Integrated Pest Management and Fumigation Safety Training

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Management of Insects in Stored Commodities: Basics and Concepts

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Storage

Transport

Farm

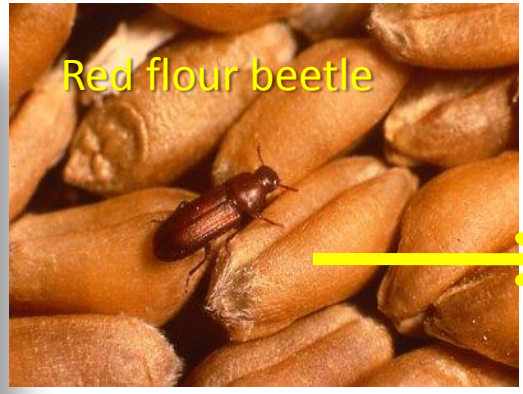
Insects can infest grain and grain products from the farm to the consumer

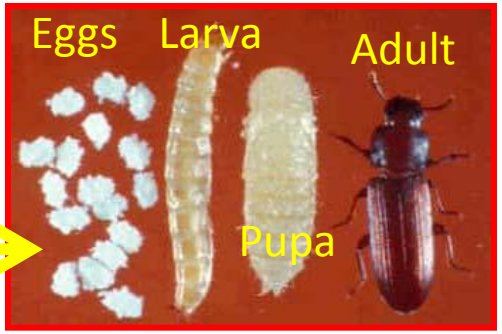
Processing plant

Retail store

Consumer

Examples of stored-product insects

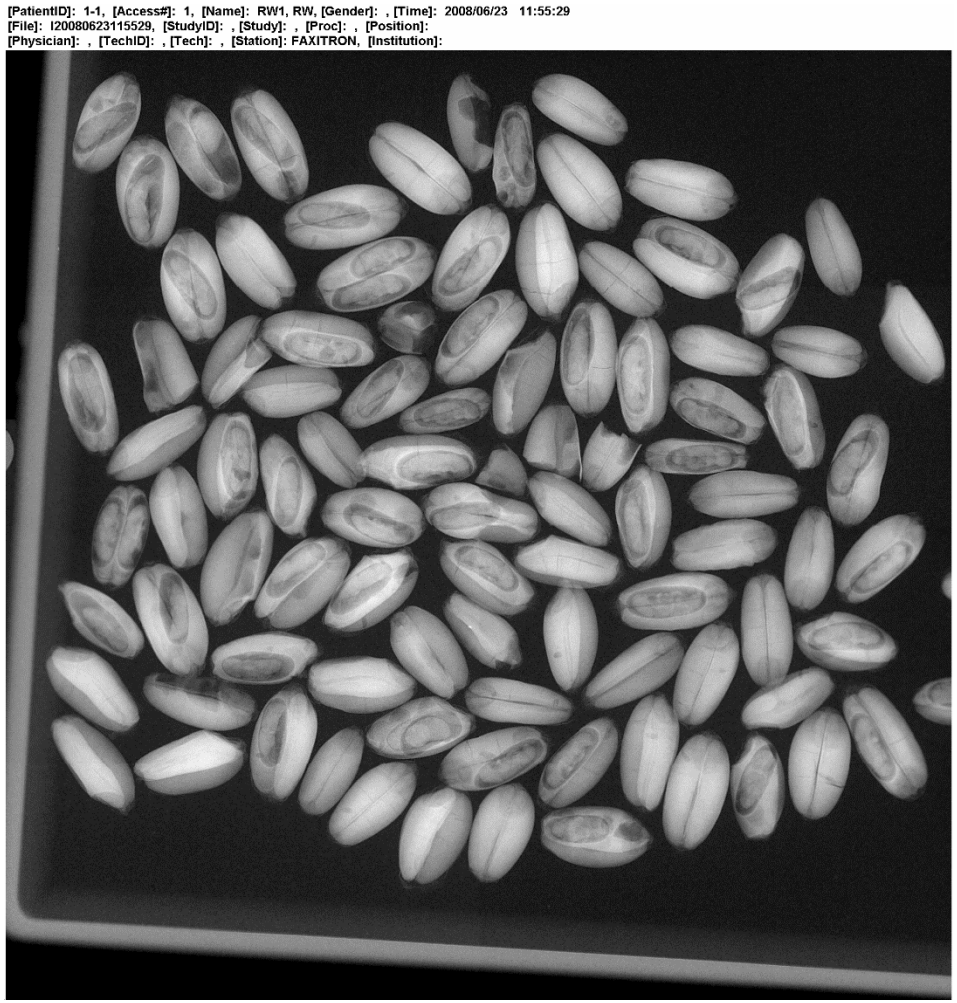


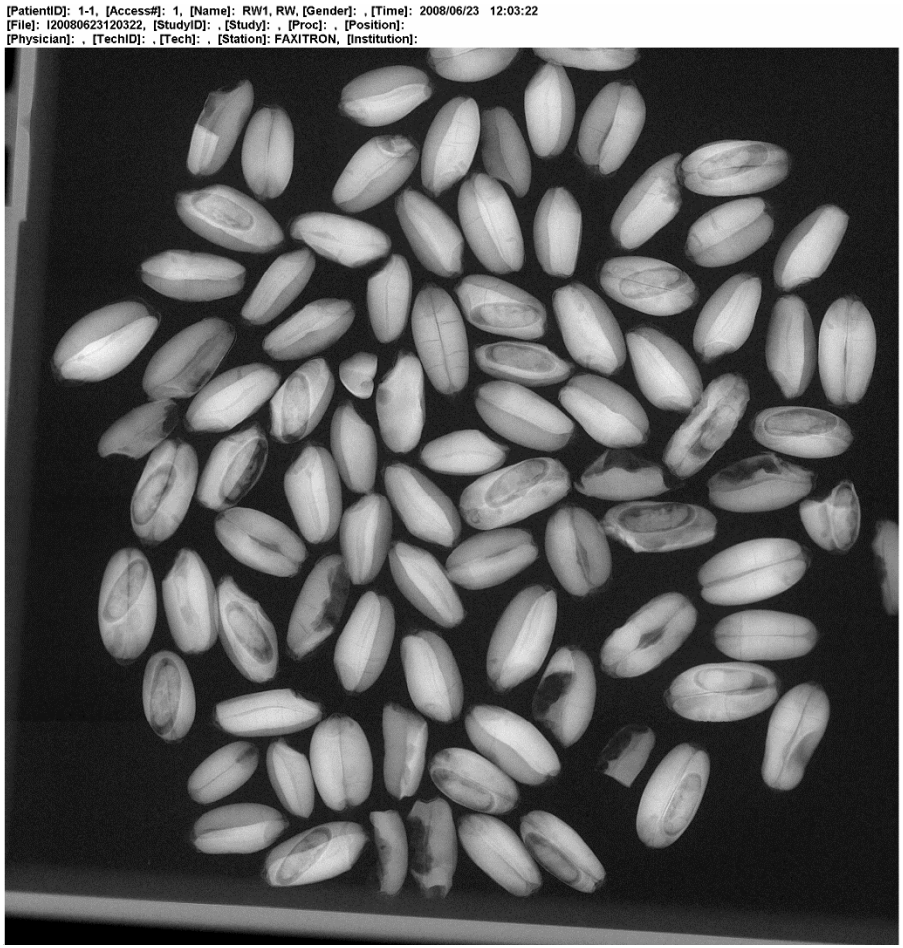


- Live at 17-45°C and at 10-65% humidity
- Optimum, 28-32°C
- Egg-to-adult development, 30-40 days at optimum

Internal Grain Feeders

- Larvae develop inside whole kernels
- Contribute to fragment counts in flour





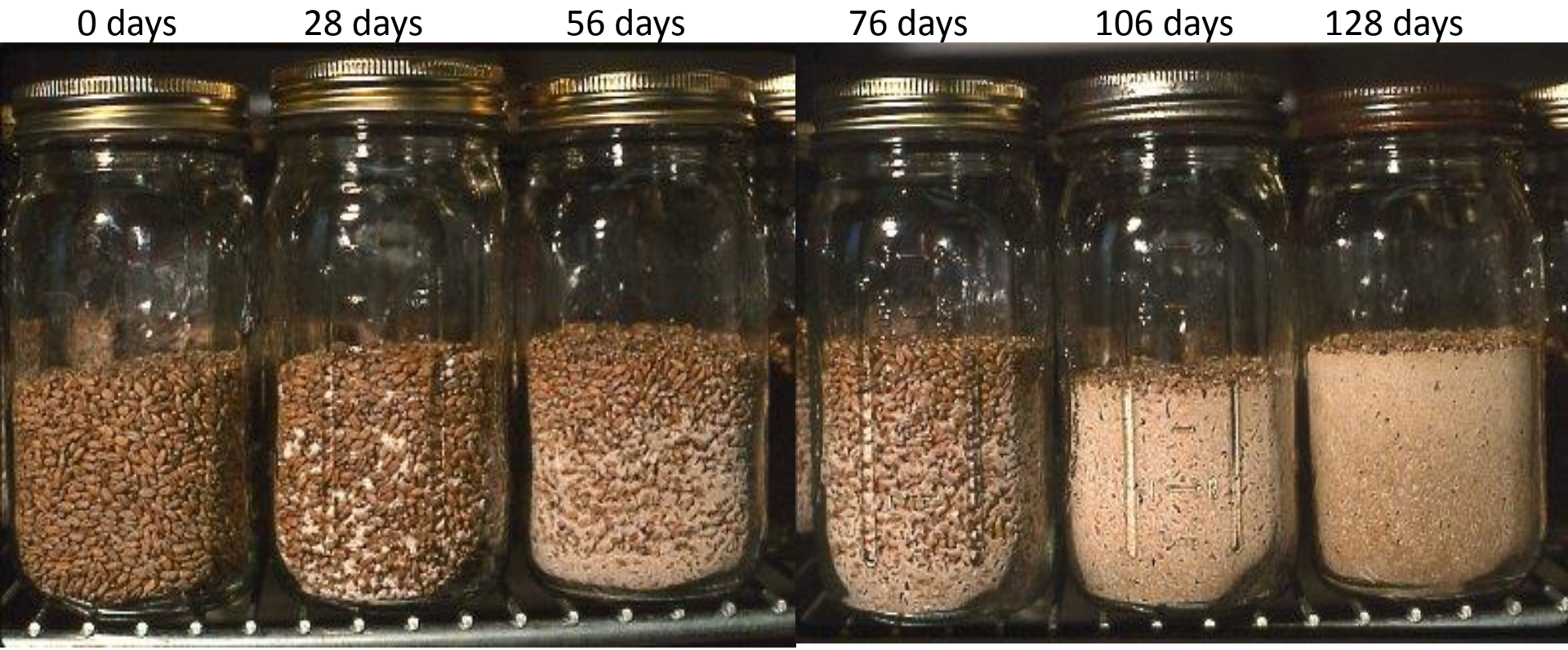
Radiographs showing internally developing insects

