) Develop recommendations for improved science- and economics-based best management practices to control the spread of insect infestations in the grain handling and storage facilities of commercial elevators and feed mills.

This research will determine typical levels of insect infestations in commercial elevator and feed mill boot pit areas, determine spread of infestations from this area to other portions of the grain elevator, correlate insects in elevator boot pit to insects found in grain stored in silos, and determine impact of sanitation and spot or whole facility treatments on insect densities in boot pits. The dynamics of the movement of infestations will be assessed in greater detail in pilot-scale tests and with computer simulations. The ultimate goal of this project is to develop mechanistic and economic models and use them to develop best management practices for pest management programs in grain elevator and feed mill facilities.

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Chapter 2 - Commingling densities of stored-grain insect populations in wheat and corn from pilot-scale bucket elevator boots

ABSTRACT

Grain elevator boot and pit areas contribute to commingling of insects with grain that moves through the elevator leg. A removable slip-boot was developed to allow removal and preservation of residual grain in the boot to facilitate measuring the magnitude of commingling as a function of stored-product insect density in wheat and corn over time. Insect species used included two species that develop within kernels, the lesser grain borer, *Rhyzopertha dominica* (F.) and rice weevil, *Sitophilus oryzae* (L.) and three that develop outside kernels, the red flour beetle *Tribolium castaneum* (Herbst); sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.); and rusty grain beetle, *Cryptolestes ferrugineus* (Stephens). Removable boots were loaded with infested residual grain and remained undisturbed for 0, 8, 16, or 24 wk. After each of these times clean, uninfested grain was transferred through the infested boot. Adults that commingled with the clean grain transfer were sifted and counted. The discharged, commingled lots were examined after 8 wk for adult progeny produced. Insect density levels in the infested bucket elevator leg boots affected density of insects transferred through the elevator leg to other locations. Insect density in clean wheat or corn transferred over infested boots was 1 insect/kg immediately after transfer; this density increased to 2 insects/kg when the infested boot was reexamined 8 wk later. Large numbers of internally-developing insects were picked up by elevator buckets when clean grain was flowing over the infested grain when compared with that of externally-developing insects. Application of β -cyfluthrin as a residual insecticide reduced insect densities in the elevator boot which consequently reduced the collection of insects by the buckets. Monthly cleaning of the bucket elevator boot area and application of a residual insecticide should minimize insect densities and prevent cross contamination of clean grain by residual infested grain in the boot areas at elevators and feed manufacturing facilities.

Keywords: Bucket elevators, Boot pit, Residual grain, Commingling, Stored-grain insects, Sanitation, Residual insecticide, Integrated pest management

2.1 Introduction

Commercial grain elevator storage facilities can quickly become infested with stored-product insect pests (Reed et al. 2003, Arthur et al. 2006). A likely source of insect pests that infest newly-harvested grain in commercial elevators is previously infested grain carried over from one crop year to the next (Good 1937). Many areas of the grain elevator serve as potential insect pest harborage sites and contribute to insect pest persistence from one year to the next. Likely sources of elevator areas being infested are grain residues in dump pits, boot pit, empty bins, discharge spouts, head houses, spills, and residual grain in handling equipment (Dowdy and McGaughey 1996, Reed et al. 2003, Arthur et al. 2006).

The elevator boot is the enclosed base of a bucket elevator leg casing, where residual grain accumulates after the first loading of material. The elevator boot is usually located in the basement or in a sub-basement pit area. The boot pit area is often damp and the temperature is moderated by the subterranean location and can provide an ideal habitat for insect development and population growth. The elevator boot area is an important source of insect pest infestation, especially if grain is allowed to accumulate inside the elevator boot and surrounding area (Good 1937). Infestations originating in the boot pit could spread to other locations. Residual grain often remains in the boot because manual clean-out of the elevator boot is not done on a regular basis in most grain elevators. Additional grain residue accumulations in the area surrounding the boot pit can result from clean-out operations or spills from worn out spouting. Arthur et al. (2006) found the boot-pit area to have one of the two highest insect densities of five areas surveyed over a two year period at nine elevators. Insect species detected in this study were the lesser grain borer, *Rhyzopertha dominica* (F.) and rusty grain beetle, *Cryptolestes ferrugineus*

(Stephens), which are common pests of wheat in Kansas, along with the rice weevil, *Sitophilus oryzae* (L.), which was common in the grain debris but rarely found in bulk grain.

Good (1937) recommended cleaning the boot area on a frequent basis and fumigating it to manage insect pests in flour mills. Common sanitation practices in the elevator boot and pit area include removal of residual grain and application of an approved residual insecticide. Sanitation improves efficacy of applied residual insecticides to surfaces (Ingemansen et al. 1986, Herron et al. 1996). Residual grain accumulation in the elevator boot likely contributes to commingling or mixing of insects with grain that moves through the elevator leg. We found no published literature on the dynamics of insect infestation of elevator boot pit, commingling insect densities, and their likely transfer via elevator buckets to other places within the elevator grain-handling system. The objectives of this research were to: (1) measure the commingling densities of stored-grain insect populations in wheat and corn from pilot-scale bucket elevator boots, (2) identify the dynamics that can lead to the spread of infestations from this area to other sections of a facility, and (3) examine the impact of a residual insecticide application to boot-pit on commingling insect densities.

2.2 Materials and Methods

2.2.1 Boot protocol

Wheat samples were infested with unsexed adults of mixed ages of *R. dominica, C. ferrugineus*, and the red flour beetle, *Tribolium castaneum* (Herbst) at different insect population densities (50, 100, and 200 insects/kg/species); whereas corn samples were infested with adults of *S. oryzae*, the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.); and *T. castaneum* at the same density levels of wheat, four days prior to testing. Each of the grain types and treatments were tested independently using one of the Model B-3 bucket elevator legs (Universal

Industries, Cedar Falls, IA, USA) (Fig. 2-1). Three pilot-scale bucket elevator legs were retrofitted with experimental slip-boots, which could be inserted and removed with ease from the bottom of the leg. The slip-boot (29.8 by 11.4 by 6.4 cm) retained 1.9 kg of residual grain. Each grain sample used a separate slip-boot. Prior to each treatment, an empty slip-boot was installed in the bucket elevator leg. The temperature and relative humidity of the boot area was measured every minute using a HOBO® data logger (Onset Computer Corporation, Bourne, MA, USA) throughout the test period.

2.2.2 BOOT-LOADING PROCESS

All grain samples were obtained from a commercial grain elevator in Manhattan, KS, USA, and stored at -13°C for at least 4 wk to kill any live insects present. Several 2 kg samples removed from the freezer were placed in a 10 L plastic bucket and warmed to room temperature. After re-warming for 24 h, each 2 kg sample was infested with 50, 100, and 200 insect adults/kg/species or 150, 300, and 600 insect adults/kg of all three species combined. Infested samples in plastic buckets were held for 4 d in an environmental chamber (model CTH-811, Percival Scientific, Perry, IA, USA) at 27.5 ± 0.5°C and 65 ± 5% r.h., prior to passing grain through the pilot-scale elevator legs to load the boot. The infested boot-loading sample was transferred through the leg at 1.72 MT/h, filling the slip-boot with infested residual grain. Some slip-boots filled with infested grain were left in position and immediately subjected to grain transfer through the leg (time 0 wk), whereas those incubated in the environmental growth chamber for 8, 16, and 24 wk simulated a boot that has not been cleaned allowing insects populations to flourish. The incubated slip-boots were covered with a 381 µm opening sieve to allow air diffusion but prevent insect escape. Infested grain in slip-boots incubated for 0, 8, 16, or 24 wk were placed at the bottom of the leg and left undisturbed for 30 min after which the pilot-scale elevator leg was turned on and run for 30 min to obtain a feeding rate of 1.72 MT/h. After the two 30-min acclimation periods, 15 kg of insect-free grain (wheat or corn) were transferred through the slip-boot, with discharged material collected and retained for further processing. Insects in the commingled slip-boot and the discharge samples were enumerated (see below).

2.2.3 PROCESSING OF ELEVATOR GRAIN DISCHARGE SAMPLES.

The 15 kg of grain that was discharged after passing over the insect-infested slip-boot samples were collected and weighed. These samples were sifted twice using an Insectomat (Samplex Ltd., Willow Park, UK) that had a motorized inclined sieve (89 cm x 43 cm, with 1.6 mm sieve openings). All adults (live) that passed through the sieve were collected, counted, and recorded for each sample. Following the removal of all adults, each discharge sample was passed through a Boerner divider (Seed Trade Reporting Bureau, Chicago, IL, USA) twice to obtain four sub-samples each weighing 3.75 kg. One of the four sub-samples was divided in thirds (1.25 kg) and added to each of the other three sub-samples resulting in a total 5 kg/subsample. One 5 kg subsample served as a reference discharge sample and was stored at -13°C. One 5 kg subsample was used to determine grain quality following Federal Grain Inspection Standards (GIPSA 1997). The last 5 kg sample was placed in a sealed 10 L plastic bucket that had a hole in the lid of 8.25 cm diameter covered with a 381 µm opening mesh. The bucket was placed in the environmental growth chamber for 8 wk to allow internally-developing insects to emerge as adults. Adult progeny produced by initial additional of parental adults were counted and recorded. After passing 15 kg through the leg, the commingled slip-boot sample with uninfested and infested grain was sifted using an Insectomat to count adults or incubated for 8 wk as explain above to count progeny produced from immature insects developing within kernels. The control treatment consisted of insect-free grain subjected to the treatments explained above. Each grain type, insect species, density, and holding time combinations were replicated three times.

2.2.4 INSECTICIDE TREATMENTS

β-cyfluthrin (Tempo SC Ultra, Bayer CropScience, Research Triangle Park, NC, USA) of 11.8% purity (120 mg active ingredient (AI)/ml was formulated in water and applied to the enclosed area of an empty slip-boot at the high label rate of 20 mg(AI)/m^2 in 3.7 ml per m^2. Each slip-boot was sprayed with the insecticide prior to the initial loading process of insect-free grain. Immediately following the initial loading an infested grain sample, exposed to the highest insect density (600 insects/kg), was transferred through the spray treated slip-boot. The exposure period and insect-free grain transfers for the insecticide treated boot included the same two 30-minute acclimation intervals as all other boot treatments and again discharge samples were collected for final grading, processing, and analysis.

2.2.5 DATA ANALYSIS

Data on insects were expressed as live adults/kg of grain, and the insect counts included those found in samples immediately after sieving and those that emerged after 8 wk. Insect numbers found in boot or in transfer samples were subjected to two-way analysis of variance (ANOVA) to determine differences between insect densities and boot holding times (SAS Institute 2008). When a significant model effect was observed, data were subjected to one-way ANOVA and Ryan-Einot-Gabriel-Welsch (REGWQ) test to determine significant differences ($P \leq 0.05$) among insect densities or among boot holding times. Insects found in initial and 8-wk sievings were combined for all species, and the percentage of total of each species was calculated.

2.3 Results

2.3.1 INSECTS IN WHEAT BOOT AND TRANSFER SAMPLES

Insects in residual grain in the elevator boot commingled with wheat that moved through the elevator leg during testing and were carried out of the boot in the discharged (transfer) grain (Table 2-1). Very few insects were found in the transferred grain samples when compared to those found in residual grain in the boot. There were significant differences in insects found in the boot wheat samples immediately after sieving among insect densities (*F* = 9.14; df = 2, 24; *P* = 0.0013) and boot holding times (*F* = 8.84; df = 3, 24; *P* = 0.0003). The insect density and holding time interaction was also significant (*F* = 4.90; df = 6, 24; *P* = 0.0021). In initial sievings, about 9 to 23 times more insects were found after 24 wk at an insect density of 600 insects/kg when compared with the other holding times. Insects in the 600 insects/kg density in initial sieving showed a significant increase over time, except between holding times of 8 and 16 wk. At all insect densities in initial sievings, insect numbers found at 16 wk were generally lower than those found at 8 or 24 wk. Insects in wheat found after 8 wk in the boot samples were similar among insect densities (*F* = 2.97; df = 2, 24; *P* = 0.0705) and boot holding times (*F* = 2.57; df = 3, 24; *P* = 0.0778). The insect density and boot holding time interaction was not significant (*F* = 0.88; df = 6 ,24; *P* = 0.5271). The insect density (df = 2, 24), boot holding time (df = 3, 24), insect density and holding time interaction (df = 6, 24) were all not significant for insects found in wheat transfer samples in both initial and 8-wk sievings (*F*, range = 0.36 – 1.57; *P*, range = 0.2222 - 0.7034).

Adults of *R. dominica* constituted a greater percentage of the species found in both the boot and transfer grain sample sievings after 15 kg of clean wheat was transferred over the infested bucket elevator boot at each holding time and density level. At each density level, in transfer grain sievings and initial boot hold time *T. castaneum* adults was the predominate species found in the samples (Table 2-2).

2.3.2 INSECTS IN CORN BOOT AND TRANSFER SAMPLES

Few insects were found in corn transfer samples compared to the number found in the boot samples (Table 2-3). Insects in residual grain in the boot commingled with corn that moved through the elevator leg during testing and were carried out of the boot in the discharged (transfer) grain. Very few insects were found in the transferred grain samples compared to the number found in residual grain in the boot. There were no differences in insects found in the boot corn samples immediately after sieving among insect densities (F = 1.03; df = 2, 24; P = 0.3727) and boot holding times (F = 1.99; df = 3, 24; P = 0.1431). The insect density and holding time interaction was also not significant (F = 0.37; df = 6, 24; P = 0.8887). In initial sievings, 5 to 6 times more insects were found after 24 wk of holding time at an insect density of 600 insects/kg when compared with other holding times. The highest insect density level (600 insects/kg) in residual grain in the boot, after progeny emergence, at the 8-wk holding time was significantly different ($P < 0.05$) than the other two density levels. Additionally, progeny emergence in the residual grain at the highest density level showed differences between the initial boot holding time and the 8 wk holding time, but not between the 16 and 24 wk. Insects in corn found after 8 wk in the boot samples were similar among insect densities (F = 3.4; df = 2, 24; P = 0.0500) and boot holding times (F = 2.777; df = 3, 24; P = 0.0634). The insect density and boot holding time interaction was not significant (F = 1.75; df = 6 ,24; P = 0.1529). The insect density (df = 2, 24), insect density and holding time interaction (df = 6, 24) were all not significant for insects found in corn transfer samples in both initial and 8 wk sievings (F, range = 0.69 - 1.08; P, range = 0.3976 - 0.6566). The number of insects found among insect densities in the initial boot holding time were not significant (*F* = 1.09; df = 2, 24; *P* = 0.3715*);* but insect numbers among densities were different in the 8 wk holding time (*F* = 3.529; df = 2, 24; *P* = 0.0302).

Live adult *S. oryzae* constituted a greater percentage of the three species in residual grain in the boot after 15 kg of clean corn was transferred over the infested boot at each boot holding time and 150, 300, and 600 adults/kg, except after 24 wk at the lowest density where *T. castaneum* predominated (Table 2-4). Additionally, transfer grain sievings had more *S. oryzae* adults than any other species, except after the initial sievings at the lowest density and after 24 wk at the 150 and 300 adults/kg where *T. castaneum* was more abundant.

2.3.3 INSECTS IN INSECTICIDE TREATED SLIP-BOOT AND TRANSFER SAMPLES OF BOTH CORN AND WHEAT

The mean number of total insects found of all three species in insecticide treated slip-boots with wheat across all boot holding times (Table 2-5) did not vary among insect densities (*F* = 0.55; df = 3, 8; *P* = 0.6647), but varied among densities in the discharge (transfer) samples (*F* = 7.55; df = 3, 8; *P* = 0.0102). The mean number of *R. dominica* (*F* = 0.24; df = 3, 8; *P* = 0.8663), *T. castaneum* (*F* = 3.50; df = 3, 8; *P* = 0.0694), and *C. ferrugineus* (*F* = 0.96; df = 3, 8; *P* = 0.4586) found in boot samples among insect densities across all boot holding times were also not significant. Similarly, mean numbers of *R. dominica* (*F* = 2.04; df = 3, 8; *P* = 0.1869), *T. castaneum* (*F* = 3.31; df = 3, 8; *P* = 0.0781), and *C. ferrugineus* (*F* = 0.730; df = 3, 8; *P* = 0.5607) in transfer samples across all boot holding times were not significant.

