Integrated Pest Management and Fumigation Safety Training

January 24 – 26, 2017
Kansas State University, Manhattan, Kansas
Management of Insects in Stored Commodities: Basics and Concepts

Bhadriraju Subramanyam, PhD

Department of Grain Science and Industry
Kansas State University
Manhattan, Kansas 66506
Tel: 785-532-4092
Fax: 785-532-7010
E-mail: sbhadrir@ksu.edu
Website: http://www.grains.ksu.edu/spirel
Insects can infest grain and grain products from the farm to the consumer.
Examples of stored-product insects

- Rice weevil
- Lesser grain borer
- Indian meal moth
- Red flour beetle

- Live at 17-45°C and at 10-65% humidity
- Optimum, 28-32°C
- Egg-to-adult development, 30-40 days at optimum
Internal Grain Feeders

- Larvae develop inside whole kernels
- Contribute to fragment counts in flour
Radiographs showing internally developing insects
Lesser Grain Borer (*Rhyzopertha dominica*)

Photo courtesy: Dr. Tom Phillips
Lesser grain borer (*Rhyzopertha dominica*) damage

100 adults left in grain for 7 days and then removed 30°C

Source: Dr. Tom Phillips
Reproductive potential of stored-product insects

Fig. 3. The intrinsic rate of population increase for *Tribolium castaneum* at 28.5°C and 65% rh. (Data from Leslie and Park, 1949)
Rice weevil (*Sitophilus oryzae*)

Photo courtesy: Dr. Tom Phillips
Weevil development
Angoumois grain moth (*Sitotroga cerealella*)

Photo courtesy: Dr. Tom Phillips
Internal feeders

- Remove energy from kernels
- Create an entry point for external feeding insects
- Create an entry point for fungi
- Seeds with holes are called insect-damaged kernels
- Contribute to fragment counts
- Some species penetrate packages
Penetrators create openings to enter packages.
Sawtoothed grain beetle larva
External grain feeders

Larvae develop on broken kernels, fine material, flour and fungi

- Red and confused flour beetles
- Sawtoothed and merchant grain beetles
- Rusty and flat grain beetles
- Cigarette and drugstore beetles
- Foreign grain beetle
- Mealworms
- Hairy fungus beetle
- Warehouse and carpet beetles
- Indian meal moth
- Book lice
Red flour beetle (*Tribolium castaneum*)

Photo courtesy: Dr. Tom Phillips
External feeders

*Tribolium castaneum*

*Trogoderma variable*
Indianmeal moth (*Plodia interpunctella*)

Photo courtesy: Dr. Tom Phillips
Foreign grain beetle (*Ahasverus advena*)
Book lice (Psocids)
Insects: Cold Blooded

• Development is dependent on temperature
• Lower, upper, and an optimum limit for development
• Extreme temperatures can be used as a management tool
Temperature and Development: Typical Development Curve

Temperature (Degrees Centigrade)

F = (C x 1.8) + 32
C = (F – 32)/1.8
# Temperature and Development Time in Days

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Rice weevil</th>
<th>Lesser grain borer</th>
<th>Bean weevil</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.5</td>
<td></td>
<td></td>
<td>82.0</td>
</tr>
<tr>
<td>20.0</td>
<td>52.9</td>
<td></td>
<td>60.4</td>
</tr>
<tr>
<td>22.5</td>
<td>43.2</td>
<td></td>
<td>45.4</td>
</tr>
<tr>
<td>25.0</td>
<td>35.9</td>
<td>58.8</td>
<td>35.7</td>
</tr>
<tr>
<td>27.5</td>
<td>30.6</td>
<td>49.9</td>
<td>30.2</td>
</tr>
<tr>
<td>30.0</td>
<td>27.4</td>
<td>42.4</td>
<td>28.9</td>
</tr>
<tr>
<td>32.5</td>
<td>26.7</td>
<td>36.1</td>
<td></td>
</tr>
<tr>
<td>35.0</td>
<td>29.1</td>
<td>31.0</td>
<td></td>
</tr>
<tr>
<td>37.5</td>
<td>36.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Subramanyam and Hagstrum (1995)
# Life History Parameters of Some Internal Feeders