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

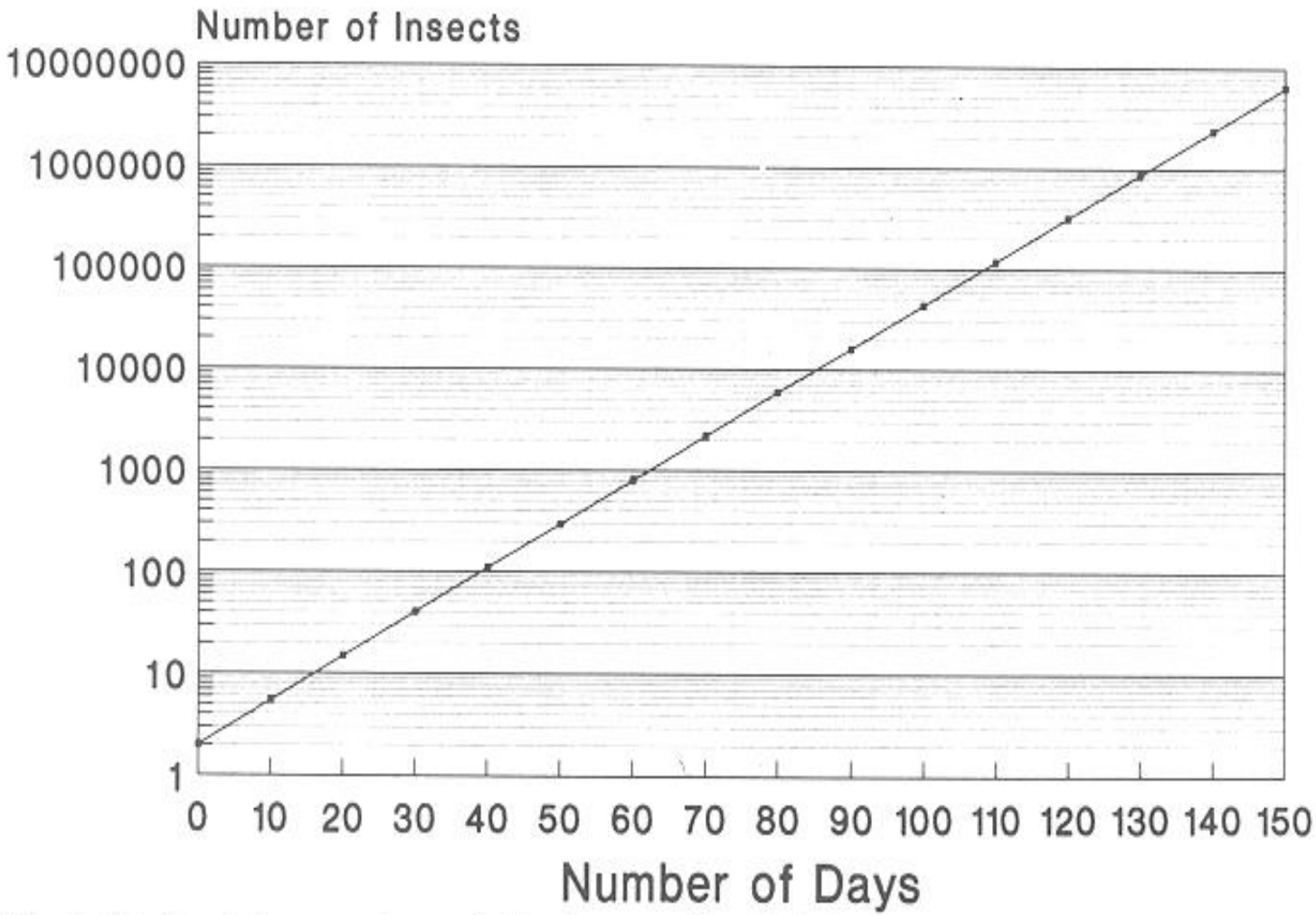
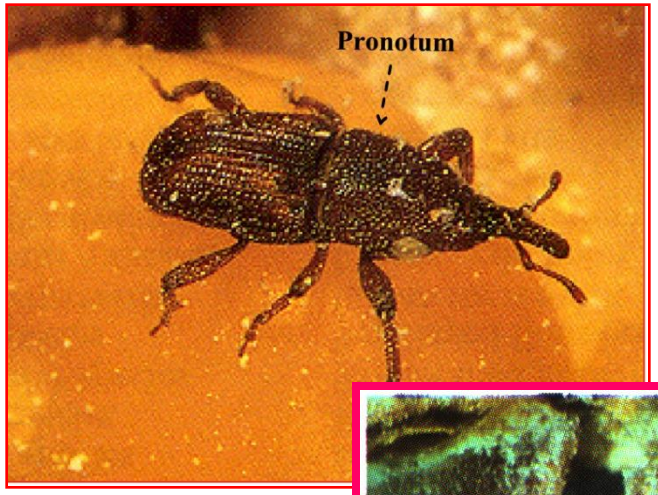


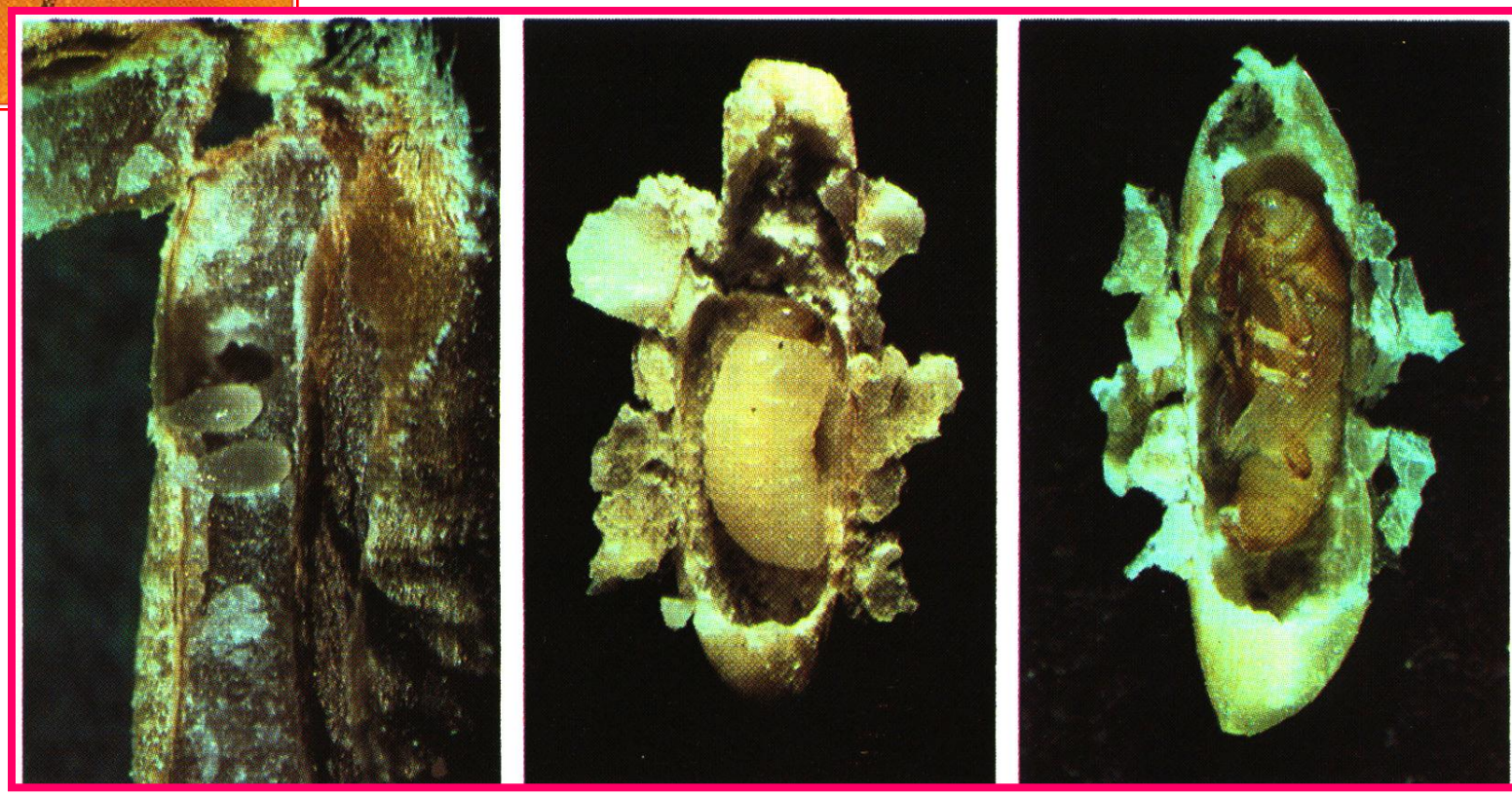
Fig. 3. The intrinsic rate of population increase for *Tribolium castaneum* at 28.5°C and 65% rh. (Data from Leslie and Park, 1949)

Rice weevil (*Sitophilus oryzae*)

Photo courtesy: Dr. Tom Phillips

Weevil development





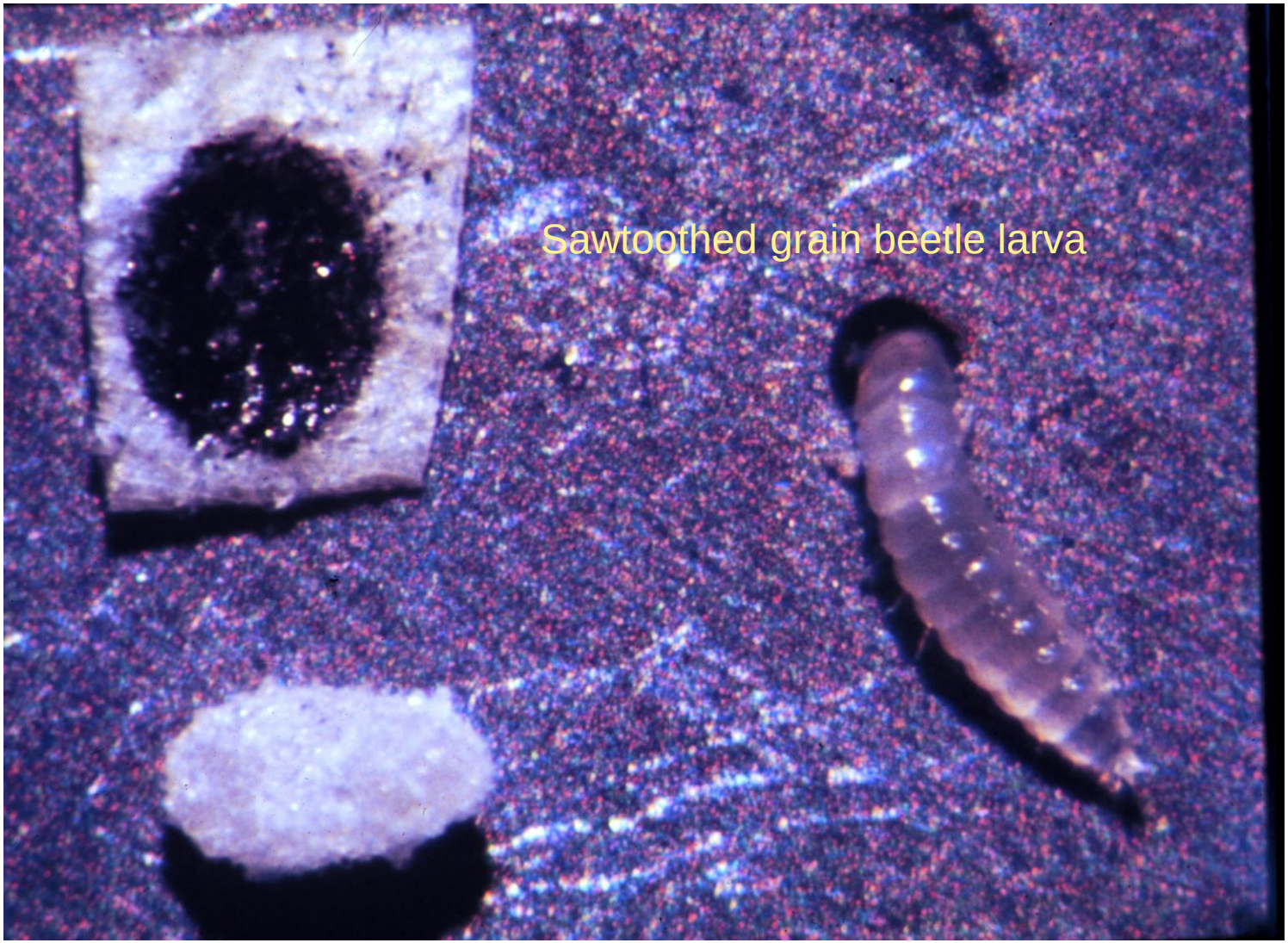
Angoumois grain moth (*Sitotroga cerealella*)

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

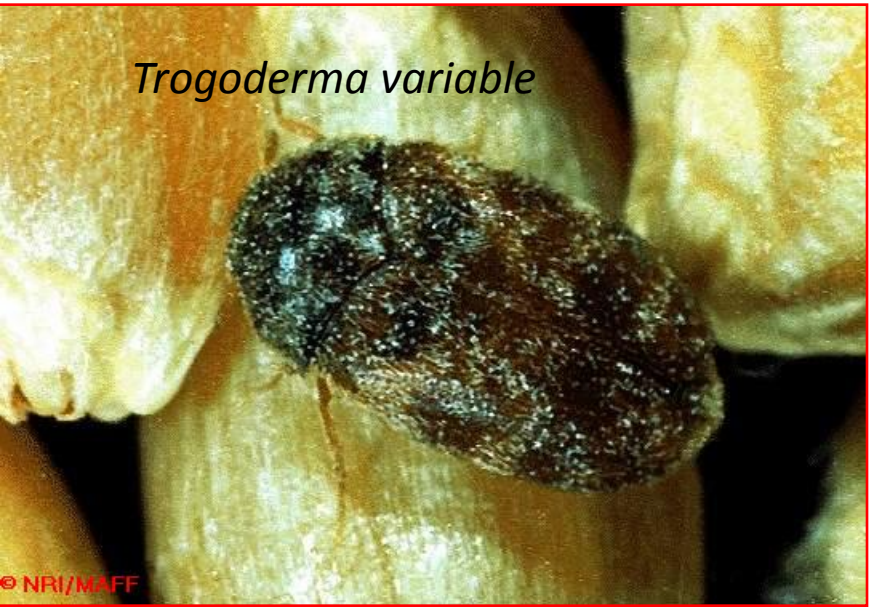
Larvae develop on broken kernels, fine material, flour and fungi

- 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



Indianmeal moth (*Plodia interpunctella*)

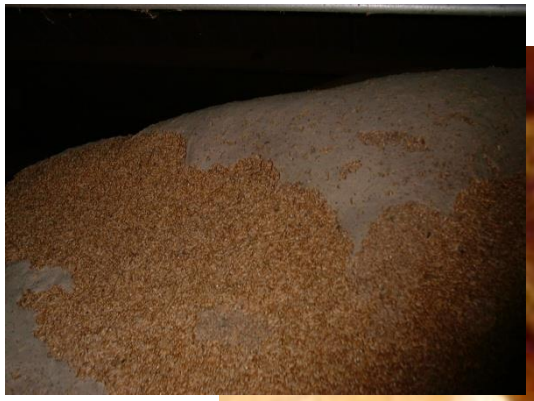
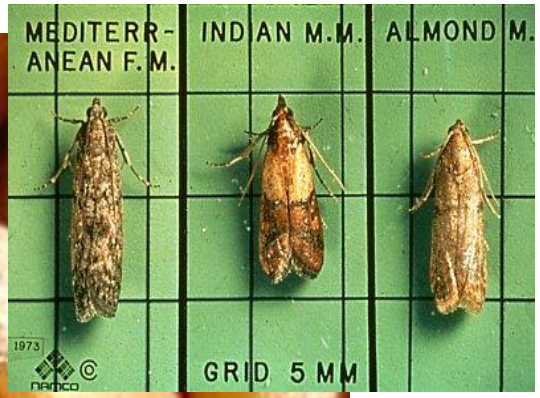