However, mean total insect numbers in insecticide treated slip-boots filled with corn across all boot holding times showed significant differences among insect densities (*F* = 8.20; df = 3, 8; *P* = 0.0080); similarly significant differences were found among insect densities in discharge (transfer) samples (*F* = 4.74; df = 3, 8; *P* = 0.0349). Mean numbers of *S. oryzae* in boot-samples across boot holding times were different among the insect densities (*F* = 7.42; df = 3, 8; *P* = 0.0107), but such differences were not observed with *T. castaneum* (*F* = 3.65; df = 3, 8; *P* = 0.0636) and *O. surinamensis* numbers (*F* = 0.83; df = 3, 8; *P* = 0.5148). Mean numbers of *S. oryzae* in transfer samples were different among the insect densities (*F* = 4.77; df = 3, 8; *P* = 0.0343), but not that of *T. castaneum* (*F* = 1.50; df = 3, 8; *P* = 0.2869) and *O. surinamensis* (*F* = 2.0; df = 3, 8; *P* = 0.1927).

2.4 Discussion

Grain received by elevators typically is discharged into bins or silos for either short or long-term storage. Elevator boot areas that are infested likely contaminate clean grain when passed over the infested boot. There are no published data regarding insect infestation of elevator-stored grain from commingling of insects in the elevator boot. Little information is available on other likely infestation sources in commercial elevator facilities (Reed et al. 2003, Arthur et al. 2006). Our results clearly show that clean wheat and corn transferred over infested boots collected about 1 insect/kg during the process and after eight weeks this density had doubled. The actual number of insects transferred from the infested boot varied with the insect density (150, 300, and 600 insects/kg), boot-holding time, grain type, and the insect species.

The mean numbers of adult progeny counted immediately after sieving the residual grain from the infested wheat boots showed few differences between either insect density levels or across boot holding times. After allowing the immature insects to emerge from the residual wheat in the boot, for the longest boot holding time of 24 wk resulted in more mean adult progeny at the highest insect density level compared to the two lower levels. Additionally, in the residual wheat, adult progeny insect counts tended to increase as a function of boot holding time, with the exception at 16 wk.

Wheat samples showed few differences in mean adult progeny counts, likely due to high standard errors among the treatment combinations. Transformation of the data and non-parametric statistics did not achieve normality. Wheat transfer samples had much fewer adult progeny than in the boots and showed no differences in means for either insect density levels or boot holding times. However, insect densities recorded from the wheat boot, after 8 and 16 week holding times correlated well with the number of insects recorded immediately following a clean grain transfer. As expected, correlations (8 wk *r* = 0.91, *n* = 9; 16 wk *r* = 0.82, *n* = 9) between insects in the infested boots and insects recorded after a clean grain transfer indicate the number of insects collected in the transferred grain is proportional to the insect numbers in the residual grain.

After 8 wk of incubation (one insect generation cycle), large numbers of immature *R. dominica* progeny adults emerged from the infested wheat boot samples. Higher insect densities of *R. dominica* adults compared to *T. castaneum* and *C. ferrugineus* in 8-wk sievings in transfer samples is likely because externally-feeding adult insects (*T. castaneum* and *C. ferrugineus*) could move away from the scooping bucket cups while the immatures inside grain kernels were collected by the cups along with other kernels. As a result, a large number of *R. dominica* infested kernels were collected by the clean grain flowing over the infested grain in the boot. Storey et al. (1982) reported low (4%) initial insect infestation from grain samples collected from 79 US elevators. However, after incubating the samples (4-6 wk), further inspection showed 16% of the samples were infested with *R. dominica* species. Thus, grain kernels infested by *R. dominica* may show no indication on their exterior but could contain hidden larvae. The immobilized hidden larvae in the residual grain commingled with the clean grain passing through the infested boot and were discharged from the bucket elevator leg. Longer boot holding times of 16 and 24 wk resulted in reduced adult progeny production perhaps due to depletion of food resources, competition due to over-population or cannibalism. Sinha and Watters (1985) reported *T. castaneum* adults and larvae are omnivorous and cannibalistic insects. Cannibalism occurs in crowded and over-populated areas, where they feed on eggs and pupa (occasionally larvae) of their own or other species, likely causing reduced adult progeny production.

The mean numbers of adult progeny produced in the infested corn boot and transfer samples showed no mean differences among insect densities and boot holding times, probably due to high standard errors observed among treatment combinations. However, mean number of insects found in the boot at the 16 week boot holding time correlated (r = 0.90; n = 9) with the number of insects recorded immediately following a clean grain transfer. As with wheat, correlations between the infested boot insect density and insects in discharged grain indicates the number of insects collected in the transfer is proportional to the insect density in the residual grain.

The mean number of adult progeny found in the corn boot peaked at the 8-week boot holding time, irrespective of the insect density, and a majority of insects found were *S. oryzae*. Residual grain and discharged grain transferred over the infested corn boot usually showed higher numbers of *S. oryzae* than *T. castaneum* and *O. surinamensis* at all insect densities and boot holding times. In a few cases, *T. castaneum* numbers were greater in boot and transfer samples. As with the wheat infestations, reduced insect densities of *T. castaneum* and *O. surinamensis* in the boot may be due to over-population, depleting food resources, inter- and intra-specific competition, and/or cannibalism, especially at longer boot holding times.

Immature life stages of *S. oryzae* develop inside the grain kernel and cannot escape as the elevator bucket passes over the residual infested corn boot sample. As a result, higher numbers of *S. oryzae* were collected in transfer samples and immature life stages developed into adults by 8 wk. Similarly, the large number of *S. oryzae* found in boot samples is due to less competition as the stages are within kernels and not free-living outside of kernels as are *T. castaneum* or *O. surinamensis*.

Low mortality of *S. oryzae* could be due to this species being less susceptible to the pyrethroid insecticide cyfluthrin compared to the other species in our study. This data is consistent with studies by Samson and Parker (1989) and Arthur (1994), who showed *S. oryzae* was less susceptible than *R. dominica* to pyrethroids compared with organophosphates. Results from their studies showed that both higher application rates of cyfluthrin emulsifiable concentrate and longer exposure intervals were required to give the same control level *for S. oryzae* compared with *R. dominica*. Mortality for *T. castaneum* and *O. surinamensis* in corn was also low or zero for the initial and 8-week boot holding time for both the boot and transfer samples. Numbers of *T. castaneum* were reduced significantly in 16- and 24-wk boot holding times, may be due to continuous exposure to the insecticide. Arthur (1998) has shown that cyfluthrin residues persist on concrete surfaces of 24 wk. The highest insect mortality was after 16 weeks for both the boot and transferred samples. In the latter case, the mortality may have been due to initial exposure in the boot and/or due to impact of the moving grain, especially for the external feeders.

Infested grain accumulations in the elevator boot contributes to commingling of insects when uninfested grain that moves through the elevator leg, and is transferred to other locations such as storage bins for either short or long-term storage. A correlation was seen between insect numbers in the boot and numbers in the transfer grain due to commingling. Control samples (uninfested samples) showed no infestation in both boot and transfer grain samples at all boot holding times, which indicated that the grain used did not contain any live insects at the time of use in tests. Additionally, our results suggest that cleaning the bucket elevator leg boot will help greatly reduce insect pest infestation levels in the boot area. Monthly cleaning of the bucket elevator leg boot area, with removal and disposal of all residual grain, will likely reduce insect pest infestation levels and reduce insect pest commingling in the boot area. Additionally, insecticide treatments in the elevator boot would help complement cleaning in reducing insect infestations.

2.5 References

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Table 2.1**.** Live adults (mean ± SE) of *R. dominica*, *T. castaneum*, and *C. ferrugineus* in the residual grain and transfer grain sample sievings after 15 kg of clean wheat was transferred over an infested bucket elevator boot, which had been held for 0, 8, 16, and 24 wk.

Location[a]	Sieving periods	Density (insects/kg)	Boot holding-time (wk) 0	8	16	24[b,c]
Boot	Initial	150	137.4 ± 28.4	737.1 ± 530.2	128.4 ± 15.9	1184.0 ± 246.9b
		300	229.7 ± 58.3	1612.3 ± 756.9	1263.0 ± 1162.0	689.3 ± 346.1b
		600[d]	230.9 ± 76.5C	2558.7 ± 1109.4B	555.1 ± 158.2BC	5186.6 ± 204.9Aa
	After 8 wk[e]	150	224.1 ± 33.6	5311.4 ± 3850.9	143.5 ± 18.3	116.1 ± 80.9b
		300	93.6 ± 38.5	1250.9 ± 554.7	1794.6 ± 1533.7	43.9 ± 22.8b
		600	175.3 ± 114.1	5746.4 ± 4242.5	4064.2 ± 1085.2	4734.9 ± 552.1a
Transfer	Initial[f]	150	2.0 ± 0.6	1.9 ± 0.8	0.5 ± 0.2	1.0 ± 0.3
		300	1.6 ± 0.1	1.3 ± 0.9	1.2 ± 1.0	3.8 ± 2.4
		600	0.6 ± 0.1	3.6 ± 1.4	0.9 ± 0.8	2.2 ± 0.2
	After 8 wk[g]	150	1.9 ± 1.1	472.8 ± 462.6	5.5 ± 1.8	8.1 ± 4.6
		300	2.7 ± 1.7	6.7 ± 2.4	144.9 ± 138.8	39.3 ± 31.9

	600	11.8 ± 5.9	99.5 ± 91.0	63.9 ± 30.3	18.1 ± 2.3

[a] In the initial sieving of the boot sample differences among insect densities ($F = 9.18$; df = 2, 24), boot holding times ($F = 8.84$; df = 3, 24) ,and insect density x boot-boot holding time ($F = 4.90$; df = 6, 24) were all significant ($P \leq 0.0021$; by two-way ANOVA).

[b] In the boot initial sieving at boot holding time of 24 wk, mean live adults among insect densities followed by different lower case letters are significantly different ($F = 81.89$; df = 2, 6; $P = 0.0001$, by one-way ANOVA and REGWQ test).

[c] In the boot 8-wk sieving at boot holding time of 24 wk, mean live adults among insect densities followed by different lower case letters are significantly different ($F = 69.49$; df = 2, 6; $P = 0.0001$, by one-way ANOVA and REGWQ test).

[d] In the boot initial sieving at the 600 insects/kg density, mean live adults among boot-holdign times followed by upper case letters are significantly different ($F = 15.97$; df = 3, 8; $P = 0.0010$, by one-way ANOVA and REGWQ test).

[e] In the 8 wk sieving of the boot sample differences among insect densities ($F = 2.97$; df = 2, 24), boot-holding times ($F = 2.57$; df = 3, 24), and insect density x boot holding time ($F = 0.88$; df = 6, 24) were all not significant ($P \geq 0.0705$; by two-way ANOVA).

[f] In the initial sieving of the transfer sample differences among insect densities ($F = 0.47$; df = 2, 24), boot holding times ($F = 1.57$; df = 3, 24), and insect density x boot holding time ($F = 1.23$; df = 6, 24) were all not significant ($P \geq 0.2222$; by two-way ANOVA).

[g] In the 8 wk sieving of the transfer sample differences among insect densities ($F = 0.36$; df = 2, 24), boot holding times ($F = 1.06$; df = 3, 24), and insect density x boot holding time ($F = 0.07$; df = 6, 24) were all not significant ($P \geq 0.3833$; by two-way ANOVA).

Table 2.2. Live adults (mean ± SE) and species percentages in the residual grain and transfer grain sample sievings after 15 kg of clean wheat was transferred over an infested bucket elevator boot, which had been held for 0, 8, 16, and 24 wk.

			Mean ± SE			
				Percent of total no. insects for each species		
Sample location	Density (insects/kg	Boot hold-time (wk)	Total (insects/kg)	*R. dominica*	*T. castaneum*	*C. ferrugineus*
Boot	150	0	361.5 ± 20.7	69.8 ± 7.7	10.8 ± 2.2	19.4 ± 6.4
	300	0	323.3 ± 69.7	57.9 ± 6.9	15.5 ± 5.0	26.5 ± 11.8
	600	0	406.3 ± 182.3	50.8 ± 5.1	30.1 ± 12.1	19.1 ± 9.4
	150	8	6048.5 ± 4374.9	93.5 ± 2.9	3.3 ± 2.3	3.2 ± 0.7
	300	8	2863.3 ± 1195.7	95.7 ± 2.1	0.7 ± 0.3	3.6 ± 1.8
	600	8	8305.1 ± 5171.6	84.8 ± 6.0	5.5 ± 4.4	9.7 ± 4.7
	150	16	271.9 ± 18.2	85.2 ± 4.9	3.8 ± 0.9	11.0 ± 4.0

	300	16	3057.6 ± 3695.4	98.5 ± 0.6	0.4 ± 0.2	1.0 ± 0.4
	600	16	4619.3 ± 1157.2	96.2 ± 1.5	1.7 ± 0.5	2.1 ± 1.2
	150	24	1300.1 ± 192.7	97.2 ± 0.5	1.2 ± 0.4	1.6 ± 0.6
	300	24	733.2 ± 352.6	95.6 ± 2.2	2.3 ± 1.3	2.0 ± 1.0
	600	24	9921.4 ± 349.2	82.4 ± 5.3	0.6 ± 0.2	17.0 ± 5.4
Transfer	150	0	3.9 ± 1.5	42.7 ± 13.6	50.9 ± 14.8	6.4 ± 3.8
	300	0	4.3 ± 1.8	35.7 ± 8.5	42.3 ± 17.0	22.0 ± 22.0
	600	0	12.4 ± 5.9	18.5 ± 5.3	79.8 ± 6.5	1.7 ± 1.7
	150	8	474.7 ± 463.4	85.5 ± 9.7	12.7 ± 10.4	1.8 ± 1.5
	300	8	8.0 ± 2.9	78.8 ± 4.2	9.9 ± 4.5	11.3 ± 8.1
	600	8	103.0 ± 91.7	77.0 ± 11.3	8.4 ± 6.7	14.5 ± 9.5
	150	16	5.9 ± 2.0	98.3 ± 1.3	1.7 ± 1.3	0.0 ± 0.0
	300	16	146.0 ± 139.9	100.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	600	16	64.8 ± 30.9	99.6 ± 0.4	0.4 ± 0.4	0.0 ± 0.0

150	24	9.1 ± 4.9	99.0 ± 0.7	1.0 ± 0.7	0.0 ± 0.0
300	24	43.1 ± 34.3	92.4 ± 5.9	7.1 ± 6.1	0.4 ± 0.4
600	24	20.3 ± 2.1	99.4 ± 0.4	0.6 ± 0.4	0.0 ± 0.0

Table 2.3. Live adults (mean ± SE) of *S. oryzae*, *T. castaneum*, and *O. surinamensis* in the residual grain and transfer grain sample sievings after 15 kg of clean corn was transferred over an infested bucket elevator boot, which had been held for 0, 8, 16, and 24 wk.

Location[a]	Sievin Period	Density (insects/kg) [b]	Boot hold-time (wk) 0	8[c]	16	24
Boot	Initial[d]	150	165.9 ± 34.4	252.5 ± 31.9	446.6 ± 206.9	937.8 ± 500.9
		300	207.5 ± 40.6	462.3 ± 141.6	1120.9 ± 566.9	1412.1 ± 1347.9
		600	502.1 ± 134.4	611.5 ± 137.7	973.8 ± 88.0	3174.7 ± 2515.9
	After 8	150	262.7 ± 52.9	140.8 ± 7.9b	278.9 ± 118.5	440.9 ± 419.6
		300	247.1 ± 73.3	560.9 ± 248.0ab	1416.2 ± 615.6	384.6 ± 129.0
		600	332.4 ± 116.0 B	994.2 ± 119.5Aa	842.6 ± 184.1AB	588.0 ± 48.7AB
Transfer	Initial[f]	150	0.3 ± 0.3	0.9 ± 0.7	0.9 ± 0.5	2.8 ± 2.4
		300	0.2 ± 0.2	2.8 ± 1.5	4.9 ± 3.9	1.7 ± 1.4
		600	1.2 ± 0.5	3.2 ± 1.6	1.6 ± 0.2	3.9 ± 1.9
	After 8	150	5.7 ± 3.0	19.9 ± 17.7	15.0 ± 7.2	17.4 ± 3.6
		300	4.3 ± 1.9	44.8 ± 20.7	42.3 ± 28.9	6.1 ± 2.6

600	7.1 ± 2.6	74.4 ± 36.0	14.9 ± 1.2	23.5 ± 10.9

[a] In the 8 wk transfer sieving differences among boot holding times were significantly different (*F* = 3.52; df = 3, 24; P = 0.0302, by one-way ANOVA and REGWQ test).

