Effect of Pneumatic Conveyance of Wheat on Mortality of Adult Stored Grain Beetles

by

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JITENDRA PALIWAL

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree

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ABSTRACT

A study was undertaken to investigate the effect of pneumatic conveyance of wheat on mortalities of the adults of the two most common insect species of stored grain in Canada. Hard red spring wheat infested with red flour beetles, *Tribolium castaneum* (Herbst) and rusty grain beetles, *Cryptolestes ferrugineus* (Stephens) at grain moisture contents of 14, 17, and 20% (wet basis) was conveyed using a pneumatic conveyor at flow rates of 3.5 and 5.0 t/h. Samples of grain were collected at three points along the grain flow path and were analysed for insect numbers. Wheat passed through the conveyor was also evaluated for any loss in germination.

Insect mortality as high as 98% was achieved for both species after a single pass through the pneumatic conveyor. In the range of 3.5 to 5.0 t/h the effect of flow rate on insect mortality was statistically insignificant. Mortality was low at high moisture content and increased significantly as the moisture content of grain decreased. The insect mortality also increased with an increase in the length of the flow path and introduction of bends in the pipeline. There was no adverse effect of pneumatic conveyance on seed germination even after conveying the grain three times.

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1. INTRODUCTION

Insects and mites usually are integral parts of stored-grain ecosystems (Sinha 1973a, 1973b; Calderon 1981, Lacey 1988). Human beings began to cultivate plants and store plant foodstuffs around 8000 BC. It can be assumed that the storage pests of today evolved in natural habitats long before this time and moved into stored products that provided conditions to which they were already adapted (White 1995). Significant quality and quantity losses may occur in stored grains and their products due to these insect pests.

Canada produces an average of 55 Mt (million tonnes) of grains and oilseeds worth about six billion dollars annually (Canadian Grains Council 1996). About 70% of these grains are exported through a grain collection, handling, and shipping system. The producers store their grain on the farm and usually deliver it in farm trucks to primary elevators (grain handling facilities). In Canada there is a zero tolerance for live insects in grain (Canada Grain Act 1975), therefore, when insects are detected in grain, it has to be disinfested, usually using chemicals prior to delivery to the primary elevators. It is important to prevent infestation prior to export or a phytosanitary certificate cannot be issued. With the increasing grain surpluses in Canada (Canada Grains Council 1996), the export trade must become increasingly important if cereal production is to increase at the present level. In this very competitive area, the quality of Canadian grain will be critical in determining export success.

Resistance to most residual insecticides is common around the world in at least 31 stored-product pest species (Champ and Dyte 1976). Resistance to fumigants including phosphine and methyl bromide has occurred to a limited extent in nine major storage species

(Champ 1985). Resistance in the rusty grain beetles, *Cryptolestes ferrugineus* (Stephens); red flour beetles, *Tribolium castaneum* (Herbst); rice weevils, *Sitophilus oryzae* (L.); granary weevils, *Sitophilus granarius* (L.); and lesser grain borers, *Rhyzopertha dominica* (F.) to the most common and effective fumigant, phosphine (Champ 1985, Zettler and Cuperus 1990), is of great concern because most of the world's grain-storage managers depend on fumigation by this insecticide for both a routine disinfestation treatment and a means of controlling insect pests that are resistant to other pesticides.

Physical methods to control insect infestations in stored grain are preferable to fumigation or insecticide application because of lack of chemical residues, safety to applicators, and minimal likelihood of the development of insect resistance. It has been observed that a good amount of insect mortality occurs in grain conveyors. A fairly thorough review by Banks (1987) of the disparate information on impact and physical removal suggests that up to 99% mortality could be achieved during conveying. Better understanding of the effects of conveying and how these may be maximised should ensure that export grain is only treated when necessary. This will also enhance the prospects of selling grain for export where there is a requirement for residue-free grain. Most of the observations related to insect mortality from pneumatic conveyance have been casual observations secondary to the study of a different control technique (Green and Taylor 1966, Cogburn et al. 1972). Published information (Loschiavo 1978, Armitage et al. 1995) suggests that conveying results in substantial mortality of insects and the relevance of this is discussed in relation to journey times and the time required for populations to recover to their initial level. Much of the published information, however, does not distinguish between different methods of conveying. Many of the most dramatic reductions in insect populations have been observed when a pneumatic conveyor is used. The objectives of this study were:

1. to quantify the rate of insect mortality in a positive-negative type pneumatic conveyor;
2. to determine in which part of the conveyor maximum mortality occurs, and on that basis suggest modifications that can be made in pneumatic conveyors to increase their effectiveness as disinfestors; and
3. to study the effect of flow rate and moisture content of grain on the rate of disinfestation and grain germination.

2. CLASSIFICATION OF INSECT CONTROL METHODS

Various methods of disinfestation of grain have evolved over the ages. Storage practices vary with climate, crop, and pest species. Methods of insect control can be classified into three categories: chemical methods; physical methods; and botanical grain protectants.

2.1. Chemical Methods

Chemical methods are the most widely used methods of insect control due to the rapid lethal effects of chemicals on insects. These methods can further be classified as: conventional methods and non-conventional methods.

2.1.1. Conventional methods The protectants and fumigants which are used in stored grain to eliminate infestation, are categorised as conventional methods. Protectants are contact insecticides that are added to the grain for pest control as it enters storage. Snelson (1987) presented a comprehensive review of the chemicals used throughout the world for this purpose and Longstaff (1988) has modelled the effect of temperature on toxicity of insecticides. Fumigants are synthetic volatile chemicals which are used to toxify the storage atmosphere for insect control e.g., carbon disulphide, chloropicrin, methyl bromide, ethylene dibromide, and phosphine. Bond (1984) gave a comprehensive review of fumigants that were used throughout the world to disinfest stored products. Currently, only phosphine and methyl bromide are widely used throughout most of the world.

2.1.2. Non-conventional methods The chemicals which impair insects genetically or morphologically, rendering them incapable of reproduction or survival come under the category of non-conventional chemical methods. Non-conventional insecticides include sterilants, repellents, antifeedants, pheromones, growth regulators, and chitin synthesis inhibitors.

Sterilants are the chemicals (e.g., apholate, thiotepa, tepa, and metapa) which cause sterility in both male and female insects. Male sterility is more practical than female sterility for control of storage insects (Prakash and Rao 1983a). Certain synthetic chemicals are effective as repellants i.e., piperonyl butoxide (Guy et al. 1970) and 2-pentynyl and 2-monynyl mandelate (Gillenwater et al. 1981) for *Tribolium* spp. Some synthetic chemicals show antifeedant activity when impregnated on packing materials and gunny bags, e.g., AC-24055 (4,3,3-Dimethyltriagenon acetanilide) for *T. castaneum* (Loschiavo 1969); brestan, brestanol, plictran, and AC-24055 for angoumois grain moth, *Sitotroga cerealella* (Olivier) (Rajan and Dale 1971). Sex pheromones are chemicals isolated from female insects and utilised to attract males of the same species. Aggregation pheromones are also produced by many insects and attract both sexes to a suitable food source. Since these chemicals are natural substances that regulate essential behaviour of the insect species, insects are less likely to become resistant (Vick et al. 1978). The synthetic sex pheromone, (7 A, 11 E)-7-11-hexadecadienyl acetate, affects mating of *S. cerealella* in the closed environment of farm godowns; the pheromone also traps males (Su and Mohny 1974, Vick et al. 1978, 1979). Growth regulators and their analogues can be used to upset the normal development of insects. These chemicals are highly active, very selective in action, and relatively non-toxic to other animals (Novak 1975). A number of chemicals effective as hormone mutants in insects are: Altozar (methoprene) against *R. dominica* and *S. oryzae* (Strong and John 1973);

Dimilin (TH-6040) against coleopteran pests (McGregor and Kramer 1976); and expoxyphenyl-ether against *R. domonica, T. castaneum*, *Ephestia* spp. and *Sitophilus* spp. (Hoppe 1976). Certain chemicals which inhibit the synthesis of chitin during the development of insects, are called chitin synthesis inhibitors (CSI) (Marx 1977, Majumdar 1978). Of several such chemicals tested, only a few are effective in suppressing the development of insects and lead to their death, these include: N(4-(4-nitrophenoxy-3,5-dichlorophenyl amino carbonyl)-2 chlorobenzamide) against *S. oryzae; R. dominica;* sawtooth grain beetle, *Oryzophilus surinamensis; E. cautella; and Tribolium* spp. (Kramer and McGregor 1979).

2.2. Physical Methods

Physical control of insect pests involves the manipulation of physical factors to eliminate pests or to reduce their populations to a tolerable level (Banks and Fields 1995). Physical factors that can be used for insect control are:

1. Temperature: The comfort zone for most of the insects is in a temperature range of 8-41°C (Howe 1965, Fields 1992). If the temperature is reduced (Navarro et al. 1973, Maier 1993) or increased (Gonen 1977a, 1977b; Lapp et al. 1986) beyond this range it becomes impossible for most of the insects to multiply or survive for long periods.
2. Relative humidity: The normal range of relative humidity (r h) for growth and survival of most of the insects is 50-70%. If r h is reduced below 50%, acute mortality occurs in most of the species (Navarro 1978, Annis 1987).
3. Controlled atmosphere storage: The controlled atmosphere techniques involve changing the CO_2, O_2, and N_2 content of the storage atmosphere to render it lethal to insects

(Banks and Annis 1990, Jayas et al. 1993). Temperature, r.h., and exposure time can further be manipulated for higher mortality rates. In general, the optimum process will depend on many factors including the air-tightness of the storage structures to be treated, logistic conditions, and the relative costs of gases (Spillman 1989).

4. Inert dusts: Inert dusts absorb lipids from the insect's cuticle causing death through desiccation. Diatomaceous earth, the most widely used inert dust, is used for grain protection in several countries either as an admixture or as a structural spray (La Hue 1965, 1978; White et al. 1975). It has low mammalian toxicity but can affect grain handling characteristics and grade of the grain.
5. Impact forces: The use of impact forces to kill insects is a marginally explored physical control method (Banks 1987, Loschiavo 1978, Bailey 1969). It has demonstrated its potential with the common use of machines such as the 'Entoleter', a machine that kills insects in flour by spinning and hurtling them against a steel plate (Stratil et al. 1987).
6. Ionizing radiation: Two types of ionizing radiation have been considered for insect control in grain: γ radiation produced from ^{60}Co or ^{137}Cs sources; and accelerated electrons (Urbain 1986). These radiations cause sterilization, gene mutations as well as reduce the vitamins A, C, E, B_1, and K levels inside the insect's body (Tilton and Brower 1987, Watters 1991). Insects exposed to high dosages stop feeding and die in a few weeks.

The features, exposure time, and effectiveness of the various physical methods of insect control are summarised in Table 2.1.

Table 2.1. Comparison of general features of physical methods for disinfestation of grain.

***Source*: Banks and Fields (1995)**

Force or Action	Typical embodiment	Does it give 100% kill ?	Speed of action	In use for bulk grain?
Heat	Heat to 63 °C	Yes	A few seconds	Experimental
Cold	Cool to 12 °C or less	Yes, eventually	Days or weeks	Widely used
CA (low O)	Reduce to < 1% O	Yes	Weeks or months	Rare
CA (high CO)	Raise to > 60% CO	Yes, for most species	Weeks	Some large scale use
Irradiation	Expose to 0.3 kGy	Yes	Weeks or months	Commercial plant prototype
Exclusion	Sealing	No	n/a	Widespread
Inert dusts	Add dust	Yes, for most species	A few days	Limited commercial use
Aridity	Dry to < 11% moisture content (depending on crop)	Yes, for some species	A few days or weeks	Widely used
Impact	Entoleter, pneumatics	Not usually	A few days	Not specifically used
Removal	Sieving	Not usually	A few seconds	Little specific use

2.3. Botanical Grain Protectants

Plant materials which are found effective, economic, and locally available may be used for insect control. Products from Neem, *Azadirachta indica* (A. Juss.) (e.g., leaf, kernel powder, oil, and crude extract) possess repellant, antifeedant, and feeding deterrent properties against storage insects (Savitri and Rao 1976, Devi and Mohandas 1982, Prakash et al. 1982). Products like leaves of begonia, *Vitex negundo* (L.); leaves of bel, *Aegle marmelos* (L.); leaves of pudina, *Mentha spicata* (L.); and bhang, *Cannabis sativa* (L.) have also been evaluated as protectants (Prakash et al. 1983b).

3. PNEUMATIC CONVEYING SYSTEMS

3.1. Pneumatic Conveying System

Pneumatic conveying system (PCS) is a conveyor for transporting solid particles in a closed (air-tight) conduit, in which the particles drag or flow under a positive, negative (vacuum), or a combination of the two pressures. These are being widely used in the grain industry these days because of their low maintenance costs, flexibility of installation, reduced dust generation, and lesser safety hazards as compared to bucket elevators and belt conveyors. The disadvantages of PCS are that they consume more power and can be noisy. Figure 3.1 shows the schematic of the pneumatic conveyor used for my experiments. Several studies intended to show the effects on other factors have demonstrated the adverse effects of pneumatic conveying on insect infestation. To understand that, a brief knowledge of the components of PCS is desirable.

A PCS essentially consists of four main components: blower, airlock, cyclone separator, and pipe and fittings (Figure 3.2).