Photo courtesy: Dr. Tom Phillips



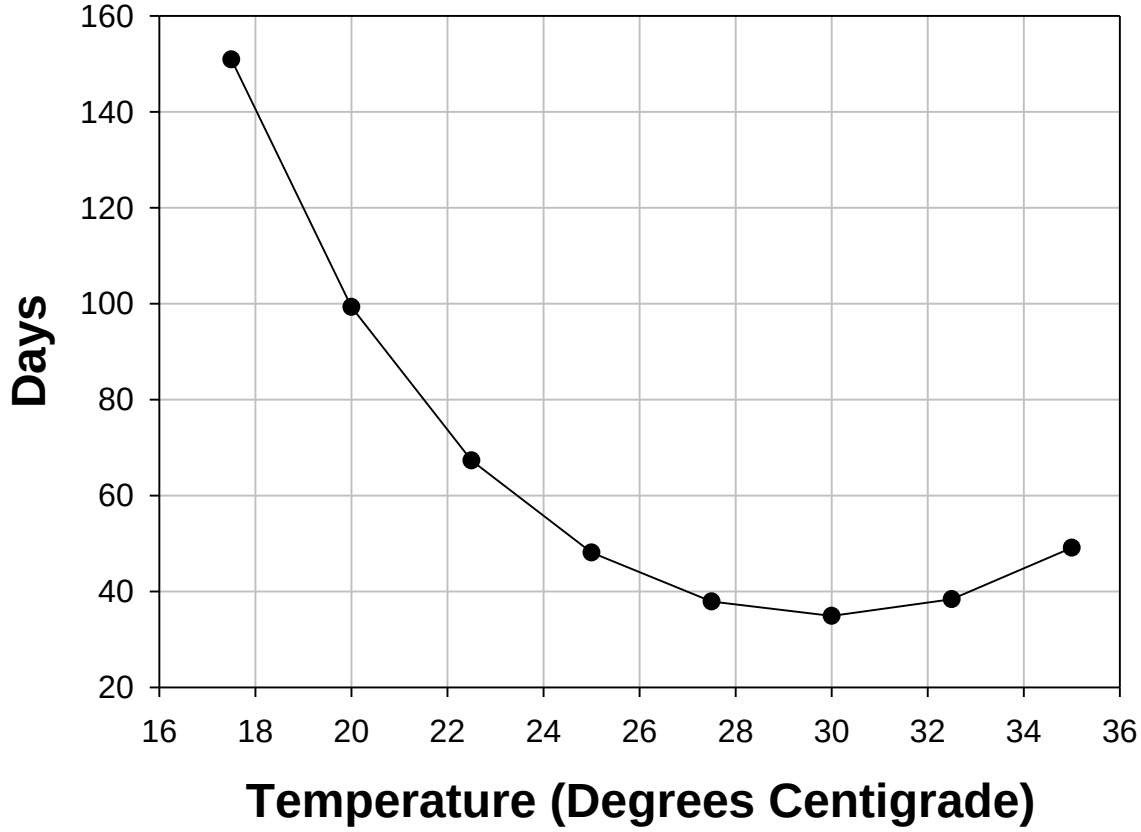
Foreign grain beetle (*Ahasverus advena*)

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



F = (C x 1.8) + 32
C = (F – 32)/1.8

Temperature and Development Time in Days

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

Source: Subramanyam and Hagstrum (1995)

Life History Parameters of Some Internal Feeders

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

Source: Subramanyam and Hagstrum (1995)

Development and Reproduction Vary with the Commodity

Granary Weevil

Grain	Development time (days)				No. progeny/20 weevils/4 days		
	Mean	SD	Range		Mean	SD	Range
Maize	45.5	1.5	32-66		21.0	7.7	10-33
Barley	41.1	1.5	30-62		96.7	17.2	73-126
Oats	40.2	2.0	34-52		9.4	3.8	4-17
Wheat	39.9	0.5	32-60		82.4	17.6	56-112
Rice	35.1	0.6	30-48		12.5	3.4	8-17

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

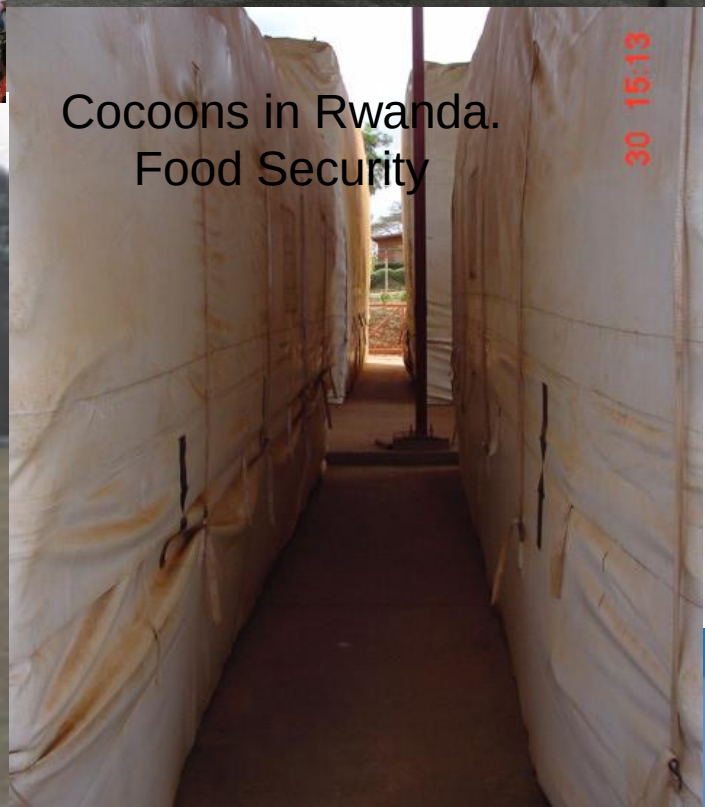
Cocoons™

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.

Cocoon in Laos. Grainbank.

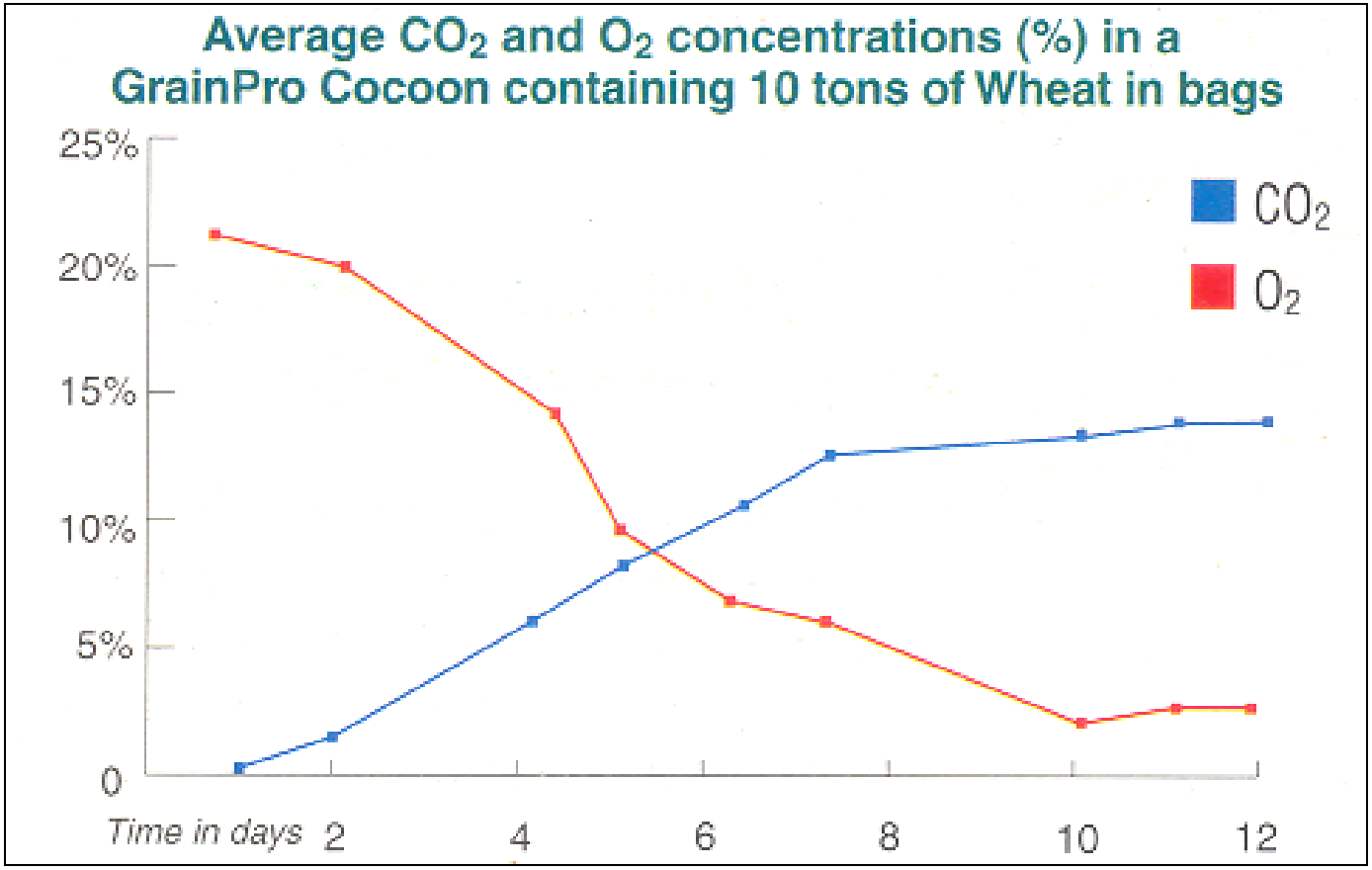
Cocoons Bayer Philippines. Hybrid Rice.

Cocoons in Miramar, Costa Rica. Organic Coffee.



Cocoons in Rwanda.
Food Security

GAS CONCENTRATIONS



G-HF and V-HF Cocoons™

G-HF Cocoons™

Hermetic Fumigation with CO_2

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 CO_2 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 O_2 in the Cocoon to a level lethal to the insects.