[b] In the 8-wk sieving of the boot sample at the 600 insects/kg, mean live adults found among boot holding times followed by different upper case letters are significantly different (*F* = 5.29; df = 3, 8; *P* = 0.0.0265, one-way ANOVA and REGWQ test).

[c] In the boot 8 wk sieving at boot holding time of 8 wk, mean live adults among insect densities followed by different lower case letters are significantly different (*F* = 7.20; df = 2, 6; *P* = 0.0.0254, one-way ANOVA and REGWQ test).

[d] In the boot, after an initial sieving, differences among insect densities (*F* = 1.03; df = 2, 24), boot holding times (*F* = 1.99; df = 3, 24), and insect density x boot holding time (*F* = 0.37; df = 6, 24) were all not significant (*P* ≥ 0.1431; by two-way ANOVA).

[e] In the boot, after an 8 wk sieving, differences among insect densities (*F* = 3.40; df = 2, 24), boot holding times (*F* = 2.77; df = 3, 24), and insect density x boot holding time (*F* = 1.75; df = 6, 24) were all not significant (*P* ≥ 0.0500; by two-way ANOVA).

[f] In the transfer sample, after an initial sieving, differences among insect densities (*F* = 0.75; df = 2, 24), boot holding times (*F* = 1.09; df = 3, 24), and insect density x boot holding time (*F* = 69; df = 6, 24) were all not significant (*P* ≥ 0.3715; by two-way ANOVA).

[f] In the transfer sample, after an 8 wk sieving, differences among insect densities (*F* = 0.96; df = 2, 24), and insect density x boot holding time (*F* = 1.08; df = 6, 24) were all not significant (*P* ≥ 0.0.3976; by two-way ANOVA).

Table 2.4. Live adults (mean ± SE) and species percentages in the residual grain and transfer grain sample sievings after 15 kg of clean corn was transferred over an infested bucket elevator boot, which had been held for 0, 8, 16, and 24 wk.

			Mean ± SE			
				Percent of total no. insects for each species		
Sample Location	Density (insects/kg)	Boot hold-time (wk)	Density (insects/kg)	*S. oryzae*	*T. castaneum*	*O. surinamensis*
Boot	150	0	428.7 ± 19.6	63.2± 5.7	20.6 ± 3.8	16.1 ± 2.1
	300	0	454.6 ± 107.4	62.2 ± 1.4	22.4 ± 4.7	15.4 ± 5.2
	600	0	834.5 ± 210.2	46.1 ± 3.7	31.2 ± 1 5.6	22.6 ± 1.9
	150	8	393.3 ± 28.5	72.4 ± 12.6	15.2 ± 3.4	12.4 ± 9.7
	300	8	1023.2 ± 196.1	85.9 ± 3.4	8.3 ± 2.4	5.8 ± 1.2
	600	8	1605.7 ± 235.0	74.6 ± 4.5	21.4 ± 3.7	4.0 ± 1.1
	150	16	725.4 ± 285.5	86.1 ± 1.5	13.3 ± 1.2	0.6 ± 0.3
	300	16	2537.1 ± 1151.8	79.0 ± 9.5	18.9 ± 10.3	2.0 ± 1.2

	600	16	1816.4 ± 172.8	79.2 ± 11.3	19.8 ± 1.0	1.0 ± 0.5
	150	24	1378.7 ± 910.6	32.7 ± 10.9	42.7 ± 21.1	24.7 ± 19.7
	300	24	1796.7 ± 1394.6	60.3 ± 24.6	35.6 ± 26.5	4.2 ± 3.9
	600	24	3762.7 ± 2541.6	43.3 ± 8.9	36.2 ± 11.4	20.5 ± 20.2
Transfer	150	0	6.1 ± 2.9	37.3 ± 3.9	57.6 ± 2.1	5.1 ± 2.7
	300	0	4.5 ± 2.2	42.1 ± 15.8	31.5 ± 12.2	26.4 ± 20.2
	600	0	8.2 ± 2.9	53.3 ± 3.1	29.9 ± 10.7	16.8 ± 8.2
	150	8	20.8 ± 18.4	84.7 ± 6.9	11.5 ± 7.4	3.8 ± 3.6
	300	8	47.6 ± 21.5	90.3 ± 6.8	9.3 ± 6.9	0.4 ± 0.4
	600	8	77.6 ± 37.6	91.7 ± 2.9	6.0 ± 1.9	2.2 ± 2.2
	150	16	15.9 ± 7.5	86.1 ± 6.7	13.9 ± 6.7	0.0 ± 0.0
	300	16	47.3 ± 32.8	86.3 ± 6.6	13.7 ± 6.6	0.0 ± 0.0
	600	16	16.6 ± 1.3	80.9 ± 11.4	19.1 ± 11.4	0.0 ± 0.0
	150	24	20.2 ± 2.8	26.3 ± 13.1	39.3 ± 19.7	34.4 ± 32.8
	300	24	7.8 ± 2.8	46.0 ± 23.1	53.0 ± 22.2	1.0 ± 0.9

600	24	27.5 ± 9.6	84.0 ± 13.0	16.0 ± 13.0	0.0 ± 0.0

Table 2.5. Live adult insect densities (mean ± SE) and mortality percentages from the residual grain and transfer grain samples after an insecticide (10% β-cyfluthrin SC ultra) spray treatment of the slip -boot and 15 kg of clean wheat was transferred over the insecticide treated slip-boot with boot hold times of 0, 8, 16, and 24 wk.

			Boot-hold time (wk)			
Sample location	Insect species[a]	Density (insects/kg)/ Mortality (%)	0	8	16	24
Boot[b]	*R. dominica*	Density	147.1 ± 73.2	199.2 ± 56.8	163.4 ± 70.3	214.4 ± 51.6
		Mortality	100 ± 0	100 ± 0	100 ± 0	100 ± 0
	T. casteneum	Density	117.8 ± 18.3	130.9 ± 18.8	63.1 ± 8.8	230.3 ± 69.1
		Mortality	100 ± 0	100 ± 0	100 ± 0	100 ± 0
	C. ferrugineus	Density	178.8 ± 88.9	92.0 ± 10.8	97.6 ± 21.5	72.9 ± 26.5
		Mortality	90 ± 1 0	100 ± 0	100 ± 0	100 ± 0
	All species	Density	443.7 ± 177.8	422.1 ± 77.9	324.0 ± 43.6	517.6 ± 84.2

		Mortality	97.2 ± 0	100 ± 0	100 ± 0	99 ± 0.1
Transfer[c]	*R. dominica*	Density	0.4 ± 0.2	0 ± 0	0.2 ± 0.1	0 ± 0
		Mortality	52.4 ± 0.3	0 ± 0	66.7 ± 0.3	0 ± 0
	T. casteneum	Density	1.0 ± 0.5	0.1 ± 0.1	0.2 ± 0.2	0 ± 0
		Mortality	77.8 ± 0.2	0 ± 0	0 ± 0	0 ± 0
	C. ferrugineus	Density	0 ± 0	0 ± 0	0 ± 0	0 ± 0
		Mortality	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	All species	Density	1.5 ± 0.3a	0.1 ± 0.1b	0.4 ± 0.3b	0.1 ± 0.1b
		Mortality	33 ± 0.2	0 ± 0	33 ± 0	0 ± 0

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[a] In the transfer grain samples, total insect density means among boot hold-times (0, 8, 16, and 24 wk) were significantly different (*F* = 7.55; df = 3, 8; *P* = 0.0102, REGWQ).

[b] In the boot, mean insect densities among boot-hold time (0, 8, 16, and 24 wk) for insect species *R. dominica* (F = 0.24; df = 3, 8), *T. casteneum* (*F* = 3.5; df = 3, 8), *C. ferrugineus* (F = 0.96; df = 3, 8) and total (*F* = 0.55; df = 3, 8) were all not significant ($P \geq 0.0694$; by one-way ANOVA and REGWQ test).

[c] In the transfer grain samples, mean insect densities among boot-hold time (0, 8, 16, and 24 wk) for insect species *R. dominica* (*F* = 2.04; df = 3, 8), *T. casteneum* (*F* = 3.31; df = 3, 8), and *C. ferrugineus* (*F* = 0.73; df = 3, 8) were all not significant ($P \geq 0.0781$; by one-way ANOVA and REGWQ test).

Table 2.6. Live adult insect densities (mean ± SE) and mortality percentages from the residual grain and transfer grain samples after an insecticide (10% β-cyfluthrin SC ultra) spray treatment of the slip -boot and 15 kg of clean corn was transferred over the insecticide treated slip-boot with boot hold times of 0, 8, 16, and 24 wk.

Sample location	Insect species	Density (insects/kg)/ Mortality (%)	Boot-hold time (wk) 0	8	16	24
Boot[a, b, c]	*S. oryzae*	Density	237.7 ± 82.2b	400.0 ± 105.5b	481 ± 182b	5935.7 ± 2031.0a
		Mortality	0 ± 0	0 ± 0	96 ± 0	33 ± .3
	T. casteneum	Density	177.2 ± 36.7	237.2 ± 43.8	62.4 ± 18.6	97.3 ± 56.6
		Mortality	33 ± 0.3	0 ± 0	91 ± 0.1	67 ± 0.3
	O. surinamensis	Density	120.7 ± 40.5	192.4 ± 22.8	88.9 ± 36.7	89.2 ± 89.2
		Mortality	33 ± 0.3	0 ± 0	99 ± 0	33 ± 0.3
	All species	Density	535.5 ± 32.7b	829.7 ± 169.3b	631.9 ± 138.9b	6122.2 ± 1894.8a
		Mortality	22 ± 0.1	0 ± 0	95 ± 0	45 ± 0.2

Transfer[d, e, f]	*S. oryzae*	Density	1.6 ± 0.6	0.2 ± 0.2	0.5 ± 0.2	24.9 ± 11.0
		Mortality	0 ± 0	0 ± 0	61 ± 0.2	36 ± 0.3
	T. casteneum	Density	0 ± 0	0.1 ± 0.1	0 ± 0	0 ± 0
		Mortality	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	O. surinamensis	Density	0.1 ± 0.0	0.1 ± 0.0	0 ± 0	0 ± 0
		Mortality	0 ± 0	0 ± 0	0 ± 0	0 ± 0
	All species	Density	1.7 ± 0.5	0.4 ± 0.1	0.5 ± 0.2	24.9 ± 11.0
		Mortality	0 ± 0	0 ± 0	31.5 ± 0.1	11.9 ± 0.1

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[a] In the boot, insect species *S. oryzae* mean densities among boot hold-times (0, 8, 16, and 24 wk) followed by different lower case letters were significantly different (F = 7.42; df = 3, 8; P = 0.0107, by one-way ANOVA and REGWQ test).

[b] In the boot, total insect density means among boot hold-times (0, 8, 16, 24) followed by different upper case letters were significantly different (F = 8.20; df = 3, 8; P = 0.0080, by one-way ANOVA and REGWQ test).

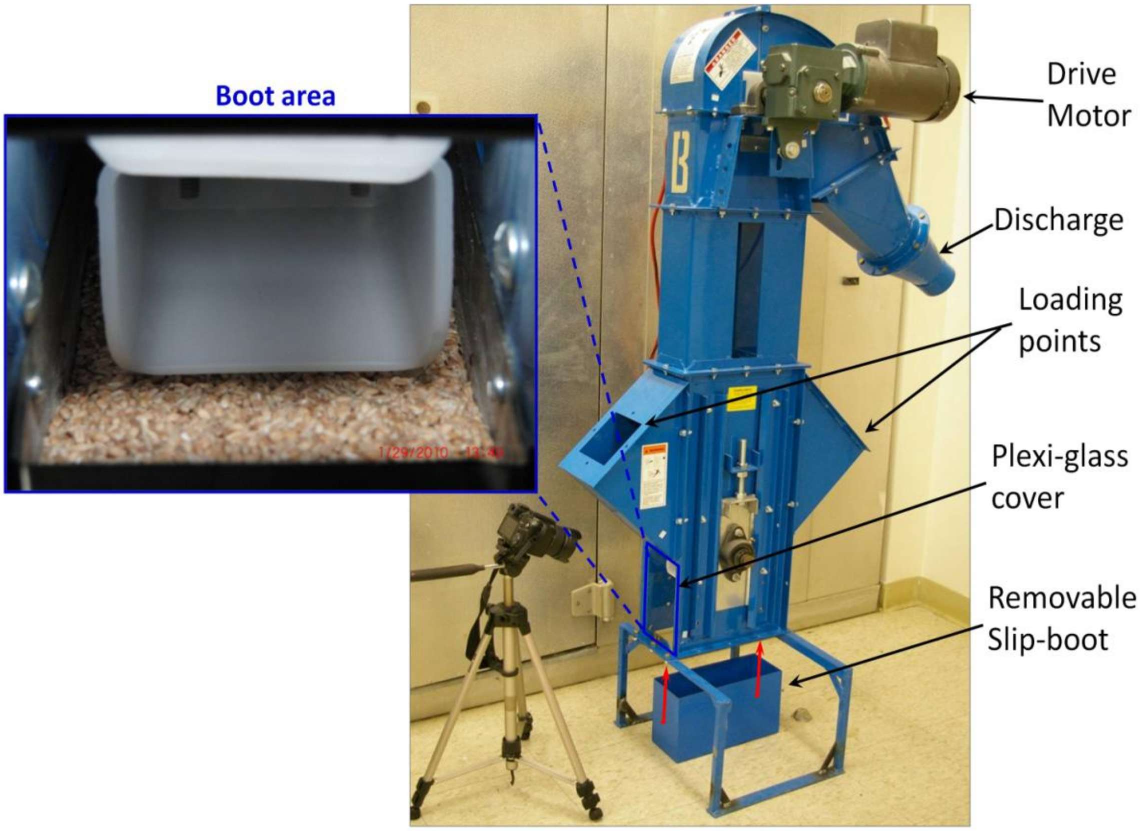
[c] In the boot, mean insect densities among boot-hold time (0, 8, 16, and 24 wk) for insect species *T. castaneum* (F = 3.65; df = 3, 8), and *O. surinamensis* (F = 0.83; df = 3, 8) were all not significant ($P \geq 0.0636$; by one-way ANOVA).

[d] In the transfer grain samples, for insect species *S. oryzae*, mean insect densities among boot-hold time (0, 8, 16, and 24 wk) were significantly different (F = 4.77; df = 3, 8; $P \geq 0.0343$; by one-way ANOVA).

[e] In the transfer grain samples, for total insect densities, means among boot-hold time (0, 8, 16, and 24 wk) for insect species were significantly different (F = 4.74; df = 3, 8; $P \geq 0.0349$; by one-way ANOVA).

[f] In the transfer grain samples, mean insect densities among boot-hold time (0, 8, 16, and 24 wk) for insect species *T. castaneum* (F = 1.50; df = 3, 8), and *O. surinamensis* (F = 2.00; df = 3, 8) were all not significant ($P \geq 0.1927$; by one-way ANOVA).

Figure 2.1. Pilot-scale bucket elevator leg boot arrangement.



Chapter 3 - Temporal changes in stored-product insect populations associated with boot, pit and load-out areas of grain elevators and feed mills

ABSTRACT

Commercial grain elevator and feed mill facilities can quickly become infested with stored-product insect pests, compromising the protection of the raw and processed cereal products stored at each facility type. Grain facilities of each type were sampled monthly for adults of stored-product insects in grain residues from the boot (pit) areas and bulk load-out samples during 2009-2010.over two Impact of boot (pit) cleaning and insecticide spray treatments on insect densities in each location was determined, by correlating insect density between the boot (pit) areas and grain storage bins. Low insect densities were recorded from the boot (pit) area during the cool winter months. Insect counts increased in the spring and peaked during the warm summer months before declining in the fall. The rice weevil, *Sitophilus oryzae* (L.) was the most prevalent species collected in all grain residues sampled and comprised 34 and 45% of total insects collected during 2009 and 2010, respectively. Other commonly collected insect species included: the red flour beetle, *Tribolium castaneum* (Herbst); rusty grain beetle, *Cryptolestes ferrugineus* (Stephens); and sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.). Our results show monthly boot and pit cleaning is critical in preventing pest population explosions during the warm summer months. We recommend new facility pest management sanitation guidelines of the boot and pit area to include (1) boot residual grain clean-out every 30 d, (2) removal of grain spillage and floor sweepings from the pit area, and (3) proper disposal of boot and pit residual grain. These boot and pit sanitation guidelines could be used to improve elevator and feed mill insect pest management programs.