3.1.1. Blower A blower is required to generate the pressure in a PCS so as to make the grain flow with air. A rotary positive-displacement blower pumps air by rotating a pair of lobed rotors within a housing so that the rotor lobes mesh with each other similar to the teeth on a pair of gears (Figure 3.2 a). The positive displacement blower delivers a nearly constant volume of air but takes more power when operating against high pressure. A centrifugal blower (Figure 3.2 b) delivers large volumes of air at low pressure. A single blower can produce up to 30 kPa pressure. The centrifugal blower delivers less air and requires less

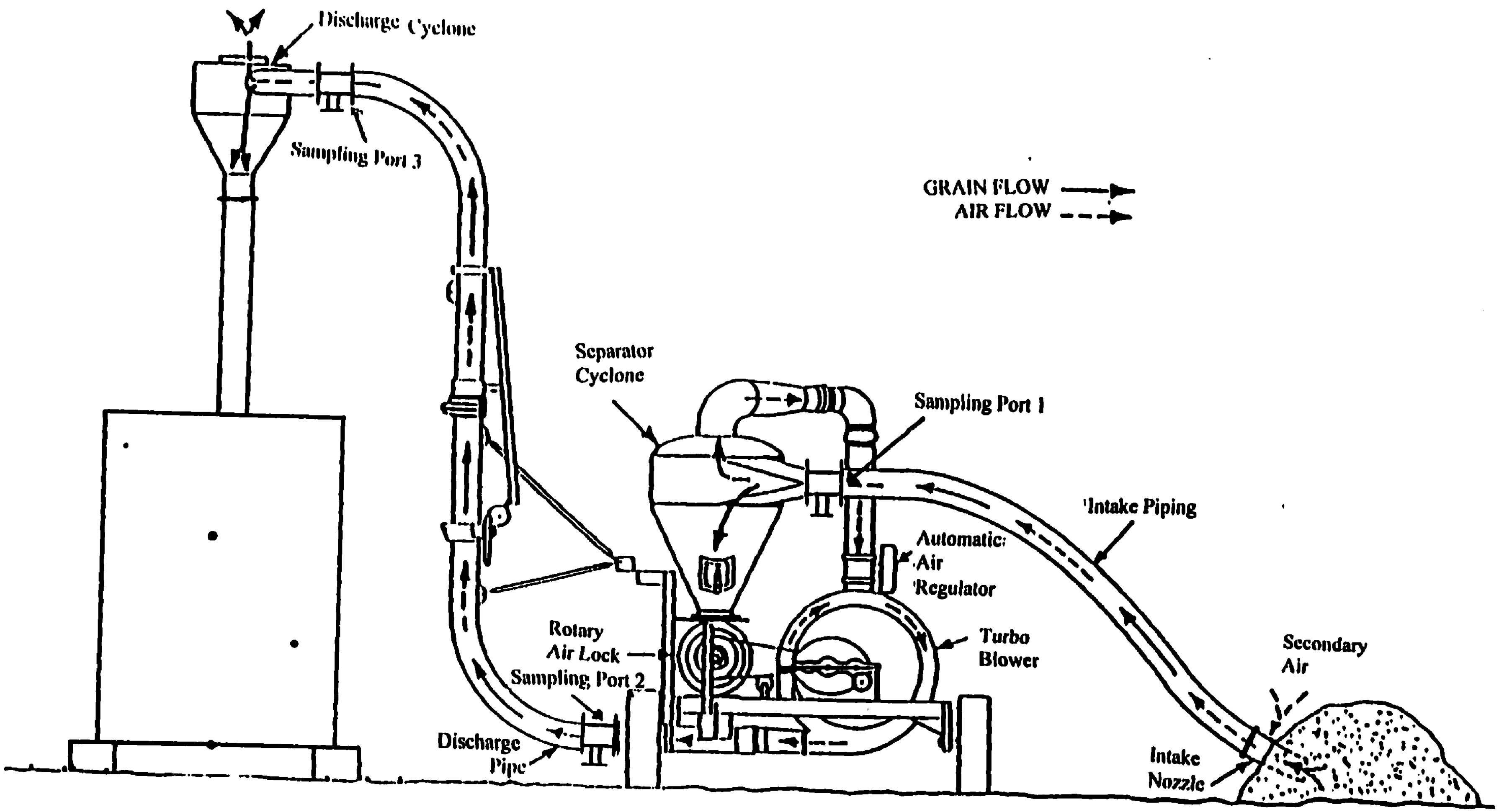
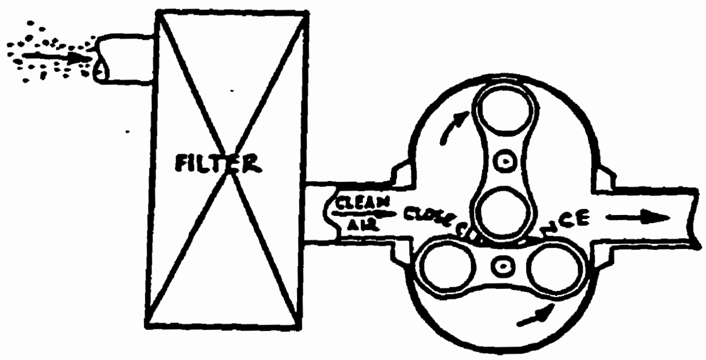
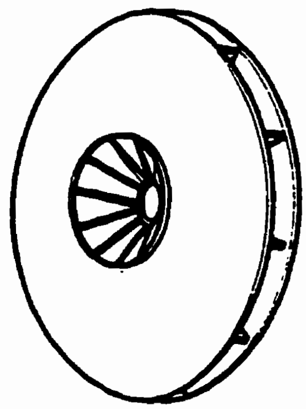


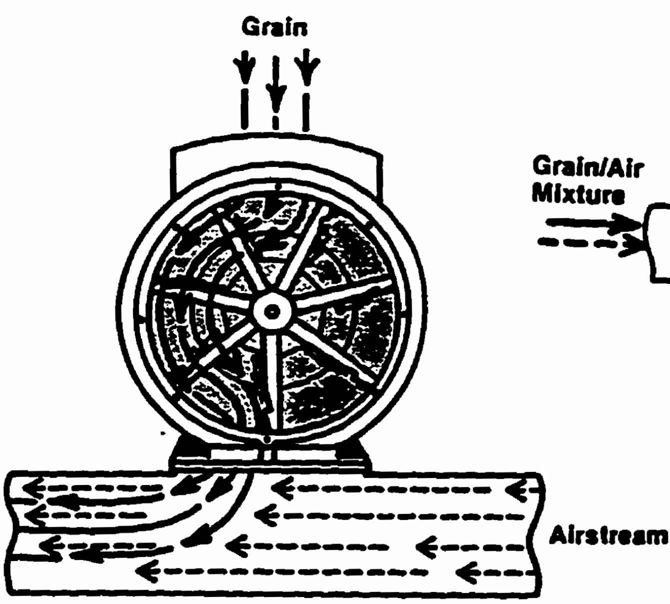
Figure 3.1. Schematic showing NEUERO pneumatic conveyor equipped with the three sampling ports.



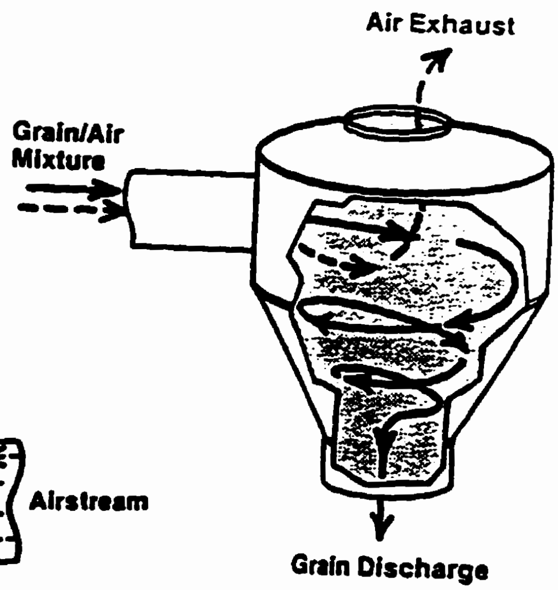
(a) Rotary Positive Displacement Blower



(b) Centrifugal Blower



(c) Rotary Air Lock



(d) Cyclone Separator

Figure 3.2. Components of a pneumatic conveying system. ***Source*: Hellevang (1985)**

power when operating against high resistance than against low resistance. For conveying grain rotary blower is the most suitable type of blower as the grain has to be moved against a low static pressure, most of the times.

3.1.2. Air lock The air lock meters the grain into the air stream while preventing the air from escaping (Figure 3.2 c). The speed of rotation of the airlock regulates the grain flow rate. Excessive rotation speeds may damage the grain and cause plugging. Large air locks turn slower and generally last longer than small air locks.

3.1.3. Cyclone separator A cyclone separator slows the grain and separates it from the air (Figure 3.2 d). A screen or filter is normally used on the air exhaust to reduce dust. Conveying capacity will be reduced as the filter or screen becomes dirty.

3.1.4. Pipe and fittings Pipes should be resistant to abrasive wear. Pipe connections should have a smooth inner surface to minimize grain damage and to reduce pipe wear. Any change in direction (bends) will reduce the flow rate and increase grain damage. The turning radius should be a minimum of six to eight times the tube diameter for bends of 45 degrees or more.

4. LITERATURE REVIEW

4.1. Effect of Disturbance on Insect Mortality

Mechanical handling of grain may be a more practical means of controlling insects in grain than using insecticides which introduce the risk of residues or building-up of resistant strains of insects. Cotton and Gray (1948) attributed the beneficial effects of turning, i.e., transferring grain from one bin to another, to a reduction in temperature and moisture which reduces the risk of spoilage. They consider turning to be of no value in insect control. Joffe (1963) found that turning not only keeps stored maize cool and in sound condition but also reduces insect infestations. Joffe and Clarke (1963) observed that adult *S. oryzae*, are sensitive to even relatively gentle pouring of grain from a height of 900 mm, and suggested that many adults are eliminated during the greater mechanical disturbance that occurs during turning of grain in grain handling facilities. Bailey (1962) found that relatively small impact forces kill adults and immature stages of *S. granarius*. Bailey (1969) demonstrated that mortality of *S. granarius* increases with increasing velocity and number of impacts in infested grain against a steel plate.

Loschiavo (1978) studied the effect of disturbance of wheat on four insect species viz. *C. ferrugineus, T. castaneum, S. granarius,* and *S. oryzae*. Wheat infested separately with different species was subjected to physical disturbance by being dropped or rotated and tumbled in small sacks, or dropped through a tube from a height of 14.1 m. He found that adults of *S. granarius* and *S. oryzae* suffer 96% mortality when grain is dropped in sacks, 5% mortality occurs when *S. granarius* are dropped with free-falling wheat, and 13% when rotated and tumbled in sacks. *Cryptolestes ferrugineus* sustain a higher mortality than the other species in free-falling wheat or sacks subjected to rotation and tumbling. He also found that these impact forces do not affect germination in any way.

4.2. Grain Damage in Handling and Conveyance

Yamazawa et al. (1972) found little effect of pneumatic conveying on germination and cracking of kernels of unhulled rice at conveying velocities of 18- 25 m/s. Chung et al. (1973) made an extensive evaluation of damage to corn from pneumatic conveying. The effects on the amount of breakage of conveying air velocity, corn moisture content, conveying distance, and kernel size and shape were evaluated. They concluded that high conveying air velocity causes the greatest amount of damage, especially in low moisture content corn. They also stated that to avoid excessive damage to low moisture corn, conveying air velocity should not exceed 27 m/s.

Martin and Stephens (1977) studied the dust generation in corn during repeated handling in a commercial conveyor and found that the accumulated breakage in corn increases with each transfer from one bin to another. The level, initially 2.0 percent, increases about 0.6 percent with each subsequent handling, reaching a level of 15.7 percent during the 21st handling.

Baker et al. (1986) studied the amount of fines and dust generated in a PCS and found that the dust generated is well below the explosive limit and is comparable to other handling systems. They reported that the amount of dust generated increases exponentially with increase in conveying velocity but the amount of fines does not increase significantly as the grain flow rate increases.

Deosthali et al. (1987) evaluated damage to the long and medium grain rough rice in a pressure PCS and found that the amount of broken and fissured grains increases as the air to solid ratio is increased. Conveying air velocity produces a less definite trend. They observed an increase in fissures as conveying air velocity increases. However, the lowest percentages of broken kernels are recorded at the highest conveying air velocity.

4.3. Performance Evaluation of Pneumatic Conveyors

Baker et al. (1984) tested the performance of a PCS using shelled corn. They found that the pressure needed to convey grain increases in proportion to the grain flow rate and the power requirement for accelerating and elevating the grain is higher than the power to convey the grain horizontally or around an elbow. The measured median grain kernel velocities are less than half of the conveying air velocity. Their system operates best at an air velocity of 20 m/s and specific power requirement (power consumed divided by grain flow rate) decreases as the grain flow rate increases, which was later confirmed by Deosthali et al. (1987) who also found that specific electrical energy consumption increases with a decrease in air to solid ratio.

4.4. Entomological Performance of Grain Conveyors

Green and Taylor (1966) who were investigating the effect of an insecticide on grain found that 95% mortality of test insects results from mechanical handling of the grain (a pneumatic conveyor, elevators, and belt conveyors). Cogburn et al. (1972), investigating radiation of grain, observed substantial mortality of several pest species by grain transfer including pneumatic conveying. Over 99% of adults of *R. dominica*, *S. oryzae*, and *Cryptolestes* spp., and over 80% of their immature stages are killed. Muir et al. (1977)

noted a mortality of 80 and 60% (adults and larvae, respectively) of *C. ferrugineus* on two transfers of the grain through screw conveyors. The observed effects are presumably a result of the combined effects of impact, abrasion, disturbance, and changes in temperature distribution resulting from the grain turning.

Sutherland et al. (1989) showed that wheat can be disinfested of all stages of *R. dominica*, the most heat tolerant of Australian grain insects, by heating to 70 °C for a few seconds only, and at a grain temperature as low as 58°C if a heat soaking period of 1 min is allowed before cooling, in a pneumatic conveyor. They obtained a mortality of 34% while conveying wheat with unheated air.

Armitage et al. (1995) conducted a series of experiments to investigate the effect of physical damage combined with insecticide treatment on the mortality of insects viz. *T. castaneum, S. granarius, and O. surinamensis*. To impart physical damage to insects they used different methods like turning and tumbling, conveying in a screw conveyor, and a pneumatic conveyor. They concluded that only pneumatic conveying is likely to inflict sufficient insect damage to cause heavy mortality. The relatively gentle forces experienced during conveying prior to export, mainly using belt conveyors, do not appear to cause sub-lethal effects that enhance insecticide treatments sufficiently to allow lower doses to be effective. Out of the three insect species studied during their experiments, *O. surinamensis* is the most susceptible to physical impact. The combination of low pesticide dose and physical disturbance do not increase the mortality of the insects compared with the effect of the pesticide on its own. They suggested that the mortalities are due to the effect of the pesticide rather than to the physical disturbance.

5. MATERIALS AND METHODS

5.1. Pneumatic Conveyor

The pneumatic conveyor used was a NEUERO 630 (Neuero Corp., West Chicago, IL). This is a positive-negative type of PCS (Figure 3.1). The turbo blower provides both suction and discharge air to convey grain without passing it through the blower. Grain is conveyed by the intake air stream through the intake nozzle, through the separator cyclone and into the rotary air lock. It then passes through the air lock into the discharge cyclone. The blower is driven from the power take off shaft through the gear box. Intake and discharge locations can be varied by adding elbows and sections of rigid and flexible pipe.

The power requirement of the conveyor is 25-35 kW depending on the type and flow rate of the grain, but due to higher initial starting torque a tractor of at least 45 kW and 1000 rpm power take-off is needed to drive it. According to the mechanical evaluation done by Prairie Agricultural Machinery Institute (PAMI 1979), the maximum conveying rates obtained are 32.1 t/h for wheat, 36.9 t/h for barley, 34.7 t/h for oats, and 27.4 t/h for rapeseed. Crackage in wheat is less than 0.2% for each pass. For my experiments, because a relatively small amount of grain was to be conveyed, the 150 mm grain inlet hose was replaced with a hose of 75 mm diameter, to fit into the outlet port of the small bins. This resulted in a lower flow rate (3.5 to 5.0 t/h) than the above mentioned grain flow rates.

5.2. Sampler Fabrication

To investigate which part of the PCS gives maximum mortality, samples of grain were taken, while conveying, at three different points. This was done by installing three specially designed samplers along the closed conduit grain path. Each sampler consisted of the following three parts (Figure 5.1 and 5.2).

Part A: A 5 mm thick pipe with 145 mm internal diameter, and 150 mm length, had a hole of 40 mm diam along the periphery. This pipe had flanges on both the ends so that it could be bolted to the main conveying pipe.

Part B: An 85 mm long, 2 mm thick pipe of 40 mm internal diameter.

Part C: A 135 mm long, 2 mm thick pipe having an outer diameter of 40 mm, closed at the upper end. It had a hole of 25 mm diam at a distance of 5 mm from the top edge. The inner surface of the pipe facing the hole was lined with a rubber sheet.This modification was made to lessen damage to the insects caused by impact on the metallic surface. The top edge had an annular ring of 2 mm width on the outer periphery. The bottom opening of the pipe was provided with an air-tight rubber cork.

The sampler was fabricated by sliding part C in part B. The periphery of part B was welded to the hole of part A so that the annular ring of part C was inside part A and the hole of part C was facing towards the direction of grain flow. Three such samplers were then introduced in the main conveying pipeline at three points viz. just before the entry into the separator cyclone, the point at which grain comes out of the rotary air lock feeder, and the point before the grain enters the discharge cyclone (points 1, 2, and 3 in Figure 3.1).