Photo courtesy: Avinash Wagh, Grain Pro

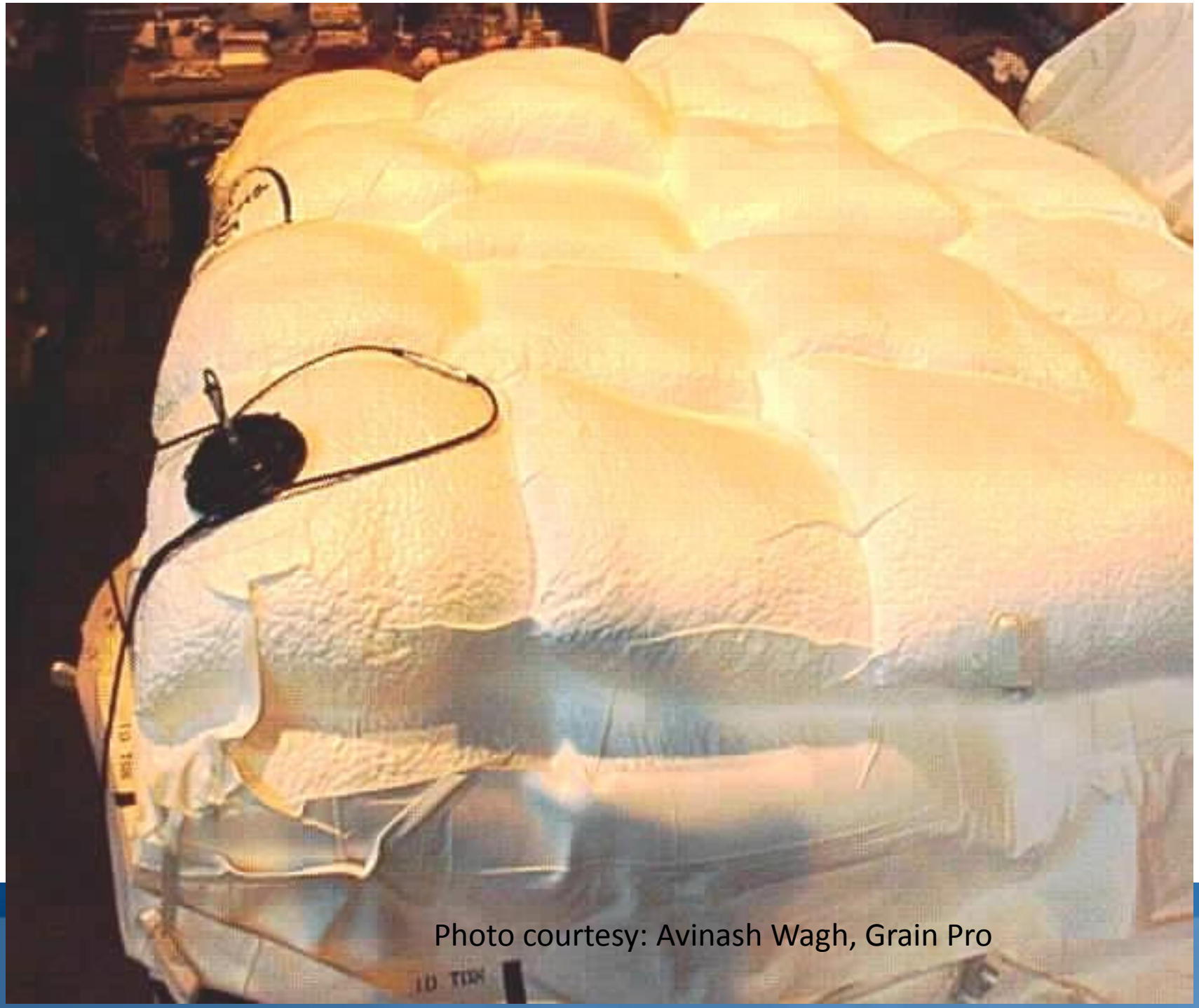


Photo courtesy: Avinash Wagh, Grain Pro

Laboratory Studies with Storage Pests

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

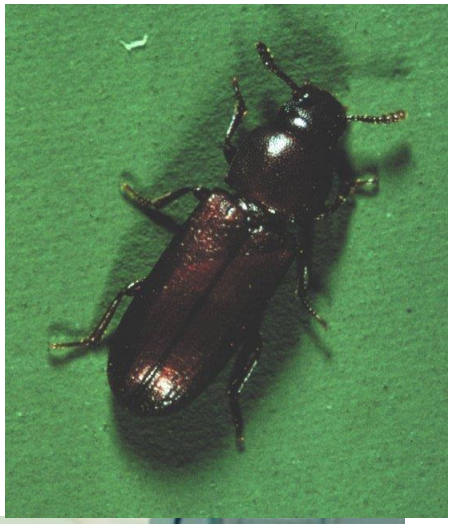
Indian meal Moth

	22.5°C	37.5°C
50 mm	58.0	17.4
100 mm	96.8	23.0

Red Flour Beetle

	22.5°C	37.5°C
50 mm	69.7	11.7
100 mm	98.1	20.7

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

GRAINPRO, INC.™
ORGANIC STORAGE SYSTEMS

The quality of agricultural commodities can be preserved in Superbags

Grainpro SuperBag™

Modified Atmosphere (MA) Storage of Dry Agricultural Commodities

Low cost SuperBags are intended for resealable safe storage of dry commodities in reusable or disposable bags in sizes from 1 to 50 kg capacity. Superbags act as a gas and moisture-proof barrier and larger sizes may be placed inside any convenient protective cover such as woven polypropylene or paper bags for physical protection. The distinctive gas barrier properties of the multi-layer plastic used for the bags, enable excellent protection against ingress of water vapor, while retaining low O_2 and high CO_2 levels created by the respiration of the commodity.

Material - Tough, transparent multi-layer with gas barrier between 2 layers of PE. 0.078 mm thick (0.003 inches), material weighs 50 gm/m (double layer).

Usable temperature range -18°C to 95°C

Some recommended uses:

- Seeds of all types to preserve germination potential without refrigeration over many months
- Coffee and cocoa beans
- Cocoa beans
- Milled rice (white and brown)
- Flour, grits
- Hygroscopic Commodities
- Spices

Hermetically seeled Superbag with paddy seeds

Closure - Bags may be closed by:

1) twisting top and using a rubber band
2) rolling and clamping top
3) heat-sealing using electric or handheld sealer

Resistance - Very strong material (see specification), low moisture and oxygen permeability. Infesting insects use oxygen and die. SuperBags are normally used as liner inside polypropylene woven, jute or equivalent protective bag. Smaller bags can be used

Transportability - Easily transported when full in similar manner to conventional jute, polypropylene or paper bags.

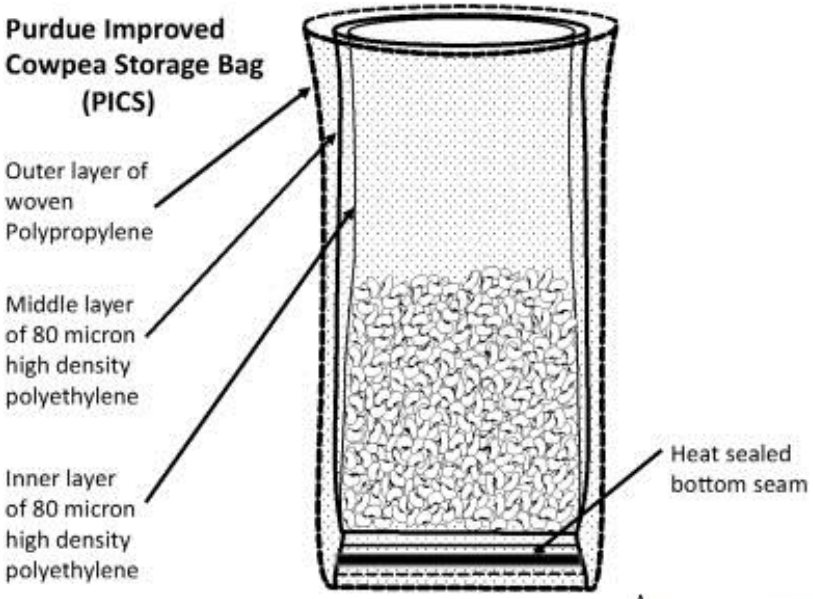
Size - Made according to customers demand.

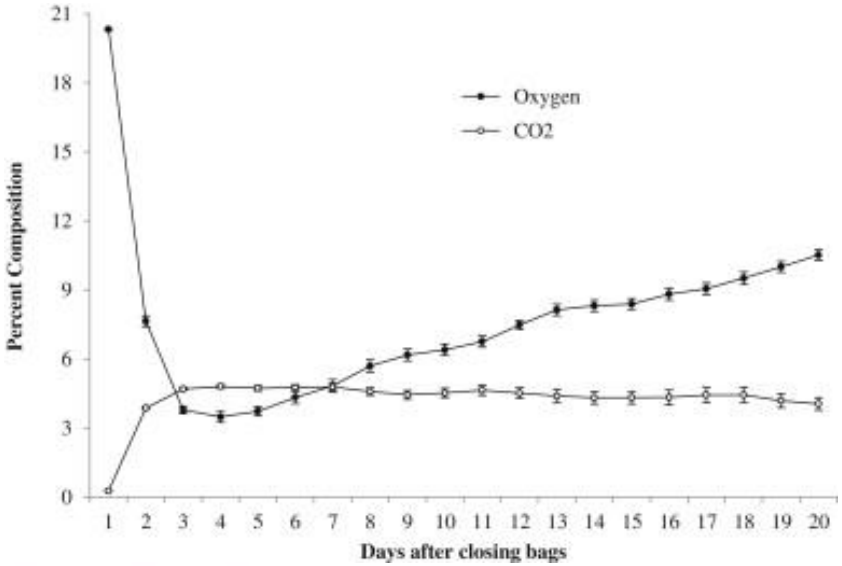
Printing - Customer specified printing on transparent surface with one to six colors.

Grainpro Superbags are made under strict quality control meeting ISO 9002 standards.

Purdue Improved Cowpea Storage (PICS)

- Triple bagging: 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=_kDFAgPJESM
- PICS and Superbags similar in performance





A

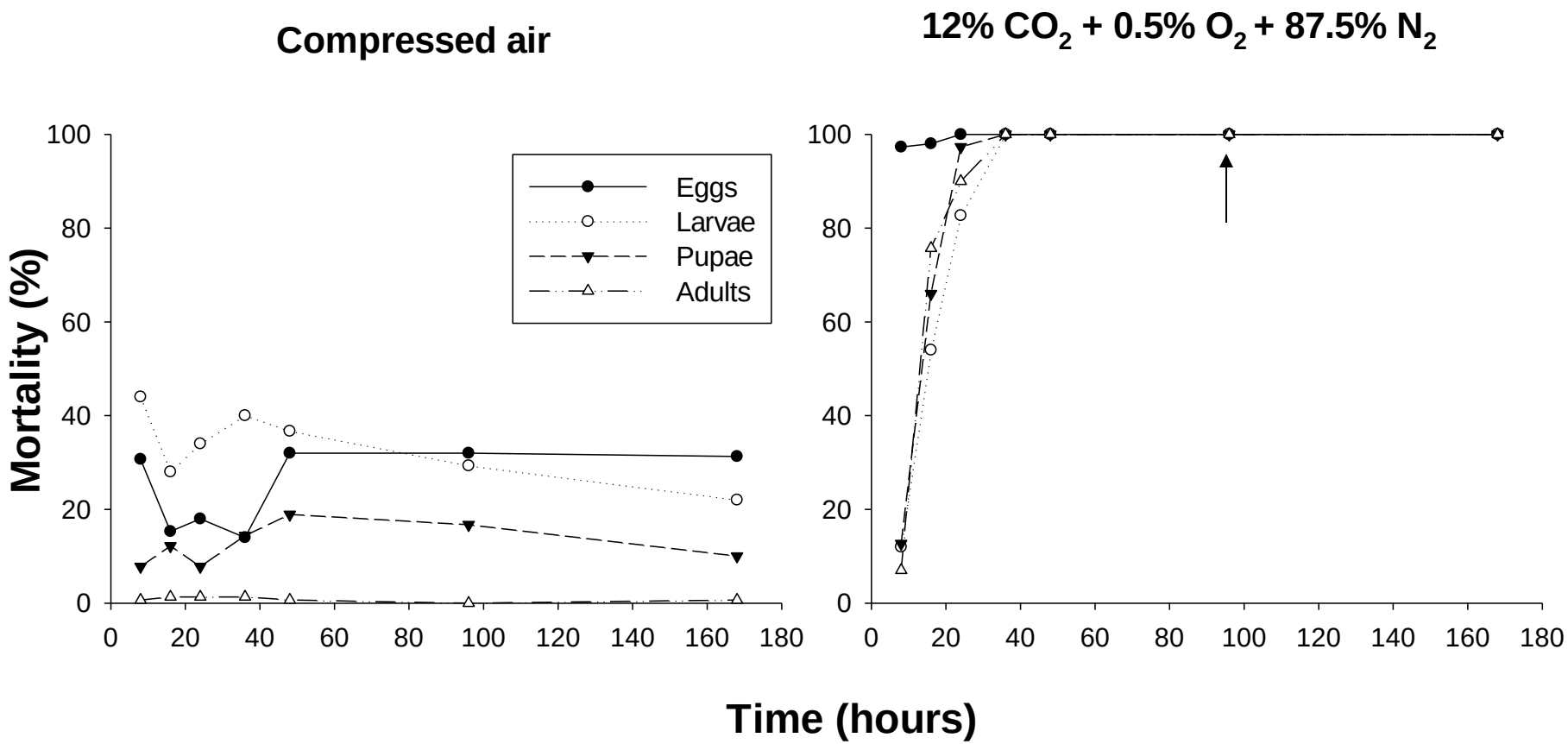
B

Murdock and Baoua (2014)