Keywords: Elevator, Feed mill, Boot, Pit, Residual grain, Sanitation, Insect pests.

3.1 Introduction

Grain elevators and feed mills, with constant availability of abundant food sources and relatively warm environments during most of the year, provide an ideal habitat for stored-product insect pest infestations. Management of stored-product insects in raw or processed grain commodities requires correct identification of the pest, knowledge of their life histories, spatial and temporal dynamics, and susceptibility to chemical and non-chemical management methods (Aitken 1975, Hagstrum and Subramanyam 2006). Surveys of grain elevators found 13 different insect species within and outside the elevators (Dowdy and McGaughey 1998, Reed et al. 2003, Arthur et al. 2006). Reed et al. (2003) reported that most of the grain residue samples (~80%) collected from empty bins were infested with insect pests. The authors concluded that cleaning empty bins resulted in a reduced insect population density in the discharge spouts. Arthur et al. (2006) reported grain residue samples obtained from the boot-pit and tunnel areas had the highest insect densities from the many facility area locations sampled. Dowdy and McGaughey (1998) emphasized the quality of sanitation practices were highly correlated with insect populations, with poor elevator sanitation practices resulting in substantially higher insect populations.

Stored-product insect populations have been found in commercial feed mills year-round (Mills and White 1993), because of warm temperatures in production areas, the accessibility of cereal grain products in raw and processed form, and improper sanitation and/or pest management (Rilett and Weigel 1956, Triplehorn 1965, Loschiavo and Okumura 1979, Pellitteri and Boush 1983, Larson et al., 2008). These surveys reported finding 23 to 100 different insect species within feed mills. The types and numbers found varied with the type of feeds manufactured at the mill. The sources of these insects were not reported in these papers, but mills cleaned every two weeks had fewer insect species and numbers than those that were not frequently cleaned (Rillett and Weigel 1956, Larson et al. 2008). Larson et al. (2008) sampled eight Midwestern feed mills in the United States and found insect numbers to be greater during the summer than during winter, spring, and fall, and a few species were also found outside the feed mills. Outdoor insects at elevators and feed mills can be a source of reinfestation if doors and windows are not closed to prevent entry of these insects into elevators and feed mills.

In both grain elevators and feed mills, insect pest management starts with good sanitation of floor areas and pieces of equipment where grain and/or grain dust accumulates (Gill 1994, Pedersen 1994). Good (1937) sampled 19 flour mills in Kansas, Missouri, and Oklahoma and found high densities of *Tribolium* spp., the rice weevil, *Sitophilus oryzae* (L.); and lesser grain borer, *Rhyzopertha dominica* (F,), in boot-pit areas. Arthur et al. (2006) also reported the boot-pit area to have high insect densities of *Sitophilus*, *Tribolium*, and *Cryptolestes* species. Infestations in boot-pit can be transfered to other areas of the facility as the elevator buckets collect infested grain from the boot area. Comingling of grain and insects can occur in the boot area, and the number of insect found is a function of time and initial density of insects infesting this area (Tilley et al. 2013). The temporal dynamics of insect infestations in elevator boot pit areas has not been studied, although Wagner and Cotton (1935) give control measures of a general fumigation supplemented by cleaning out the elevator boots every two weeks as a means of reducing overall insect populations in flour mills. The objectives of this study were to determine types and numbers of stored-grain insect species found in the boot (pit) area and in grain stored in silos of commercial elevator and feed mill facilities in Kansas sampled monthly during 2009-2010, and to correlate numbers found between boot area and storage bins determining potential spread of insects from the boot/pit area to other locations. No comparisons between grain elevators and feed mills are made, because feed mills have a complex of major and minor ingredients of cereal and non-cereal origin in whole or processed form, whereas grain elevators predominantly handle one or two types of whole grains.

3.2 Materials and Methods

3.2.1 INSECT SAMPLING IN BOOT-PIT AREA

Three commercial elevator and three feed mill facilities in Kansas were visited monthly during 2009 and 2010 to collect spilled grain samples from the elevator boot, pit, and load-out areas. The boot and pit area temperatures at each elevator and feed mill site were measured hourly using HOBO® data loggers (Onset Computer Corporation, Bourne, MA, USA). Spilled grain from each boot and the pit area was accessed through the slide gate used for cleaning operations. Whole grain samples were also collected from load-out areas of each facility, by opening a slide gate by personnel at the facility. Two 1-kg samples were collected from each boot, pit, and load-out locations. Labeled samples were transported to the laboratory within a day of collection where they were weighed, and analyzed. Each grain sample was passed first through a 2.38 mm opening sieve, followed by a 0.59 m bottom sieve placed above a collection pan to separate insects from the grain samples.

In addition to collecting spilled grain samples from the boot-pit area, commercial food-baited pitfall traps (Dome Trap; Trécé, Adair, OK, USA) were placed on the floor at each facility next to the boot in the boot-pit area. The food bait included 15 drops of a proprietary oil supplied by the manufacturer. The cover of the pitfall trap was fitted with an aggregation pheromone lure, also from Trécé, to capture *Tribolium* spp. (Obeng-Ofori 1990). In each boot-pit area a sticky trap (Storgard II; Trécé) with three pheromone lures was hung at eye level (2 m) above the boot). The three lures included an aggregation pheromone lure for the lesser grain borer, *R. dominica* (F.); a sex pheromone lure each for the Indianmeal moth, *Plodia interpunctella* (Hübner), and the warehouse beetle, *Trogoderma variabile* (Ballion). Both the pitfall and sticky traps were collected monthly and replaced with new traps, food-baited oil, and pheromones.

The types and numbers of adult insect species found in spilled grain samples and whole grain from boot, pit, and load-out areas, and those captured in pitfall and sticky traps were counted. The number of insects found in grain samples in the boot, pit, and load-out locations was an average of two samples and insect density was expressed on a per kg basis, whereas insects density in traps was corrected for the duration of trapping and was expressed number of insects per trap per 30 d.

3.2.2 DATA ANALYSIS

Insect density, across all insect species found during 2009 and 2010, in grain samples and traps by elevator and feed mill was plotted as a function of sample collection time. The temperature data from the HOBO® data-logging units was also plotted as a function of time and overlaid on insect density data to determine if insect numbers fluctuated with temperature increases. The percentage of each insect species found in 2009 or 2010 was calculated from the total adults collected during those years for elevators and feed mills. Similarly, the percentage of each insect species found in pitfall and sticky traps in 2009 or 2010 in each type of facility was calculated.

In order to compare insect density differences between years and over time, insects collected monthly the following adjustments were made to the data. Insect density in elevators (boot, pit, and load-out samples as well as pitfall traps) included *Cryptolestes* spp., *Sitophilus* spp., and *Tribolium* spp. In feed mills, insect density in grain samples collected from boot, pit, and load-out areas and those from pitfall traps included *Cryptolestes* spp., *Oryzaephilus* spp., *Sitophilus* spp., and *Tribolium* spp. Insects in sticky traps included three species namely *P.interpunctella*, *R. dominica*, and *T. variabile*. The collection times for both facility types, irrespective whether density of the insect species was based on grain samples or traps, were assigned to winter, spring, summer, and fall seasons, and included collection months of January through March, April through June, July through September, and October through December, respectively. Insect density data from grain samples or traps (x) for feed mills or elevators were subjected to two-way analysis of variance (ANOVA) (SAS Institute 2008), after transformation of insect counts to logarithmic scale ($x + 1$), to determine differences among the two years of sampling and among the four seasons. These same data were analyzed further by year using one-way ANOVA to determine differences in insect density among the seasons. If ANOVA was significant ($P < 0.05$), means among seasons were separated by Ryan-Einot-Gabriel-Welsch multiple comparison test.

3.3 Results

3.3.1 INSECTS IN GRAIN SAMPLES

Insect numbers collected from the boot, pit, and load-out areas in feed mill facilities were three to six times higher than in elevator facilities during 2009 and 2010 (Table 1). The most common and abundant insect pest species collected from feed mill facility boot, pit and load-out samples were *C. ferrugineus, O. surinamensis*, *S. oryzae*, and *T. castaneum*. Common insect genera collected from elevator facility boot, pit and load-out samples were *C. ferrugineus, S. oryzae,* and *T. castaneum*. Other minor insect species collected at each facility type were the foreign grain beetle, *Ahasverus advena* (Waltl)*; Carpophilus* spp., longheaded flour beetle, *Latheticus oryzae* Waterhouse; small-eyed flour beetle, *Palorus ratzeburgi* (Wissmann); *Philonthus* spp., *R. dominica, T. variabile,* and the hairy fungus beetle, *Typhaea sterorcea* (L.).

Insect numbers from feed mills collected from pitfall traps were four to seven times higher than elevator facilities during 2009 and 2010 (Table 2). The most common and abundant insect species collected from feed mill and elevator facility pitfall traps was *C. ferrugineus, S. oruzae*, and *T. castaneum*. Numbers of *P. ratzeburgi* in pitfall traps peaked during 2009 in elevator facilities and *T. variabile* peaked in feed mill facilities during 2010. Other minor species collected at each facility type were the larger black flour beetle, *Cyaneus angustus* (LeConte), *Oryzaephilus* spp., and yellow mealworm*, Tenebrio molitor* L. The most common insect species collected from sticky traps were *P. interpunctella* and *T. variabile* at both facility types during both years (Table 3). During 2010 feed mills had more *P. interpunctella* than elevators. However, elevators had more *T. variabile* than feed mills during the same trapping year.

Two-way ANOVA showed that insect numbers in grain samples in the elevator boot (df = 1, 64), pit (df = 1, 64), and load-out (df = 1, 40) areas were not significantly different between the two years (*F*, range among locations = 0.11 – 1.87; *P*, range = 0.1763 – 0.7378). However, insect numbers in grain samples in the elevator boot (df = 3, 64) and pit (df = 3, 64) areas were significantly different among the four seasons (*F*, range = 7.41 – 9.24; $P < 0.0002$), but not load-out areas ($F = 1.71$; df = 3, 40; $P \leq 0.1800$). The interaction of year and seasons was not significantly different for insect numbers found in the boot (df = 3, 64), pit (df = 3, 64), and load-out (df = 3, 40) samples (*F*, range = 0.15 – 1.50; *P*, range = 0.2290 – 0.9316). There were significant differences among seasons in insect numbers found during 2009 and 2010 in the pit (*F*, range = 3.43 – 4.45; df = 3, 32; $P < 0.0285$; one-way ANOVA) and boot (*F* =, range = 4.61 – 4.77; df = 3, 32; $P < 0.0086$; one-way ANOVA) areas (Table 5). In pit and boot areas where significant differences among seasons were observed in 2009 and 2010, insect numbers during the summer months were 2 to 122 times greater ($P < 0.05$) than those observed during the winter, spring, and fall months. In general, insect numbers gradually increased from winter and spring months and peaked during the summer months with a decrease during the fall months. Very few insects were collected in load-out samples and numbers in 2009 and 2010 were similar among the seasons (*F*, range among seasons and years = 1.38 – 1.93; df = 3, 20 (2009); 3, 20 (2010); $P > 0.2782$). During the summer months of 2010, 14 to 51 times more insects were observed in the pit area compared with the other seasons, but differences among seasons were not significant (F = 3.43; df = 3, 32; P > 0.0285), because of the large variation in insects found.

Two-way ANOVA showed that insect numbers in grain samples in the boot area of feed mills were significantly different between the two years ($F = 30.47$; df = 1, 61; $P \leq 0.0001$). However, insect numbers in grain samples in the pit (df = 1, 61) and load-out (df = 1, 33) areas were not significantly different between the two years (*F*, range among locations = 0.23 – 2.32; *P*, range = 0.1326 – 0.6347). Insect numbers in grain samples in the feed mill boot (df = 3, 61) and pit (df = 3, 61) areas were significantly different among the four seasons (*F*, range = 6.71 – 11.65; $P < 0.0005$), but the load-out areas ($F = 0.64$; df = 3, 33; $P \leq 0.0807$) did not have such differences. The interaction of year and seasons was not significant for insect numbers found in the boot (df = 3, 61), and load- out (df = 2, 33) samples (*F*, range = 0.21 – 2.67; *P*, range = 0.0553 – 0.8111). However, year and season interaction was significant for the pit area (F = 6.81; df = 3, 61; $P = 0.0005$) of feed mill facilities. One-way ANOVA showed that only the insect numbers found in the pit (df = 3, 32) and boot (df = 3, 32) areas were significantly different among seasons (*F*, range = 4.45 – 4.61; $P < 0.0101$) during 2009 (Table 5). During 2010, only insect numbers in the boot area were different among seasons ($F = 4.77$; df = 3, 32; $P < 0.0074$). In cases where significant differences among seasons was observed, insect numbers during the summer months were generally 23 to 64 time greater ($P < 0.05$) than those found during the winter months. Unlike insect numbers observed at elevators, in feed mills insect numbers during the summer months were similar to those found during fall and spring months. Very few insects were found in load-out samples and differences among seasons were not significant (*F*, range = 1.38 – 1.93; df = 3, 20 (2009), 3, 20 (2010); $P > 0.2782$). Although in 2010, insect numbers in the pit area during the summer months was two to five times greater than during the other seasons, but differences among seasons were not significant ($F = 2.89$; df = 3, 32; $P > 0.0506$), because of the large variation in insects found.

3.3.2 TEMPERATURES IN BOOT PIT AREA

Two-way ANOVA showed that the temperatures observed in the pit area at elevators (df = 1, 64) and feed mills (df = 1, 64) were not different between the two years (*F*, range = 0.51 – 2.78; $P > 0.4784$). However, temperatures at elevators (df = 1, 64) and feed mills (df = 1, 64) were significantly different among seasons (*F*, range = 0.51 – 2.78; $P < 0.0001$). The years and season interaction was not significantly different for elevators ($F = 0.64$; df = 3, 64; $P > 0.5928$) and feed mills ($F = 1.57$; df = 3, 64; $P > 0.255$). One-way ANOVA showed significant differences in temperatures among seasons at elevators and feed mills in 2009 (*F*, range = 28.04 – 32.56; df = 3, 32 (elevators), 3, 32 (feed mills); $P < 0.0001$) and 2010 (*F*, range between facilities = 34.97 – 54.26; df = 3, 32 (elevators),3, 32 (feed mills); $P < 0.0001$) (Table 5). Temperatures during the spring and summer months for 2009 and 2010 were significantly greater ($P < 0.05$) than temperatures during the winter and fall months. However, at feed mills, the temperatures during summer months of 2009 and 2010 were significantly greater ($P < 0.05$) than temperatures during winter, spring, and fall months. Generally, temperatures during the winter were significantly lower ($P < 0.05$) at elevators and feed mills when compared with other seasons.

3.3.3. INSECTS IN TRAP SAMPLES

Two-way ANOVA showed that insect collections from elevator pitfall (df = 1, 58) and sticky (df = 1, 58) traps were not significantly different between the two years (*F*, range = 0.03 – 0.37; *P*, range = 0.5463 – 0.8576). However, insect collections from pitfall (df = 3, 58) and sticky (df = 3, 58) traps were significantly different among the four seasons (*F*, range = 7.61 – 31.47; $P < 0.0002$). The interaction of year and seasons was not significantly different for insect collections from pitfall (df = 3, 58) and sticky (df = 3, 58) traps (*F*, range = 0.61 – 1.99; *P*, range = 0.1251 – 0.6143). There were significant differences among seasons in insect collections from pitfall ($F = 7.73$; df = 3, 62; $P < 0.0002$; one-way ANOVA) and sticky ($F =38.35$; df = 3, 62; $P < 0.0001$; one-way ANOVA) traps (Table 5). Elevator pitfall traps were significantly different among seasons during the two year survey, insect collections during the summer and fall months were 4 to 37 times greater ($P < 0.05$) than those observed during the winter and spring months.

However, elevator sticky trap insect collections during the summer were significantly higher (*P* < 0.05) than the other seasons.