To take the samples while conveying, part C was pushed upwards so the hole of part C was exposed to the flowing grain. This led to filling of part C with the grain. After a few seconds part C was slid downward, the cork was opened, and the sample was collected in plastic bags. Many such samples were collected at 1 min interval to give a composite grain

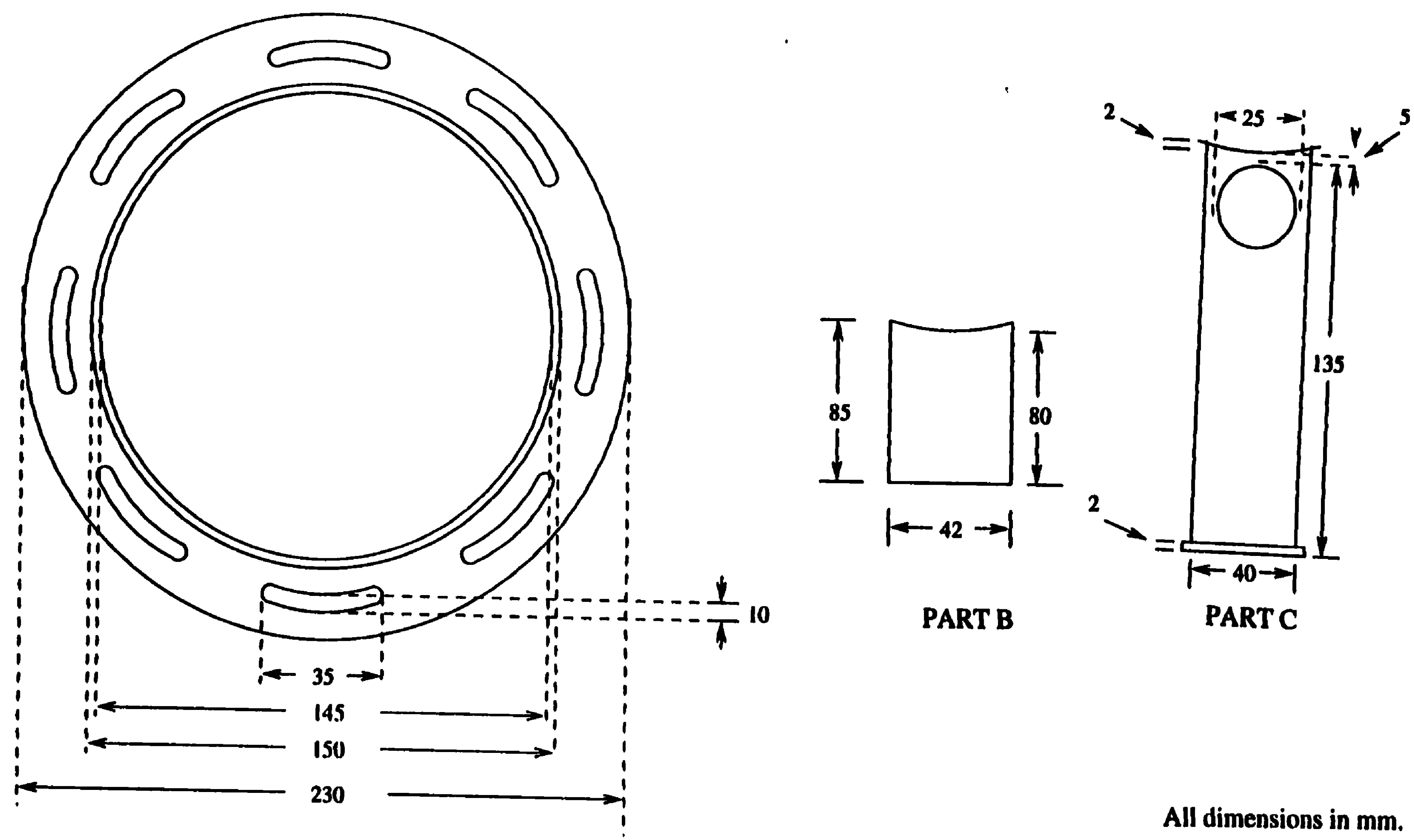


Figure 5.1. Components used for fabricating the grain sampling port.

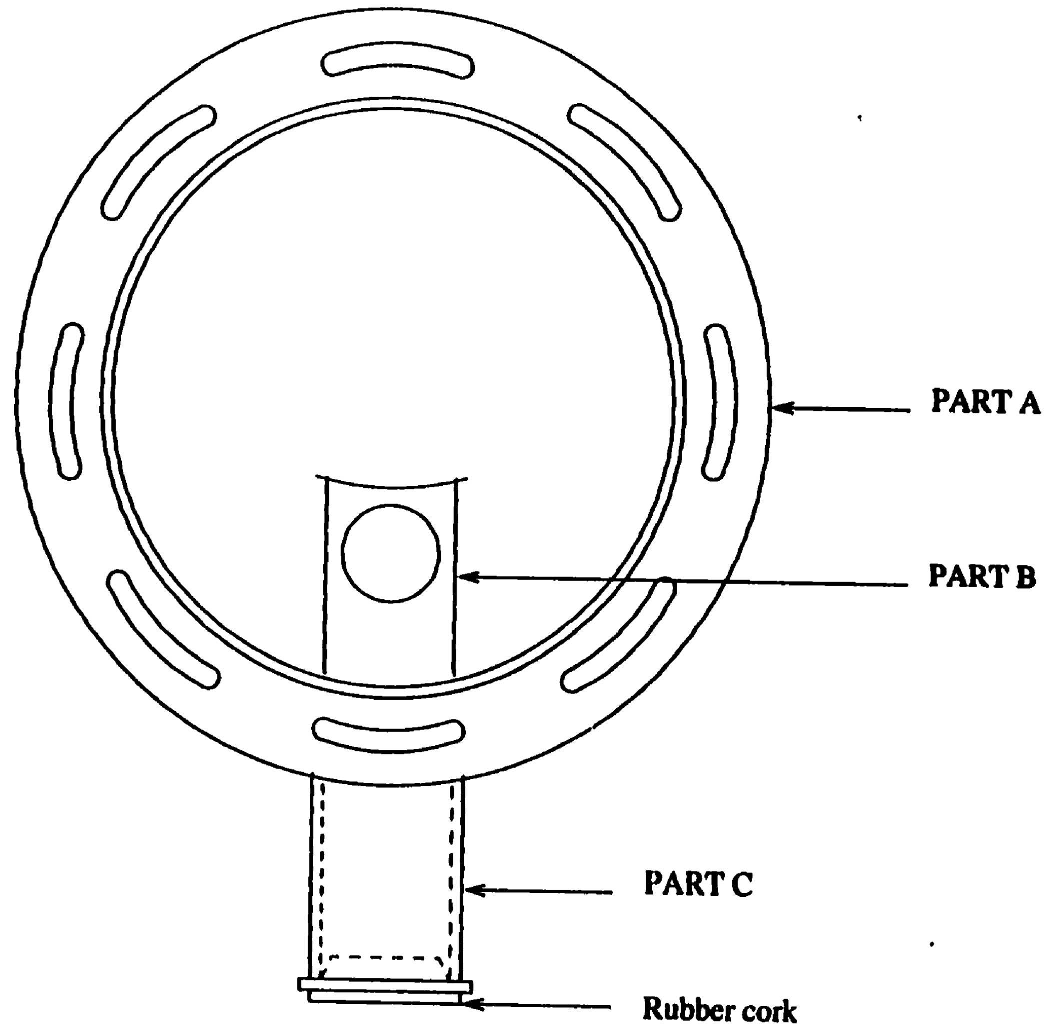


Figure 5.2. Schematic showing the sampling port installed in the pneumatic conveyor used for taking out wheat samples while the grain was being conveyed.

sample from each location. All the three sampling ports were made air tight to avoid any pressure loss in the system. The composite sample which was about 500 ● 100 g, was then put in a small plastic bag, marked according to bin and sampler number and was used for analysis of insect abundance.

Prior to starting the experiments, the PCS was calibrated for two different flow rates of 3.5 and 5.0 t/h. This was done by timing a known amount of wheat flow with different opening adjustments of the slide at the intake nozzle.

5.3. Bin Fabrication

A total of fifteen bins, 1680 mm high x 580 mm diameter, were used for storage and testing. Each bin was manufactured by welding two 45 gallon steel drums end to end in a vertical arrangement. Each of the bins had a capacity to hold 340 ● 10 kg of wheat. Three sampling ports, with removable rubber septa, were located along the vertical axis of each bin in a spiral pattern. (#1 at the top to #3 at the bottom) (Figure 5.3). The first port was 170 mm from the top of the bin with each successive port 500 mm lower. A fourth port (#4) was located on the bottom centre of the bin. The bins were supported off the ground on cinder blocks to access the bottom port. A 60 mm diameter hole in the lid of each bin was left open for ventilation but covered with a fine mesh to prevent the insects from escaping. The lids were sealed with metal duct tape once the bins were filled. A small 75 mm diameter opening on the bottom front face of the bin was used for unloading the grain. The opening was mounted with a bolted plate to avoid the insects from escaping as well as the grain from coming out of the bin.

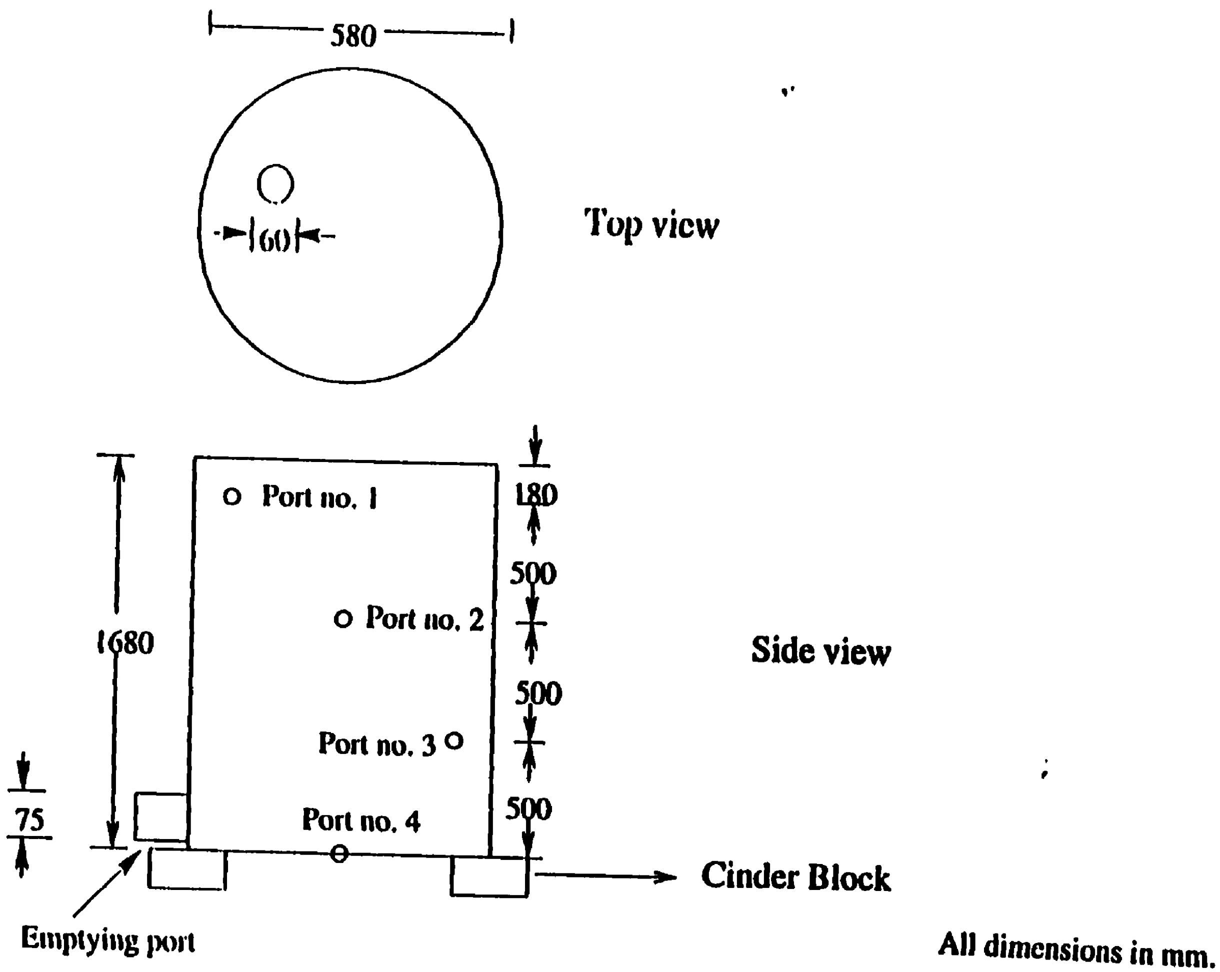


Figure 5.3. Schematic of the grain bin showing the different sampling ports.

5.4. Insect Cultures

Two insect species viz. *T. castaneum* and *C. ferrugineus* were selected for this study. The insect cultures were reared in the laboratory under a controlled temperature of 30 ± 1°C and a relative humidity (r h) of 70 ● 5%.

Tribolium castaneum were bred on the substrate of wheat flour plus brewer's yeast (19:1, wt:wt) and for *C. ferrugineus* the diet consisted of whole wheat plus wheat germ (19:1, wt:wt). Pure cultures of 500 adult insects of each species were introduced in separate 4 L glass jars containing 500 g substrate. The lid of each jar had a 40 mm diameter hole covered with fine wire mesh and filter paper to provide air circulation. The lid was put on the jar and sealed with masking tape. Twenty such jars, for each species, were then put in the environment chamber for three months to allow them to build up populations. After three months the jars were taken out and the contents were sifted. For *T. castaneum* a No. 20 (mesh opening 0.84 mm) sieve was used and the insects and larvae were collected on the sieve. A No. 10 (mesh opening 2 mm) sieve was used for *C. ferrugineus* to separate all the present life stages from the substrate. The insects were transferred to a white tray and one thousand adults were picked up using a vacuum tube device and the accumulated insects were then weighed. This mass was multiplied by five to estimate the mass of 5000 beetles. Using the mass of 5000 beetles, the remaining samples were estimated. Each sample of 10000 insects (5000 of each species) was then put in a small ventilated plastic box to be added to the grain bins on the next day. The plastic box was then put in the environment chamber at 30 ± 1°C and 70 ± 5% r h.

5.5. Bin Sampling

The bins were cleaned and nine of them were filled manually with wheat at a pre-conditioned moisture content (mc) of 14% wet basis (wb). They were artificially infested with 5000 adults of each of the two insect species by adding the insects while the grain was being poured into the bins. A 200 mm long pitfall type insect trap (Canadian Grain Commission 1989) was then inserted into the top centre of the grain in each bin at a depth of 1m from the top surface. The bins were then sealed and left for 3 d to allow the insects to distribute themselves throughout the grain. At the end of this period, the initial sample set was taken from the three side sample ports with a 1m long Seedboro sampling probe. The probe was inserted, open side down, and rotated 180 degrees so the openings could fill with grain from a cross section of the bin. The probe was withdrawn and emptied into a small trough held close to the sample port. The process was repeated a total of three times for an average sample mass of 120 ± 10 g. The grain sample was emptied into a plastic bag, labelled by bin number and port, sealed and kept at 25°C until the number of insects was counted. The bottom port (#4) was sampled by opening it and draining grain out for the same average sample mass. After counting the insects, the same grain samples were then used for calculating the moisture content, and percent germintaion. The pitfall trap was also taken out and emptied into glass vials. The insects were counted by using the vacuum tube device on a white tray. The insects were put back in the respective bins once the counting was done.

