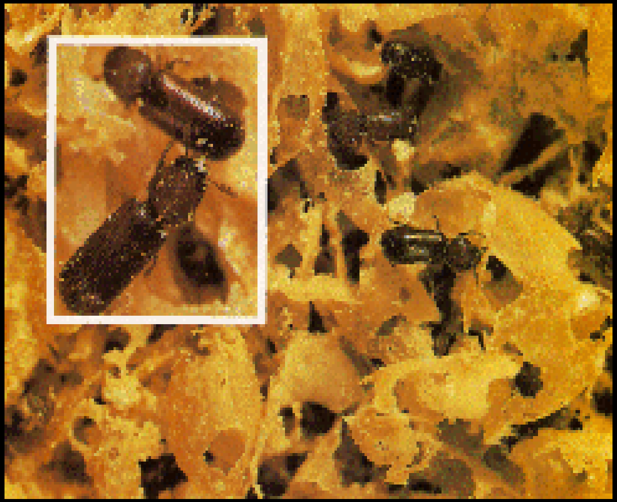


Integrated control of storage pests

Introduction

Direct loss

- **Serious postharvest losses, from 9% (in developed countries) to 20% or more in developing countries**

Indirect loss

- **Contamination of food products through presence of live insects**
- **Insect products such as chemical excretions or silk, dead insects and insect body fragments**
- **Accumulation of chemical insecticide residues in food**

Management of stored product pests

- Undergoing a rapid change from an insecticide-based system to a more integrated approach
- Many safe, effective, and relatively simple prevention and control methods available to manage populations of stored-product insect pests without use of chemical insecticides

Ethnoecology

- Traditional ecological knowledge and indigenous practices
- Farmers' indigenous knowledge - provide a foundation for optimizing existing practices or identifying novel environmentally benign and appropriate management strategies
- In Northeast India, dried leaves and stems of *Artimesia vulgaris-* put in and around granaries to repel storage pests and rats by ethnic tribes
- Pulses -coated with pork oil and dried before storing as a post-harvest storing method
- Fused electric bulbs - ground and mixed with ground rice -used as rodenticides

Ethnoecology

- Plants-*Dendrocnide sinuata* and *Entada purseatha* -used as rodenticides
- Plants like *Cyathula tomentosa* and *Scorulla parasitica* - used for trapping rats
- Few indigenous traps -used to catch rats
- Storing grains in kitchen- common method of post-harvest storage among indigenous tribes-smoking from cooking place may protect grains from insects, fungus and increase self life of grains
- Tribes store grains in an traditional granaries usually built in an open place nearer to their houses to ensure proper aeration
- Materials like tin and wooden sheets -put in poles as rat barriers

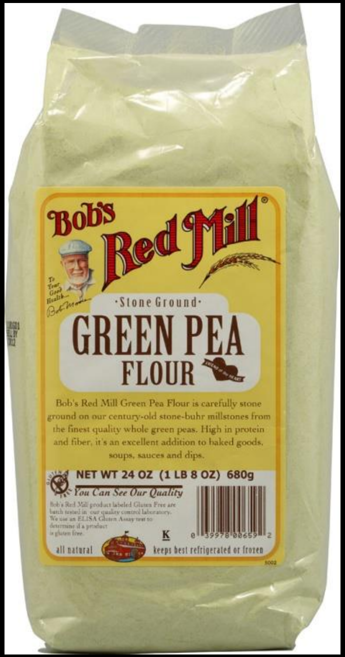
Plant products

- **Traditionally-farmers used various forms of herbal products for control ling post-harvest insect pests**
- **Local communities still continue to use an array of insecticidal plants for control of specific pests**
- **Ethno-botanical research -documented traditional uses of various plants in protection of agricultural crops against pre-harvest and post-harvest pests**
  - **Azadirachtin (from neem)**
  - **Rotenone (from *Derris* spp.)**
  - **Pyrethrum**
- ***Tephrosia vogelii* leaf powder -used as grain protectant for management of *Sitophilus* spp. and *Tribolium* spp. in stored maize in Malawi and eastern Zambia**

Plant products

Neem

- **Extracts from neem tree, *Azadirachta indica*- commercially available botanical insecticides and local formulations -widely used in many parts of the world for stored-product insect control- commercial formulations show only moderate levels of efficacy**
- **Crude pea flour, and protein-rich fraction of field peas, *Pisum* spp., and other food legumes, *Pisum*, *Phaseolus,* and *Vigna*- toxic and repellent to stored-product insects**
- **Direct application of protein-enriched pea flour to bulk grain at 0.1% -resulted in substantial reductions in stored-grain beetle populations**
- **(Phillips and Throne, 2010)**



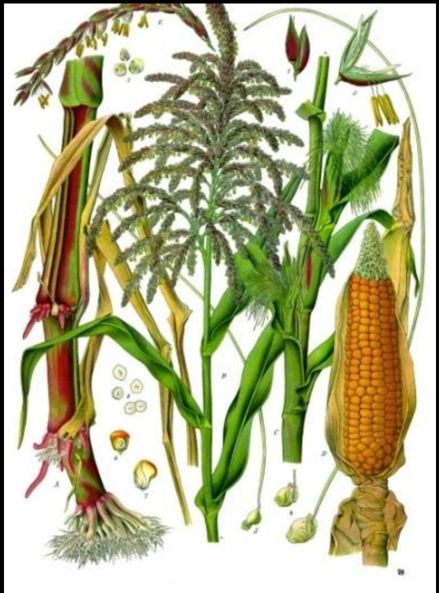
Plant product

Pyrethrum

- **Commercial mixture of compounds derived from *Chrysanthemum cinerarifolium*-most successful botanical insecticide against storage pests**
- **Active ingredients –pyrethrins**
- **Synergized pyrethrum –contains synergist piperonyl butoxide- PBO- suppresses metabolic degradation of pyrethrins in insect**
- **Synergized pyrethrum -commonly used as an aerosol in flour mills**
- **Synergized pyrethrum -combined with another insecticide that has longer residual activity -as pyrethrum achieves quick knockdown of insect pests at best-while other insecticide provides longer activity**