Two-way ANOVA showed that insect collections from feed mill pitfall (df = 1, 57) and sticky (df = 1, 57) traps were not significantly different between the two years (*F*, range = 2.05 – 2.74; *P*, range = 0.1034 – 0.1582). However, insect collections from pitfall (df = 3, 57) and sticky (df = 3, 57) traps were significantly different among the four seasons (*F*, range = 10.89 – 23.35; *P* < 0.0001). The interaction of year and seasons was not significant for insect collections from pitfall (df = 3, 57) and sticky (df = 3, 57) traps (*F*, range = 0.19 – 0.23; *P*, range = 0.8724 – 0.9026). There were significant differences among seasons in insect collections from pitfall (*F* = 12.19; df = 3, 61; *P* < 0.0001; one-way ANOVA) and sticky (*F* =25.69; df = 3, 61; *P* < 0.0001; one-way ANOVA) traps (Table 5). Feed mill pitfall trap insect collections during the summer and fall months were 12 to 243 times greater (*P* < 0.05) than those observed during the winter and spring months. However, feed mill sticky trap insect collections during the summer were significantly higher (*P* < 0.05) than the other seasons.

3.4 Discussion

A total of 12 different insect species were found in elevator and feed mill facility boot, pit, and load-out locations during monthly sampling of a two year survey. The most common and abundant species collected from feed mill facility locations was *C. ferrugineus, O. surinamensis, S. oryzae*, and *T. castaneum*. The most abundant species collected from elevator facility locations was *C. ferrugineus, S. oryzae,* and *T. castaneum*. Good (1937) sampled 24 elevator boots and other mill stream fractions from Midwest flour mills finding 19 different insect species. A total of 1202 live adult insects were collected from the whole wheat boot location, with the most common and abundant species was *Sitophilus* spp. which represented 23.8% of the total insects found; *Tribolium* spp. and *R. dominica* constituted 34.6% and 21.7% of the total insects found, respectively.

Insect counts from all sampling locations (boot, pit, and load-out) showed *S. oryzae* was the most prevalent insect pest found in feed mill and elevator facilities, comprising a maximum of 69.2% and 35.8% respectively during 2009 (Table 3-1). Arthur et al. (2006) reported *Sitophilus* spp. was in 46.2% of all grain elevator residue samples. Reed et al. (2003) found *Sitophilus* spp. commonly associated with grain residue left inside empty bins, comprising about one-third of all pests collected. *T. castaneum* and *C. ferrugineus* were frequently collected in each location of both feed mill and elevator facilities during both sampling years. Other stored-grain pests less frequently found in all trapping locations of both feed mill and elevator faculties were *O. surinamensis* and *A. advena*. Reed et al. (2003) frequently observed species of *Cryptolestes, Oryzaephilus,* and *Sitophilus* in grain residues from the bottom of empty elevator silos and from discharge spouts.

Insect pest numbers collected from monthly residual grain samples of feed mill (Fig. 3-1) and elevator (Fig. 3-2) facilities increased during warm summer months (July and August) of both years before declining during the fall. Low insect densities were recorded from area locations (boot, pit, and load-out) during cold winter months of both facility types. Insect pest population peaks commonly occurred in the pit area, especially during the warmest seasonal periods of both feed mill and elevator facilities. However, insect numbers peaked in either the boot or pit locations during cooler months when sanitation practices did not occur. Increased insect densities in the boot or pit area are likely due to unsanitary conditions, and insects increase the temperature due to their infestation and activity (Cotton et al. 1960). Observations indicated that the boot or pit was not cleaned during this time period. Cleaning and disposing of the boot residual grain material will likely reduce insect counts and reduced the likelihood of future insect infestation levels from the boot or pit area. Pellitteri and Boush (1983) reported insect infestation levels were directly proportional to the quantity of residual grain found on the floor in a given area of a facility.

Insect populations from both pitfall and sticky traps peaked during the warm summer months of both trapping years in elevators (Fig. 3-3) and feed mills (Fig. 3-4). However, insect populations from pit fall traps peaked during November and December of 2010 in feed mill 2 (FM2), likely due to decreased sanitation in the pit area of this facility. Monthly observations indicated that the pit area was not cleaned during this time period. Total insect counts from pitfall traps were higher in feed mills compared to elevator facilities during both trapping years, perhaps due to sanitation practices adopted by each facility.

Insect populations that persist through the winter months likely contribute to increased insect pest activity during the summer months. Rilett and Weigel (1956) concluded that sanitation practices and insect control must be continued throughout the entire year, even during winter when insect numbers may be low, because residual breeding stocks carried over inunfavorable environments within the mill facility may account for increased insect pest activity during the warm summer months.

Low insect densities from load-out areas of both elevator and feed mill facilities may be due to the volume of stored-grain being higher than the amount of grain residues found in boot and pit areas. The volume of grain in a storage bin would dilute the number of insects found. Flinn et al. (2010) reported similar results from a survey of commercial grain elevator facilities, with insect densities in grain residues were more than 10 times greater than those in the grain stored in bins.

Differences between mean insect densities, locations, and facility types are likely due to sanitation practices adopted by each facility. Rilett and Weigel (1956) conducted an insect pest survey of 11 feed and flour mills near Buffalo, NY, USA. The authors concluded insect control is achieved by good sanitation practices, which included cleaning crack and crevice floor locations containing refuse every 2 wk throughout the entire year reduced the number of insects carried over to favorable environments during warm seasonal months. Tilley et al. (2013) reported a model showed boot sanitation (clean-out) on a regular basis avoids costly grain discounts from insect commingling and increases facility net income.

Personnel at elevators and feed mills should thoroughly clean the boot and pit areas every 30 d to reduce and possibly eliminate insect pest harborage areas. Cleaning the boot and pit areas on a 30 d cycle corresponds to insect generation length of four to six weeks, preventing eclosion of immature to the adult stage and reproduction (Hagstrum and Subramanyam 2006). Frequent clean-out of the boot residual grain, with removal of floor sweepings and grain spillage from the pit and other facility area locations, with proper disposal will likely reduce insect pest harborage. Maintaining good sanitation practices, eliminating insect pest refuse areas, will likely reduce insect pest carry over from one year to the next.

The importance of year-round sanitation practices is critical in preventing insect pest population explosions during the warm seasonal summer months. Mills and White (1993) emphasized the importance of year-round sanitation in all areas to reduce insect population explosions during the warm seasonal summer months. Elevator and feed mill managers' knowledge of insect species diversity, insect population densities, and commingling of insects in clean grain causing spread of an infestation from an elevator boot and pit area is vital for elevator and feed mill insect pest management programs. Insect density levels in infested bucket elevator leg boots affect the level of insects transferred through the elevator leg to other locations within a facility. Recent laboratory studies of insect densities in clean wheat or corn transferred over infested boots was 1 insect/kg immediately after the clean grain transfer; increasing to 2 insects/kg after an 8 wk slip-boot holding time (Tilley 2013). The density increase after the holding time, was due to the large numbers of internally developing insects being picked-up by clean grain flowing over the infested boot residual grain. Bucket elevator boot and pit sanitation that should be conducted by facility managers requires a boot residual grain clean-out every 30 d as well as removal and disposal of residual grain, floor sweepings, and grain spillage from the pit area. Frequent clean-out of the boot residual grain and general sanitation of the pit area should reduce the number of insects of both external and internal infesters that are picked-up in the boot area and transferred to other locations of a facility.

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Table 3.1. Total number of live adult insects and species percentages collected from three feed mill and three elevator facilities during monthly visits in 2009 and 2010.

	% of total live adults found in:			
	Feed mills		Elevators	
Species	2009	2010	2009	2010
A. advena	—[a]	1.0	0.3	1.4
Carpophilus spp.	—	—	0.5	—
C. ferrugineus	4.2	15.4	29.4	49.3
L. oryzae	—	—	4.1	—
O. surinamensis	21.2	11.8	—	0.3
P. ratzeburgi	—	—	0.6	—
Philonthus spp.	—	—	0.3	0.2
R. dominica	0.1	0.1	0.3	0.1
S. oryzae	69.2	32.3	35.8	23.6
T. castaneum	5.2	39.0	27.5	22.9
T. variabile	0.1	0.4	1.1	2.2
T. sterorcea	—	—	0.1	—
Total no. adults	6374	3450	1226	1257

[a] Live adult species were not found in the facility.

Table 3.2. Percent of insect species trapped from a pitfall trap, located in the boot (pit) area, from three feed mills and three elevator facilities during monthly visits in 2009 and 2010.

	% of total live adults in[a]:			
	Feed mills		Elevators	
Species	2009	2010	2009	2010
C. ferrugineus	2.1	2.8	3.6	8.4
C. angustus	0.1	—[b]	0.4	—
O. surinamensis	0.7	6.4	0.4	0.9
P. ratzeburgi	0.2	—	12.8	—
S. oryzae	92.7	31.4	51.6	36.2
T. molitor	1.6	—	0.4	—
T. castaneum	2.5	17.9	30.4	49.6
T. variabile	0.1	41.5	0.4	4.9
Total no. adults	1833	1529	250	345

[a] Pheromone-baited pitfall traps for *Tribolium spp.* located in the boot (pit) area of each facility type.

[b] Live adult species were not found in the facility.

Table 3.3. Percent of insect species trapped with a sticky trap, located in the boot (pit) area, from three feed mills and three elevator facilities during monthly visits in 2009 and 2010.

	% of total live adults in[a]:			
	Feed mills		Elevators	
Species	2009	2010	2009	2010
P. interpunctella	99.8	87.8	78.1	60.9
R. dominica	0.1	2.6	0.4	0.8
T. variabile	0.1	9.6	21.5	38.3
Total no. adults	1413	1273	1316	1774

[a] Pheromone-baited sticky traps for *P. interpunctella*, *R. dominica*, and *T. variabile* were located in the boot (pit) area of each facility type.

Table 3.4. Live adults (Mean ± SE) collected from the pit, boot and load-out areas, with hourly pit temperature (Mean ± SE) recorded from three feed mills and three grain elevators during 2009 and 2010.

			Number of insects (Mean ± SE)[a]			
Facility type	Year	Season	Pit	Boot	Load-out	Temperature
Feed mill	2009[b]	Winter	—	0.3 ± 0.3b	—	5.7 ± 0.0d
		Spring	12.0 ± 9.4b	0.6 ± 0.3b	0.1 ± 0.1	17.8 ± 0.2b
		Summer	274.5 ±	20.3 ± 13.2a	7.1 ± 4.1	23.5 ± 1.0a
		Fall	127.6 ± 53.5a	3.0 ± 2.1a	1.7 ± 1.4	9.2 ± 0.8c
	2010[c]	Winter	60.8 ± 19.1	1.5 ± 0.8b	0.2 ± 0.2	2.5 ± 0.7d
		Spring	43.1 ± 20.6	73.7 ± 44.7ab	0.3 ± 0.3	19.2 ± 0.7b
		Summer	133.7 ± 47.8	95.4 ± 34.9a	0.7 ± 0.7	26.3 ± 0.6a
		Fall	24.2 ± 9.8	60.7 ± 13.3a	—	11.1 ± 0.2c
Elevator	2009[d]	Winter	0.3 ± 0.3b	1.0 ± 0.6b	0.2 ± 0.2	2.6 ± 1.1b
		Spring	9.0 ± 5.4ab	3.8 ± 2.3ab	1.1 ± 0.5	15.7 ± 1.8a
		Summer	36.5 ± 12.0a	18.6 ± 8.9a	1.2 ± 0.8	19.6 ± 1.3a
		Fall	15.3 ± 14.3ab	2.2 ± 1.6b	—	4.2 ± 1.9b
	2010[e]	Winter	4.4 ± 3.2	3.9 ± 2.9b	0.6 ± 0.4	0.3 ± 2.7b
		Spring	2.5 ± 1.1	2.8 ± 1.1b	—	18.7 ± 2.1a
		Summer	128.5 ± 67.6	20.0 ± 4.9a	2.6 ± 2.3	23.3 ± 1.2a
		Fall	8.9 ± 7.4	6.3 ± 3.5b	—	8.9 ± 2.0b

[a] Denotes live adult species were not found in the facility.

[b] Feed mill means among seasons during 2009 for pit (F = 10.36; df = 3, 29), boot (F = 3.58; df = 3, 29), and temperature (F = 114.01; df = 3, 7),were all significant ($P \leq 0.0001$; by one-way ANOVA and REGWQ test). Load-out samples were not significantly different (F = 2.27; df = 3, 29, $P \geq 0.1011$; by one-way ANOVA).

[c] Feed mill means among seasons during 2010 for boot (F = 9.13; df = 3, 32) and temperature (F = 297.88; df = 3, 8),were all significant ($P \leq 0.0001$; by one-way ANOVA and REGWQ test). Pit (F = 2.89; df = 3, 32, $P \geq 0.0506$) or load-out samples were not significantly different (F = 0.53; df = 2, 4, $P \geq 0.6261$; by one-way ANOVA).

[d] Elevator means among seasons during 2009 for pit (F = 4.45; df = 3, 32), boot (F = 4.61; df = 3, 32), and temperature (F = 29.10; df = 3, 8); were all significant ($P \leq 0.0001$; by one-way ANOVA and REGWQ test). Load-out samples were not significantly different (F = 1.93; df = 3, 20, $P \geq 0.1578$; by one-way ANOVA).

[e] Elevator means among seasons during 2010 for pit (F = 3.43; df = 3, 32), boot (F = 4.77; df = 3, 32) and temperature (F = 25.37; df = 3, 7),were all significant ($P \leq 0.0285$; by one-way ANOVA and REGWQ test). Load-out samples were not significantly different (F = 1.38; df = 3, 20, P ≥ 0.2782; by one-way ANOVA).

Table 3.5. Commonly collected (Mean ± SE) adult insect species from pitfall traps were *S. oryzae* and *T. castaneum* and from sticky traps were *P. interpunctella* and *T. variabile* in the pit area of three feed mill and three elevator facilities during 2009 and 2010.

		Number of insects (mean ± SE)[a]	
Facility type	Season	Pitfall trap	Sticky trap
Feed mills[b]	Winter	0.4 ± 0.2c	0.0 ± 0.0c
	Spring	7.8 ± 2.2b	35.1 ± 10.6b
	Summer	49.4 ± 17.7a	96.1 ± 9.3a
	Fall	97.1 ± 48.7a	21.8 ± 8.0b
Elevators[c]	Winter	0.4 ± 0.3c	0.0 ± 0.0c
	Spring	2.6 ± 0.7bc	28.6 ± 11.2b
	Summer	9.8 ± 2.8ab	126.5 ± 22.4a
	Fall	15.0 ± 4.8a	11.8 ± 6.1bc

[a] Pheromone-baited pitfall traps for *T. confusum* and *castaneum* and sticky traps for *P. interpunctella*, *R. dominica*, and *T. variabile* in the boot (pit) area of each facility type.

[b] Feed mill means among seasons for pitfall (F = 12.19; df = 3, 61) and sticky traps (F = 25.69; df = 3, 61) were both significant ($P \leq 0.0001$; by one-way ANOVA and REGWQ test).

[c] Elevator means among seasons for pitfall (F = 7.73; df = 3, 62) and sticky traps (F = 28.35; df = 3, 62) were both significant ($P \leq 0.0001$; by one-way ANOVA and REGWQ test).

Figure 3.1. Live adult insect counts (Mean ± SE) from residual grain samples of boot, pit and load-out areas and hourly temperature profiles from three elevator facilities during monthly visits in 2009 and 2010.