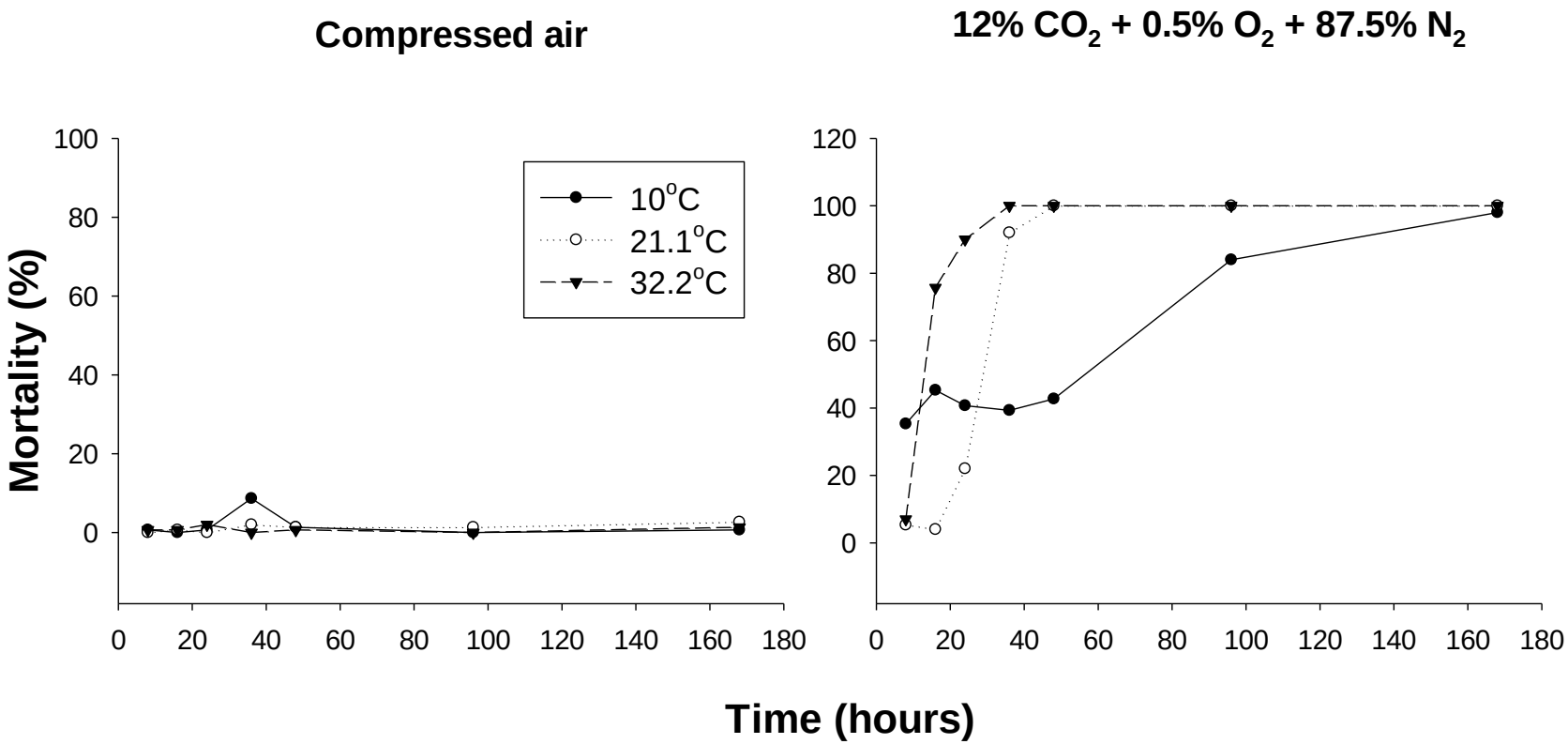
Oxygen scavengers/absorbers

Removes oxygen from an enclosure
Ferric oxide is commonly used
Vitami

Mortality of *Tribolium castaneum* (Red flour beetle) Adults at 32.2°C



Tribolium confusum (Confused flour beetle) Adult Mortality at Three Temperatures



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

Date	Day	O_2 level (%)
Mar. 26, 08	0	20.00
Mar. 27, 08	1	0.19
Mar. 28, 08	2	0.32
Mar. 31, 08	5	0.10

n = 1 replication

Mitsubishi Chemical Company

Use of O_2 Scavengers Inside Pouches

Oxygen levels inside pouches with ascorbic acid

Day	1 g Ascorbic acid	5 g Ascorbic acid	10 g Ascorbic acid
1	1.23 ± 0.19	1.26 ± 0.03	1.47 ± 0.14
13	0.61 ± 0.03	0.66 ± 0.11	0.66 ± 0.04

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 covers 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 in 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

No. 1-kg samples per 1000 bushels	Mean no. insects per kg of grain					
	0.02	0.06	0.20	0.60	2.0	6.0
1	0.02	0.06	0.19	0.43	0.76	0.95
2	0.04	0.12	0.34	0.67	0.94	1.00
5	0.10	0.28	0.64	0.94	0.99	1.00
10	0.19	1.48	0.87	1.00	1.00	1.00
25	0.42	0.80	0.99	1.00	1.00	1.00
100	0.89	1.00	1.00	1.00	1.00	1.00

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

Source: Hagstrum et al. (1991)

Pneumatic Truck Sampler

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

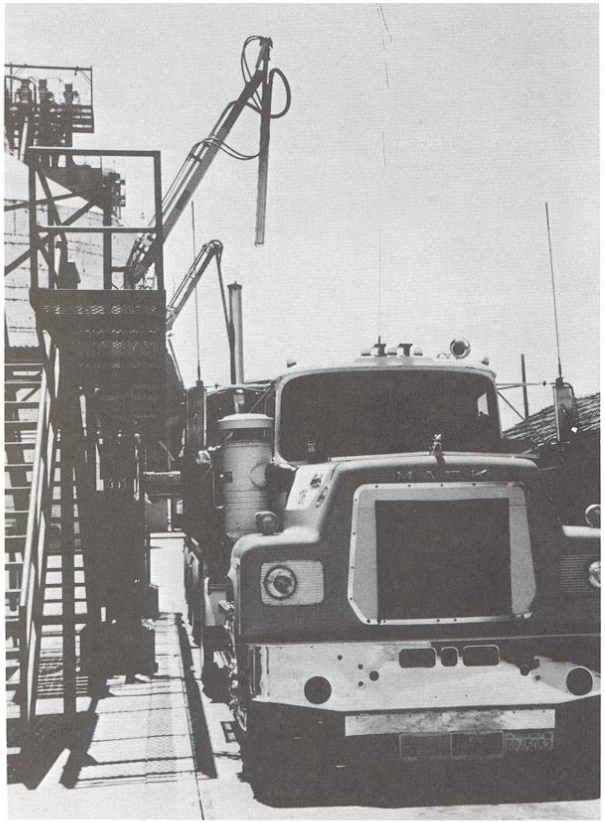
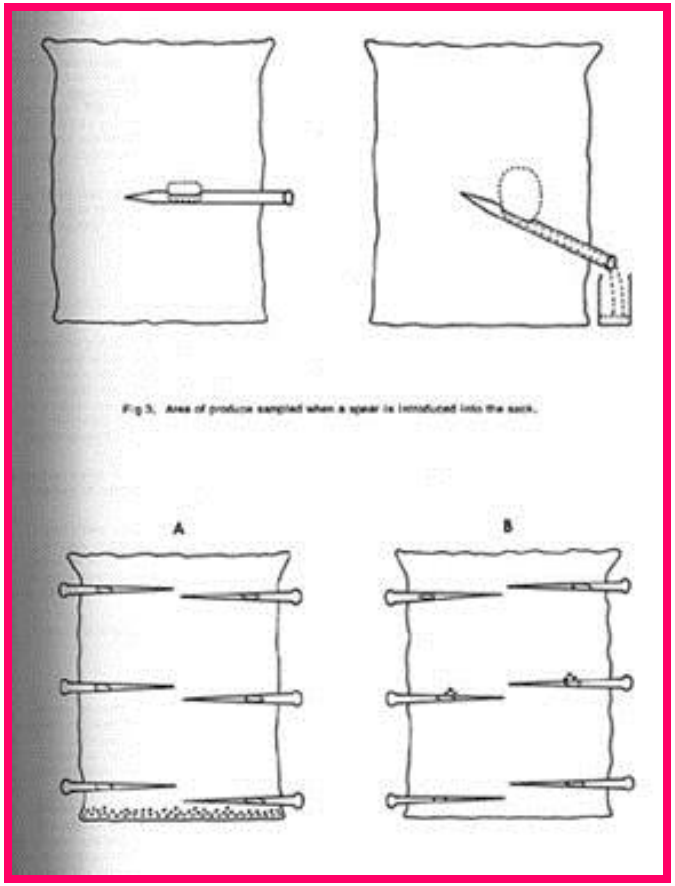
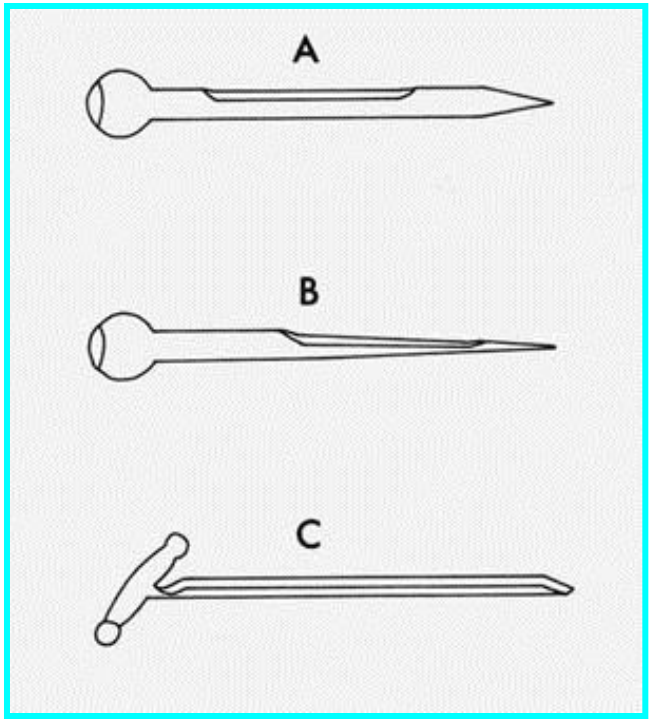


Fig. 8. Probe-type mechanical sampler.

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

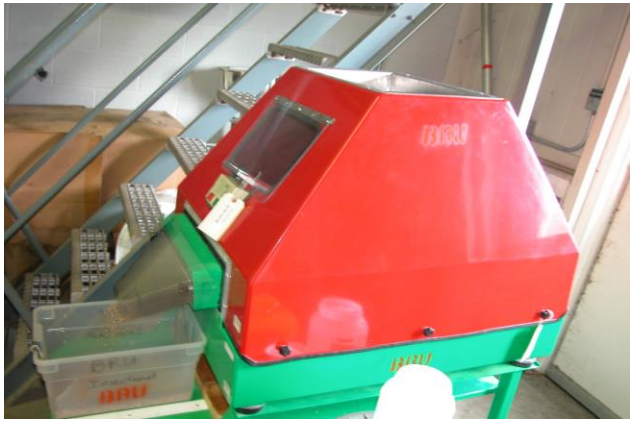
Bag Samplers (Torpedo Probe)





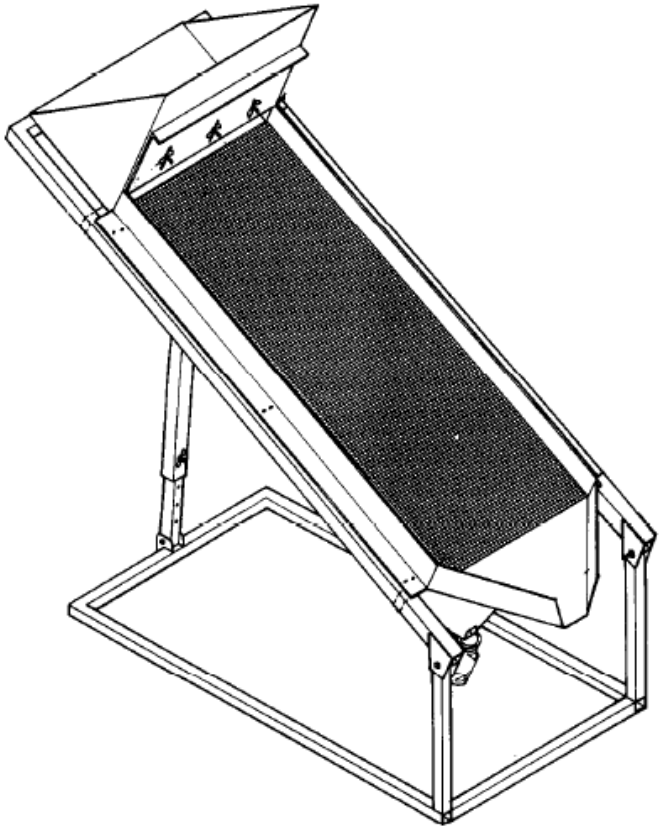
Insectomat-Separates Insects from Grain

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



Inclined Sieve

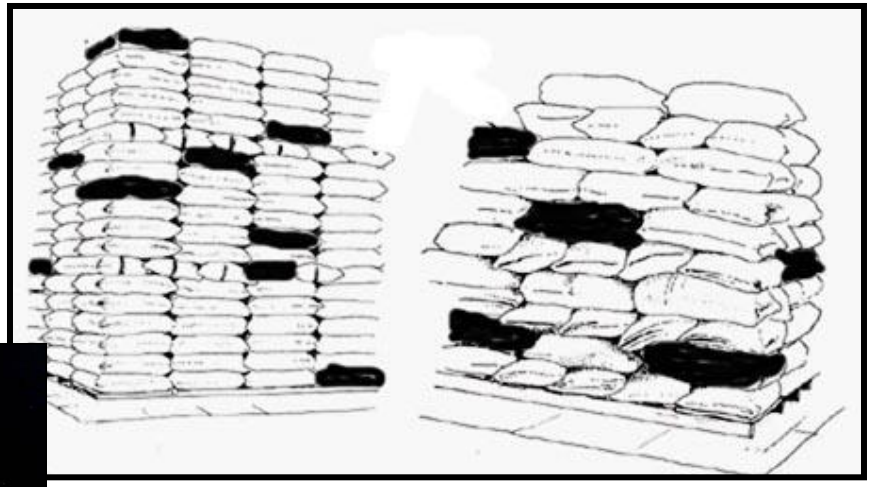
- Used to separate insects from large grain samples
- Need to pass grain twice
- Use wooden frames and mesh with greater than 2 mm openings



Hagstrum, D.W., Flinn, P.W., and Fargo, W.S. (1991). How to sample grain for insects. Figure 2 in FGIS Handbook on Management for Grain , Bulk Commodities, and Bagged Products, Oklahoma State Univ. Coop. Ext. Serv. Circ. E-912, pp. 66