<table>
<thead>
<tr>
<th>Common name</th>
<th>Total adult life span (days)</th>
<th>No. egg/female</th>
<th>Optimum temp. (°C)</th>
<th>Minimum humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granary weevil</td>
<td>210-240</td>
<td>50-250</td>
<td>26-30</td>
<td>50</td>
</tr>
<tr>
<td>Maize weevil</td>
<td>120-150</td>
<td>Up to 150</td>
<td>25-30</td>
<td>50</td>
</tr>
<tr>
<td>Rice weevil</td>
<td>90-185</td>
<td>300-400</td>
<td>27-31</td>
<td>50</td>
</tr>
<tr>
<td>Lesser grain borer</td>
<td>Up to 180</td>
<td>300-500</td>
<td>32-35</td>
<td>30</td>
</tr>
<tr>
<td>Angoumois grain</td>
<td>6-10</td>
<td>100-150</td>
<td>28-30</td>
<td>40</td>
</tr>
</tbody>
</table>

Source: Subramanyam and Hagstrum (1995)
Development and Reproduction Vary with the Commodity

Granary Weevil

<table>
<thead>
<tr>
<th>Grain</th>
<th>Development time (days)</th>
<th>No. progeny/20 weevils/4 days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Maize</td>
<td>45.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Barley</td>
<td>41.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Oats</td>
<td>40.2</td>
<td>2.0</td>
</tr>
<tr>
<td>Wheat</td>
<td>39.9</td>
<td>0.5</td>
</tr>
<tr>
<td>Rice</td>
<td>35.1</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Source: Schwartz and Burkholder (1991)
Management of Insects in Grain

Preventive
- Tactics applied prior to infestation or when infestation is low (below damaging levels)
- Cheaper
- Long-term management

Responsive
- Tactics applied when infestation is at or above damaging levels
- Short-term management
- Re-infestation will occur
- May be cheaper or expensive
Factors Affecting Insect Management Decisions

- End use of commodities
  - Human food versus animal feed
  - Value of commodity
  - Organic versus non-organic
- Length of storage
- Is commodity infested or un-infested at time of storage?
- Insect species to be controlled
  - Population dynamics and damage caused
  - Cost-effectiveness of tactics
  - Insect resistance to tactics
- Compliance with phyto-sanitary (export) requirements
Preventive Tactics

- Sanitation of storages and grain
- Application of insecticides to empty storages
- Application of insecticides to grain (grain protectants)
- Exclusion practices
- Cooling grain
  - Use of aeration
  - Grain chilling
Responsive Tactics

- Use of modified atmospheres (Nitrogen, Carbon dioxide)
- Heat
  - Empty storages and grain
  - Grain heat treatment (only in Australia)
- Fumigants
  - Primarily for grain treatment
  - Predominantly used in the US post-farmgate
  - Most commonly used fumigant is phosphine
Modified Atmospheres
Cocoons™

Having the shape of a cube, impermeable to gases (hermetic), manufactured of white PVC, flexible, UV resistant. Designed for in or outdoor storage, for agricultural and non-agricultural commodities, dry and in bags. Can be installed at any location in minutes. Annual post harvest loss less than 0.25%. Effective life span 10-15 years.
Cocoons in Laos. Grainbank.

Cocoons in Rwanda. Food Security


Cocoons Bayer Philippines. Hybrid Rice.
GAS CONCENTRATIONS

Average CO$_2$ and O$_2$ concentrations (%) in a GrainPro Cocoon containing 10 tons of Wheat in bags

![Graph showing the change in CO$_2$ and O$_2$ concentrations over time. CO$_2$ concentration decreases while O$_2$ concentration increases.]
G-HF and V-HF Cocoons™

G-HF Cocoons™
Hermetic Fumigation with CO₂
Available in 5MT till 50MT, with identical configuration as standard Cocoons. In addition there is a gas inlet near the bottom and a gas outlet of 6” Ø at the top. Provided with all additional equipment for CO₂ injection. This method is being used for “fumigation” of a commodity and rapid elimination of all stages of insect development.

V-HF Cocoons™
Vacuum-Hermetic Fumigation
For rapid fumigation of commodities of high value or for storage of commodities at low O₂ levels. This technology eliminates all stages of insect development in three days at room temperature. El Cocoon The V-HF Cocoon is connected to a vacuum pump to reduce the O₂ in the Cocoon to a level lethal to the insects.