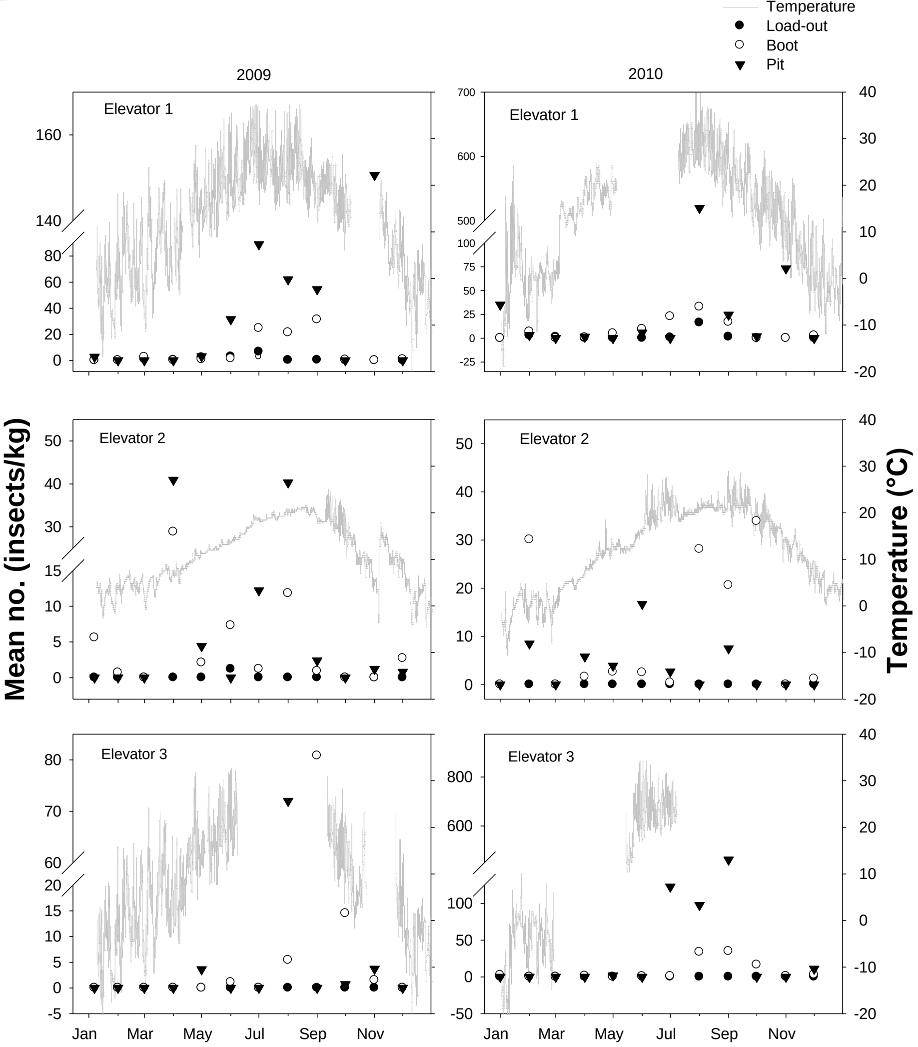


Figure 3.2. Live adult insect counts (Mean ± SE) from residual grain samples of boot, pit, and load-out areas and hourly temperature profiles from three feed mills during monthly visits in 2009 and 2010.

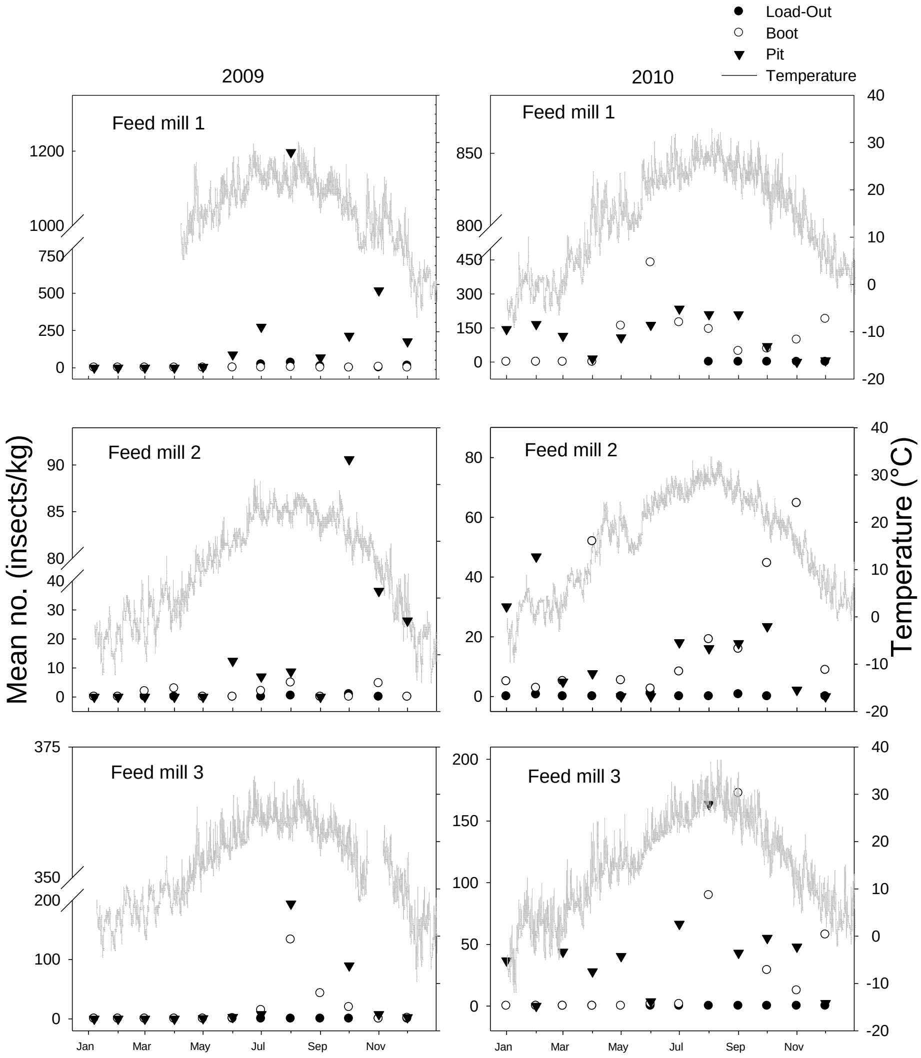


Figure 3.3. Adult insect counts (Mean ± SE) from pitfall and sticky traps located in the boot (pit) area and hourly temperature profiles from three elevator facilities during monthly visits in 2009 and 2010.

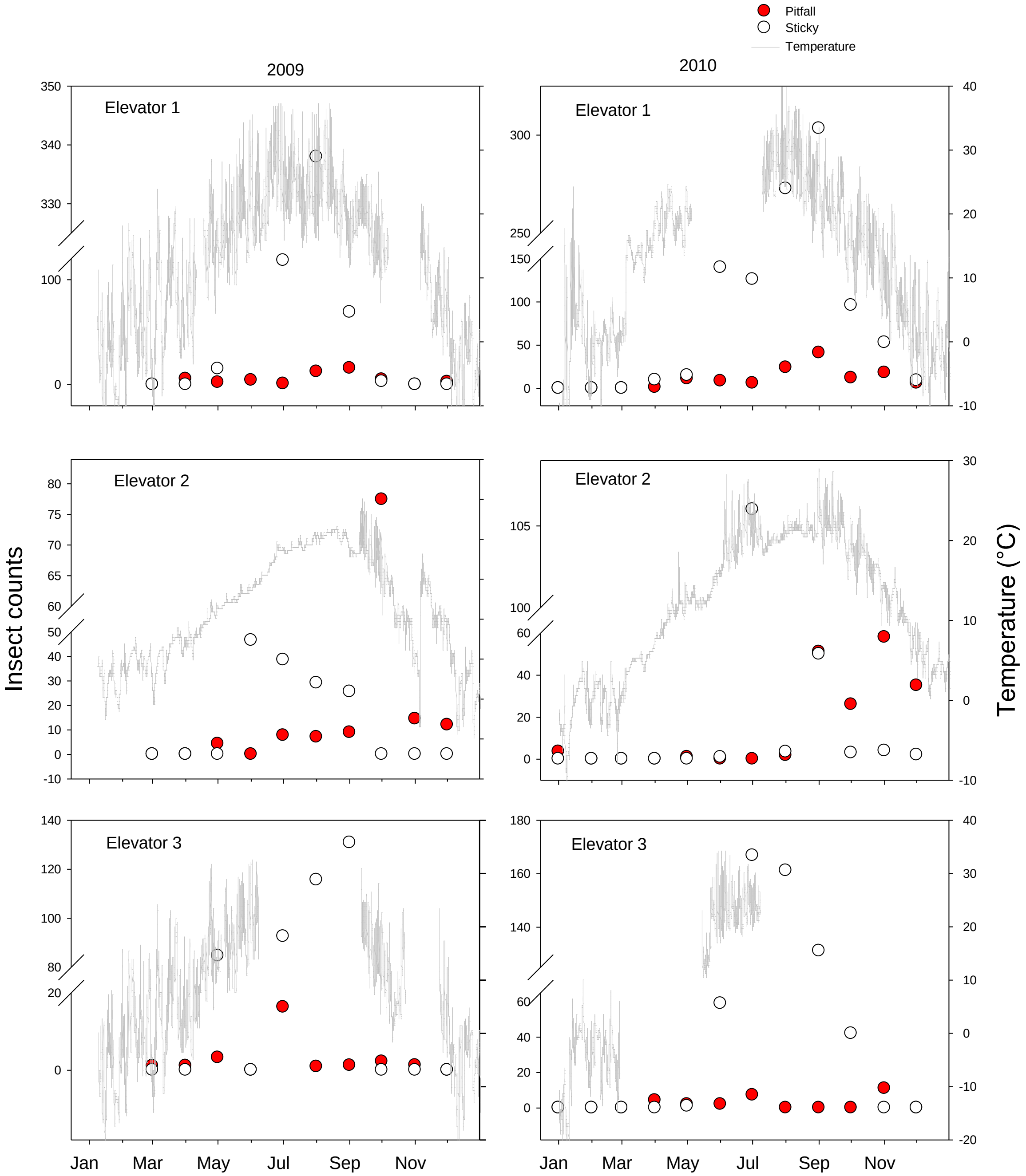
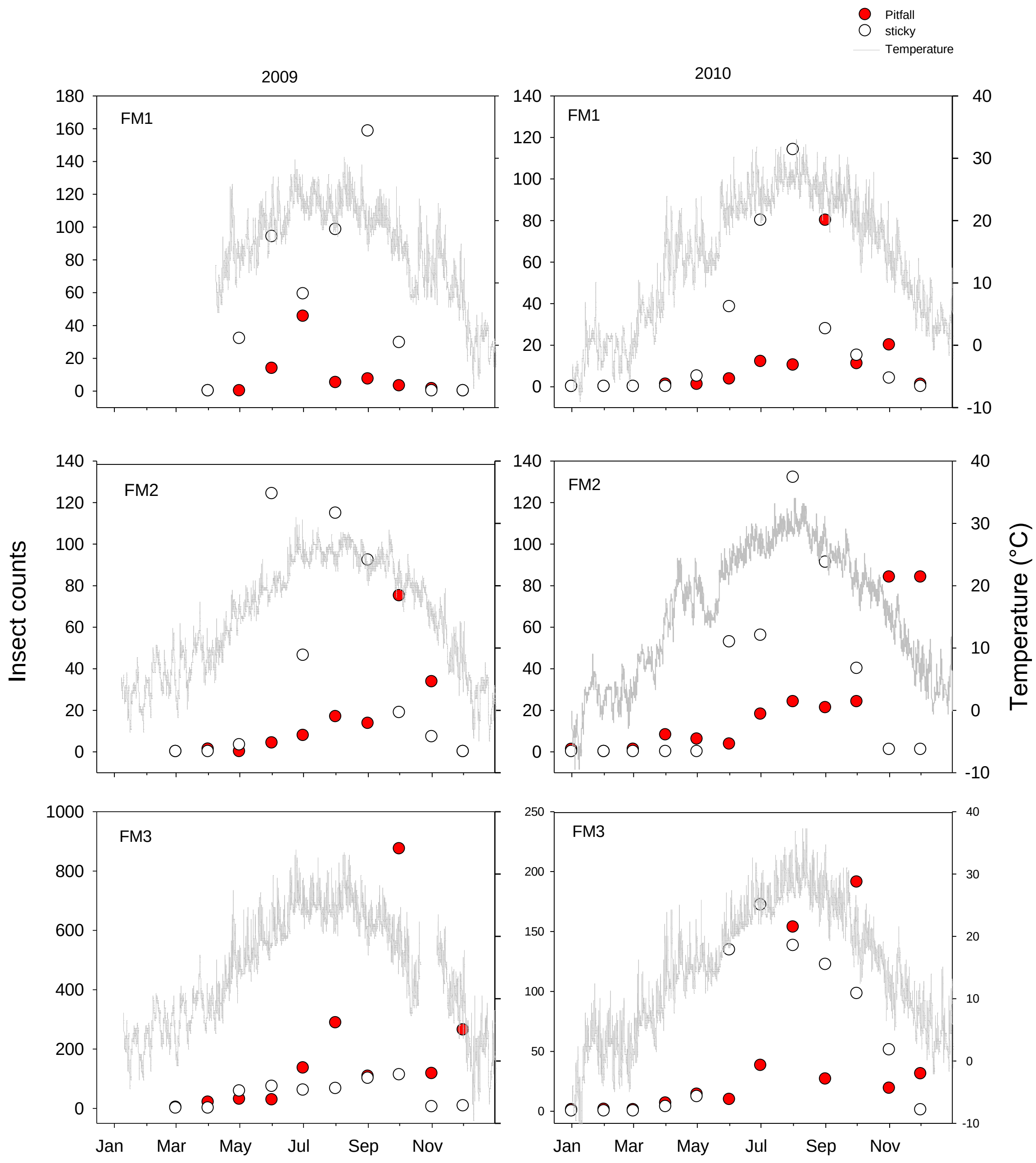


Figure 3.4. Adult insect counts (Mean ± SE) from pitfall and sticky traps located in the boot (pit) area and hourly temperature profiles from three feed mill facilities during monthly visits in 2009 and 2010.



Chapter 4 - A conceptual framework for economic analysis of commingling effects of insect activity in the elevator boot area

ABSTRACT

Boot areas in commercial grain elevators and feed mills contribute to commingling of insects with grain that moves through the elevator leg. A partial budget and stochastic dominance model were developed to improve pest management decision-making and risk analysis assessment from commingling effects of insect activity in the boot area. A modified pilot-scale bucket elevator leg, containing residual wheat or corn, was infested with different insect pest densities prior to clean grain transfers. Appropriate grain discounts were applied to grain samples obtained from clean grain transfers over either: (1) insect-free and untreated boots, (2) infested and untreated boots, or (3) infested and chemical (10% β-cyfluthrin SC ultra) treated boots. The insect-free boots simulated performing clean-out of the boot area. Partial budget analysis and stochastic dominance modeling indicate that boot sanitation (cleanout) about every 30 days, avoiding costly grain discounts from insect commingling, is the preferred choice. Although chemical spray treatments of the empty boot may reduce insect populations of some boot residual grains; boot cleanout always had lower and usually zero insect pest populations in the boot residual grain, providing higher facility operational net income without the use of chemicals.

Keywords: Partial budget, Stochastic dominance, Risk, Pest management.

4.1 Introduction

A partial budget and stochastic dominance (SD) model were developed for pest management decision-making and risk analysis assessment from commingling effects of insect activity in an elevator boot area. Partial budget analysis and SD modeling were used to compare different grain treatments and provide a systematic framework for the decision-making process in pest management programs of grain elevator and feed mill facilities. Risks associated with insects harboring in the boot area are quantified using SD criterion. The impacts of different grain treatments were quantified by applying typical grain discounts that were used as input data for SD modeling.

The basic principles of partial budget analysis describe a planning and decision-making framework used to compare costs and benefits of a business operation (Kay et al. 2008). Partial budgeting allows direct comparisons of alternatives using a reduced amount of data. Specifically, a partial budget analyzes only the specific costs and incomes that change with a proposed business adjustment. Thus, only relevant costs and incomes are included in the analysis. A partial budget typically has four categories: additional income, reduced costs, reduced income, and additional costs. The four categories, shown on the partial budget form in Table 4-1, provide a systematic framework for the decision-making process in pest management programs of grain elevator and feed mill facilities. Pest management decisions are usually probabilistic, with most decisions made in the presence of risk. Risk exists when there are different possible outcomes in which probabilities can be assigned. In contrast, uncertainty involves making decisions when the outcomes and probabilities are not known (Hardaker 1997). The use of a stochastic dominance modeling provides a useful decision-making framework. Stochastic dominance is a means of comparing alternative risky choices directly on the basis of their outcomes cumulative probability distributions (Dillion and Anderson 1990). A cumulative probability distribution is a mathematical relationship that enumerates the probability associated with each possible outcome and which can be used to determine the probability that the outcome of a random variable will be less than or equal to any particular level. Stochastic dominance analysis does not necessarily lead to the one best choice. Rather, by comparison of their outcome distributions, stochastic dominance analysis sorts possible risky choices into two groups: those that should not be taken because they are dominated by or are less preferred/inferior to a second group which is not dominated. Stochastic dominance analysis uses pair-wise comparisons to evaluate strategies and to derive the most efficient set of strategies. Given specified restrictions on the decisions maker’s preference, an efficiency criterion provides a partial ordering of strategies. The greater the number of restrictions placed on preferences, the greater the discriminatory power of the criterion. However, this requires more specific information about the preferences which may not be available. Fewer restrictions, which are easier to apply as a criterion, may reduce the ability of the criterion to eliminate choices from consideration, making it of little use as a decision making tool. Different stochastic dominance rules depend on different assumptions regarding the utility function of the decision maker. First degree stochastic dominance (FSD) holds for all decision makers who prefer more to less. No assumptions are made regarding risk preferences. This decision criteria holds for most decision makers. The usefulness of FSD is limited because in some applications few choices are eliminated for consideration.