5.6. Conveyor Sampling

Grain from six bins was pneumatically transferred at a rate of 3.5 t/h to six empty bins. The grain in the three control bins was not moved. Wheat samples of approximately

500 g were taken from each of the three sampling ports in the conveyor (Figure 3.1), while conveying the grain of each bin. Insects collected from these samples were counted. After conveying, the insect traps were placed and the bins were sealed. Three days after grain movement, all the experimental as well as control bins were again sampled at four locations per bin for evaluation of insect numbers and grain germination. Insects captured in the traps were also counted.

To investigate if the insects were leaving with the air coming out from the separator cyclone, a fabric sock was attached to the air outlet of the cyclone and the dust collected was checked for any live or fragmented insects. As no live or fragmented insects were found in the first six trials, dust collection was stopped for the subsequent tests. The dust collection system was then used only to redirect the dust generated to the outside of the closed building.

The same procedure was then followed for grain moisture content of 17 and 20% and also for a flow rate of 5.0 t/h at each of the three moisture levels. To increase the moisture content of the grain to the desired value, it was artificially wetted. This was done by calculating the amount to water required to raise the grain moisture content to the desired level. Thereafter the measured amount of water was sprayed on the grain while the grain was poured into the applicator. The wet grain coming out of the applicator was transferred to a grain wagon using an auger. The moisture content of the grain was measured to ascertain moisture percentage after a 3 d period.

5.7. Germination and Moisture Determination

To find out the effect of conveyance on germination of the grain, three replicates of 25 kernels each were removed for germination. This was done by incubating the kernels on a 90 mm diameter filter paper dampened with 10 mL water for 7 d at 25 ± 1°C and 70 ● 5% r h. The same procedure was followed before and after conveyance. Because the initial germination level of the commercial grade wheat was not high, the germination data were inconclusive. Therefore, germination tests were run separately on high quality seed-grade wheat (cultivar Domain), to observe any decrease in germination after one, two, and three passes through the conveyor. Germination test on seed-grade wheat was conducted on 14% moisture content wheat at a flow rate of 5.0 t/h, which was assumed to be the worst treatment condition for loss in germination of wheat.

To determine moisture content of each bin, ten replicates of 10 g wheat samples were dried at 130°C for 19 h (ASAE 1993). Loss in mass from the original mass was recorded to calculate the moisture content.

5.8. Data Analysis

5.8.1. Bin data To analyse the mortality obtained by conveying the wheat through the conveyor, procedure GLM of SAS (SAS 1990) was used. The experiment was organised as a randomised complete block design (RCBD) with a 2 x 3 factorial treatment structure with flow rate and moisture content as the main effects. The model chosen for analysis of variance (ANOVA) was

$$Y_{ijk} = \mu + B_i + F_j + M_k + F_j M_k + \epsilon_{ijk}$$

where Y_{ijk} is the insect mortality at ith bin, jth flow rate, and kth moisture content; B_i is the effect of ith bin; F_j is the effect of the jth flow rate; M_k is the effect of the kth level of moisture content; $F_j M_k$ is the interaction of the jth flow rate and kth moisture content; and ϵ_{ijk} is the random error of the experiment. The number of insects of each species from a sample were divided by the mass of the sample and converted into insect density per kg. There were four sampling ports in each bin and the mean of the four insect densities was calculated and assumed to be the average density of each bin (Appendix A). The insect densities were calculated before and after conveyance for each bin, and their difference divided by the insect density before conveyance gave the mortality which was expressed in percent.

5.8.2. Trap data The mean number of insects was calculated at each flow rate and moisture content level, for all the six test bins, both before and after conveyance. These two mean values of the total number of insects trapped were used to calculate the insect mortality. A simple one way ANOVA was done to analyze the results.

5.8.3. Conveyor sampling port data For each flow rate and moisture content level, the total number of live insects collected at each sampling port were converted into live insect density per kg, by dividing the number of live insects by the sample mass. A three way ANOVA test (Sigma Stat 2.0, 1995: Jandel Scientific, San Rafael, CA) was then used to analyze the data at the different ports of the pneumatic conveyor at different flow rates and moisture contents.

5.8.4. Germination data The total number of seeds germinated out of the 25 seeds used for this test, were multiplied by four to convert the germination into percentage points. The mean of all the three replicates was taken to obtain mean germination per bin at each flow rate and moisture content. The mean germination before and after conveyance was then compared using a one way ANOVA (Sigma Stat 2.0, 1995: Jandel Scientific, San Rafael. CA).

6. RESULTS AND DISCUSSION

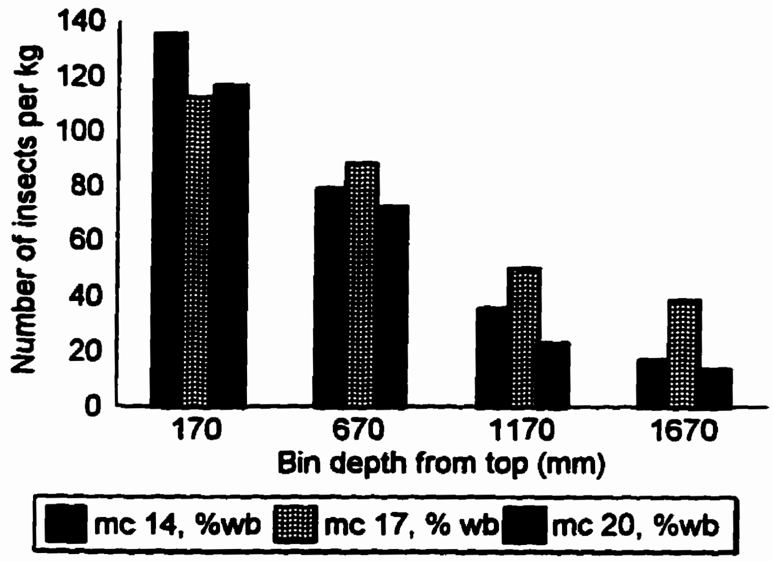
6.1. Insect Distribution in the Bins

The initial sampling of the bins for the infestation level in the wheat was done 3 d after filling the bins. During this period insects of both species distributed themselves throughout the depth of the bins. Figure 6.1 shows the number of *T. castaneum* and *C. ferrugineus* collected, respectively, on a per kg basis, from the four ports along the bin depth. Adults of *T. castaneum* moved upwards whereas *C. ferrugineus* concentrated in the lower half of the bin. The insect distribution is very typical and complied with the results of previous studies (White and Loschiavo 1986). Table 6.1 and 6.2 (also refer to Appendix A) indicate that the movement of the insects is not affected by the moisture of the grain. The large values of the standard deviation (S.D.) indicate a large sampling variability among the number of insects caught using the Seedboro sampling probe. After conveying the grain no specific pattern was observed (Appendix A), although the sampling was done after the same 3 d period. This might be due to the fact that the number of insects survived after conveying is too small to give any specific trend.

6.2. Insect Mortality in the Bins

Bin sampling and pitfall traps were used to calculate the mortality of insects (Appendix A). Table 6.3 shows the mean mortalities obtained at different flow rates and moisture contents calculated on the basis of bin sampling. Mortalities of as high as 98% were obtained for both *T. castaneum* and *C. ferrugineus*. These results were in compliance with the insect mortalities obtained during pneumatic conveyance in the previous studies

T. castaneum



C. ferrugineus

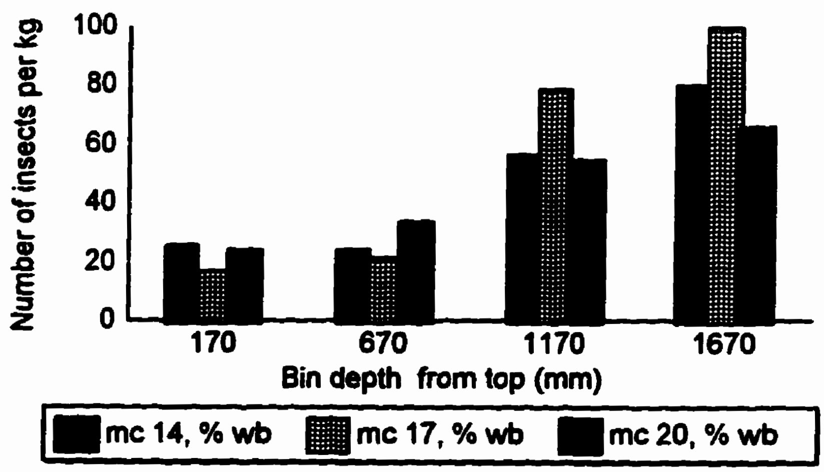


Figure 6.1. Distribution of *T. castaneum* and *C. ferrugineus* with bin depth and moisture content.

Table 6.1. Mean distribution of adult *T. castaneum* with bin depth and moisture content before conveyance.

Moisture content†	Bin depth (mm)* 170 Mean	170 S.D.**	670 Mean	670 S.D.	1170 Mean	1170 S.D.	1670 Mean	1670 S.D.
14	135	43	79	29	36	14	17	12
17	112	27	88	22	50	17	39	13
20	117	25	73	25	23	19	14	12

* Refer to Figure 5.4 for location of port numbers
** S.D. = Standard deviation based on n = 54 samples
† Moisture content measured with an error of ±0.01 percentage points

Table 6.2. Mean distribution of adult *C. ferrugineus* with bin depth and moisture content before conveyance.

Moisture content†	Bin depth (mm)* 170 Mean	170 S.D.**	670 Mean	670 S.D.	1170 Mean	1170 S.D.	1670 Mean	1670 S.D.
14	26	12	24	17	56	28	80	26
17	17	11	21	13	79	27	100	21
20	24	16	34	20	55	13	67	21

* Refer to Figure 5.4 for location of port numbers
** S.D. = Standard deviation based on n = 54 samples
† Moisture content measured with an error of ±0.01 percentage points

(Cogburn 1972, Bahr 1991, Armitage et al. 1995). In both the insect species, the highest mortalities were obtained at the lowest moisture content (14% wb) and highest conveying rate (5.0 t/h) used in this study.

Table 6.3. Mean adult mortalities at different flow rates and moisture contents calculated on the basis of bin sampling.

Flow rate (t/h)	Moisture content† (% wb)	*Tribolium castaneum* Mean Mortality (%)	*Tribolium castaneum* Standard* deviation	*Cryptolestes ferrugineus* Mean Mortality (%)	*Cryptolestes ferrugineus* Standard deviation
3.5	14	96.2	1.6	96.5	4.3
3.5	17	92.1	5.6	87.7	7.8
3.5	20	79.0	6.1	81.0	6.5
5.0	14	98.1	2.3	98.2	3.0
5.0	17	90.8	3.5	89.4	3.9
5.0	20	84.9	5.6	86.2	6.4

* based on n = 24 samples

† Moisture content measured with an error of ±0.01 percentage points

Analysis of variance was done on the bin sampling data for both *T. castaneum* and *C. ferrugineus* before and after conveyance. The highly significant F values (6.18 and 4.82) indicated that the models chosen for mortality as the dependent variable are reliable (Appendices B.1.a and B.2.a). A further analysis of the main effects (Appendices B.1.b and B.2.b) showed that for both species the effect of bins and flow rate was not significant at the 5% level. The effect of moisture content was highly significant but the interaction of flow rate and moisture content was not statistically significant. The analysis of the least squares means indicated that the flow rate, moisture content, and their interactions individually were statistically significant when compared with the controls (where bins were not conveyed) (Appendices B.1.c and B.2.c).

Pitfall traps were put in the bins before and after conveying and were sampled after a 3 d period. Table 6.4 summarises the total number of insects caught in the traps. The

Table 6.4. Means of the number of adult insects collected in the pitfall traps at different flow rates and moisture contents.

		Tribolium castaneum				*Cryptolestes ferrugineus*			
Flow rate	Moisture content †	Before conveyance		After conveyance		Before conveyance		After conveyance	
(t/h)	(% wb)	Mean	S.D.*	Mean	S.D.**	Mean	S.D.*	Mean	S.D**
3.5	14	53	18	1	1	21	7	1	1
3.5	17	42	16	2	1	34	11	1	1
3.5	20	43	17	3	1	37	10	3	1
5.0	14	50	17	0	0	20	8	1	1
5.0	17	31	9	2	1	29	5	1	1
5.0	20	37	12	2	1	29	6	1	1

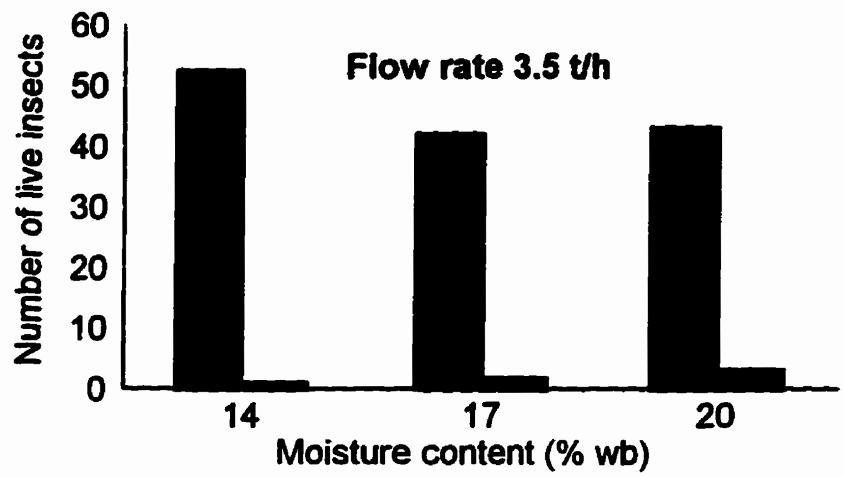
* S.D. = Standard deviation based on n = 9

** S.D. = Standard deviation based on n = 6

† Moisture content measured with an error of ±1%

number of insects captured in the insect traps is a relative estimate (White et al. 1990). The bar charts (Figures 6.2 and 6.3) clearly depict the relative decrease in the number of insects caught in the traps after pneumatic conveyance.

The results of ANOVA done on the trap catches are shown in Appendices C.1.a and C.2.a. Highly significant F values were observed for the models chosen for ANOVA. For *T. castaneum* a significant difference was seen between the treatments (i.e., before and after conveyance) (Appendix C.1.b). However, the effect of flow rate, moisture content, the interactions of treatments and flow rates, and that of treatments and moisture contents were not significant at 5% level. In contrast to *T. castaneum*, trapping of *C. ferrugineus* was



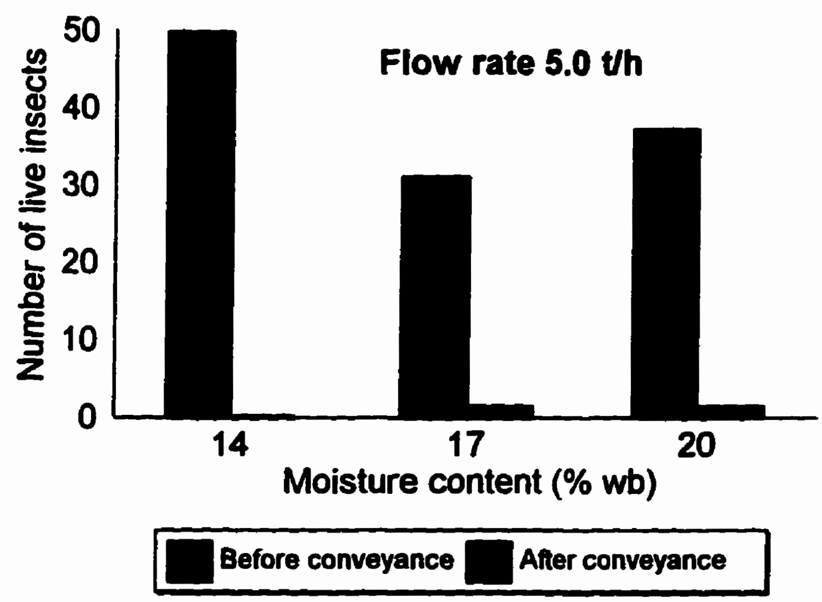


Figure 6.2. Mean number of *T. castaneum* captured in the insect traps before and after conveyance.