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

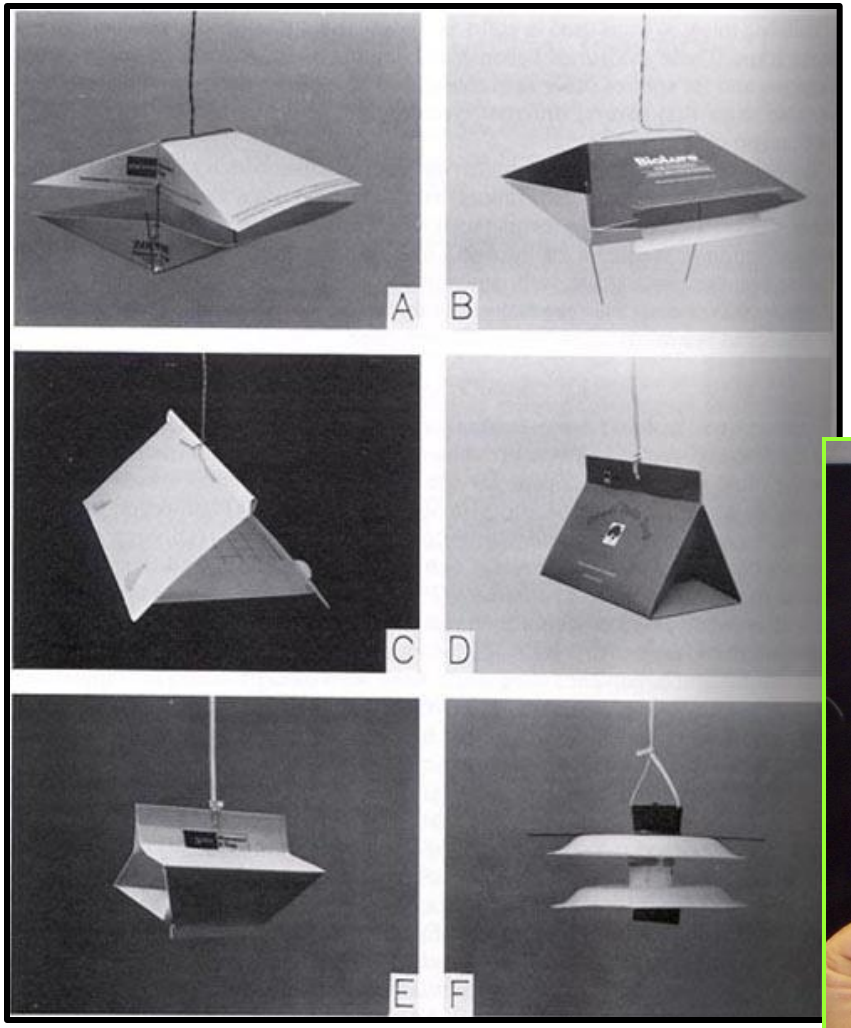
Trap Types

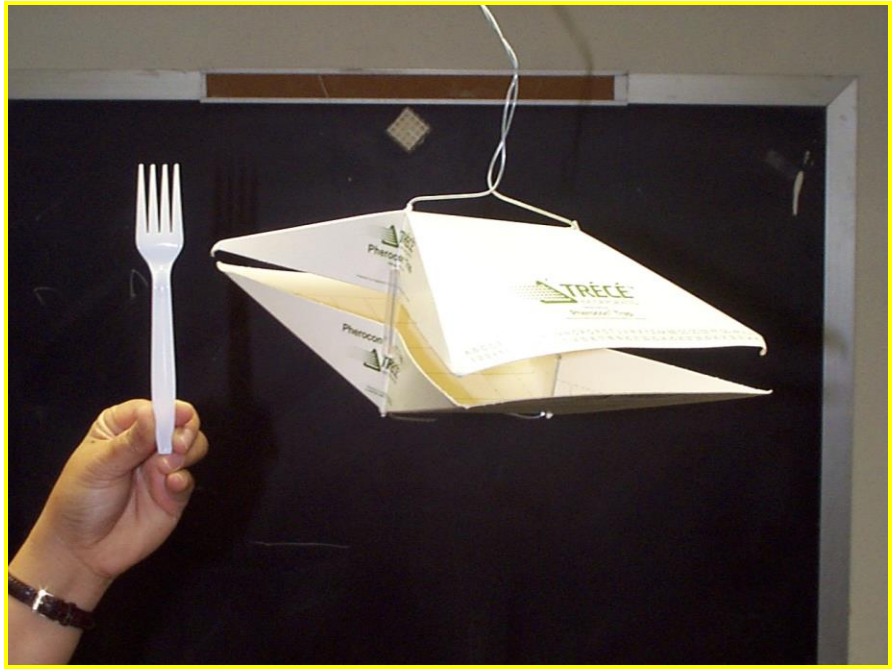
- Sticky, funnel, dome traps or pitfall traps
- Sometimes combined with pheromone or light as attractants
- Good for moths and beetles
- Need insects to be mobile
- May compete with food odors
- Will not tell you where the insects are!

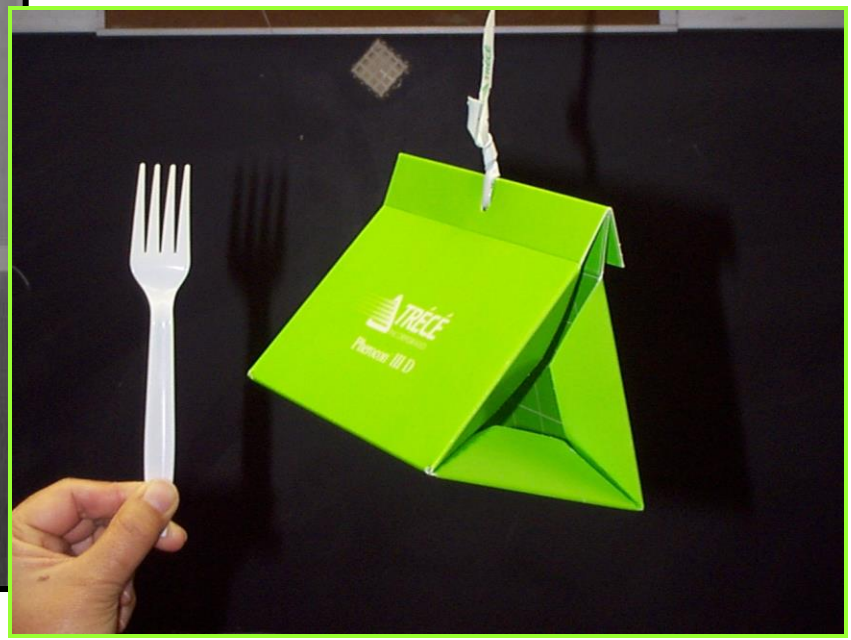
Traps for Aerial Insects

- 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

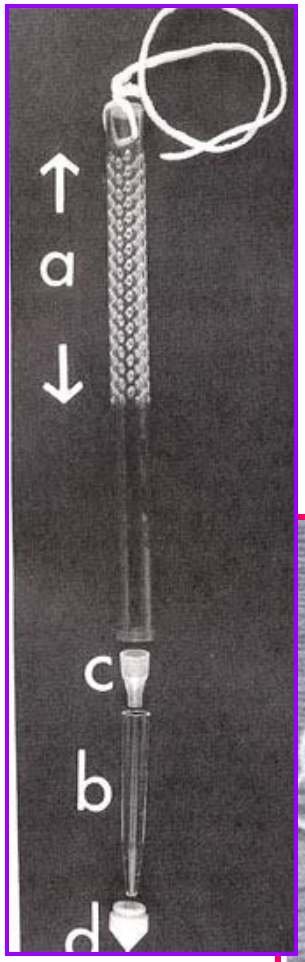
Traps Used in Grain

- 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

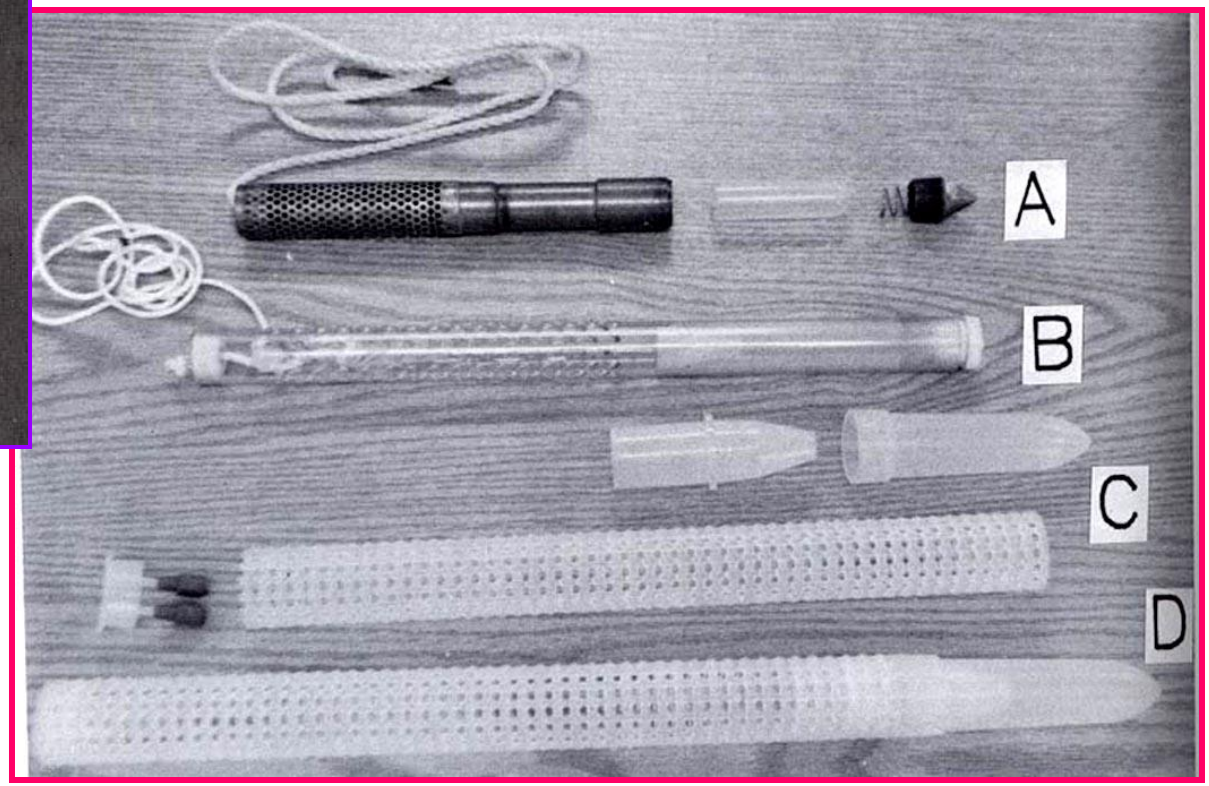
Pitfall Cone Trap

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

Probe Traps



Funnel and collecting tube
Can be inserted in to 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.)

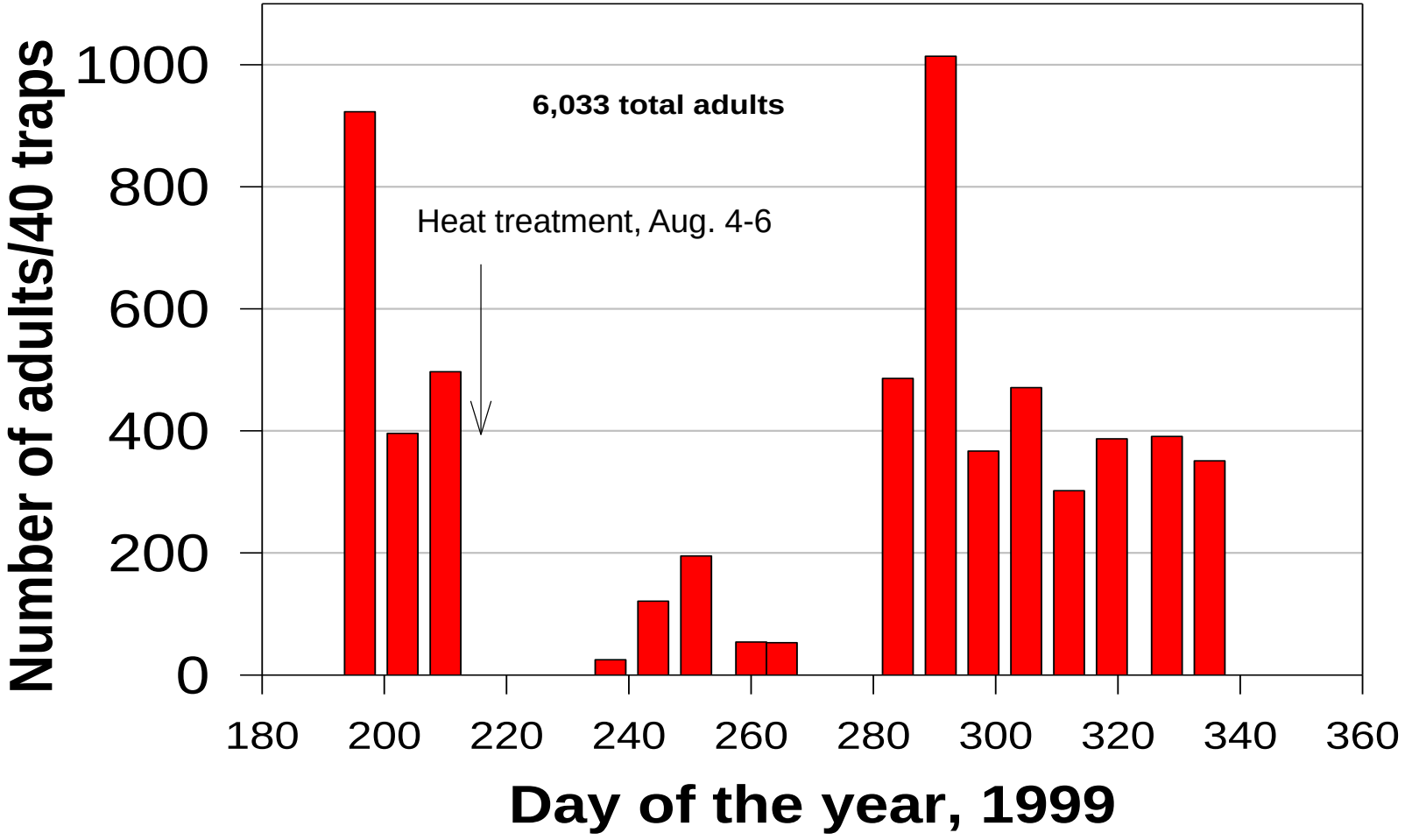
Sampling Procedure for Relative Estimates