Cocoa in USA
Tobacco in Israel
Photo courtesy: Avinash Wagh, Grain Pro
Laboratory Studies with Storage Pests

Hours to Kill 99% \((LT_{99})\) of Eggs at Two Temperatures and Pressures

Indian meal Moth

<table>
<thead>
<tr>
<th>Pressure</th>
<th>22.5°C</th>
<th>37.5°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 mm</td>
<td>58.0</td>
<td>17.4</td>
</tr>
<tr>
<td>100 mm</td>
<td>96.8</td>
<td>23.0</td>
</tr>
</tbody>
</table>

Red Flour Beetle

<table>
<thead>
<tr>
<th>Pressure</th>
<th>22.5°C</th>
<th>37.5°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 mm</td>
<td>69.7</td>
<td>11.7</td>
</tr>
<tr>
<td>100 mm</td>
<td>98.1</td>
<td>20.7</td>
</tr>
</tbody>
</table>

Source: Dr. T. W. Phillips
Grain Pro’s Superbag:

- Is made of plastic materials which are as close as possible to glass in “permeability”
- Can be made in any size up to a 50 kg bag
- Has an oxygen barrier

www.grainpro.com
Purdue Improved Cowpea Storage (PICS)

- **Triple bagging:** [http://www.ag.purdue.edu/ipia/pics](http://www.ag.purdue.edu/ipia/pics)
- HDPE (80-100 micrometer thick)
- Outer bag made of polypropylene
- 6% oxygen after 5 days

- Cowpea weevils (*Callosobruchus chinensis*) alive for 28 days
- Damage can be expected
- Used by subsistence farmers in Africa
- [https://www.youtube.com/watch?v=KDFAgPJE SM](https://www.youtube.com/watch?v=KDFAgPJE SM)
- PICS and Superbags similar in performance
Murdock and Baoua (2014)
Oxygen scavengers/absorbers

Removes oxygen from an enclosure
Ferric oxide is commonly used
Vitami
Mortality of *Tribolium castaneum* (Red flour beetle)
Adults at 32.2°C

Compressed air

12% CO$_2$ + 0.5% O$_2$ + 87.5% N$_2$
**Tribolium confusum** (Confused flour beetle) Adult Mortality at Three Temperatures

Compressed air

- 10°C
- 21.1°C
- 32.2°C

12% CO₂ + 0.5% O₂ + 87.5% N₂
Commercial Iron Powder Sachets

- Bulk (5 kg) dog bone pet product intended for Japan
- 3 commercial sachets per 5 kg
- $O_2$ levels over time

<table>
<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>$O_2$ level (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar. 26, 08</td>
<td>0</td>
<td>20.00</td>
</tr>
<tr>
<td>Mar. 27, 08</td>
<td>1</td>
<td>0.19</td>
</tr>
<tr>
<td>Mar. 28, 08</td>
<td>2</td>
<td>0.32</td>
</tr>
<tr>
<td>Mar. 31, 08</td>
<td>5</td>
<td>0.10</td>
</tr>
</tbody>
</table>

$n = 1$ replication

Mitsubishi Chemical Company
Use of $O_2$ Scavengers Inside Pouches

Oxygen levels inside pouches with ascorbic acid

<table>
<thead>
<tr>
<th>Day</th>
<th>1 g Ascorbic acid</th>
<th>5 g Ascorbic acid</th>
<th>10 g Ascorbic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.23 ± 0.19</td>
<td>1.26 ± 0.03</td>
<td>1.47 ± 0.14</td>
</tr>
<tr>
<td>13</td>
<td>0.61 ± 0.03</td>
<td>0.66 ± 0.11</td>
<td>0.66 ± 0.04</td>
</tr>
</tbody>
</table>

Two-way ANOVA:
- No significant differences among treatments ($F=0.94; \ df=2, 6; \ P=0.441$)
- Significant differences between days ($F=57.87; \ df=1, 6; \ P=0.0003$)
- Interaction of treatment x days ($F=0.60; \ df = 2, 6; \ P=0.5807$)

Ascorbic acid was placed in vials of 4.9 cm long and 2.6 cm diam (24 ml volume)
Insecticide-treated bags

Insecticide-treated nets to cover bagged product

Originally used for mosquito control
Commercial products being developed for use
In warehouses to cover bagged/boxed products
Evaluation of CARIFEND for the control of stored tobacco pests

Source: C. Athanassiou (Unov. Of Thessaly, Volos, Greece)
Chemicals Have Been Cheap Alternatives to IPM

• In the US, fumigation and other chemicals are commonly used for managing insects at elevators

• Chemical use accounted for 3% of the total costs of storing and handling grain in commercial elevators (Kenkel and Anderson 1992)
Pest Management Decisions

- Should be based on sampling information
- US standards
  - For infested wheat, 2 live insects/kg of grain
- Without sampling information one commits two errors:
  - Treating unnecessarily
  - Not treating when needed
Correct identification of the pest is important.
Summary

- There are preventive and responsive tactics available.
- Sampling and segregating infested and uninfested grain at may important.
- Choose a method that fits your needs/costs.
- More research is needed on non-chemical methods.
- Phosphine is still a valuable product to use.
  - Use should be based on insect sampling data.
- Understand pest dynamics and intervene at the right time to avoid losses.
- Use exclusion and sanitation tactics to complement other IPM strategies.
Sampling and Monitoring Stored-Product Insects
What is Sampling?