Second degree stochastic dominance (SSD) is more discriminating and provides a basis for eliminating distributions from the FSD set that are inefficient or dominated. The rule for identifying cases of SSD depends on the additional behavioral assumption that the decision maker is averse to risk (Fishburn 1964). SSD is useful to rank alternative choices under the assumption that risk aversion is the general behavior of individuals, a common assumption used in decision making. Stochastic dominance with respect to a function is an evaluative criterion that orders uncertain choices for decision makers whose aversion to risk lies within specified lower and upper bounds, which depend on the preferences of the decision maker. The greatest strength of stochastic dominance with respect to a function is its flexibility in allowing the decision maker to specify the degree of precision with which preferences are represented by specifying how narrow or wide of a range to set with the upper and lower bounds.

Common sanitation practices are incorporated into the partial budget and SD analyses. Common sanitation practices include removal of residual grain and chemical treatment. In this case chemical treatment is the spray application of a residual insecticidal chemical (β-cyfluthrin) to the surface area of either floors or equipment, causing insect mortality. Ingemansen et al. (1986) found that more grain residue left in empty bins corresponded with an increased probability of a severe pest infestation. However, Herron et al. (1986) found no significant effect of removal of grain residues on pest infestation inside farm bins in Australia. They concluded that good grain sanitation practices improved the efficacy of grain pesticide protectant treatment. Residual insecticide spray treatments of empty on-farm wheat storage bins reduced insect infestation but did not always show an economic benefit (Reed et al., 1990). Removal of residual grain from the boot pit area, timely cleanout practices of the boot, and insecticidal spray treatments in the elevator boot would be expected to reduce insect infestation occurrences, based on inferences from studies conducted in empty storage facilities.

The elevator boot and pit area are important sources for insect pest infestation in commercial grain and elevator facilities. Knowledge of costs and risks associated with stored product insect pests found in residual grain from the boot and pit area of commercial grain facilities is vital for facility operator managers. Our objective was to compare costs associated with an elevator and/or feed mill sanitation program, identifying the most cost effective and economical pest management practices for each facility type, while reducing risk associated with insect commingling in a bucket elevator leg boot.

4.2 Materials and Methods

Residual grain (corn and wheat) in pilot-scale bucket elevator leg boots was infested with different insect population densities (50, 100, and 200 insects/kg/species) and incubated for different boot holding times (0, 8, 16, and 24 wk), prior to transferring clean grain through the boot (Table 1; sections 2.2.1 and 2.2.2 above). Wheat samples were infested with adults of *Rhyzopertha dominica* (F.), the lesser grain borer; *Cryptolestes ferrugineus* (Stephens), rusty grain beetle; and *Tribolium castaneum* (Herbst), red flour beetle. Corn samples were infested with adults of *Sitophilus oryzae* (L.), the rice weevil; *Oryzaephilus surinamensis* (L.), sawtoothed grain beetle; and *T. castaneum*. Insect-free grain was transferred over the infested boot and collected. Adult insects were removed from the transferred grain and counted. Transferred grain samples were graded and quality parameters recorded (White and Johnson 2003, Seabourn, 2006). Transfer grain boot treatments, insecticidal spray treated boots, and control samples with no insects were replicated three times for both wheat and corn. After grain grading and quality parameters were recorded, grain discounts were applied to each respective treatment based on quality parameters including insect infestation levels found. Grain discount schedules from a local elevator were used to acquire grain discounts of all treatments for both wheat and corn. A numeric example of an applied grain discount is given below (section 4.2.3.1). Grain discounts calculated for clean grain transfers over infested boot residual grain, insecticide-treated boots, and controls were used as input data for SD modeling, partial budget analysis, and subsequent grain discount data were analyzed separately using one-way analysis of variance (ANOVA) and the Ryan-Einot-Gabriel-Welsch Q (REGWQ) multiple comparison test at the $\alpha = 0.05$ level (SAS Institute 2008).

4.2.1 INSECTICIDE TREATMENT

β-cyfluthrin (Tempo SC Ultra, Bayer CropScience, Research Triangle Park, NC, USA) of 11.8% purity (120 mg (AI)/ml was formulated in water and applied to the enclosed area of an empty boot at the high label rate of (20 mg (AI)/m^2 in 3.7 ml per m^2. Each boot was sprayed with the insecticide prior to the initial loading of insect-free grain. Immediately following the initial loading an infested grain sample, exposed to the highest insect density (600 insects/kg), was transferred through the spray treated boot. The exposure period and insect-free grain transfer runs, for the insecticide treated boot, followed the same time interval (boot hold time) as all other boot treatments, prior to collecting discharge samples for analysis (Tilley 2013).

4.2.2 PARTIAL BUDGET ANALYSIS

The relevant costs included in the partial budget developed for commingling effects of insect activity in an elevator boot area were: (1) additional sanitation labor ($/h) in the boot-pit area, (2) applied grain discounts from commingling insect levels, (3) chemical spray treatment application, and (4) transportation charges from rejected shipments. The listed activities include all costs associated with commingling insect levels in an elevator leg boot and pit area. The associated additional income would be from insect-free grain sold at market value rather than being sold at a discount.

4.2.2.1 Partial budget example

A partial budget example using 236 bushels of wheat was constructed for both the chemical spray treatment (Table 4-1) and cleanout (Table 4-2) of the boot area. The volume of grain used to construct each partial budget was based on experimental data of handling effects on commingling and residual grain (Ingles et al. 2003). The authors found boot residual grain commingling values returned to within 0.5% of normal after transferring 235 bushels (bu) of grain through the boot area, with an average flow rate of 1,852 bu/h; we assume the same flow rate in these tests. McNeill (2010) developed a grain hauling cost calculator for aspects of grain hauling and transportation costs of US $1.40 per metric ton for the farmer, for a distance of 8.0 km between delivery points to figure total hauling costs. Labor charges were calculated using $12.50/h. Chemical solution was calculated at $2.18 per treated boot. Grain discounts for wheat (Table 4-11) were calculated from mean test weight TW), damaged grain, foreign material (FM), shrunken and broken material (S&B), insect damage kernels (IDK) and number of live adult stored-product insects enumerated (Seabourn 2006). Grain discounts for corn (Table 4-4) were calculated from moisture content (MC), mean test weight (TW), broken corn and foreign material (BCFM), damage and adult live weevils found (White and Johnson 2003).

4.2.3 STOCHASTIC DOMINANCE MODEL

A PC based program was used to perform Quasi-First Degree Stochastic Dominance (FSD), Quasi-Second Degree Stochastic Dominance (SSD), and SD with respect to a function was used to analyze risk associated with insects harboring in the boot area (Goh et al. 1989). Input data was from applied grain discounts of corn (Table 4-4) and wheat (Table 4-11). Grain discounts were acquired from grain quality factors, live adult insect counts, and IDK for both grain types. Applied corn quality discounts were from MC, TW, BCFM total damage material, and number of adult weevils per kg of grain (Table 4-4). Corn quality factors of each grain treatment were evaluated against corn discount schedules (Tables 4-5 to 4-9). Applied wheat quality discounts were from MC, TW, FM, S&B, total damage material, IDK, and number of adult insects per kg of grain (Table 4-11). Wheat quality factors of each grain treatment were evaluated against wheat discount schedules (Tables 4-12 to 4-18). Both corn and wheat discounts were from grain transfer treatments of non-insecticide insect infested boot residual grain, insecticidal spray treated boots, and control with insect-free grain. Applied grain discounts were calculated in cents/bu.

4.2.3.1 Applied grain discount example

A numeric example of the applied wheat discount for a grain treatment (replication 4) of an infested and non-insecticidal treated boot (Table 4-10) follows:

- Grain moisture content (MC) of 12.53 is below the initial moisture discount (Table 4-12) and no discount was applied.
- TW of 58.5 lb/bu, from Table 4-13, has a discount of 0.04 cents/bu.
- Foreign material (FM) of 0.1 percent is below the initial FM discount (Table 4-14) and no discount was applied,
- Shrunken and broken (S&B) of 1.4 percent is below the initial S&B discount (Table 4-15) and no discount was applied.
- Total damage percentage of 3.3 percent (Table 4-16), had a discount of 0.15 cents/bu.
- Insect damage kernels (IDK) of zero is below the initial IDK discount (Table 4-18) and no discount was applied.
- Number of live adult insects per kg was 5.07, had a discount of 0.10 cents/bu (Table 4-17).

  Note: Total damage percentage equals the sum of damage percent, foreign material and shrunken-broken where are the abbreviations here material.

The sum of all grain discounts equals 0.29 cents/bu and is shown in the discount column of Table 4-11 (replication 4, infested and non-insecticidal treated boots). All other grain discounts for both corn and wheat were calculated in a similar manner.

4.3 Results and Discussion

Pest management decisions are usually probabilistic, with decisions made in a risky environment. A partial budget framework and stochastic dominance model were developed for pest management decision-making and risk analysis assessment from commingling effects of insects in the boot and pit area of elevator and feed mill facilities. An example of a partial budget analysis of costs and income associated with commingling insect levels in an elevator leg boot with wheat, following a chemical spray treatment, showed an 8.0 cents/bu net change (Table 4-1). However, the partial budget corresponding with cleanout of the boot area showed a higher net change of 11.3 cents per bushel (Table 4-2). These results indicate that cleanout of the boot, on a regular basis (every 30 d) will increase income of the business operation. Both partial budget statements increased operational income by avoiding grain discounts and transportation costs.

A risk analysis assessment from commingling of insects in the boot area of elevator and feed mill facilities was conducted using a SD model. Corn quality factors (Table 4-3) were used to acquire associated grain discounts after a clean grain transfer over either an insect-free, untreated boots; infested, untreated slip-boots; or infested, chemical (11.8% purity β-cyfluthrin SC ultra, high label rate) treated boots. Applied corn quality and weevil infested grain discounts (Table 4-4) from the insect-free treated boots were significantly different ($F = 4.03$; df = 2, 33; $P \leq 0.0273$) than the other two treatment groups (infested, untreated and infested, chemical treated boots). The insect-free boots would simulate doing cleanout of the boot area on a regular basis. Additionally, FSD was shown for the insect-free and untreated boots. Thus, cleanout of the boot area is preferred over all other choices, including chemical treatment of the corn residual grain boot, no matter how risk-averse or risk-seeking decision makers are. Treatment of boots with β-cyfluthrin recorded low *S. oryzae* insect mortality, which may likely be due to the species being less susceptible to pyrethroid insecticide cyfluthrin. These data are consistent with studies by Samson and Parker (1989) and Arthur (1994), where both showed *S. oryzae* being less susceptible than *R. dominica* to pyrethroids compared with organophosphate protectants. Results from their studies showed that both higher application rates of cyfluthrin EC and longer exposure intervals were required to give the same control level for *S. oryzae* compared with *R. dominica*.

Wheat quality factors (Table 4-10) were used to acquire associated grain discounts after a clean grain transfer over the following groups: (1) an insect-free, untreated boots, (2) infested, untreated boots, or (3) infested, chemical treated boots. Applied wheat quality grain discounts (Table 4-11) from the insect-free boots and the infested, chemical treated boots were both significantly different ($F = 7.98$; df = 2, 33; $P \leq 0.0015$) than the infested, untreated boots. The insect-free and untreated boots simulated doing a clean-out of the boot area. Stochastic dominance results suggest that both (1) insect-free and untreated boots and (2) infested - chemcial treated boots are part of the FSD set.

In conclusion, partial budget analysis and SD modeling indicate that boot cleanout that keeps the boot free of insect infestations, avoiding costly grain discounts from insect commingling, is the preferred choice. Although chemical spray application treatments of the empty boot may reduce insect populations of some boot residual grains; boot cleanout always had lower and usually zero insect pest populations in the boot residual grain, and higher net income.

4.4 References

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Table 4.1 . Budget analysis of costs and income associated with commingling insect levels in an elevator leg boot following a chemical spray treatment of the boot using 10% cyfluthrin SC Ultra at the high label rate.

Added income:	**Amount**	**Added costs:**	**Amount**
Grain discounts (8 cents per bu)	**$17.70**	Labor ($12.50/h x 0.5 h)	**$6.25**
Transportation (rejected load, 4 cents/bu)	**$8.97**	Chemical spray (per boot)	**$2.18**
Reduced costs:		**Reduced income:**	
None		None	
Subtotal	**$26.67**	Subtotal	**$8.43**

Net change: $18.24 (subtotal from column 1 minus subtotal from column 2) or approximately 8 cents/bu.

The example is based off of one semi truck load or 235 bushel of wheat.

Table 4.2 . Partial budget analysis of costs and income associated with commingling insect levels in an elevator leg boot. Boots loaded with insect free grain correspond with doing sanitation and cleanout of the boot area.

Added income:	**Amount**	**Added costs:**	**Amount**
Grain discounts (10 cents/bu)	**$23.99**	Labor ($12.50/h x 0.5 h)	**$6.25**
Transportation (rejected load, 4 cents/bu)	**$8.97**		
Reduced costs:		**Reduced income:**	
None		None	
Subtotal	**$32.96**	Subtotal	**$6.25**

Net change: $26.71 (subtotal from column 1 minus subtotal from column 2) or approximately 11.3 cents/bu.

The example is based off of one semi truck load or 235 bushels of wheat.

Table 4.3. Corn quality factors after a clean grain transfer over either an insect-free and untreated boots; infested and untreated boots, or infested and chemical (10% β-cyfluthrin SC ultra, high label rate) treated boots.

Rep	TRT	Density (Insects/kg)	MC	TW (lb/bu)	BCFM	Damage (percent)	Live weevils (Insects/kg)
Insect-free, untreated boots							
1	0	0	14.48	56.8	0.46	0.0	0.0
2	0	0	14.93	56.7	0.94	0.0	0.0
3	0	0	14.72	56.8	0.52	0.0	0.0
4	0	0	14.27	58.1	0.43	0.0	0.0
5	0	0	14.38	58.4	0.26	0.0	0.0
6	0	0	14.51	56.3	0.38	0.0	0.0
7	0	0	15.03	56.5	0.38	0.0	0.0
8	0	0	14.00	56.7	0.62	0.0	0.1
9	0	0	1.3.76	58.6	0.46	0.0	0.0
10	0	0	15.46	58.1	0.12	0.0	0.0
11	0	0	14.00	56.3	1.02	0.0	0.0
12	0	0	13.98	56.6	0.18	0.0	0.0
Infested, untreated boots							
1	0	200	14.58	58.1	1.20	0.48	0.7
2	0	200	13.94	57.2	0.32	2.88	1.2
3	0	200	14.02	57.9	0.19	1.08	0.1
4	0	200	14.97	56.7	0.28	4.08	2.8
5	0	200	13.26	57.9	1.00	0.7	0.0
6	0	200	15.34	56.9	0.3	4.88	6.1
7	0	200	19.3	57.3	0.6	2.08	1.1
8	0	200	15.05	57.5	0.34	2.96	1.7
9	0	200	14.71	56.5	1.64	2.48	1.3
10	0	200	14.88	57.4	0.28	1.92	4.3
11	0	200	14.67	57.1	1.44	4.4	0.9
12	0	200	14.11	57.9	0.51	0.93	1.9
Infested, chemical treated boots							
1	1	200	13.96	57.9	0.32	0.52	0.5
2	1	200	14.36	57.8	0.17	1.44	2.5
3	1	200	13.82	57.2	0.46	2.32	1.8
4	1	200	15.3	56.4	0.22	2.44	0.0
5	1	200	12.72	57.5	0.34	3.44	0.0
6	1	200	17.46	51.3	0.37	5.49	0.5
7	1	200	15.46	58.3	1.01	3.05	0.1
8	1	200	14.48	52.8	0.21	5.53	0.3
9	1	200	14.01	57.7	0.38	3.15	0.0
10	1	200	13.92	56.6	0.66	5.76	34.1
11	1	200	14.01	55.5	0.23	2.5	0.0
12	1	200	13.77	57.6	0.28	3.6	35.1

Abbreviations: Rep is replication, TRT is chemical spray treatment of boot (0 = non-insecticidal and 1 = insecticidal), MC is moisture content, TW is test weight, BCFM is broken kernels and foreign material.