Resistant crops

- Varietal resistance -once considered a useful tool for management of stored-product insects
- Much variation in resistance to stored-product insects- documented in commercially available crops
- Hull integrity-best predictor of rice resistance to *R. dominica*
- Phenolic content in corn-related to kernel hardness- linked to resistance to maize weevil, *S. zeamais,* and larger grain borer, *Prostephanus truncates*



Resistant crops

- Variability in resistance of sorghum to storage insect pests-correlated with integrity of hull, hardness, and thickness of endosperm
- High variability in wheat in resistance to stored-product insects-factors responsible - poorly understood
- United States oat cultivars vary in susceptibility to storage pests-with some varieties almost immune to insect population development



Resistant crops

- **Transgenic avidin maize -developed for harvesting avidin for medical testing- resistant to all storage insect pests except for *P. truncatus***
- **Avidin kills insects by sequestering vitamin biotin**
- **Two Bt transgenic rice lines developed for control of Asiatic rice borer, *Chilo suppressalis-* incorporate *cry1Aa* and *cry1B* genes- mixed non target effects on storage insects**

Temperature management

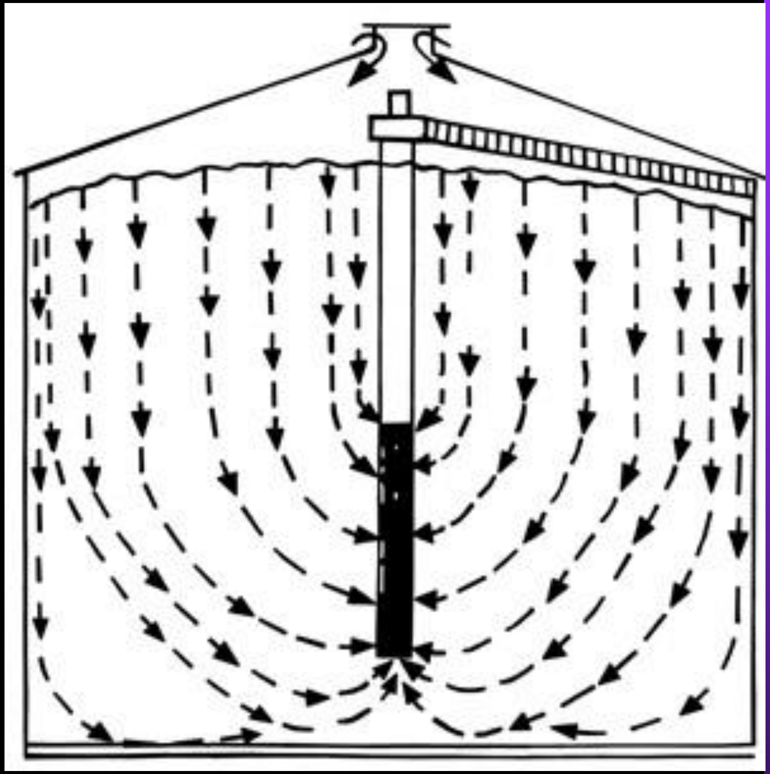
- Stored-grain environment- unique among most agro ecosystems- entirely human-made and not subject to rapid and extreme changes in environmental conditions
- After harvest, grain- placed into storage structures such as steel bin, concrete silo, a flat storage such as a steel building, or simply on a concrete slab with grain covered with plastic
- Steel bins -vary in size with volumes of 30 to 8000 tons of grain
- A concrete silo at a grain elevator -contain 500 to 800 tons of grain
- Flat storage-grain dumped into a large pile in a protected building-contain 80,000 tons of grain

Temperature management

- Temperature-based preventive pest management -more challenging in grain stored in tropical and subtropical climates
- Both temperature and moisture content of grains -carefully controlled during storage to maintain quality
- Season-harvested crops (cereals and pulses) in cooler climates- dried with forced-air heating to reduce moisture content shortly after harvest and before being placed into storage
- Stored cereal grains - cooled with ambient aeration after storage if aeration equipment available-to lower temperature and to reduce insect population growth
- Grain should not be exposed to rainfall or direct sunlight that would cause degradation

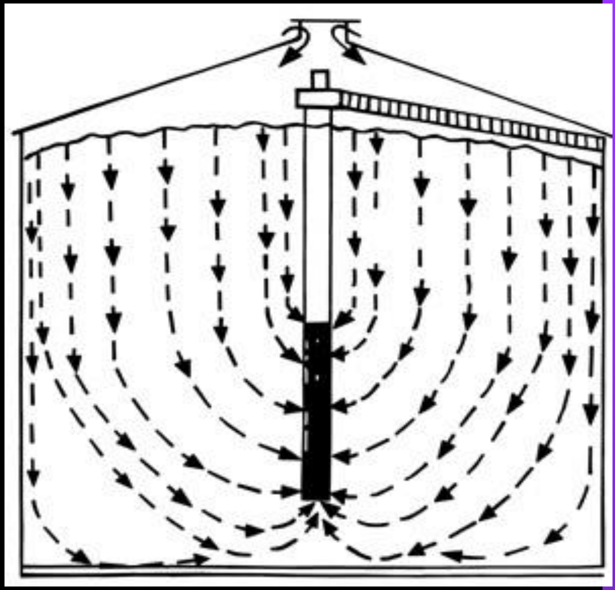
Temperature management

- Maximum rate of growth and reproduction for most insects - between 25 and 33°C and reduced at temperatures above and below
- Complete cessation of development and eventual death at 13 and 35°C
- Use of aeration to cool grain and reduce insect population growth rate -regularly used in steel bins- but less common in concrete silos and flat storages



Temperature management

- Aeration of large government owned flat storages- common- Aeration useful for summer harvested crops-grain temperatures reduced 3 to 4°C by running aeration fans at night
- Aeration -effective for pest management in season-stored crops in cool climates
- Aeration- compatible with other control strategies such as chemical or biological control
- Use of automatic aeration controllers- which turn fans on and off based on grain and ambient temperatures-can be more efficient than manual aeration for cooling grain



Typical cabinet example shown.