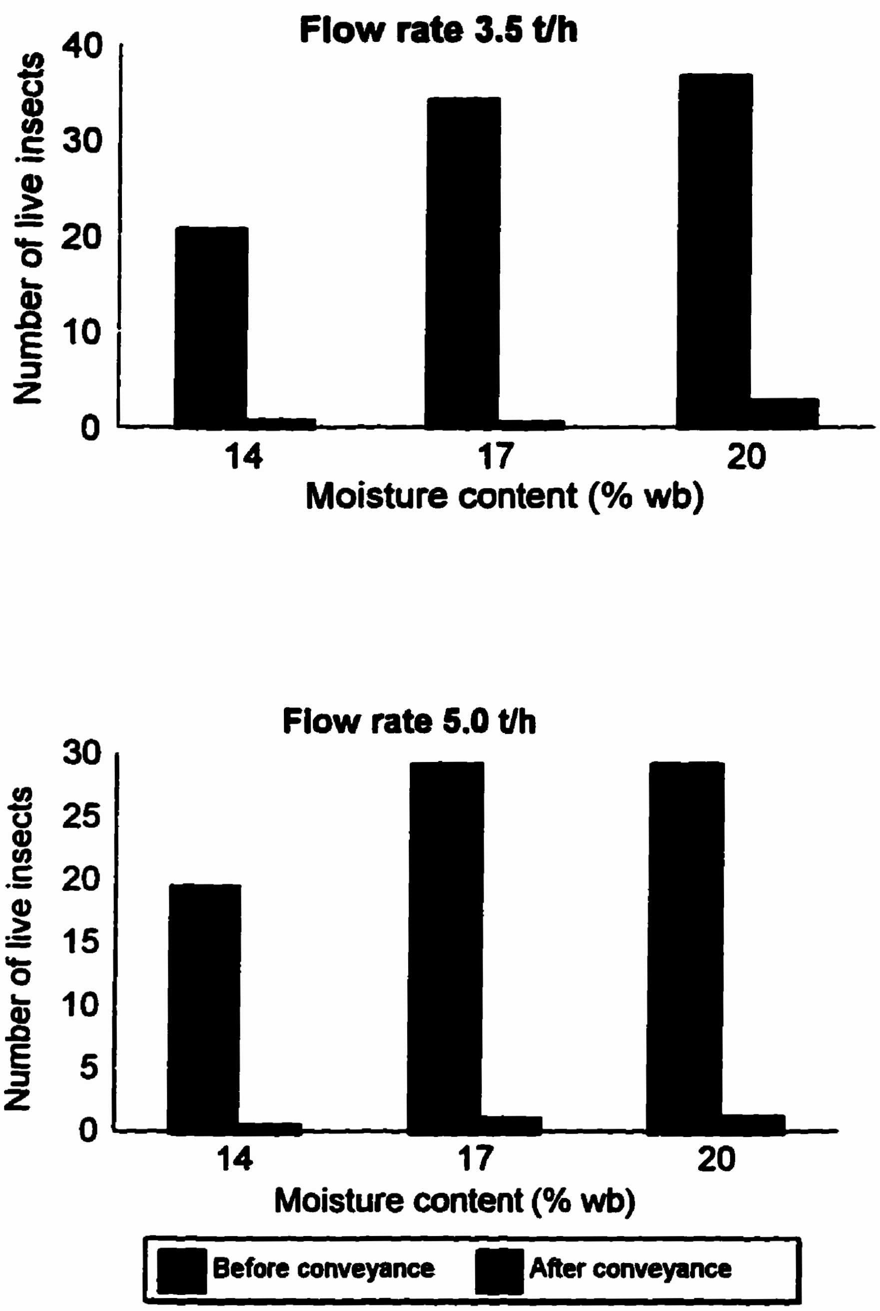


Figure 6.3. Mean number of *C. ferrugineus* captured in the insect traps before and after conveyance.

affected by the moisture content of the grain (Appendix C.2.b). The difference in behaviour, and consequently the trap catches, of the two insect species, at different moisture contents can be attributed to geotropism. *C. ferrugineus* tends to concentrate in the lower half of the bins. At higher moisture contents the temperature of the lower half of the bins ranged from 26 °C to 29 °C (Appendix D), which happens to be the most favourable temperature range for the activity of *C. ferrugineus*. Due to higher insect concentration and increased activity in the lower half of the bin, the trap catches for *C. ferrugineus* at higher moisture content increased. Appendices C.1.b and C.2.b also show that the effect of flow rate and its interaction with treatment was not statistically significant. But the effect of treatment and its interaction with moisture content was significant at the 5% level. The results in Table 6.4, however, should be read with caution due to high S.D. values caused by the sampling variability.

From the bin sampling and trap catches it can be seen that in the flow rate range of 3.5 to 5.0 t/h the difference in the grain velocity and consequently the impact and abrasions of the kernels was not large enough to significantly affect the mortality. However, the change in moisture content changes the flow properties of the grain. At higher moisture content, the grain becomes softer (Multon et al. 1981) and the relative abrasions among the grain kernels is less. This is correlated with a reduced mortality rate.

6.3. Mortality of Insects as Affected by the Different Parts of the Conveyor

The three samplers installed in the conveyor along the grain flow path were used to determine the effectiveness of different sections of the conveyor to kill the insects by catching the live insects flowing with the grain (Appendices E.1 to E.6). Tables 6.5 and 6.6

Table 6.5. Number of live adult *T. castaneum* captured at the three sampling ports while conveying the grain.

Flow rate (t/h)	Moisture content † (% wb)	Number of live insects (per kg of wheat) captured					
		Sampling Port 1*		Sampling Port 2		Sampling Port 3	
		Mean	S.D.**	Mean	S.D.	Mean	S.D.
3.5	14	16	1	13	5	2	3
3.5	17	7	3	10	4	1	1
3.5	20	10	4	17	10	2	1
5.0	14	18	6	10	3	2	2
5.0	17	6	2	12	3	0	1
5.0	20	8	2	14	7	1	1

* Refer to Figure 5.1 for location of sampling ports
** S.D. = Standard deviation based on n = 6 samples
† Moisture content measured with an error of ±0.01 percentage points

Table 6.6. Number of live adult *C. ferrugineus* captured at the three sampling ports while conveying the grain.

Flow rate (t/h)	Moisture content † (% wb)	Number of live insects (per kg of wheat) captured					
		Sampling Port 1*		Sampling Port 2		Sampling Port 3	
		Mean	S.D.**	Mean	S.D.	Mean	S.D.
3.5	14	10	6	10	7	1	2
3.5	17	9	3	7	2	0	1
3.5	20	6	4	11	5	0	1
5.0	14	15	6	11	7	1	1
5.0	17	9	4	7	2	0	1
5.0	20	7	2	10	4	1	1

* Refer to Figure 5.1 for location of sampling ports
** S.D. = Standard deviation based on n = 6 samples
† Moisture content measured with an error of ±0.01 percentage points

give the mean number of live *T. castaneum* and *C. ferrugineus,* respectively at the three sampling locations. It is observed from ANOVA (Appendices F.1.a and F.2.a) that for both insect species the effect of moisture content and sampling ports was significant after allowing for the effects of difference in flow rates and sampling ports for the former and flow rate and moisture content for the latter. There was a statistically significant difference between the interaction of moisture level and sampling port. However, the effect of flow rate on the number of insects captured at the sampling ports was not significant at the 5% level of confidence. The interactions of flow rate and moisture content and flow rate and sampling port were not statistically significant.

To identify which moisture content level differs from the others, the Tukey test was applied (Appendices F.1.b and F.2.b). The number of insects caught in the sampling ports at the three moisture levels were significantly different ($P < 0.05$) for *T. castaneum* and *C. ferrugineus*. The significant difference within the ports can be attributed to the differences between sampling ports 2 and 3, and 1 and 3. However, the differences between the number of live insects captured at sampling ports 1 and 2 were not significant. It is inferred that the maximum mortality occurred between the 2nd and the 3rd sampling ports. It may be because there were two 90° bends along the grain path between these two sampling ports. Due to this sudden change in the direction of flow the insects were subjected to a high impact force when they hit the bends. Also, this section of the conduit was the longest flow path, so the time for which the insects were subjected to the abrasive action due to moving kernels and the conduit walls was maximum. These two reasons may explain the high mortality obtained at the third sampling port.

6.4. Effect of Pneumatic Conveyance on Germination

To investigate if pneumatic conveyance has any adverse effect on the germination of wheat, germination tests were performed prior to and after conveyance. Table 6.7 shows the percentage germination before and after each test. The percent germination before and after conveyance ranged between 48 and 62 % and 48 and 61%, respectively. Statistical analysis indicates that the difference in the mean values of the two groups is not great enough to reject the possibility that the difference is due to random sampling variation (Appendices G.1.a to G.1.f). The difference in germination level due to pneumatic conveyance was not statistically significant. However, as the germination level of the commercial grade CWRS wheat was poor (57%), seed-grade wheat (cultivar Domain) was used for further germination tests. Germination of the seeds was tested before conveyance and after one, two, and three passes (Figure 6.4) at the flow rate of 5 t/h and 14% moisture content. The results of the tests were

Table 6.7. Effect of pneumatic conveyance on germination of CWRS wheat.

Flow Rate (t/h)	Moisture content † (% wb)	Percentage Germination			
		Before conveyance		After conveyance	
		Mean	S.D.*	Mean	S.D.**
3.5	14	50	3	52	2
3.5	17	57	2	56	3
3.5	20	48	3	48	2
5.0	14	60	4	61	3
5.0	17	62	4	61	3
5.0	20	60	3	59	3

* S.D. = Standard deviation based on n = 9 samples
** S.D. = Standard deviation based on n = 6 samples
† Moisture content measured with an error of ±0.01 percentage points

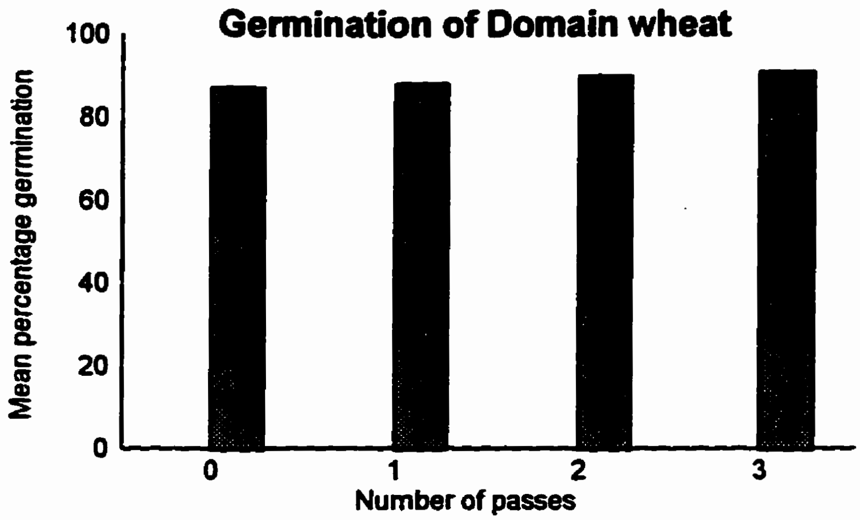


Figure 6.4. Mean germination of seed-grade wheat (cultivar Domain) before conveyance and after one, two, and three passes.

analyzed using a one way ANOVA. The effect on the level of germination of passing the grain through the conveyor was statistically insignificant (Appendix G.2). Therefore, it can be concluded that the physical forces experienced by wheat during pneumatic conveyance are strong enough to kill the insects that are external to the kernels but do not cause any loss in germination, in the flow rate range of 3.5 to 5.0 t/h.

7. CONCLUSIONS

The following conclusions can be drawn from this study:

1. Insect mortality was independent of the grain flow rate between 3.5 to 5.0 t/h.
2. Insect mortality obtained with a pneumatic conveyor depended on the moisture content of wheat; mortality was lower at the high moisture content and increased with a decrease in moisture content.
3. In a pneumatic conveyor, mortality of insects increased with an increase in the length of flow path and introduction of bends in the pipeline. This was evident from the fact that maximum mortality occurred between the second and the third sampling ports.
4. Insect mortalities of as high as 98% could be achieved when a pneumatic conveyor is used for disinfestation of wheat.
5. Germination of wheat in the moisture range of 14 to 20% was not affected when it was pneumatically conveyed at a flow rate of 3.5 to 5.0 t/h.
6. The maximum disinfestation in wheat using a pneumatic conveyor was at 14% grain moisture content and 5.0 t/h flow rate.

8. RECOMMENDATIONS FOR FUTURE WORK

The study was undertaken with the objective to quantify the rate of insect mortality in a pneumatic conveyor and to find the optimal conditions to achieve the maximum level of disinfestation. It is documented (PAMI 1979, Armitage et al. 1995) that pneumatic conveyors are useful in emptying granaries and are safer to operate than augers. Pneumatic conveyors can convey materials over longer horizontal and vertical distances than augers because unlike augers they do not have the constraint of the inclination angle. Their use as effective insect disinfestors has now been established. Chemical insecticides, which are commonly used for insect control are facing an increasing number of challenges. Consumers are increasingly reluctant to accept chemicals in their food. Until now pneumatic conveyors have not been used widely for transportation of grains at the farm level because they consume more power than augers. Because pneumatic conveyors can serve the dual purposes of transportation and disinfestation of grain, they have a great potential to be used at grain handling facilities. To make them more effective and economic, the following studies are recommended:

1. Effect of pneumatic conveying of grain on insect disinfestation at different moisture contents and flow rates for other crops such as rye, oats, barley, and canola should be studied to determine a wider application of pneumatic conveyors for killing insects.
2. The effect of pneumatic conveyance on the immature life stages of *T. castaneum* and *C. ferrugineus* need to be studied for maximum disinfestation.
3. A study on *S. granarius, R. dominica, S. oryzae* and other cosmopolitan stored-product

insects should be conducted to explore the potential of pneumatic conveyance for disinfestation because they have immature stages that develop inside the kernels.

4. This study indicated that there was no effect of grain flow rate on disinfestation in the range of 3.5 to 5.0 t/h. However, as the maximum capacity of the machine is much higher (32 t/h for wheat), it is desirable to study the effect of pneumatic conveyance on insect mortality and grain damage at higher flow rates for optimal application of the machine.

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APPENDIX A - Insect distribution in the bins.

Table A.1. Distribution of *T. castaneum* (T.C.) and *C. ferrugineus* (C.F.) at 14% moisture content and 3.5 t/h flow rate.