Table 4.4. Applied corn quality and weevil infested grain discounts after a clean grain transfer over either an insect-free and untreated boot, infested and untreated boot or infested and chemical (10% cyfluthrin SC ultra, high label rate) treated boot. Risk analysis using stochastic dominance modeling and means between grain discounts, within treatment groups, with different letters are significantly different ($P < 0.05$, REGWQ).

			Applied discounts (cents/bu)					
Rep	TRT	Density (insects/kg)	MC	TW	BCFM	Damaged	Weevil Infested	Discount
Insect-free, untreated boots(A)								
1	0	0	0.00	0.00	0.00	0.00	0.00	0.00
2	0	0	0.00	0.00	0.00	0.00	0.00	0.00
3	0	0	0.00	0.00	0.00	0.00	0.00	0.00
4	0	0	0.00	0.00	0.00	0.00	0.00	0.00
5	0	0	0.00	0.00	0.00	0.00	0.00	0.00
6	0	0	0.00	0.00	0.00	0.00	0.00	0.00
7	0	0	0.00	0.00	0.00	0.00	0.00	0.00
8	0	0	0.00	0.00	0.00	0.00	0.00	0.00
9	0	0	0.00	0.00	0.00	0.00	0.00	0.00
10	0	0	0.00	0.00	0.00	0.00	0.00	0.00
11	0	0	0.00	0.00	0.00	0.00	0.00	0.00
12	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Infested, untreated boots (B)								
1	0	200	0	0	0	0	0	0
2	0	200	0	0	0	0	0	0
3	0	200	0	0	0	0	0	0
4	0	200	0	0	0	0	0.1	0.1
5	0	200	0	0	0	0	0	0
6	0	200	0	0	0	0	0.1	0.1
7	0	200	0.49	0	0	0	0	0.49
8	0	200	0	0	0	0	0	0
9	0	200	0	0	0	0	0	0
10	0	200	0	0	0	0	0.1	0.1
11	0	200	0	0	0	0	0	0
12	0	200	0	0	0	0	0	0
Infested, chemical treated boots (B)								
1	1	200	0	0	0	0	0	0
2	1	200	0	0	0	0	0.1	0.1
3	1	200	0	0	0	0	0	0
4	1	200	0	0	0	0	0	0
5	1	200	0	0	0	0	0	0
6	1	200	0.27	0.08	0	0.02	0	0.37
7	1	200	0	0	0	0	0	0
8	1	200	0	0.06	0	0.02	0	0.08
9	1	200	0	0	0	0	0	0
10	1	200	0	0	0	0.02	0.1	0.12
11	1	200	0	0	0	0	0	0
12	1	200	0	0	0	0	0.1	0.1

Abbreviations: Rep is replication, TRT is chemical treated boot (0 = untreated and 1 = treated) , MC is moisture content, TW is test weight, BCFM is broken kernels and foreign material.

Table 4.5. Corn moisture content (MC) discount schedule.

MC	**Discount (cents/bu)**	**MC**	**Discount (cents/bu)**
15.6	0.07	18.0	0.34
15.7	0.08	18.1	0.35
15.8	0.09	18.2	0.36
15.9	0.10	18.3	0.37
16.0	0.11	18.4	0.38
16.1	0.12	18.5	0.40
16.2	0.14	18.6	0.41
16.3	0.15	18.7	0.42
16.4	0.16	18.8	0.43
16.5	0.17	18.9	0.44
16.6	0.18	19.0	0.45
16.7	0.19	19.1	0.46
16.8	0.20	19.2	0.48
16.9	0.21	19.3	0.49
17.0	0.23	19.4	0.50
17.1	0.24	19.5	0.51
17.2	0.25	19.6	0.52
17.3	0.26	19.7	0.53
17.4	0.27	19.8	0.54
17.5	0.28	19.9	0.56
17.6	0.29	20.0	0.57
17.7	0.31	20.1	0.58
17.8	0.32	20.2	0.59
17.9	0.33	20.3	0.60

Table 4.6. Corn weevil infested discount schedule.

No. weevils	**Discount (cents/bu)**
2	0.10
3	0.10
4	0.10
5	0.10
6	0.10
7	0.10
8	0.10
9	0.10
10	0.10

Table 4.7. Applied corn damage quality factor discount schedule.

Percentage	**Discount (cents/bu)**
5.0	0.02
6.1	0.04
7.1	0.07

Table 4.8. Applied corn broken kernels & foreign material quality factor discount schedule.

Percentage	Discount (cents/bu)
3.0	0.02
4.1	0.04
5.1	0.07
6.1	0.10

Table 4.9. Applied corn Test Weight (TW) quality factor discount schedule.

TW (lbs/bu)	**Discount (cents/bu)**
48	0.14
49	0.12
50	0.10
51	0.08
52	0.06
53	0.04
54	0.02
55	0.0

Table 4.10. Wheat quality factors after a clean grain transfer over either an insect-free and untreated boots, infested and untreated boots or infested and chemical (10% cyfluthrin SC ultra, high label rate) treated boots.

Rep.	TRT	Density (Insects/kg)	MC	TW (lb./bu)	Damage (percent)	FM	S & B	Total damage (Percent)	IDK	No. insects (Insects/kg)
Insect-free — untreated boots										
1	0	0	12.15	59.0	0.11	0.3	0.20	0.7	0.0	0.0
2	0	0	12.25	59.8	0.15	0.4	0.15	0.7	0.0	0.0
3	0	0	11.99	58.3	0.10	0.0	0.80	0.9	0.0	0.0
4	0	0	12.44	59.0	0.09	0.2	0.66	1.0	0.0	0.0
5	0	0	12.24	58.6	0.14	0.0	0.69	0.8	0.0	0.0
6	0	0	12.25	58.2	0.10	0.0	0.48	0.6	0.0	0.0
7	0	0	12.15	58.0	0.44	0.0	0.28	0.7	0.0	0.0
8	0	0	11.79	59.0	0.27	0.0	0.40	0.7	0.0	0.0
9	0	0	11.99	58.4	0.36	0.0	0.18	0.5	0.0	0.0
10	0	0	12.42	58.7	0.50	0.0	0.55	1.1	0.0	0.0
11	0	0	11.95	58.8	0.42	0.0	0.29	0.7	0.0	0.0
12	0	0	8.68	58.5	0.60	0.0	0.33	0.9	0.0	0.0
Infested —untreated boots										
1	0	200	13.44	58.7	0.5	0.0	0.5	1.0	0.0	0.60
2	0	200	11.93	58.4	0.7	0.0	0.4	1.1	0.0	0.80
3	0	200	12.34	58.5	0.4	0.0	0.48	0.9	0.0	0.53
4	0	200	12.53	58.5	1.81	0.1	1.4	3.3	0.0	5.07
5	0	200	12.57	58.2	0.3	0.0	0.46	0.8	0.0	0.67
6	0	200	12.50	57.2	1.7	0.0	0.48	2.2	0.0	4.93
7	0	200	12.46	58.6	0.21	0.0	0.32	0.5	0.0	0.13
8	0	200	12.93	57.6	0.7	0.0	0.45	1.2	0.0	2.47
9	0	200	11.88	58.9	0.23	0.0	0.24	0.5	0.0	0.07
10	0	200	12.34	58.1	1.17	0.0	1.85	3.0	0.0	2.40
11	0	200	12.22	58.6	0.54	0.0	0.16	0.7	0.0	1.67
12	0	200	12.17	58.8	0.8	0.0	0.6	1.4	0.0	2.40
Infested — chemical treated boots										
1	1	200	12.73	58.2	0.3	0.0	0.18	0.5	0.0	0.00
2	1	200	12.41	58.7	0.3	0.0	0.36	0.7	0.0	0.00
3	1	200	12.12	58.9	0.7	0.3	1.25	2.3	0.0	0.47
4	1	200	14.24	57.0	0.68	0.0	0.24	0.9	0.0	0.00
5	1	200	11.74	58.2	0.2	0.0	0.6	0.8	0.0	0.00
6	1	200	12.27	58.5	1.2	0.0	0.08	1.3	0.0	0.00
7	1	200	10.87	58.6	0.1	0.0	0.46	0.6	0.0	0.00
8	1	200	12.41	58.7	0.99	0.0	0.33	1.3	0.0	0.00
9	1	200	12.32	59.0	0.1	0.0	0.56	0.7	0.0	0.00
10	1	200	10.91	58.6	0.17	0.0	0.48	0.7	0.0	0.00
11	1	200	12.74	58.2	0.3	0.0	0.12	0.4	0.0	0.00
12	1	200	12.20	58.7	0.18	0.0	0.17	0.4	0.0	0.00

Abbreviations: Rep is replication, TRT is chemical treated boot (0 = untreated and 1 = treated), MC is moisture content, TW is test weight, FM is foreign material, S&B is shrunken and broken, IDK is insect damage kernels.

Total damage equals the summation of damage, foreign material and shrunken and broken.

Table 4.11. Applied wheat quality discounts after a clean grain transfer over either an insect-free and untreated boots, infested and untreated boots or infested and chmical (10% cyfluthrin SC ultra, high label rate) treated boots. Risk analysis using stochastic dominance modeling and means between grain discounts, within treatment groups, with different letters are significantly different (*P* < 0.05,REGWQ).

			Applied discounts (cents/bu)							
Rep	TRT	Density (insects/kg)	MC	TW	FM	S & B	Damage	IDK	Insects	Discount
Insect-free —untreated boots (A)										
1	0	0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
2	0	0	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.02
3	0	0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
4	0	0	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.02
5	0	0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
6	0	0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
7	0	0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
8	0	0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
9	0	0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
10	0	0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
11	0	0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
12	0	0	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
Infested —untreated boots (B)										
1	0	200	0.0	0.04	0.0	0	0.0	0.0	0.0	0.04
2	0	200	0.0	0.04	0.0	0.0	0.05	0.0	0.0	0.09
3	0	200	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
4	0	200	0.0	0.04	0.0	0.0	0.15	0.0	0.10	0.29
5	0	200	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
6	0	200	0.0	0.08	0.0	0.0	0.10	0.0	0.10	0.28
7	0	200	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
8	0	200	0.0	0.08	0.0	0.0	0.05	0.0	0.10	0.23
9	0	200	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
10	0	200	0.0	0.04	0.0	0.0	0.10	0.0	0.10	0.24
11	0	200	0.0	0.04	0.0	0.0	0.0	0.0	0.10	0.14
12	0	200	0.0	0.04	0.0	0.0	0.05	0.0	0.10	0.19
Infested —chemical treated boots (A)										
1	1	200	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
2	1	200	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
3	1	200	0.0	0.04	0.0	0.0	0.10	0.0	0.0	0.14
4	1	200	0.06	0.08	0.0	0.0	0.0	0.0	0.0	0.14
5	1	200	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
6	1	200	0.0	0.04	0.0	0.0	0.05	0.0	0.0	0.09
7	1	200	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
8	1	200	0.0	0.04	0.0	0.0	0.05	0.0	0.0	0.09
9	1	200	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.02
10	1	200	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
11	1	200	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04
12	1	200	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.04

Abbreviations: Rep is replication, TRT is chemical treated boot (0 = untreated and 1 = treated), MC is moisture content, TW is test weight, FM is foreign material, S& B is shrunken and broken, IDK is insect damage kernels.

Table 4.12. Wheat moisture content (MC) applied discount schedule.

MC	Discount (cents/bu)
13.6	0.02
13.8	0.04
14.1	0.06
14.3	0.10
14.6	0.12
14.8	0.15
15.1	0.18
15.3	0.22
15.6	0.26

Table 4.13. Applied wheat test weight (TW) quality factor discount schedule.

TW (lbs/bu.)	**Discount (cents/bu.)**
45	1.1
46	1.0
47	0.9
48	0.8
49	0.7
50	0.6
51	0.5
52	0.4
53	0.32
54	0.24
55	0.18
56	0.12
57	0.08
58	0.04
59	0.02
60	0.0

Table 4.14. Applied wheat foreign material (FM) quality factor discount schedule.

FM percentage	Discount (cents/bu)
0.5	0.04
0.8	0.05
1.4	0.06
2.1	0.07
2.6	0.08
3.1	0.10
3.6	1.2
4.1	1.4
4.6	1.6
5.0	1.8

Table 4.15. Applied wheat Shrunken and Broken (S & B) quality factor discount schedule.

S & B percentage	**Discount (cents/bu.)**
3.1	0.05
5.1	0.10
8.1	0.15
9.1	0.20

Table 4.16. Applied wheat damage quality factor discount schedule.

Damage percentage	**Discount (cents/bu.)**
1.1	0.05
2.1	0.10
3.1	0.15
5.1	0.20

Table 4.17. Live adult insect counts in wheat, quality factor discount schedule.

Insects	**Discount (cents/bu)**
0	0
1	0.10
2	rejected

Table 4.18. Applied wheat Insect Damage Kernels (IDK) quality factor discount schedule.

IDK	**Discount (cents/bu)**
6	0.02
11	0.03
16	0.04
21	0.05
26	0.06
31	rejected

Chapter 5 - Summary and conclusions

Grain elevator and feed mill facilities boot residual grain accumulation contributes to commingling of insects with grain that moves through the elevator leg. Residual grain often remains in the boot because manual cleanout of the elevator boot is not done on a regular basis in most grain elevator and feed mill facilities. Common sanitation practices in the elevator boot and pit area include removal of residual grain and residual insecticidal chemical spray applications. Removal of residual grain from the boot pit area, timely cleanout practices of the boot, and insecticidal spray treatments in the elevator boot and pit areas would be expected to reduce insect infestation occurrences, based on inferences from studies conducted in empty storage facilities. This research determined typical levels of insect infestations in commercial elevator and feed mill boot pit areas, evaluated spread of infestations from this area to other portions of the grain elevator, correlated insects in elevator boot pits to insects found in grain stored in silos, and determined impact of sanitation and spot facility treatments on insect densities in boot pits.

Laboratory tests found a correlation between boot insect density and commingling in these results. Clean corn transferred over an infested boot was infested with increasing insect densities of external insects between different time intervals (rest periods) of 0, 8, 16, and 24 wk. Transferring clean grain (wheat and corn) over an infested boot, with a rest period of 8 weeks, will likely infest the transferred grain with at least 2 insects/kg. The number of internal insects that emerged from the transferred grain, after an 8 week grow-out period, was much greater than the initial number of external insects sieved off of the transferred grain for both wheat and corn. However, the emergence of internal insects significantly decreased, for both grain types, after rest periods of 16 and 24 wk; the decreased insect density levels may be due to insect crowding or over population.

Field surveys of insects in elevator leg boots and pits showed significant variation of insect density between facility type and during summer seasonal periods of both years. The most common and abundant insect pest species collected from feed mill facility boot, pit and load-out residual grain samples was *Cryptolestes, O. surinamensis, Sitophilus*, and *Tribolium*. Grain elevator facilities commonly recorded insect pest species, from residual grain samples of the boot, pit and load-out areas, was *Cryptolestes, Sitophilus,* and *Tribolium*. Insect density at load out was low during both trapping years, likely due to the size of samples collected in relation to the volume of grain in load out bins.

Partial budget analysis and stochastic dominance modeling confirms the decision-makers preference of boot sanitation (cleanout) on a regular basis, avoiding costly grain discounts from insect commingling. Although chemical spray application treatments of the empty boot may reduce insect populations of some boot residual grains; boot sanitation (cleanout) always had lower and usually zero insect pest populations in the boot residual grain, increasing net change of the partial budget cost and income statement.

5.1 Boot and pit insect prevention and control procedures for elevator and feed mill facilities.

The importance of year-round sanitation practices is critical in preventing insect pest population explosions during the warm seasonal summer months. Feed mill and elevator managers' knowledge of insect species diversity, insect population densities, and commingling of insects in grain causing spread of an infestation from an elevator boot and pit area is vital for elevator and feed mill insect pest management programs. Insect density levels in infested bucket elevator leg boots affect the level of insects transferred through the elevator leg to other locations within a facility. Bucket elevator boot and pit sanitation guidelines:

- *boot residual grain cleanout every 30 days,*
- *removal of residual grain, floor sweepings and grain spillage from the pit area, and*
- *proper disposal of boot and pit residual grain.*

Feed mill and elevator managers following these sanitation guidelines will likely reduce insect pest carry over in their facility. Frequent cleanout of the boot residual grain should reduce the number of insects of both external and internal infesters from being picked-up in the boot area and transferred to other locations of a facility.