Temperature management

- Chilled aeration- process of blowing refrigerated air through a grain mass-reduce grain temperatures and insect populations below those achievable using ambient aeration or no aeration
- Chilled aeration -not commonly used for bulk grains due to cost
- A solar adsorption cooling system -successfully tested for chilling bulk grain -provide a more cost-effective alternative

Temperature management

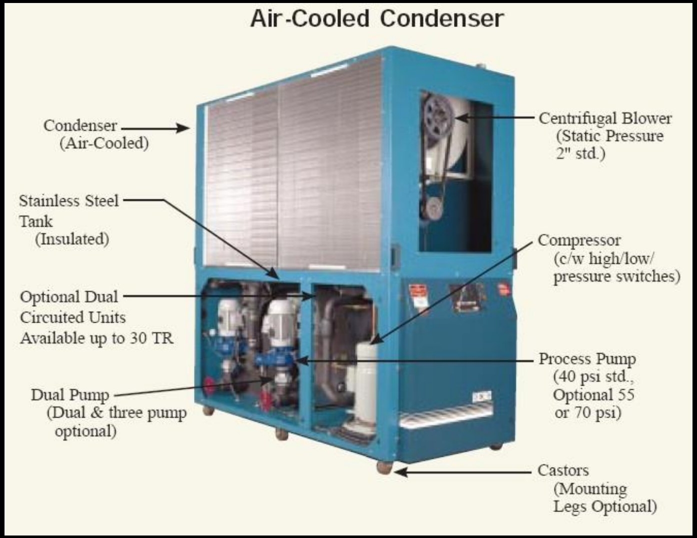
- Various forms of heating -used to kill insects in bulk grain, such as microwave or infrared radiation- methods not been widely used because of time required to treat large amounts of grain
- Recent studies show efficacy of infrared catalytic heaters for disinfestation of rice-but method not widely used
- A propane heater -effective for disinfestation of empty grain bins by raising temperature to 50°C for 2 h- cost greater compared with using insecticides

Temperature management

- Heat -long been used to kill insects in mills
- Heat-popular as an alternative method of disinfestation-Either whole plant or problem areas may be heated
- Goal -to raise temperature of mill to 50–60°C for 24 h-which can be effective for insect control
- Heat treatment in a pilot feed mill eliminated populations of different stored product insects-but *P. interpunctella* population gradually increased after a few weeks-Gradual increase in *P. interpunctella* could have been due to immigration of *P. interpunctella* from outside
- Heat and cold treatments -used in combination with other control methods such as modified atmospheres

Temperature management

- **Low temperature storage and heat treatment of storage facilities -potential to control *P. interpunctella***
- **At 10°C-a stress imposed on adult moths, causing an increase in adult mortality- surviving adults exhibited decreased egg production and eggs laid had lower viability**
- **One-day-old *P. interpunctella* eggs - more tolerant of heat treatment (42°–48°C) than 2- or 3-day-old eggs**
- **While at cold temperatures (0–10.5°C)-older eggs more resistant and took longer to die**



Controlled and modified atmosphere

- Exposure of insects to toxic concentrations of atmospheric gases - practiced for centuries and promoted in recent years as a biorational substitute for chemical fumigations
- A controlled atmosphere- one in which a target concentration of a particular gas maintained
- A modified atmosphere - one in which there is a dynamic change in atmospheric gases over time
- Target gas concentrations for insect toxicity- 3% or less of oxygen and/or 60% or more of carbon dioxide
- One type of controlled atmosphere - addition of CO_2 to levels above 60% for 24 h or more
- Flushing an exposed space with an inert gas such as nitrogen to displace O_2 below 3%

Controlled and modified atmosphere

- A low-oxygen atmosphere also be achieved and maintained by applying vacuum, or low pressure, to an infested commodity in a gas-tight chamber so that all atmospheric gases decrease, including oxygen
- Toxicity responses of insects to controlled or modified atmospheres - similar to those with chemical fumigants
- Exposure times needed for effective kill decrease as temperature increases
- Life stages most susceptible to altered atmospheres-most active larvae and adults- whereas eggs and pupae- typically more tolerant of controlled atmospheres
- Cereal grains and oilseeds treated with controlled or modified atmospheres experience virtually no adverse effects

Controlled and modified atmosphere

- A gas-tight or minimally permeable chamber to treat infested commodity
- Treatment of a typical mill or food plant -impractical in most cases because these buildings -too leaky to maintain needed gas concentrations
- Well-sealed grain bins, either metal or concrete, filled with grain and have 40% or less free air space -good candidates for CO_2 treatment if gas can be maintained for several days at temperatures over 25°C
- Best structure for controlled atmosphere treatment -a gas-tight chamber that can maintain desired gas concentration for times needed