Before conveyance						After conveyance							
Port No.	Mass of sample (g)	Insect count		Insect density (per kg)		Mass of sample (g)	Insect count		Insect density (per kg)		Insect mortality (%)	
		T.C.	C.F.	T.C.	C.F.		T.C.	C.F.	T.C.	C.F.	T.C.	C.F.
BIN A												
1	120.3	7	1	58	8	112.4	1	0	9	0		
2	116.7	5	0	43	0	123.1	0	0	0	0		
3	109.5	4	2	37	18	108.6	0	0	0	0		
4	118.4	1	6	8	51	110	0	0	0	0		
	Mean			37*	19*	Mean			2*	0*	93.90	100.00
	Trap	33	9			Trap	2	0				
BIN B												
1	109.5	12	3	110	27	112.3	1	0	9	0		
2	100.8	7	1	69	10	116.7	0	0	0	0		
3	121.6	3	5	25	41	120	0	1	0	8		
4	118.4	2	9	17	76	113.5	0	0	0	0		
	Mean			55*	38*	Mean			2*	2*	95.96	94.60
	Trap	81	19			Trap	2	0				

* Mean mortality

cont....

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Port No.	Before conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	After conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
					BIN C							
1	115.6	23	4	199	35	109.8	1	1	9	9		
2	116.1	10	5	86	43	117.2	0	0	0	0		
3	120.7	2	7	17	58	124.8	1	0	8	0		
4	100.8	2	12	20	119	115.9	0	2	0	17		
	Mean			80*	64*	Mean			4*	7*	94.67	89.65
	Trap	57	23			Trap	1	1				
					BIN D							
1	113.6	17	3	150	26	111.1	0	0	0	0		
2	117.1	15	2	128	17	120.3	0	0	0	0		
3	122.2	4	5	33	41	118.9	1	0	8	0		
4	111.5	2	12	18	108	106.4	0	0	0	0		
	Mean			82*	48*	Mean			2*	0*	97.44	100.00
	Trap	38	22			Trap	0	2				
					BIN E							
1	112.4	19	5	169	44	114.5	1	1	9	9		
2	113.8	9	2	79	18	130.5	0	0	0	0		
3	120.4	8	6	66	50	119.1	0	0	0	0		
4	109.7	2	5	18	46	116.6	0	0	0	0		
	Mean			83*	39*	Mean			2*	2*	97.38	94.45
	Trap	61	19			Trap	0	1				

* Mean mortality

cont....

cont....

	Before conveyance					After conveyance						
Port	Mass of	Insect count		Insect density (per kg)		Mass of	Insect count		Insect density (per kg)		Insect mortality (%)	
No.	sample (g)	T.C.	C.F.	T.C.	C.F.	sample (g)	T.C.	C.F.	T.C.	C.F.	T.C.	C.F.
						BIN F						
1	105.8	22	6	208	57	113.5	0	0	0	0		
2	112.4	12	5	107	44	115.1	0	0	0	0		
3	113.4	4	8	35	71	111.9	0	0	0	0		
4	108.3	3	9	28	83	108.3	1	0	9	0		
	Mean			94*	64*	Mean			2*	0*	97.56	100.00
	Trap	45	32			Trap	1	0				
						BIN X						
1	108.2	13	2	120	18	112.3	15	1	134	9		
2	102.7	4	3	39	29	113.2	7	3	62	27		
3	121.5	5	5	41	41	108.4	4	5	37	46		
4	119.4	4	7	34	59	114.6	0	7	0	61		
	Mean			58*	37*	Mean			58*	36*	0.62	3.30
	Trap	18	14			Trap	35	26				
						BIN Y						
1	112.1	8	2	71	18	102.3	14	2	137	20		
2	107.1	12	2	112	19	120.4	11	5	91	42		
3	118.5	5	13	42	110	115.5	4	9	35	78		
4	113.3	5	12	44	106	119.7	1	14	8	117		
	Mean			67*	63*	Mean			68*	64*	-0.54	-1.52
	Trap	23	9			Trap	51	27				

* Mean mortality

cont....

cont....

Port No.	Before conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	After conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
						BIN Z						
1	113.8	13	2	114	18	112.6	12	3	107	27		
2	114.7	5	5	44	44	117.8	7	1	59	8		
3	120.2	7	8	58	67	116.4	2	4	17	34		
4	102.5	0	5	0	49	109.1	3	11	27	101		
	Mean			54*	44*	Mean			53*	43*	2.49	3.50
	Trap	16	21			Trap	41	31				

* Mean mortality

Table A.2. Distribution of *T. castaneum* (T.C.) and *C. ferrugineus* (C.F.) at 17% moisture content and 3.5 t/h flow rate.

	Before conveyance					After conveyance							
Port No.	Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
					BIN A							
1	106.77	14	1	131	9	113.4	2	0	18	0		
2	115.36	9	2	78	17	111.9	0	0	0	0		
3	117.21	4	5	34	43	110.6	1	1	9	9		
4	110.2	1	12	9	109	112.4	2	1	18	9		
	Mean			63*	45*	Mean			11*	4*	82.38	89.94
	Trap	35	26			Trap	3	0				
					BIN B							
1	118.63	17	3	143	25	114.8	0	1	0	9		
2	118.26	10	2	85	17	116.1	0	2	0	17		
3	116.47	5	5	43	43	119.2	1	0	8	0		
4	114.38	6	14	52	122	115.3	0	0	0	0		
	Mean			81*	52*	Mean			2*	6*	97.40	87.50
	Trap	19	23			Trap	1	2				
					BIN C							
1	111.64	15	1	134	9	120.9	0	2	0	17		
2	116.27	8	2	69	17	115.5	1	0	9	0		
3	111.02	10	6	90	54	116.2	0	0	0	0		
4	138.68	4	9	29	65	130.5	1	3	8	23		
	Mean			81*	36*	Mean			4*	10*	94.93	72.76
	Trap	47	35			Trap	2	1				

* Mean mortality

cont....

cont....

Port No.	Before conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	After conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
					BIN D							
1	110.43	14	3	127	27	120.0	1	0	8	0		
2	115.41	12	1	104	9	111.7	1	0	9	0		
3	112.68	6	8	53	71	109.5	0	1	0	9		
4	105.37	5	9	47	85	98.6	0	0	0	0		
	Mean			83*	48*	Mean			4*	2*	94.78	95.25
	Trap	57	28			Trap	1	0				
					BIN E							
1	114.97	12	2	104	17	108.7	1	0	9	0		
2	116.2	14	2	120	17	113.8	0	0	0	0		
3	110.71	4	9	36	81	113.3	1	0	9	0		
4	123.8	5	10	40	81	125.7	2	2	16	16		
	Mean			75*	49*	Mean			8*	4*	88.74	91.91
	Trap	61	52			Trap	1	0				
					BIN F							
1	107.39	20	3	186	28	110.9	0	1	0	9		
2	114.37	15	5	131	44	114.5	2	0	17	0		
3	115.88	9	8	78	69	113.3	0	1	0	9		
4	112.3	7	11	62	98	120.1	1	1	8	8		
	Mean			114*	60*	Mean			6*	7*	94.36	89.03
	Trap	34	41			Trap	3	0				

* Mean mortality

cont....

cont....

Port No.	Before conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	After conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
BIN X												
1	115.47	14	0	121	0	109.1	15	3	137	27		
2	113.55	15	4	132	35	108.4	10	3	92	28		
3	111.72	4	6	36	54	107.4	5	5	47	47		
4	128.4	5	15	39	117	110.4	2	9	18	82		
	Mean			82*	51*	Mean			74*	46*	10.26	10.94
	Trap	26	35			Trap	44	39				
BIN Y												
1	113.16	13	1	115	9	111.4	14	2	126	18		
2	115	8	2	70	17	109.8	10	2	91	18		
3	113.11	6	7	53	62	105.9	5	5	47	47		
4	130.02	7	11	54	85	120.4	2	10	17	83		
	Mean			73*	43*	Mean			70*	42*	3.69	3.64
	Trap	20	39			Trap	27	41				
BIN Z												
1	112.73	9	1	80	9	110.6	10	3	90	27		
2	110.9	9	4	81	36	109.9	9	2	82	18		
3	107.66	8	15	74	139	109.8	5	11	46	100		
4	153.04	3	12	20	78	118.7	3	13	25	110		
	Mean			64*	66*	Mean			61*	64*	4.62	2.91
	Trap	25	21			Trap	40	26				

* Mean mortality

Table A.3. Distribution of *T. castaneum* (T.C.) and *C. ferrugineus* (C.F.) at 20% moisture content and 3.5 t/h flow rate.

Port No.	Before conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	After conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
BIN A												
1	114.7	11	2	96	17	116.3	1	2	9	17		
2	119	8	4	67	34	118.8	2	3	17	25		
3	114.8	5	6	44	52	124.6	1	1	8	8		
4	133.6	5	9	37	67	101.1	2	0	20	0		
	Mean			61*	43*	Mean			13*	13*	78.19	70.43
	Trap	40	36			Trap	4	3				
BIN B												
1	118.7	15	4	126	34	120.6	4	1	33	8		
2	115	6	4	52	35	121.7	1	2	8	16		
3	118.5	2	8	17	68	126.7	0	2	0	16		
4	98.5	0	6	0	61	133.2	0	1	0	8		
	Mean			49*	49*	Mean			10*	12*	78.82	75.61
	Trap	71	53			Trap	3	2				
BIN C												
1	121.1	19	2	157	17	123	3	1	24	8		
2	116.3	12	6	103	52	120.7	0	0	0	0		
3	116.3	5	5	43	43	122.1	1	2	8	16		
4	135.1	0	14	0	104	99.1	0	1	0	10		
	Mean			76*	54*	Mean			8*	9*	89.25	83.89
	Trap	43	25			Trap	2	2				

* Mean mortality

cont....

cont....

Port No.	Before conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	After conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
BIN D												
1	109.4	14	4	128	37	116.0	4	0	34	0		
2	115.2	8	5	69	43	123.7	1	0	8	0		
3	118.2	7	5	59	42	116.7	0	2	0	17		
4	101.3	1	6	10	59	110.5	1	1	9	9		
	Mean			67*	45*	Mean			13*	7*	80.63	85.57
	Trap	33	42			Trap	5	3				
BIN E												
1	114.8	13	8	113	70	119.5	1	1	8	8		
2	122.2	6	5	49	41	119.2	1	2	8	17		
3	117.9	0	6	0	51	120.6	3	0	25	0		
4	120.6	1	9	8	75	118.1	1	1	8	8		
	Mean			43*	59*	Mean			13*	8*	70.64	85.76
	Trap	22	27			Trap	1	4				
BIN F												
1	113.7	15	2	132	18	113.4	4	0	35	0		
2	115.1	12	0	104	0	112.2	4	0	36	0		
3	120.1	8	4	67	33	119.5	1	0	8	0		
4	133.2	5	7	38	53	128.4	0	2	0	16		
	Mean			85*	26*	Mean			20*	4*	76.70	84.94
	Trap	50	37			Trap	4	3				

* Mean mortality

cont....

cont....

Port No.	Before conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	After conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
					BIN X							
1	112.3	18	2	160	18	112.3	15	2	134	18		
2	114	15	10	132	88	116.6	13	5	111	43		
3	113.1	1	8	9	71	119.8	4	8	33	67		
4	99.1	0	8	0	81	99	1	12	10	121		
	Mean			75*	64*	Mean			72*	62*	4.04	3.23
	Trap	49	33			Trap	52	28				
					BIN Y							
1	113.4	10	0	88	0	113.4	9	1	79	9		
2	115.9	8	2	69	17	115.1	7	2	61	17		
3	114.5	0	6	0	52	114.2	3	9	26	79		
4	101.5	2	12	20	118	105.7	1	8	9	76		
	Mean			44*	47*	Mean			44*	45*	0.57	3.83
	Trap	34	40			Trap	47	36				
					BIN Z							
1	113.5	12	3	106	26	116.2	8	2	69	17		
2	116.1	7	6	60	52	118.7	6	2	51	17		
3	112.1	0	4	0	36	112.6	4	6	36	53		
4	110.4	0	5	0	45	100.1	1	7	10	70		
	Mean			42*	40*	Mean			41*	39*	0.67	1.14
	Trap	28	35			Trap	38	44				

* - Mean mortality

Table A.4. Distribution of *T. castaneum* (T.C.) and *C. ferrugineus* (C.F.) at 14% moisture content and 5.0 t/h flow rate.

Before conveyance						After conveyance						
Port No.	Mass of sample (g)	Insect count		Insect density (per kg)		Mass of sample (g)	Insect count		Insect density (per kg)		Insect mortality (%)	
		T.C.	C.F.	T.C.	C.F.		T.C.	C.F.	T.C.	C.F.	T.C.	C.F.
						BIN A						
1	117.8	8	2	68	17	118.5	0	0	0	0		
2	120.6	6	1	50	8	114.8	1	0	9	0		
3	119.2	3	3	25	25	117.5	0	0	0	0		
4	115.7	2	7	17	61	111.3	0	0	0	0		
	Mean			40*	28*	Mean			2*	0*	94.56	100.00
	Trap	29	7			Trap	0	1				
						BIN B						
1	117.6	15	2	128	17	118.3	0	0	0	0		
2	110.4	9	1	82	9	111.5	0	0	0	0		
3	113.7	3	4	26	35	119.4	0	0	0	0		
4	110.8	1	10	9	90	120.4	1	0	8	0		
	Mean			61*	38*	Mean			2*	0*	96.60	100.00
	Trap	55	13			Trap	0	0				
						BIN C						
1	115.2	20	3	174	26	110.4	0	0	0	0		
2	112.5	9	4	80	36	118.2	0	0	0	0		
3	121.7	3	9	25	74	119	0	0	0	0		
4	110.5	2	13	18	118	119.4	0	0	0	0		
	Mean			74*	63*	Mean			0*	0*	100.00	100.00
	Trap	79	22			Trap	0	1				

* Mean mortality

cont....

cont....

Port No.	Before conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	After conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
BIN D												
1	112.2	15	4	134	36	117.7	1	0	8	0		
2	119.2	15	1	126	8	115.1	0	0	0	0		
3	123.3	5	7	41	57	119.2	0	0	0	0		
4	110.6	1	13	9	118	116.8	0	1	0	9		
	Mean			77*	55*	Mean			2*	2*	97.25	96.08
	Trap	48	24			Trap	0	0				
BIN E												
1	114.1	20	2	175	18	115.3	0	1	0	9		
2	119.8	8	0	67	0	112.6	0	0	0	0		
3	117.5	6	6	51	51	119	0	0	0	0		
4	110.5	0	6	0	54	120.7	0	0	0	0		
	Mean			73*	31*	Mean			0*	2*	100.00	92.94
	Trap	48	20			Trap	1	1				
BIN F												
1	114.2	20	4	175	35	114.6	0	0	0	0		
2	113.4	14	4	123	35	112.3	0	0	0	0		
3	111.1	3	4	27	36	119.7	0	0	0	0		
4	119.9	1	10	8	83	112.1	0	0	0	0		
	Mean			83*	47*	Mean			0*	0*	100.00	100.00
	Trap	40	31			Trap	0	0				

* · Mean mortality

cont....

cont....

Port No.	Before conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	After conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
						BIN X						
1	119.8	17	3	142	25	113.2	12	0	106	0		
2	112.2	5	3	45	27	112.2	9	2	80	18		
3	114.1	6	5	53	44	118.1	6	6	51	51		
4	120	4	5	33	42	117.3	3	8	26	68		
	Mean			68*	34*	Mean			66*	34*	3.59	0.32
	Trap	39	26			Trap	53	45				
						BIN Y						
1	116.3	12	3	103	26	115.6	12	3	104	26		
2	114.1	10	4	88	35	121.4	10	4	82	33		
3	123.1	2	17	16	138	112.8	5	9	44	80		
4	114.2	3	11	26	96	117.7	0	18	0	153		
	Mean			58*	74*	Mean			58*	73*	1.22	1.24
	Trap	33	33			Trap	44	29				
						BIN Z						
1	119.6	17	1	142	8	113.5	8	0	70	0		
2	118.4	7	6	59	51	114.9	8	2	70	17		
3	116	3	7	26	60	112.6	7	8	62	71		
4	112.4	0	9	0	80	111	2	12	18	108		
	Mean			57*	50*	Mean			55*	49*	3.01	1.45
	Trap	27	43			Trap	31	22				

* Mean mortality

Table A.5. Distribution of *T. castaneum* (T.C.) and *C. ferrugineus* (C.F.) at 17% moisture content and 5.0 t/h flow rate.