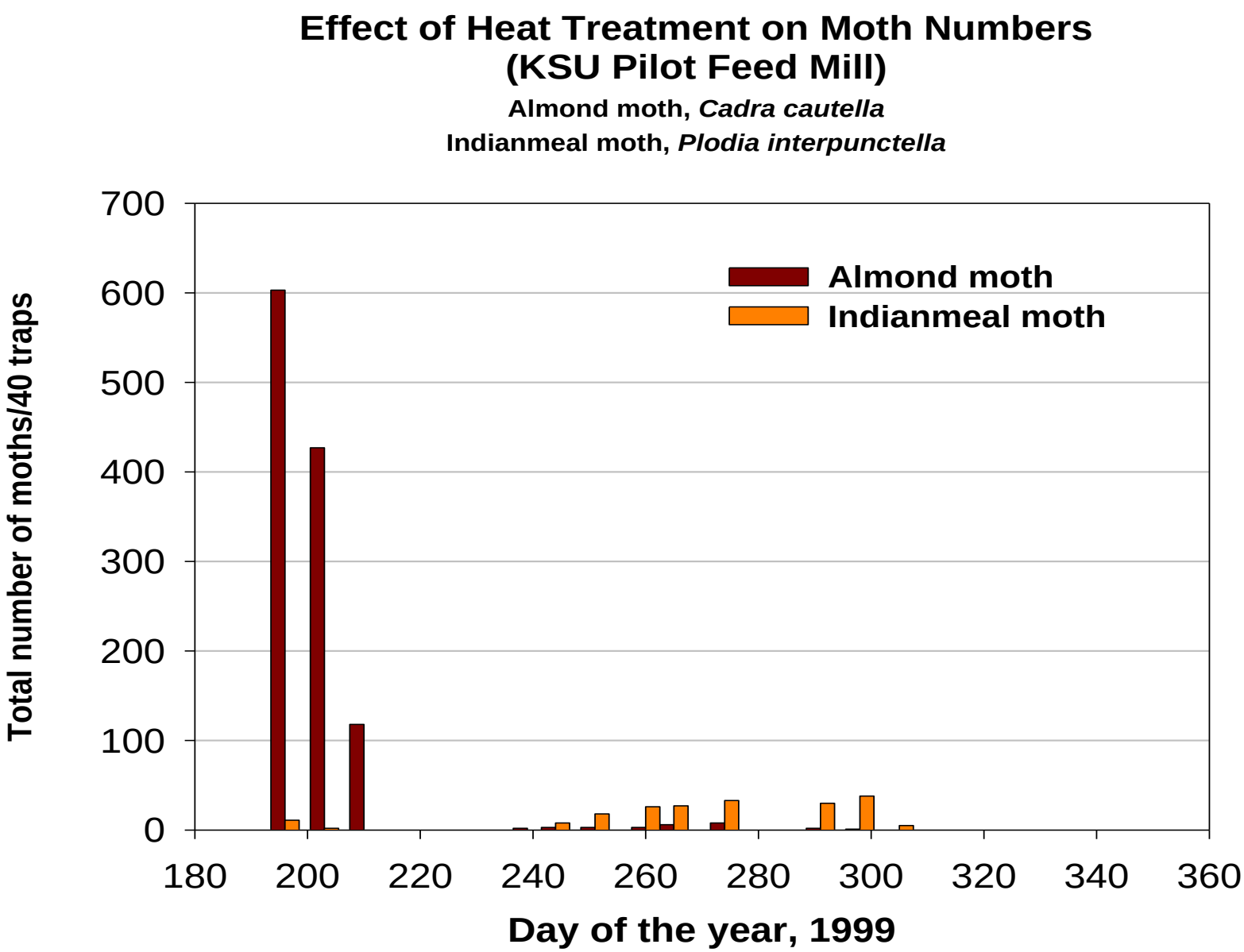
Assemble and place the traps

Collecting insect catches

Identification & counting
Express insects as numbers captured/trap

Total Number of Beetles
KSU Pilot Feed Mill




Effect of Heat Treatment on Moth Numbers
(KSU Pilot Feed Mill)
Almond moth, Cadra cautella
Indianmeal moth, Plodia interpunctella
Almond moth
Indianmeal moth
Total number of moths/40 traps
700
600
500
400
300
200
100
0
180
200
220
240
260
280
300
320
340
360
Day of the year, 1999

Using Surfer® Software for Contour Mapping

Spatial Statistics Made Easy

- 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

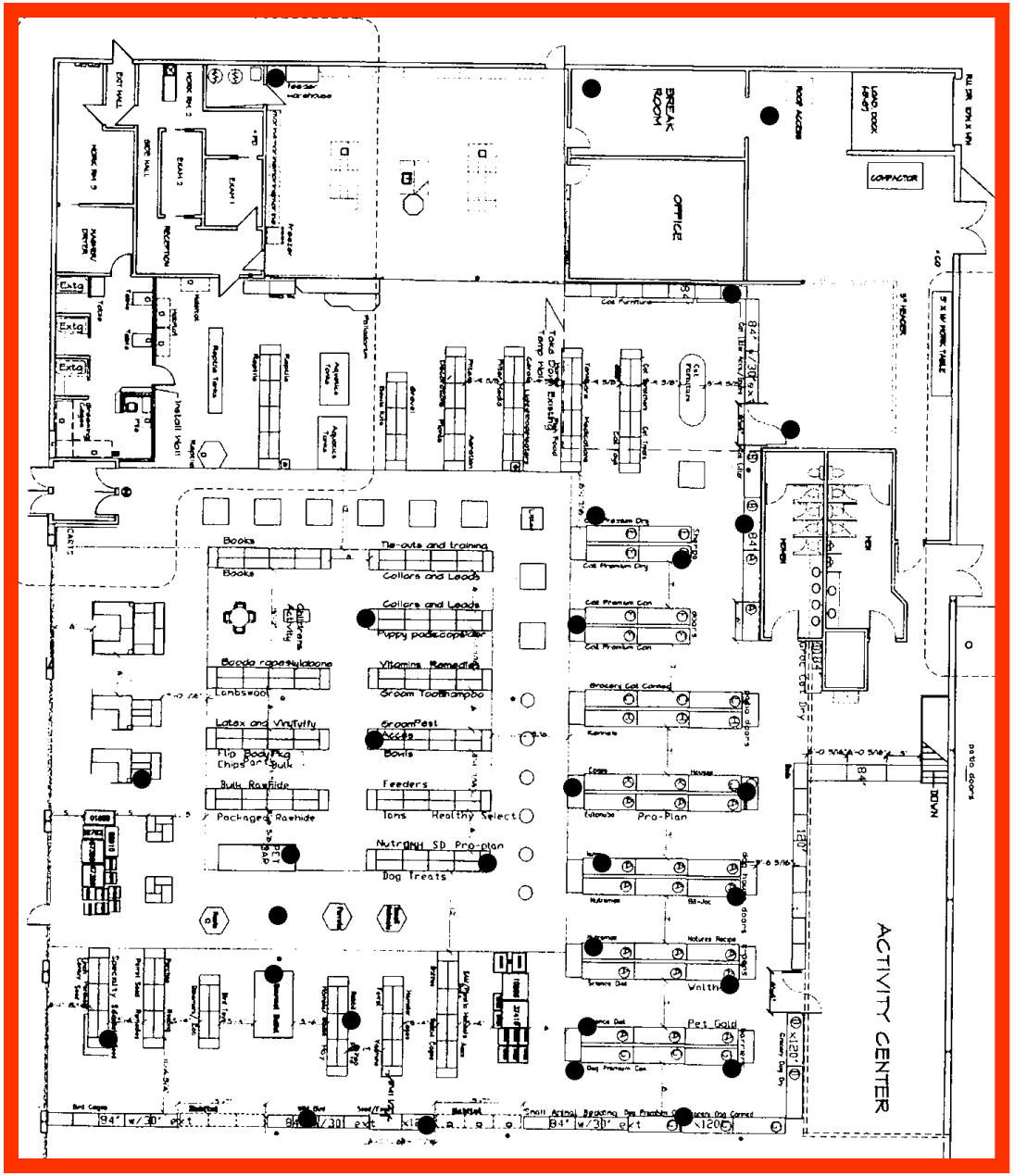
An Example Showing How Contour Maps are Generated

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

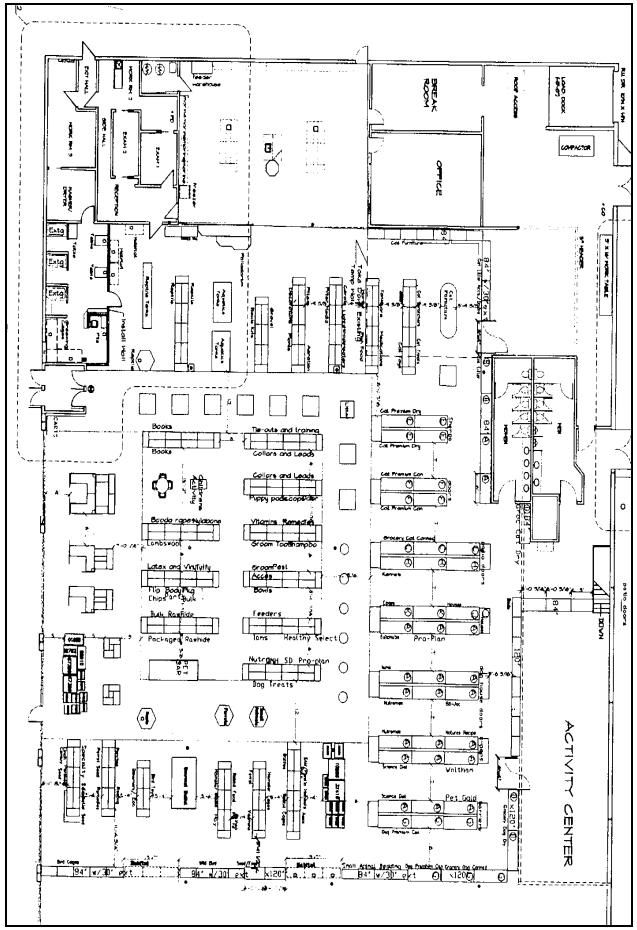


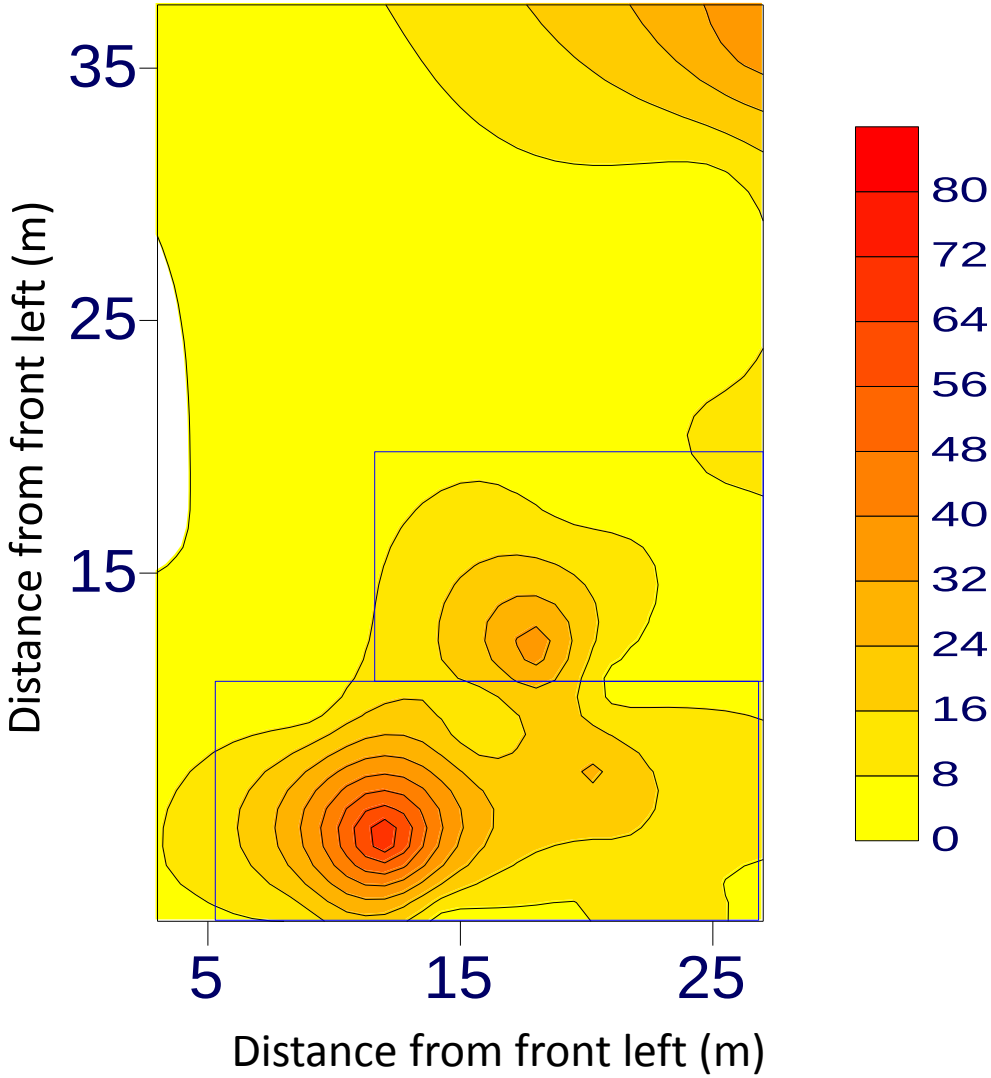
Traps were concealed from customer's view