It is the process of taking a representative portion of stored grain to make inferences about the population or an attribute of the population (e.g., test weight, moisture, dockage, number of insects, etc.).

Visual sampling: Inspecting warehouse/bags with naked eyes.

- Number of locations inspected
- Spending more time at a location is same as taking more samples
- Spend more time in areas where there are problems
Sampling for Insects is Done to Determine...

• Types of insect species present
• Density or number of insects occupying a given area
• Number of individuals of various life stages (larvae, pupae, or adults) in a commodity or product
• Percentage of product that is infested (insects present/absent)
Why Resort to Sampling?

- Counting all insects in a grain bin or silo or bags of grain is difficult because:
  - It takes time and effort
  - Insect distribution is unknown
- Time, money, and personnel are limited
Population Estimates

• Absolute estimates
  • Number of insects/kg or cubic meter or square meter

• Relative estimates
  • Number of insects/trap

• Converting relative to absolute estimates
  • Need to take a large number of samples to relate absolute and relative estimates

• Population indices
  • Sampling insect activity or insect damage and not insects
Grain Trier

- Used to sample grain at rest
- Need containers to carry samples
- More probe samples can be taken by sampler if needed
- For bags use torpedo probes
# Probability of Detection for Insects in Stored Wheat

<table>
<thead>
<tr>
<th>No. 1-kg samples per 1000 bushels</th>
<th>Mean no. insects per kg of grain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td>1</td>
<td>0.02</td>
</tr>
<tr>
<td>2</td>
<td>0.04</td>
</tr>
<tr>
<td>5</td>
<td>0.10</td>
</tr>
<tr>
<td>10</td>
<td>0.19</td>
</tr>
<tr>
<td>25</td>
<td>0.42</td>
</tr>
<tr>
<td>100</td>
<td>0.89</td>
</tr>
</tbody>
</table>

Probability of 0.02 is same as 2% (0.02 x 100)

Source: Hagstrum et al. (1991)
Pneumatic Truck Sampler

For bagged grain in trucks-inspect trucks and bags prior to loading/unloading

http://ecatalog.rusbiz.com/product/truck_sampler_63634.html

Fig. 8: Probe-type mechanical sampler.
Bag Samplers (Torpedo Probe)
Insectomat-Separates Insects from Grain

- Capable of processing large samples
- Pass grain sample twice for extraction of all insects present
- Determine accuracy of insect extraction
**Inclined Sieve**

- Used to separate insects from large grain samples
- Need to pass grain twice
- Use wooden frames and mesh with greater than 2 mm openings

Sampling procedure for absolute estimate

Sampling

Weigh the samples and extract insects from samples

Identification & counting
Express number of live insects/kg
Absolute Estimates

- Advantage: more reliable estimates
- Disadvantages: time consuming, laborious and expensive
Relative Estimates

• Based on sampling device used, i.e. various traps
• Types of traps: aerial insects, surface deployed, used in grain
• Combined with food-baits or attractants and pheromones
• Understand limitations
Trap Types

- Sticky, funnel, dome traps or pitfall traps
- Sometimes combined with pheromone or light as attractants
- Good for moths and beetles
- Need insects to be mobile
- May compete with food odors
- Will not tell you where the insects are!
Traps for Aerial Insects

- Including sticky and funnel traps
- Often combined with pheromone as an attractant
- Good for moths and active beetles
- Hang or suspend traps at eye level
- Can use multiple lures for different species
Sticky Traps
For almond moths and Indian meal moths
Floor Traps

- Traps for crawling insects
- Provide hiding place
- Include harborage, sticky, pitfall, and bait-bag traps
- Can be combined with pheromone
Pitfall traps with a dust cover (DOME Traps)
Bait-bag Traps
Traps Used in Grain

- Designed for use within bulk grain
- Perforated metal or plastic probes or cones inserted into grain bulks
- Insects crawl through the holes and are trapped in a collecting tube or cone
- Work as pitfall traps
Pitfall Cone Trap