Before conveyance						After conveyance						
Port No.	Mass of sample (g)	Insect count		Insect density (per kg)		Mass of sample (g)	Insect count		Insect density (per kg)		Insect mortality (%)	
		T.C.	C.F.	T.C.	C.F.		T.C.	C.F.	T.C.	C.F.	T.C.	C.F.
BIN A												
1	116.2	12	2	103	17	110.8	1	1	9	9		
2	114.9	11	2	96	17	119.4	0	1	0	8		
3	117.6	5	9	43	77	119.3	0	1	0	8		
4	116.8	2	10	17	86	121.7	2	0	16	0		
	Mean			65*	49*	Mean			6*	6*	90.16	86.90
	Trap	42	29			Trap	2	1				
BIN B												
1	122.1	16	4	131	33	110.1	1	1	9	9		
2	115.2	9	2	78	17	119.7	0	0	0	0		
3	119.1	4	8	34	67	116.2	0	1	0	9		
4	111	5	13	45	117	112.8	0	2	0	18		
	Mean			72*	59*	Mean			2*	9*	96.84	84.89
	Trap	21	27			Trap	1	1				
BIN C												
1	116.3	10	1	86	9	112.5	1	1	9	9		
2	117.2	9	1	77	9	114.6	1	0	9	0		
3	120	6	12	50	100	118.3	0	0	0	0		
4	110	5	11	45	100	118.7	1	0	8	0		
	Mean			65*	54*	Mean			7*	2*	89.92	95.91
	Trap	36	28			Trap	1	2				

* Mean mortality

cont....

cont....

Port No.	Before conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	After conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
						BIN D						
1	117.6	11	2	94	17	115.8	1	1	9	9		
2	110.1	9	6	82	54	116.3	2	0	17	0		
3	119.9	5	8	42	67	118.9	0	0	0	0		
4	121	4	11	33	91	116.7	0	2	0	17		
	Mean			63*	57*	Mean			6*	6*	89.67	88.75
	Trap	37	36			Trap	2	0				
						BIN E						
1	122.3	10	3	82	25	117.7	0	0	0	0		
2	115	11	0	96	0	110.8	1	0	9	0		
3	119.1	5	10	42	84	116.4	1	2	9	17		
4	120.5	4	11	33	91	116.7	2	0	17	0		
	Mean			63*	50*	Mean			9*	4*	86.24	91.40
	Trap	31	21			Trap	2	0				
						BIN F						
1	111.2	13	4	117	36	119.4	0	0	0	0		
2	119.4	7	2	59	17	112.6	0	0	0	0		
3	116.2	9	12	77	103	120.9	3	1	25	8		
4	102.7	5	16	49	156	110.8	0	4	0	36		
	Mean			75*	78*	Mean			6*	11*	91.77	85.77
	Trap	19	34			Trap	1	2				

* Mean mortality

cont....

cont....

Port No.	Before conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	After conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
BIN X												
1	116.5	10	3	86	26	118.2	13	1	110	8		
2	112.4	12	2	107	18	122.3	9	3	74	25		
3	119.7	4	9	33	75	116.7	7	3	60	26		
4	124.1	5	13	40	105	118.8	2	19	17	160		
	Mean			67*	56*	Mean			65*	55*	2.22	2.17
	Trap	33	32			Trap	37	31				
BIN Y												
1	114.1	9	0	79	0	117.5	12	2	102	17		
2	122.4	8	2	65	16	118.7	8	2	67	17		
3	119.1	5	11	42	92	113.7	6	5	53	44		
4	120.2	5	10	42	83	109.8	0	12	0	109		
	Mean			57*	48*	Mean			56*	47*	2.42	2.48
	Trap	22	19			Trap	30	31				
BIN Z												
1	110.7	11	1	99	9	111.5	13	1	117	9		
2	112.1	7	3	62	27	112.7	10	1	89	9		
3	118.6	5	16	42	135	119.6	2	15	17	125		
4	120.3	5	15	42	125	114	2	17	18	149		
	Mean			61*	74*	Mean			60*	73*	2.42	1.02
	Trap	19	23			Trap	36	35				

* Mean mortality

Table A.6. Distribution of *T. castaneum* (T.C.) and *C. ferrugineus* (C.F.) at 20% moisture content and 5.0 t/h flow rate.

	Before conveyance					After conveyance						
Port No.	Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
BIN A												
1	112.4	9	1	80	9	114.8	1	1	9	9		
2	115.9	6	2	52	17	117.9	1	2	8	17		
3	117.4	4	7	34	60	116.7	0	1	0	9		
4	112.6	2	7	18	62	107.6	1	0	9	0		
	Mean			46*	37*	Mean			7*	9*	85.58	76.85
	Trap	22	19			Trap	1	2				
BIN B												
1	115.8	12	3	104	26	118.6	3	0	25	0		
2	117.3	5	2	43	17	119.1	1	1	8	8		
3	118.9	2	7	17	59	118.7	0	1	0	8		
4	109.8	1	4	9	36	123.4	0	1	0	8		
	Mean			43*	35*	Mean			8*	6*	80.43	81.97
	Trap	55	34			Trap	2	1				
BIN C												
1	122.1	14	1	115	8	118.3	4	0	34	0		
2	116.7	7	5	60	43	114.5	1	0	9	0		
3	113.4	3	4	26	35	113.4	0	1	0	9		
4	122.2	1	6	8	49	101.5	0	1	0	10		
	Mean			52*	34*	Mean			11*	5*	79.67	86.21
	Trap	37	26			Trap	1	0				

* Mean mortality

cont....

cont....

Before conveyance						After conveyance						
Port No.	Mass of sample (g)	Insect count		Insect density (per kg)		Mass of sample (g)	Insect count		Insect density (per kg)		Insect mortality (%)	
		T.C.	C.F.	T.C.	C.F.		T.C.	C.F.	T.C.	C.F.	T.C.	C.F.
BIN D												
1	114.2	8	3	70	26	115.7	2	0	17	0		
2	116.7	8	5	69	43	117.9	1	0	8	0		
3	117.4	2	8	17	68	113.4	0	0	0	0		
4	119.3	1	7	8	59	112.2	0	1	0	9		
	Mean			41*	49*	Mean			6*	2*	84.29	95.45
	Trap	42	37			Trap	2	2				
BIN E												
1	116.8	12	3	103	26	114.6	1	0	9	0		
2	127.4	7	4	55	31	115	0	1	0	9		
3	114	1	5	9	44	118.3	0	0	0	0		
4	115.7	2	8	17	69	117.9	0	1	0	8		
	Mean			46*	43*	Mean			2*	4*	95.25	89.90
	Trap	24	31			Trap	1	2				
BIN F												
1	115.7	17	3	147	26	111.2	2	1	18	9		
2	116.7	7	0	60	0	118.2	2	0	17	0		
3	119.7	1	8	8	67	119.6	0	0	0	0		
4	119.4	1	5	8	42	117.3	0	1	0	9		
	Mean			56*	34*	Mean			9*	4*	84.39	86.99
	Trap	43	28			Trap	2	0				

*- Mean mortality

cont....

cont....

Port No.	Before conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	After conveyance: Mass of sample (g)	Insect count T.C.	Insect count C.F.	Insect density (per kg) T.C.	Insect density (per kg) C.F.	Insect mortality (%) T.C.	Insect mortality (%) C.F.
BIN X												
1	114.7	16	1	139	9	113.4	12	1	106	9		
2	117.4	10	4	85	34	114.3	11	0	96	0		
3	119.2	2	7	17	59	116.8	4	7	34	60		
4	109.8	1	5	9	46	108.7	1	9	9	83		
	Mean			63*	37*	Mean			61*	38*	2.02	-3.06
	Trap	31	31			Trap	40	34				
BIN Y												
1	114.5	12	6	105	52	116	11	1	95	9		
2	116.8	7	2	60	17	113.7	5	3	44	26		
3	118.2	2	9	17	76	112.1	5	11	45	98		
4	113.3	2	10	18	88	109.5	2	11	18	100		
	Mean			50*	58*	Mean			50*	58*	-1.19	0.15
	Trap	22	34			Trap	51	23				
BIN Z												
1	114.2	15	2	131	18	111.1	15	0	135	0		
2	119.7	14	5	117	42	118.8	13	0	109	0		
3	116	4	8	34	69	116.3	4	12	34	103		
4	113.3	4	8	35	71	108.8	4	10	37	92		
	Mean			80*	50*	Mean			79*	49*	0.78	1.89
	Trap	34	33			Trap	46	33				

* Mean mortality

APPENDIX B - Statistical Analysis of Bin Data

Table B.1.a. Analysis of variance for mortality of *T. castaneum* adults.

Source	D F	Sum of squares	Mean squares	F Value	Pr > F
Model	10	1997.98	199.80	6.18	0.0001
Error	25	808.55	32.34		
Corrected total	35	2806.53			

	R - Square	C.V.	Root MSE	Mean Mortality
	0.71	6.34	5.69	89.73

Table B.1.b. Analysis of variance of the main effects of *T. castaneum* mortality.

Source	D F	Type I SS	Mean square	F Value	Pr > F
Bin	5	78.92	15.78	0.49	0.7819
Flow Rate	1	84.30	84.30	2.61	0.1190
Moisture	2	840.47	840.47	25.99	0.0001
Flow Rate* Moisture	2	76.91	76.91	2.38	0.1134

Table B.1.c. Analysis of Least Squares Means for *T. castaneum* mortality.

Flow Rate (t/h)	Moisture (% wb)	Mortality Mean	Std Error	Pr > |T|
5.00	-	91.2566	1.3404	0.0001
3.50	-	88.1961	1.3404	0.0001
-	14	97.1108	1.6417	0.0001
-	17	91.4325	1.6417	0.0001
-	20	80.6358	1.6417	0.0001
5.00	14	98.0683	2.3217	0.0001
5.00	17	90.7667	2.3217	0.0001
5.00	20	84.9350	2.3217	0.0001
3.50	14	96.1533	2.3217	0.0001
3.50	17	92.0983	2.3217	0.0001
3.50	20	76.3367	2.3217	0.0001

Table B.2.a. Analysis of variance for mortality of *C. ferrugineus* adults.

Source	D F	Sum of squares	Mean squares	F Value	Pr > F
Model	10	1443.87	144.39	4.82	0.0001
Error	25	749.55	29.98		
Corrected total	35	2193.41			

	R - Square	C.V.	Root MSE	Mean Mortality	
	0.66	6.10	5.48	89.76	

Table B.2.b. Analysis of variance of the main effects of *C. ferrugineus* mortality.

Source	D F	Type I SS	Mean square	F Value	Pr > F
Bin	5	190.45	38.09	1.27	0.3076
Flow Rate	1	65.93	65.93	2.20	0.1506
Moisture	2	1159.23	579.61	19.33	0.0001
Flow Rate* Moisture	2	28.26	14.13	0.47	0.6296

Table B.2.c. Analysis of Least Squares Means for *C. ferrugineus* mortality.

Flow Rate (t/h)	Moisture (% wb)	Mortality Mean	Std Error	Pr > |T|
5.00	-	91.1116	1.2906	0.0001
3.50	-	88.4050	1.2906	0.0001
-	14	97.3100	1.5807	0.0001
-	17	88.3341	1.5807	0.0001
-	20	83.6308	1.5807	0.0001
5.00	14	98.1700	2.2354	0.0001
5.00	17	88.9367	2.2354	0.0001
5.00	20	86.2283	2.2354	0.0001
3.50	14	96.4500	2.2354	0.0001
3.50	17	87.7317	2.2354	0.0001
3.50	20	81.0333	2.2354	0.0001

APPENDIX C - Statistical Analysis of Trap Data

Table C.1.a. Analysis of variance for mortality of *T. castaneum* adults.

Source	D F	Sum of squares	Mean squares	F Value	Pr > F
Model	7	32228.38	4604.06	42.44	0.0001
Error	64	6943.11	108.49		
Corrected total	71	39171.50			

	R - Square	C.V.	Root MSE	Mean Mortality
	0.82	47.17	10.42	22.08

Table C.1.b. Analysis of variance of the main effects of *T. castaneum* mortality.

Source	D F	Type I SS	Mean square	F Value	Pr > F
Treatment	1	30422.22	30422.22	280.43	0.0001
Flow Rate	1	256.89	256.89	2.37	0.1288
Moisture	2	571.75	285.88	2.64	0.0795
Treatment* Flow Rat	1	144.50	144.50	1.33	0.2527
Treatment * Moisture	2	833.03	416.51	3.84	0.0266

Table C.2.a. Analysis of variance for mortality of *C. ferrugineus* adults.

Source	D F	Sum of squares	Mean squares	F Value	Pr > F
Model	7	14634.89	2090.70	42.44	0.0001
Error	64	2189.11	34.20		
Corrected total	71	16824.00			

	R - Square	C.V.	Root MSE	Mean Mortality
	0.87	39.88	5.85	14.67

Table C.2.b. Analysis of variance of the main effects of *C. ferrugineus* mortality.

Source	D F	Type I SS	Mean square	F Value	Pr > F
Treatment	1	13230.22	13230.22	386.79	0.0001
Flow Rate	1	112.50	112.50	3.29	0.0744
Moisture	2	694.75	347.38	10.16	0.0001
Treatment* Flow Rat	1	76.06	76.06	2.22	0.1408
Treatment * Moisture	2	521.36	260.68	7.62	0.0011

APPENDIX D - Temperature variation in the bins.

Table D.1. Temperature variation in the bins with depth at different moisture contents.

Bin No.	Temperature before conveyance			Temperature after conveyance		
	Port 1 *	Port 2 *	Port 3 *	Port 1	Port 2	Port 3
			Grain moisture content 14%			
A	23	21	20	22	22	20
B	23	21	19	22	21	21
C	22	22	20	23	21	20
D	23	22	19	22	21	20
E	23	22	19	23	22	20
F	22	22	20	23	21	20
Mean	22.66	21.66	19.50	22.50	21.33	20.16
S.D.	0.47	0.47	0.50	0.50	0.47	0.37
			Grain moisture content 17%			
A	24	24	25	23	25	26
B	22	25	25	24	25	25
C	23	25	25	23	25	25
D	23	25	25	23	25	25
E	24	25	25	23	25	25
F	24	24	25	23	25	25
Mean	23.33	24.66	25.00	23.16	25.00	25.16
S.D.	0.74	0.47	0.00	0.37	0.00	0.37
			Grain moisture content 20%			
A	26	27	28	27	28	28
B	27	27	28	26	28	29
C	26	27	29	26	27	29
D	26	27	28	26	27	28
E	26	27	28	26	27	29
F	27	27	29	26	28	29
Mean	26.33	27.00	28.33	26.16	27.50	28.66
S.D.	0.47	0.00	0.47	0.37	0.50	0.47

* Refer to Figure 5.3

APPENDIX E - Insects Collected while Conveying the Grain

Table E.1. Insects collected at 14% moisture content and 3.5 t/h.