Controlled and modified atmosphere

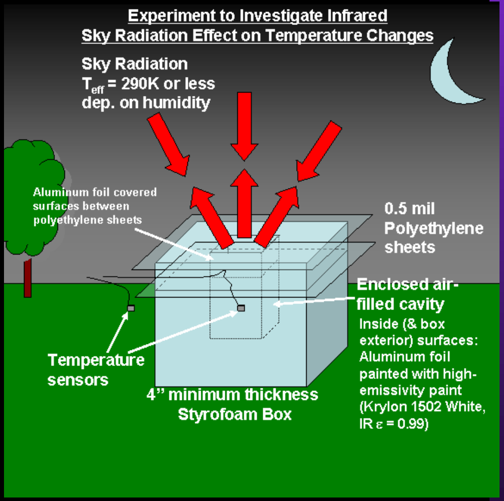
- Cost of gases in controlled atmospheres - a hindrance to adoption
- CO_2 -expensive and available in large supply for certain applications
- N_2 for use in low O_2 treatments -less expensive and can be generated from ambient air-it is close to 80% concentration, via membrane-adsorption technology
- Technology exists for generation of low O_2 and high CO_2 burner gas through cleaned effluent from an exothermic gas-burning generator

Controlled and modified atmosphere

- A low-cost alternative to a gas-tight chamber made of rigid construction -use of a flexible polyvinyl chloride bag, or cocoon-hold from 1 to 20 tons of infested commodity -treated with CO_2 or subjected to low O_2 by attachment of a vacuum pump to achieve low pressure
- Hermetic storage for generating a dynamic modified atmosphere – used in Israel and parts of Asia and Africa-provides a means of safe storage in locations where electricity or access to gases or permanent storage structures - limited

Irradiation

- Irradiation of durable stored products- legal in most countries
- Using ionizing radiation such as gamma rays- potential to dislodge electrons from chemical bonds in molecules
- Using non ionizing radiation such as radio frequencies, microwaves, or infrared rays- do not break bonds but essentially heat products and insects by vibrating bonds in water
- Irradiation -used to disinfest product entering a grain storage system or as a remedial treatment for infested product in a storage system
- Infrared irradiation -same as heating, and applied to air and surfaces of structures as well as directly to commodities
- Microwaves and radio frequency also heat water in insects or surrounding commodity, causing death by cellular disruption

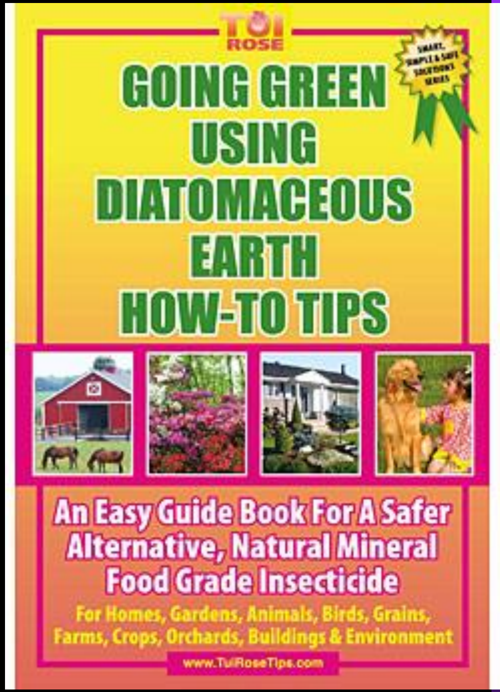


Irradiation

- Ionizing radiation at dosages of up to 10 kGy (kilogrey) for grain-safe for commodity –usually delayed mortality of insects through cell cycle disruption following damage to DNA
- Doses of 0.4 kGy or less-effective dose for most insects
- Insect eggs and young larvae exposed to effective doses of gamma rays fail to develop to adults, and treated adults-reproductively sterile
- Sources of ionizing radiation - from radioisotopes such as cesium or cobalt, or generated from X-rays via an electron beam
- Adoption of ionizing irradiation treatments for agricultural products -minimal to nil owing to public concerns regarding safety of radioisotope facilities and public misperception that treated food becomes radioactive and those eating the food could suffer radiation poisoning
- Doses to prevent reproduction of stored product pests range from 0.05 kGy for *Tenebrio molitor* to 0.45 kGy for *Sitotroga cereallela*

Humidity control and desiccation

- Most insects occur in stored grain thrive at moisture contents of 12 to 15%-reducing moisture content -an option for control
- Control of stored-product insects by desiccation -facilitated by treatment of infested commodity and spaces with diatomaceous earth (DE)
- DE represents fossilized silicon dioxide skeletons of diatoms-unicellular aquatic algae-Deposits of diatoms from ancient seas and lakes- plentiful for mining locations worldwide
- DE kills insects following contact exposure by absorbing hydrocarbons from cuticles- causes dehydration and death
- Activity of DE- increased under low humidity and higher temperatures
- An enhanced DE -developed -utilizes added silica gel-a finer homogenous source of silicon dioxide



Humidity control and desiccation

- DE -nontoxic to vertebrates -a common food additive and food-processing agent with designation GRAS (generally regarded as safe)
- Efficacy of DE varies significantly among geographic locations where mined-so users must follow label instructions closely to ensure control
- Application of DE at effective rates to an entire grain mass-cause a significant loss in bulk density-lowering quality and value of treated grain
- Care -to use minimal effective rates or to treat problem areas only (e.g., the top or bottom layers of the grain mass)
- DE- effective against larvae of *P. interpunctella*.-up to 86–97% of first instar *P. interpunctella* -killed by DE Insectos applied at 500 and 1000 ppm
- Disadvantages of DE –workers bothered by high dust levels-and abrasive property of material

Sanitation and exclusion

Keys to preventive management of storage insects

- Sanitation of grain and food storage facilities
- Effective exclusion of stored-product insects from such structures and from food packages
- For bulk-stored grain-newly harvested commodities be stored in clean bins and not be loaded into bins that contain older products that may harbor insects
- Harvesting equipment, transportation containers, loading areas, and storage bins need to be as clean as possible before harvest
- Storage of new crop, and surfaces of inside walls, floors, and ceilings of such structures and machinery with a residual insecticide to kill any insects that may remain following previous storage season
- In mills and other food-processing facilities- raw grains that stored for several months -physically located in bins and separate from processing areas -even further separated from packaging and finished-product warehouse or loading areas