- 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

X (in meters)	Y (in meters)	No. of insects
5	15	2
13	22	25
24	56	0

A Contour Map





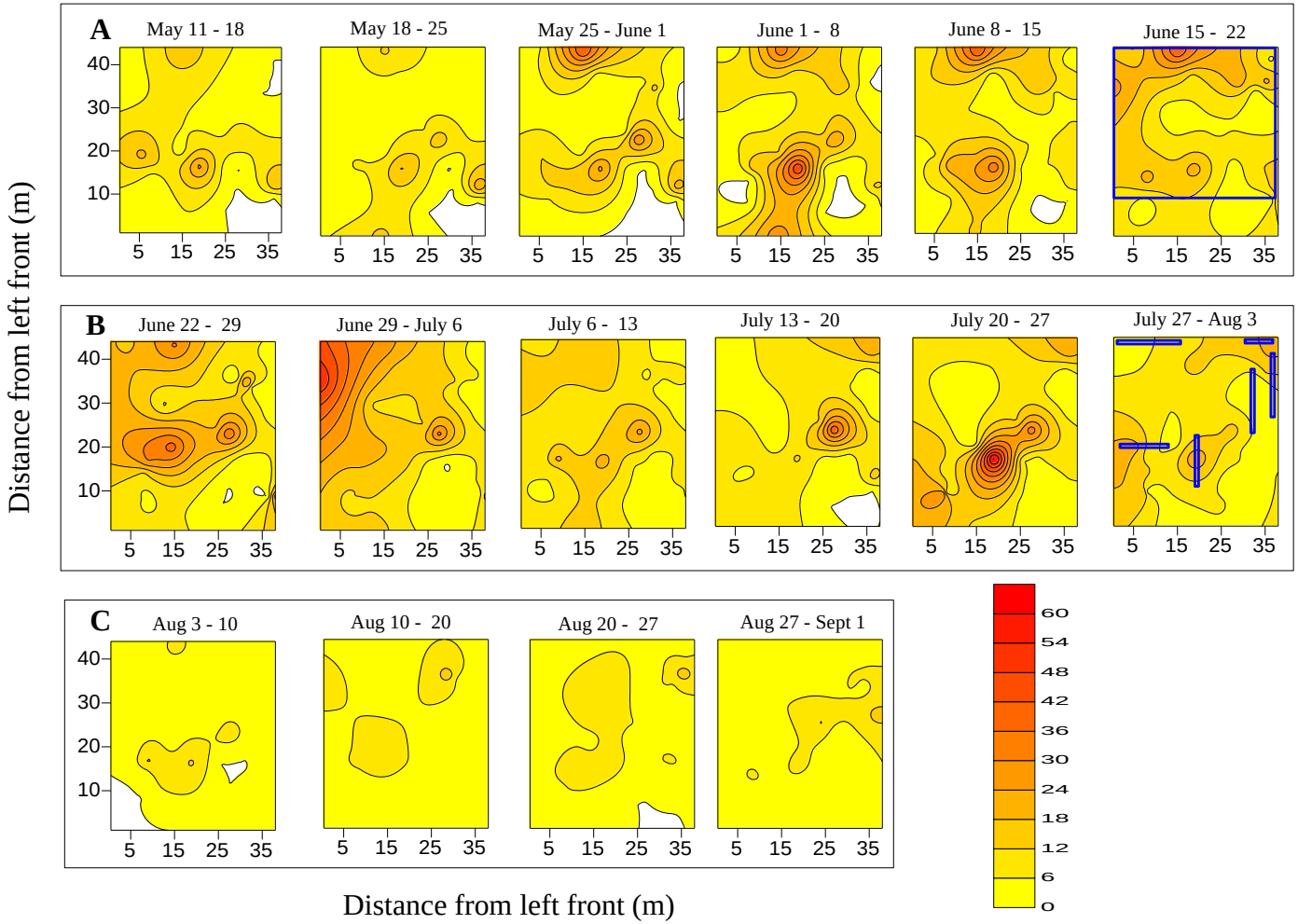
Contour Maps: Advantages

- 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



Before sanitation

After sanitation before Tempo

After Tempo

Sequential contour maps

Threshold-based sampling or presence/absence sampling

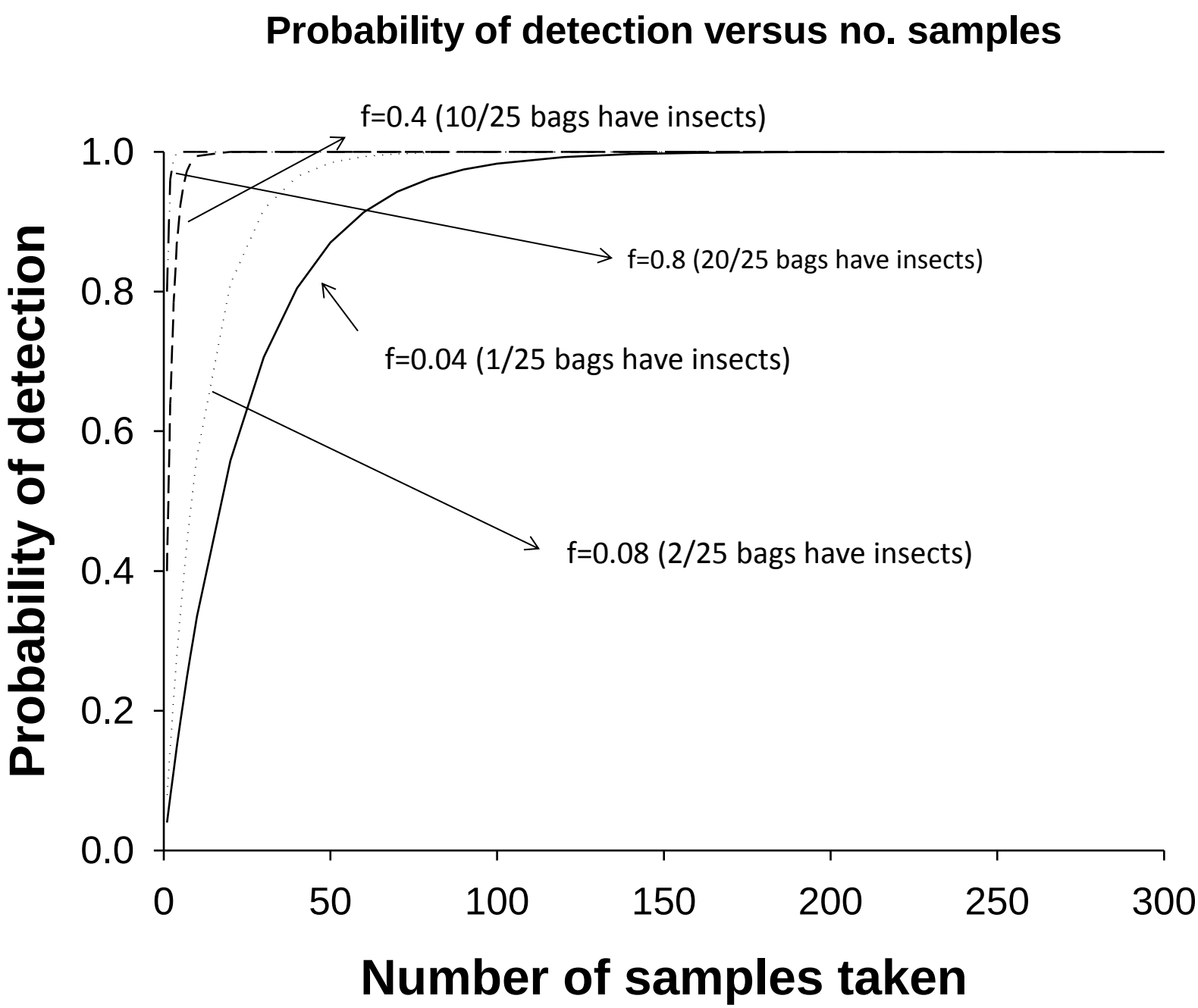
Example: Determining probability of detection

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

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


Probability of detection versus no. samples
f=0.4 (10/25 bags have insects)
f=0.8 (20/25 bags have insects)
f=0.04 (1/25 bags have insects)
f=0.08 (2/25 bags have insects)
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
Probability of detection
Number of samples taken

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

$n = \ln(1 - P)/\ln(1 - f)$

$n = \ln(1 - 0.95)/\ln(1 - 0.05)$

$n = 58.4$ or 58 samples

Example: Determining frequency of infestation

$f = 1 - (1 - P)^{1/n}$

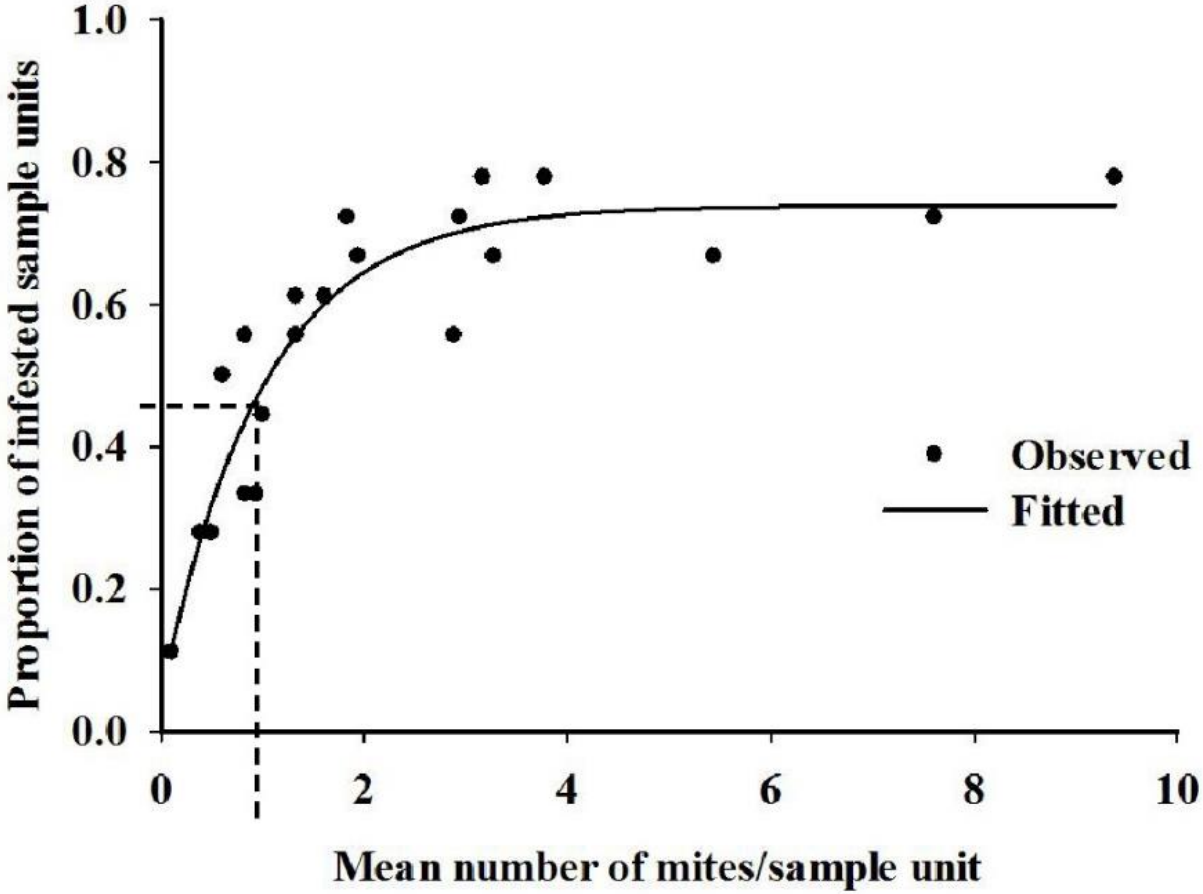
$f = 1 - (1 - 0.95)^{1/30}$

$f = 0.095$ or 9.5% 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
- Collct 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?

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