- 95mm x 125mm cone-shaped with catching holes
- For surface area of the grain bulk
Probe Traps

Funnel and collecting tube
Can be inserted into the grain bulk
Relative Estimates

• Advantages: multispecies, faster, cheaper, easier, good for monitoring purposes
• Disadvantages: insects no. does not equal insect population
• Insects caught depend on other factors (placement, lures, trapping period, temperature, mobility of insects, etc.)
Sampling Procedure for Relative Estimates

Assemble and place the traps

Collecting insect catches

Identification & counting
Express insects as numbers captured/trap
Total Number of Beetles
KSU Pilot Feed Mill
Day of the year, 1999

Number of adults/40 traps

6,033 total adults

Heat treatment, Aug. 4-6
Effect of Heat Treatment on Moth Numbers
(KSU Pilot Feed Mill)

Almond moth, *Cadra cautella*

Indianmeal moth, *Plodia interpunctella*

Total number of moths/40 traps

Day of the year, 1999

Almond moth

Indianmeal moth
Using Surfer® Software for Contour Mapping
Detailed research projects may require generating semi-variograms.

Surfer® (www.goldensoftware.com) is a computer program that analyzes spatial data using mathematical models.

If specific mathematical models are not selected, the software program uses default settings.

Contour maps (lines) are drawn among sample locations to estimate pest numbers in unsampled locations.

The type of interpolation technique used in default settings is the kriging procedure.
An Example Showing How Contour Maps are Generated
Traps were Used for Sampling Stored-Product Insects in Retail Pet Stores

30 dome or Flite-Trak traps (each with 3 beetle lures) per store

30 Pherocon II traps (with IMM lure) per store
Traps were placed in loosely arranged grid pattern inside stores
Traps were concealed from customer’s view
Trap locations were identified by X and Y coordinates using the Disto meter (see picture).

Trap captures were recorded every 1-3 weeks.

Contour map of trap capture distributions was generated using Surfer® software.

<table>
<thead>
<tr>
<th>X (in meters)</th>
<th>Y (in meters)</th>
<th>No. of insects</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>22</td>
<td>25</td>
</tr>
<tr>
<td>24</td>
<td>56</td>
<td>0</td>
</tr>
</tbody>
</table>
A Contour Map
Contour Maps: Advantages
Qualitative representation of how insects are distributed

Helps in identifying infestation foci
Additional investigation may show possible sources or identify reasons for infestation

Helps in targeting control measures

Can be used to gauge impact of control measures on pests if sequential contour maps are drawn
Sequential contour maps help in evaluating effectiveness of control measures
Sanitation and pesticide application in the stores
Indian Meal Moths in a Retail Store

Sequential contour maps
Threshold-based sampling or presence/absence sampling
Example: Determining probability of detection

\[ P(x > 0) = 1 - (1 - f)^n \]

\( P \) = Probability of detecting 1 or more live insects
\( f \) = Frequency of detection (how frequently do you find insects in a set of bags examined)
\( n \) = Number of samples
Find $P$ given $f = 5\%$ (or 5 bags out of 100 had live insects or 0.05)

$n = 30$ bags

$P = 1 - (1 - 0.05)^{30}$

$P = 0.785$ or 78.5\%
Example: Determining number of samples needed

\[ n = \frac{\ln(1 - P)}{\ln(1 - f)} \]

\[ n = \frac{\ln(1 - 0.95)}{\ln(1 - 0.05)} \]

\[ n = 58.4 \text{ or } 58 \text{ samples} \]
Example: Determining frequency of infestation

\[ f = 1 - (1 - P)^{1/n} \]

\[ f = 1 - (1 - 0.95)^{1/30} \]

\[ f = 0.095 \text{ or } 9.5\% \text{ or approximately } 10\% \]
Sampling information needed

- Number of bags/locations (samples) examined
- Number of live or dead insects found in samples (take 10-30 samples).
  - Calculate mean number of insects/sample
  - Calculate variance
- Percentage of samples that had insects
- Collect above information every time you sample for 1 or more years
Relationship between mean number of organisms/sample and proportion of sample units with organisms
Questions?
This presentation was made possible by a grant from The Technical and Operational Performance Support (TOPS) Program. The TOPS Micro Grants Program is made possible by the generous support and contribution of the American people through the U.S. Agency for International Development (USAID). The contents of the materials produced through the Micro Grants do not necessarily reflect the views of TOPS, USAID, or the U.S. Government.