Sanitation and exclusion

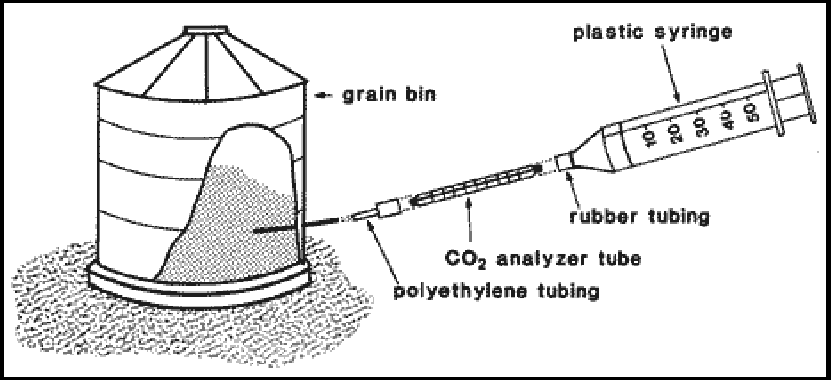
- Lighting can attract insects of all kinds, including stored-product insects
- Light fixtures not be mounted directly over outside doors but mounted on poles
- Window screens and doors to outside of buildings-between major processing, bulk storage, and warehouse areas in a building or complex of buildings- need to be in good service
- Machinery -can be easily accessed and dismantled for thorough cleaning
- Cleaning in large processing plants -employ careful sweeping and/or vacuum cleaning of food debris for complete removal
- Double-wall construction and suspended ceilings -to be avoided or removed so that hidden voids in food plants do not retain food debris and cryptic insect infestations

Sanitation and exclusion

- Two commonly encountered groups of stored product insects that invade food packages
  - Those actually chew through and penetrate packaging material
  - Those invade packages through breaches or other weak points in seals or closures of package
- Thus, food packages need to be sealed very well to deter invaders and need to be constructed of durable materials to resist penetrators
- Technology -developed to impregnate food packaging material with low-risk insecticides-especially on insect repellents applied to packages to reduce infestation
- *P. interpunctella* larvae -invade packaged foods, and insect-resistant packaging can prevent entry of larval stages and oviposition by adults
- Larvae -susceptible to low-oxygen conditions through use of modified atmospheres- but they can survive up to 6 days under such conditions

Sampling and population estimation

- Sampling -an essential step in pest management
- Allows pest manager to take remedial actions only when pest populations reach levels that justify cost of remediation
- Commonly used manual commercial method for grain stored in steel bins and grain in transit vehicles -use of a grain trier
- A metal spear up to 4 m in length -can be inserted into grain to withdraw a sample-Once grain sample removed with trier-external-feeding pests in grain -removed by sieving
- Mechanically operated pneumatic grain triers -used to sample grain at points of sale in commercial transport by truck, rail

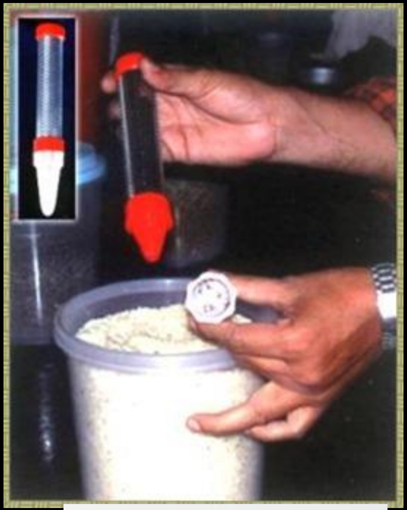


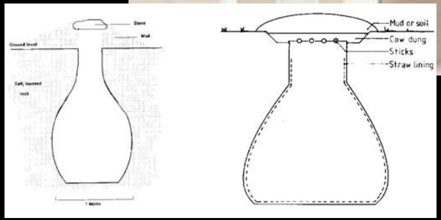
Sampling and population estimation

- A deep-bin probe cup -used to take samples from deeper in a grain mass-not usually done because of difficulty in pushing probe into grain mass
- Sieving sample to remove insects –dis advantage of not sampling internal-feeding stages
- Internal-feeding pests -detected by various techniques- Use of digital X-ray equipment-at an elevator for detection of internal insects- quick method-only a small sample can be scanned (10 × 10 cm area) –equipment relatively expensive
- Image analysis of digital X-rays-accurate for detecting insects-number of false positives can be high

Sampling and population estimation

- Probe traps -available for detection of insects in grain-but not widely used because of costs and safety concerns associated with bin entry
- An automated probe trap-incorporates infrared beams to count and determine species of insects falling into traps, overcomes these shortcomings- accuracy of species determination varies
- Conventional probe-pitfall traps -used throughout grain mass-rarely used - difficulty of pushing them into grain mass and need for regular servicing
- Insects in concrete silos -sampled throughout grain mass using a vacuum probe sampler



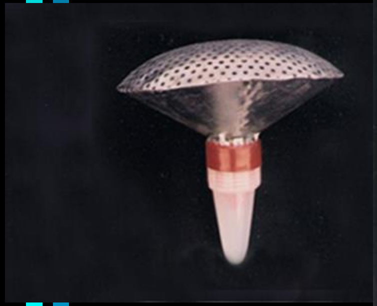


Sampling and population estimation

- Several automatic grain sampling devices- used in large terminal and export grain handling facilities to collect samples from flowing grain at regular time intervals for purpose of quality grading and insect detection
- Although probe traps catch more insects- collecting insects as they move through grain mass
- Relative estimates of population level - converted to absolute estimates of insect density by incorporating temperature into regression equations
- A major problem with probe traps -only able to sample surface of the grain- A vacuum probe sampling system overcomes problem by taking a 3 kg sample of grain every 1.3 m in grain down to depths of 13 m or more