Sampler No.	Mass of sample (g)	Number of alive insects collected			
		T. castaneum		*C.ferrugineus*	
		Insects	Density *	Insects	Density *
			BIN A		
1	589.3	10	17	7	12
2	938.4	22	23	15	16
3	627.4	5	8	3	5
			BIN B		
1	472.6	8	17	3	6
2	875.4	10	11	5	6
3	622.1	2	3	1	2
			BIN C		
1	687.5	12	17	15	22
2	465.7	7	15	11	24
3	583.6	0	0	0	0
			BIN D		
1	708.1	12	17	4	6
2	625.4	5	8	2	3
3	882.8	1	1	0	0
			BIN E		
1	765.1	11	14	6	8
2	615.0	6	10	3	5
3	784.3	0	0	0	0
			BIN F		
1	857.1	12	14	6	7
2	763.9	7	9	7	9
3	823.5	1	1	0	0

* No. of insects per kg.

Table E.2. Insects collected at 17% moisture content and 3.5 t/h.

Sampler No.	Mass of sample (g)	Number of alive insects collected			
		T. castaneum		*C.ferrugineus*	
		Insects	Density *	Insects	Density *
		BIN A			
1	555.9	4	7	5	9
2	684.9	10	15	5	7
3	741.7	1	1	0	0
		BIN B			
1	578.7	4	7	6	10
2	800.9	5	6	6	7
3	725.4	0	0	0	0
		BIN C			
1	678.1	2	3	4	6
2	782.4	4	5	2	3
3	896.5	1	1	0	0
		BIN D			
1	623.6	7	11	6	10
2	593.5	7	12	6	10
3	671.0	1	1	1	1
		BIN E			
1	617.8	5	8	9	15
2	709.6	11	16	4	6
3	560.0	0	0	0	0
		BIN F			
1	812.8	3	4	5	6
2	643.7	5	8	4	6
3	597.4	1	2	0	0

* No. of insects per kg.

Table E.3. Insects collected at 20% moisture content and 3.5 t/h.

Sampler No.	Mass of sample (g)	Number of alive insects collected			
		T. castaneum		*C.ferrugineus*	
		Insects	Density *	Insects	Density *
			BIN A		
1	788.1	5	6	3	4
2	675.2	24	36	14	21
3	605.6	2	3	0	0
			BIN B		
1	623.4	7	11	4	6
2	497.2	9	18	6	12
3	545.0	2	4	0	0
			BIN C		
1	583.7	6	10	7	12
2	525.0	4	8	4	8
3	703.0	1	1	0	0
			BIN D		
1	807.0	7	9	8	10
2	747.0	5	7	8	11
3	792.0	2	3	0	0
			BIN E		
1	570.0	10	18	0	0
2	615.0	6	10	4	7
3	820.0	0	0	0	0
			BIN F		
1	990.0	8	8	6	6
2	683.0	15	22	7	10
3	905.0	1	1	2	2

* No. of insects per kg.

Table E.4. Insects collected at 14% moisture content and 5.0 t/h.

Sampler No.	Mass of sample (g)	Number of alive insects collected			
		T. castaneum		*C.ferrugineus*	
		Insects	Density *	Insects	Density *
		BIN A			
1	673.8	9	13	12	18
2	887.1	14	16	14	16
3	623.1	3	5	1	2
		BIN B			
1	547.2	6	11	5	9
2	779.8	8	10	4	5
3	645.9	1	2	2	3
		BIN C			
1	567.4	16	28	14	25
2	465.7	5	11	12	26
3	801.6	0	0	0	0
		BIN D			
1	663.5	9	14	5	8
2	622.4	4	6	4	6
3	798.2	2	3	0	0
		BIN E			
1	599.4	11	18	7	12
2	627.3	5	8	4	6
3	801.2	0	0	1	1
		BIN F			
1	567.5	13	23	12	21
2	649.5	5	8	5	8
3	745.0	1	1	0	0

* No. of insects per kg.

Table E.5. Insects collected at 17% moisture content and 5.0 t/h.

Sampler No.	Mass of sample (g)	Number of alive insects collected			
		T. castaneum		*C.ferrugineus*	
		Insects	Density *	Insects	Density *
			BIN A		
1	625.4	4	6	3	5
2	782.4	10	13	5	6
3	741.7	1	1	0	0
			BIN B		
1	523.8	3	6	8	15
2	593.4	4	7	5	8
3	625.0	1	2	0	0
			BIN C		
1	772.0	6	8	8	10
2	501.0	7	14	5	10
3	587.0	0	0	0	0
			BIN D		
1	668.3	3	4	7	10
2	705.6	7	10	3	4
3	794.0	0	0	1	1
			BIN E		
1	765.4	8	10	5	7
2	800.8	12	15	4	5
3	353.0	0	0	0	0
			BIN F		
1	801.7	3	4	3	4
2	598.0	9	15	4	7
3	746.5	0	0	1	1

* No. of insects per kg.

Table E.6. Insects collected at 20% moisture content and 5.0 t/h.

Sampler No.	Mass of sample (g)	Number of alive insects collected			
		T. castaneum		*C.ferrugineus*	
		Insects	Density *	Insects	Density *
		BIN A			
1	668.2	4	6	3	4
2	581.4	16	28	11	19
3	557.3	2	4	1	2
		BIN B			
1	659.4	4	6	7	11
2	754.1	7	9	5	7
3	673.6	1	1	0	0
		BIN C			
1	701.4	7	10	5	7
2	647.1	8	12	5	8
3	688.7	1	1	0	0
		BIN D			
1	708.1	5	7	6	8
2	669.0	6	9	6	9
3	671.2	0	0	1	1
		BIN E			
1	652.0	7	11	4	6
2	649.2	7	11	8	12
3	742.6	1	1	0	0
		BIN F			
1	809.7	7	9	5	6
2	749.8	13	17	6	8
3	874.2	0	0	1	1

* No. of insects per kg.

APPENDIX F - Statistical Analysis of Conveyor Sampling Data

Table F.1.a. Analysis of variance of data for *T. castaneum* captured at the three sampling ports while conveying the grain.

Source of Variation	DF	SS	MS	F	P
Flow Rate	1	10.52	10.516	0.55	0.462
Moisture	2	289.77	144.88	7.527	<0.001
Ports	2	2623.39	1311.69	68.14	<0.001
Flow Rate x Moisture	2	21.88	10.938	0.57	0.569
Flow Rate x Ports	2	2.894	1.45	0.07517	0.928
Moisture x Ports	4	571.41	142.85	7.421	<0.001
Flow Rate x Moisture x Ports	4	47.78	11.944	0.62	0.649
Residual	90	1732.40	19.25		
Total	107	5300.02	49.53		

Table F.1.b. Results of the Tukey test done on the *T. castaneum* captured at the sampling ports.

Comparison	Diff of Means	p	q	P<0.05
14% vs. 17%	3.937	3	5.384	Yes
14% vs. 20%	1.300	3	1.777	No
20% vs. 17%	2.637	3	3.607	Yes
Sampling port 2 Vs Sampling port 3	11.216	3	15.339	Yes
Sampling port 2 Vs Sampling port 1	1.741	3	2.381	No
Sampling port 1 Vs Sampling port 3	9.475	3	12.958	Yes

Table F.2.a. Analysis of variance of data for *C. ferrugineus* captured at the three sampling ports while conveying the grain.

Source of Variation	DF	SS	MS	F	P
Flow Rate	1	11.662	11.662	0.64	0.427
Moisture	2	160.445	80.223	4.37	0.015
Ports	2	1864.61	932.304	50.80	<0.001
Flow Rate x Moisture	2	23.823	11.912	0.65	0.525
Flow Rate x Ports	2	16.762	8.381	0.46	0.635
Moisture x Ports	4	199.297	49.824	2.72	0.035
Flow Rate x Moisture x Ports	4	38.597	9.649	0.5258	0.717
Residual	90	1651.7	18.352		
Total	107	3966.9	37.074		

Table F.2.b. Results of the Tukey test done on the *C. ferrugineus* captured at the sampling ports.

Comparison	Diff of Means	p	q	P<0.05
14% vs. 17%	2.881	3	4.034	Yes
14% vs. 20%	2.12	3	2.969	Yes
20% vs. 17%	0.7606	3	1.065	Yes
Sampling port 2 Vs Sampling port 3	8.811	3	12.34	Yes
Sampling port 2 Vs Sampling port 1	0.0075	3	0.0105	No
Sampling port 1 Vs Sampling port 3	8.818	3	12.35	Yes

APPENDIX G - Effect of Conveyance on Germination

Table G.1.a. Results of germination test done on CWRS wheat at 14% moisture content and 3.5 t/h flow rate.

No. of seeds put for germination = 25

Bin No.	Sample No.	Number of seeds germinated Before conveyance		Number of seeds germinated After conveyance	
			Mean germination		Mean germination
A	1	14		12	
	2	13	13.00	14	13.67
	3	12		15	
B	1	13		13	
	2	12	11.67	14	12.67
	3	10		11	
C	1	13		11	
	2	12	12.33	12	13.00
	3	12		16	
D	1	15		14	
	2	14	13.67	13	13.67
	3	12		14	
E	1	11		11	
	2	14	12.33	13	12.67
	3	12		14	
F	1	10		11	
	2	13	11.33	15	12.00
	3	11		10	
X	1	12			
	2	11	12.33		
	3	14			
Y	1	13			
	2	12	13.33		
	3	15			
Z	1	11			
	2	13	12.67		
	3	14			

Table G.1.b. Results of germination test done on CWRS wheat at 17% moisture content and 3.5 t/h flow rate.

No. of seeds put for germination = 25

Bin No.	Sample No.	Number of seeds germinated Before conveyance		Number of seeds germinated After conveyance	
			Mean germination		Mean germination
A	1	13		12	
	2	13	13.67	14	13.00
	3	15		13	
B	1	14		14	
	2	14	14.33	15	15.00
	3	15		16	
C	1	12		14	
	2	16	14.67	13	14.67
	3	16		17	
D	1	15		15	
	2	14	14.00	13	14.00
	3	13		14	
E	1	13		14	
	2	15	15.00	12	13.67
	3	17		15	
F	1	13		13	
	2	16	14.00	14	13.67
	3	13		14	
X	1	13			
	2	16	15.33		
	3	17			
Y	1	15			
	2	17	15.00		
	3	13			
Z	1	17			
	2	18	16.33		
	3	14			

Table G.1.c. Results of germination test done on CWRS wheat at 20% moisture content and 3.5 t/h flow rate.

No. of seeds put for germination = 25

Bin No.	Sample No.	Number of seeds germinated Before conveyance		Number of seeds germinated After conveyance	
			Mean germination		Mean germination
A	1	12		13	
	2	12	12.33	9	12.67
	3	13		16	
B	1	14		14	
	2	10	11.00	11	11.67
	3	9		10	
C	1	9		12	
	2	13	11.67	12	11.67
	3	13		11	
D	1	17		14	
	2	12	13.00	14	13.00
	3	10		11	
E	1	12		12	
	2	15	12.67	11	11.67
	3	11		12	
F	1	11		9	
	2	13	11.33	14	11.33
	3	10		11	
X	1	11			
	2	13	11.33		
	3	10			
Y	1	11			
	2	13	12.67		
	3	14			
Z	1	12			
	2	14	13.67		
	3	15			

Table G.1.d. Results of germination test done on CWRS wheat at 14% moisture content and 5.0 t/h flow rate.

No. of seeds put for germination = 25

Bin No.	Sample No.	Number of seeds germinated Before conveyance		Number of seeds germinated After conveyance	
			Mean germination		Mean germination
A	1	14		15	
	2	12	14.67	11	13.67
	3	18		15	
B	1	12		15	
	2	17	14.33	15	16
	3	14		18	
C	1	13		17	
	2	13	13.33	15	15.33
	3	14		14	
D	1	15		16	
	2	17	15.33	12	15
	3	14		17	
E	1	15		14	
	2	18	16.33	17	16
	3	16		17	
F	1	16		15	
	2	17	16	14	15.33
	3	15		17	
X	1	17			
	2	17	16		
	3	14			
Y	1	15			
	2	14	14.33		
	3	13			
Z	1	16			
	2	12	13.33		
	3	12			

Table G.1.e. Results of germination test done on CWRS wheat at 17% moisture content and 5.0 t/h flow rate.

No. of seeds put for germination = 25

Bin No.	Sample No.	Number of seeds germinated Before conveyance	Mean germination	Number of seeds germinated After conveyance	Mean germination
A	1	15		16	
	2	15	16.00	13	15.00
	3	18		16	
B	1	17		13	
	2	14	15.33	18	15.33
	3	15		15	
C	1	15		18	
	2	13	14.33	14	14.67
	3	15		12	
D	1	16		14	
	2	15	15.67	17	15.67
	3	16		16	
E	1	17		15	
	2	18	17.33	17	16.33
	3	17		17	
F	1	13		14	
	2	15	14.67	14	14.00
	3	16		14	
X	1	17			
	2	15	16.33		
	3	17			
Y	1	18			
	2	15	15.33		
	3	13			
Z	1	14			
	2	16	15.66		
	3	17			

Table G.1.f. Results of germination test done on CWRS wheat at 20% moisture content and 5.0 t/h flow rate.

No. of seeds put for germination = 25

Bin No.	Sample No.	Number of seeds germinate Before conveyance	Mean germination	Number of seeds germinated After conveyance	Mean germination
A	1	16		14	
	2	15	14.33	14	13.67
	3	12		13	
B	1	14		15	
	2	18	14.67	16	15.33
	3	12		15	
C	1	13		13	
	2	17	16.00	16	15.00
	3	18		16	
D	1	12		14	
	2	13	14.67	11	14.00
	3	19		17	
E	1	17		15	
	2	12	14.33	14	14.33
	3	14		14	
F	1	17		13	
	2	15	16.00	17	15.67
	3	16		17	
X	1	16			
	2	15	15.33		
	3	15			
Y	1	15			
	2	14	15.33		
	3	17			
Z	1	16			
	2	14	14.33		
	3	13			

Table G.2. Number of seeds of Domain wheat germinated at 14% moisture content and 5.0 t/h flow rate.

No. of seeds put for germination = 25

Bin No.	Sample No.	Total number of seeds germinated											
		Before conveyance			After one pass			After two passes			After three passes		
		Germination	Mean	S.D.	Germination	Mean	S.D.	Germination	Mean	S.D.	Germination	Mean	S.D.
A	1	20			18			19			21		
	2	19	20.00	0.82	20	19.00	0.82	21	21.00	1.63	22	20.67	1.25
	3	21			19			23			19		
B	1	24			23			22			24		
	2	21	21.33	2.05	20	21.67	1.25	24	22.00	1.63	29	24.33	3.68
	3	19			22			20			20		
C	1	22			25			23			23		
	2	22	22.67	0.94	23	24.00	0.82	23	22.33	0.94	25	24.00	0.82
	3	24			24			21			24		
D	1	19			21			24			23		
	2	23	21.33	1.70	25	23.00	1.63	25	23.67	1.25	22	22.00	0.82
	3	22			23			22			21		
E	1	22			19			19			20		
	2	23	22.67	0.47	25	22.33	2.49	21	21.00	1.63	22	21.67	1.25
	3	23			23			23			23		

cont..

cont....

Bin No.	Sample No.	Total number of seeds germinated											
		Before conveyance			After one pass			After two passes			After three passes		
		Germination	Mean	S.D.	Germination	Mean	S.D.	Germination	Mean	S.D.	Germination	Mean	S.D.
F	1	20			20			20			24		
	2	24	22.33	1.70	22	21.67	1.25	24	22.00	1.63	22	23.33	0.94
	3	23			23			22			24		
X	1	22											
	2	24	23.66	1.25									
	3	25											
Y	1	23											
	2	20	20.66	1.70									
	3	19											
Z	1	20											
	2	21	20.00	0.82									
	3	19											