Sampling and population estimation

- TNAU Insect Probe Trap
- TNAU Pitfall Trap
- TNAU Two-in-One model trap
- Indicator Device
- TNAU Automatic Insect Removal Bin
- UV – Light Trap for grain storage godowns
- Device to remove insect eggs from stored pulse seeds
- TNAU stored grain insect management kit



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Biological control agents

- Biological control -often-underutilized component of integrated pest management of stored grain
- Grain managers tend to look only at chemical alternatives to control insects in stored grain
- Use of natural enemies to control stored-grain insect pests- may seem relatively new
- Recent legislation in USA- allowed for augmentative releases of beneficial insects in stored products
- Biological control using hymenopteran parasitoids presents an attractive alternative to insecticides for reducing infestations and damage from Indianmeal moth, *P. interpunctella* in retail and warehouse environments

Biological control agents

- *Trichogramma* spp. -explored as potential natural enemies for a variety of stored product moths in bulk peanut storage, bulk wheat storage, and bakeries
- *Habrobracon hebetor* -as a biological control agent of stored product moths in bulk peanuts, packaged products, and residual populations in grain spillage
- Laboratory and field trials with predatory insects and with hymenopteran parasites- Effective field control of *P. interpunctella* and other pyralid moths achieved with *H. hebetor*
- Several studies indicated presence and abundance of parasites and predators of *P. interpunctella* in and around storage facilities

Biological control agents

- *Theocolax elegans* - a small pteromalid wasp attacks *Rhizopertha dominica* and *Sitophilus* spp
- Field studies -effectiveness of *T. elegans,* in reducing insect fragments in flour by suppressing populations of *R. dominica* in six bins- each containing 27 tonnes of wheat
- Beetles were released into all the six bins at monthly intervals for 3 months
- Parasitoid wasps -released into three of the bins, 21 days after first beetle release-Wheat samples from bins -milled to determine effects of parasitoid releases on insect fragment counts in flour
- In first year -after 198 days of storage-insect fragment counts were 9.4 and 31 per 50 g flour in treatment and control bins-Same trend was resulted during second year of study
- Augmentative releases of parasitoid wasps into bins of stored wheat reduced damage to wheat kernels and number of insect fragments in flour

Biological control agents

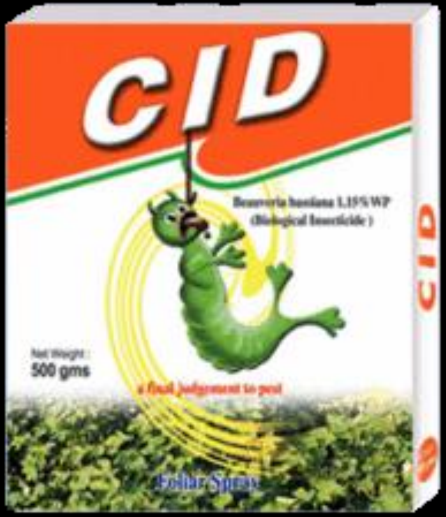
- Potential for using combinations of egg parasitoid *T. deion* and the larval parasitoid *H. hebetor* for preventing infestations of *P. interpunctella* in coarse-ground cornmeal as well as influence of packaging on parasitoid effectiveness
- Treatments included one or both parasitoids and either corn meal infested with *P. interpunctella* eggs or eggs deposited on surface of plastic bags containing corn meal
- *H. hebetor* had a significant impact on number of live *P. interpunctella*, suppressing populations by 71% in both unbagged and bagged cornmeal
- In contrast, *T. deion* did not suppress *P. interpunctella* in unbagged cornmeal. However, when released on bagged cornmeal, *T. deion* significantly increased level of pest suppression (87%) over bagging alone (15%)
- These findings suggest that combined release of both *T. deion* and *H. hebetor* -greatest impact

Biological control agents

- Parasitoid wasps from Pteromalidae- solitary ectoparasitoids of internal-feeding grain-infesting species of beetles
- Species of Ichneumonidae and Braconidae as ecto- and endoparasitoids associated with stored-product Lepidoptera
- Free-living predatory beetles, true bugs (Heteroptera: Anthocoridae), and mites prey on any life stages of stored-product insect pests
- Population declines of stored product pest species -typically followed by increases in natural enemy populations
- Key regulations allow addition of insect natural enemies to stored-products systems and present an opportunity for biologically based management of storage pests with careful and knowledgeable use by pest managers

Microbial insecticides

- **Insect pathogens -tested for control of stored-product insects- not in use due to lack of sufficient, broad-spectrum efficacy**
- **Many tests -conducted to synergize pathogens with other control technologies, to increase efficacy of pathogens, such as DE by abrading cuticle, or grain varietal resistance by delaying larval development, both – make insect more susceptible to pathogen**
- **Laboratory evaluations of fungi *Beauveria bassiana* and *Metarhizium anisopliae* and bacterium *Bacillus thuringiensis* , alone or in conjunction with another insecticidal material such as DE- result in complete control of only some stages of species, while other stages -poorly controlled**



Microbial insecticides

- Bt -most effective against Lepidoptera and Diptera-some strains show increased efficacy for beetles-efficacy still poor compared with conventional insecticides-Lack of efficacy limits use of pathogens in commercial application
- Bt -registered for control of stored-product Lepidoptera for decades- rarely been used -not control beetle pests
- An effective granulosis virus specific for *P. interpunctella* - described and a method for low-cost mass-production- developed

Microbial insects

- **Spinosad- an insecticide derived from metabolites in fermentation of actinomycete bacterium *Saccharopolyspora spinosa***
- **Spinosad -currently registered by U.S. EPA with a residue tolerance concentration of 1.5 ppm for use on stored grain in both conventional and organic formulations**
- **Spinosad -very effective against larvae of *P. interpunctella*-About 97.6–99.6% mortality -obtained when applied at 1 ppm**
- **Spinosad-effective for season long control of *R. dominica* in stored wheat- highly toxic to larvae of many stored-product insects-showed good compatibility with insect natural enemies**

Pheromones and other semiochemicals

- Use of semiochemicals in stored-product pest management -an important option for many years
- Semiochemicals -used in form of sex pheromone lures for monitoring stored-product pests- have a broader potential for controlling insect populations as well
- Semiochemicals-used for mass trapping, attracting and killing, mating disruption, as repellents, and as specific behavioral stimulants or deterrents
- Chemical attractants, repellents, mating disruptors, and sex stimulants -evaluated -do not receive widespread commercial use
- Attractant pheromones- intraspecific chemical signals and other attractant semiochemicals - identified for over 40 species of stored-product insects

Pheromones and other semiochemicals

- **Pheromones -commercially available for 20 species of stored-product insects- as slow-release formulations of lures- in monitoring**
- **Most commonly used pheromones for**
  - ***P. interpunctella***
  - **Cigarette beetle, *Lasioderma serricorne***
  - ***R*ed and confused flour beetles, *Tribolium castaneum* and *T. confusum***
  - **Warehouse beetle, *Trogoderma variabile***
- **Efficacy of pheromone-baited sticky traps vary according to their placement within a building (i.e., proximity to walls, floors, and ceilings), and other flat landing sites enhance response of *P. interpunctella* males to pheromone-baited traps**
- **Beetles that tend to land and crawl to an odor source-traps are designed to sit on a floor or flat surface and capture insects that walk into trap and stuck to trapping surface**

Pheromones and other semiochemicals

- **Barak & Burkholder developed a trap with horizontal layers of corrugated cardboard- responding beetles walked through tunnels of corrugations to reach a cup of oil in to which they fell and became suffocated**
- **A popular alternative design -a ramp-and-pitfall trap- beetles walk to trap, climb up an inclined side of trap, and fall into a receptacle of oil- oil in floor traps serves both as a trapping medium and as a pheromone synergist or additive attractant-**
- **Odors from larval foods- also serve as attractants for adult moths, technically considered kairomones-developed for monitoring females of *P. interpunctella* and other stored-product moths**

Pheromones and other semiochemicals

- Traps provide relative population samples
- Pheromone traps -used to help determine efficacy of a management tactic- such as fumigation or heat treatment, by comparing trap captures before and after treatment
- Pheromones -also be used to suppress and control pest populations of stored-product insects
- Mass-trapping males with a sex pheromone –can control a population if a large number of males are removed from the population
- Male moths of *P. interpunctella* can inseminate an average of six females in their lifetimes- a few surviving males in a population under mass-trapping treatment maintain reproductive rate of population

Pheromones and other semiochemicals

- **Attract-and-kill, or attracticide method -similar to mass-trapping, but instead of using traps-an insecticide-treated surface coupled with pheromone lure -males contact insecticide briefly and then die soon after**
- **Mating disruption-in which a treatment area - saturated with an unnaturally high concentration of synthetic sex pheromone and males- unable to locate and successfully mate with females- proven successful for stored-product moths under controlled conditions, and recently in commercial field settings**
- **Primary registration of synthetic sex pheromone of stored-product moths, *Z,E*-9,12-tetradecadienyl acetate- recently granted in USA**

Chemical control methods

Empty-bin insecticide applications

- Encouraged to prevent infestation of new grain by existing insect populations
- Empty-bin sprays- highly recommended when grain stored in summer- if areas difficult to clean-or if there is history of insect problems
- After bins properly cleaned and inspected and prior to adding new grain- treat facility with a labeled insecticide
- Spray to run-off inside surface and as much of outside, including nearby ground surfaces, aeration ducts, and grain handling equipment

Chemical control methods

Empty-bin insecticide applications

- **Sprays - be concentrated on cracks, crevices, and areas difficult to clean**
- **Applications -made at least two weeks prior to adding new grain**
- **Allow 24 hours for sprays to dry**
- **Treatments provide a barrier to insects -and also control insects not removed during cleaning operation**
- **Recommended empty bin insecticides -*Bacillus thuringiensis,* chlorpyrifos-methyl+ deltamethrin, cyfluthrin or beta-cyfluthrin, methoprene, silicon dioxide, etc.**

Chemical control methods

Chemical grain protectants

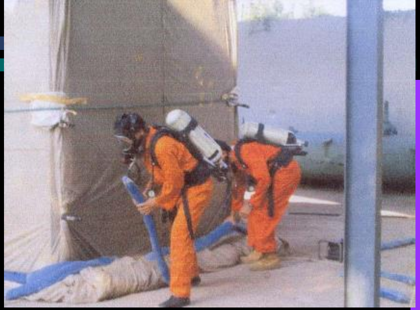
- Grain protectants - added when bin filled- to guard against insect damage
- Protectants -also be added to upper surface of grain once in bin to guard against damage from moths and other insects entering top of storage facility
- Protectants -will not eliminate existing infestations- recommended if grain is going to be stored for extended periods, in flat structures, under circumstances that favor pest development, or in facilities with a history of insect damage
- Combination of high grain moisture and high temperatures will shorten residual life of grain protectants
- Recommended that grain protectants be applied after high-temperature drying-completed and grain –cooled
- Chemical protectants-*Bacillus thuringiensis,* malathion, chlorpyrifos-methyl+ deltamethrin, cyfluthrin or beta-cyfluthrin, methoprene, pirimiphos-methyl and silicon dioxide

Chemical control methods

Top-dressing and air/head space treatments

- Necessary to apply an insecticide to top few inches of grain mass (top dressing) to prevent introduction of insects (primarily moths)
- *Bacillus thuringiensis*, chlorpyrifos-methyl, methoprene, pirimiphos-methyl, pyrethrins + piperonyl butoxide and silicon dioxide applied as a top dress treatment – prevent introduction of most insects including Indian meal moth
- Resin (pest) strips (dichorvos or DDVP) -also be hung in air/head space in top of bin to help control adult moths-One strip per 1000 cubic feet of air/head space and replace after 3 months
- To be effective, top of bin must be temporarily sealed-including roof vent- Aeration disrupt - Remember to open roof vents before aerating

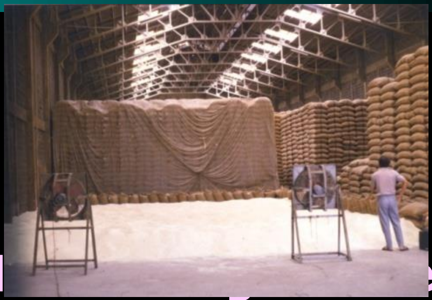
Chemical control methods



Fumigation

- Fumigation -conduct by trained, experienced, registered applicators- If insects above suggested thresholds
- Goal- to maintain a toxic concentration of gas long enough to kill target pest population- toxic gases penetrate into cracks, crevices, commodity, and facility treated-Provide no residual protection
- Fumigants come in several forms and formulations-All label instructions and precautions -read and carefully followed
- Fumigant selection based on pest susceptibility, volatility, penetrability, corrosiveness, safety, flammability, residues, odors, application method, required equipment, and economics
- Methyl bromide and phosphine producing materials such as magnesium phosphide and aluminum phosphide- most common
- Important management option and control all stages of *P. interpunctella* in grain bins, elevators, warehouses, and other mass grain storage structures
- Methyl bromide-being withdrawn in most developed countries as a result of the Montreal Protocol, an international agreement

Chemical control methods



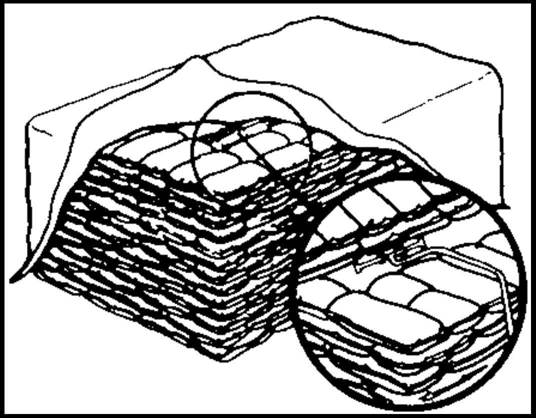
Phosphine fumigation

- No adverse effects on seed germination when applied [illegible]el directions and at labeled rates
- Phosphine react with metals such as copper, brass, bronze, gold, and silver- Reactions result in discoloration and corrosion-problem with electrical and mechanical systems that utilize these metals- problem only occurs when there are high concentrations of phosphine in combination with high humidity and temperature
- If liberation of hydrogen phosphide occurs in a confined area, an explosion or fire result
- Aluminum phosphide-formulated with ammonium carbamate or aluminum stearate and calcium oxide to control release and lower combustibility-formulations contain ammonium carbamate release a garlic odor -serves as a warning odor
- Time required for phosphine release-shorter under warm, humid conditions and longer under cool, dry conditions
- Gas diffuses through grain rapidly-structures must be sealed properly, especially under cooler conditions.

Chemical control methods

Methyl bromide fumigation

- Fumigation with methyl bromide -not harm germination-high doses (generally used for insects) for more than 24 hours coupled with temperatures above 85° F and moisture greater than 12 percent -can negatively impact seed germination
- Methyl bromide does not harm electronic equipment and wiring, and requires less time to kill insects when compared to phosphine- but does give certain products containing sulfur, rubber (foam and sponge rubber also), feathers, hairs, and cinder blocks an odor
- When using methyl bromide at temperatures below 60° F- dosage of fumigant - be increased to compensate for cooler conditions



Insect growth regulators -IGRs

- Used in stored product systems include insect juvenile hormone analogs methoprene, hydroprene, and pyriproxyfen
- All three compounds mimic effects of sustained increased titer of insect juvenile hormone by disrupting normal development between larval instars and in metamorphosis from larvae to pupae and then from pupae to normal adults
- IGRs -not directly toxic to adults-and with low levels of toxicity to mammals and inherent high level of food safety
- Methoprene -considered so nontoxic-exempted from a requirement of a tolerance by EPA in United States
- LD50 value of methoprene- when administered orally to rats- >34500 mg/kg
- Methoprene applied at 1 ppm to stored grain can retain insecticidal activity for over a year

Insect growth regulators -IGRs

- Hydroprene -a structurally close isomer of methoprene with slightly more volatility - considered to function better as an aerosol in space treatments of structures -its ability to penetrate voids and spaces
- Structurally different pyriproxyfen -qualities slightly superior to hydroprene with regard to length of residual activity when applied to a variety of surfaces
- Despite safety and efficacy of IGRs for storage systems-they not been widely adopted for stored grain when compared to traditional residual contact insecticides and fumigants
- IGRs-used for aerosol treatment of food-processing and finished product storage areas- combined with pyrethrum or dichlorvos-
- Increased use of IGRs- attributed to pest managers seeking alternatives to methyl bromide
- IGRs represent low-risk, biologically based insecticides with potential for more adoption in food industry in the future.

THANK YOU