Nutritional Ecology of Stored Product Insects and Mites: Relevance to Sanitation and Pest Management

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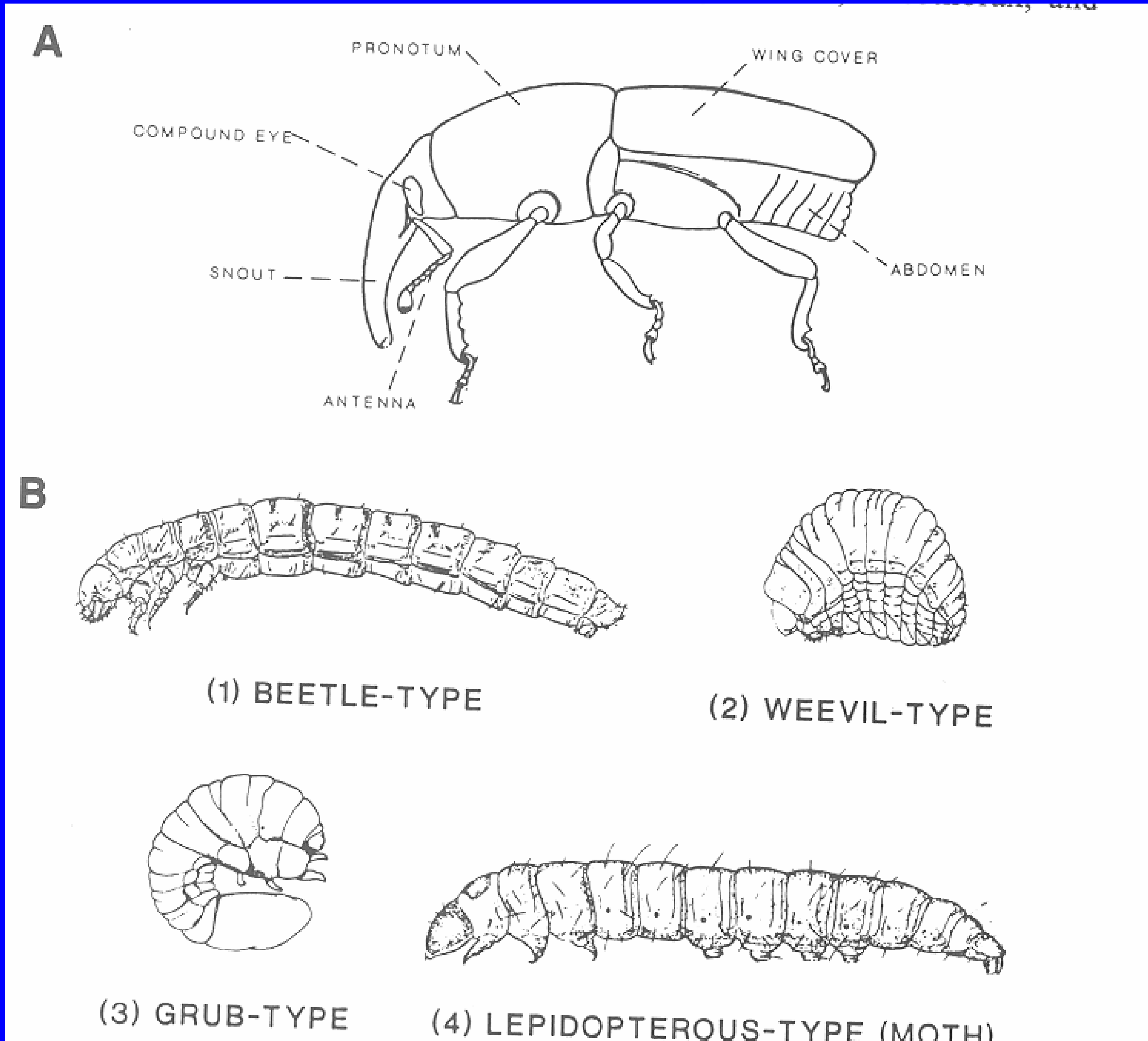

A
PRONOTUM
WING COVER
COMPOUND EYE
SNOUT
ABDOMEN
ANTENNA
B
(1) BEETLE-TYPE
(2) WEEVIL-TYPE
(3) GRUB-TYPE
(4) LEPIDOPTEROUS-TYPE (MOTH)

TABLE I
Major Insect Pests of Stored Grain[a]

Scientific Name	Common Name	Family
Acarus siro L.	Grain Mite	Acaridae
Anagasta kuehniella (Zeller)	Mediterranean flour moth	Pyralidae
Cadra cautella (Walker)	Almond moth	Pyralidae
Cryptolestes ferrugineus (Stephens)	Rusty grain beetle	Cucujidae
C. pusillus (Schönherr)	Flat grain beetle	Cucujidae
C. turcicus (Grouv.)	Flour-mill beetle	Cucujidae
Ephestia elutella (Hübner)	Tobacco moth	Pyralidae
Oryzaephilus mercator (Fauvel)	Merchant grain beetle	Cucujidae
O. surinamensis (L.)	Sawtoothed grain beetle	Cucujidae
Plodia interpunctella (Hübner)	Indianmeal moth	Pyralidae
Rhyzopertha dominica (F.)	Lesser grain borer	Bostrichidae
Sitophilus granarius (L.)	Granary weevil	Curculionidae
S. oryzae (L.)	Rice weevil	Curculionidae
S. zeamais Motschulsky	Maize weevil	Curculionidae
Sitotroga cerealella (Olivier)	Angoumois grain moth	Gelechiidae
Tenebroides mauritanicus (L.)	Cadelle	Trogositidae
Tribolium castaneum (Herbst)	Red flour beetle	Tenebrionidae
T. confusum Jacquelin du Val	Confused flour beetle	Tenebrionidae
Trogoderma granarium Everts	Khapra beetle	Dermestidae

[a]Adapted from Cotton and Wilbur (1982).

19 species

TABLE II
Minor Pests Most Frequently Encountered in Stored Grain

Scientific Name	Common Name	Family
Ahasverus advena (Waltl)	Foreign grain beetle	Cucujidae
Alphitobius diaperinus (Panzer)	Lesser mealworm	Tenebrionidae
Araecerus fasciculatus (DeGeer)	Coffee-bean weevil	Anthribidae
Attagenus unicolor (Brahm)	Black carpet beetle	Dermestidae
Carpophilus dimidiatus (F.)	Corn sap beetle	Nitidulidae
C. hemipterus (L.)	Driedfruit beetle	Nitidulidae
Caulophilus oryzae (Gyllenhal)	Broadnosed grain beetle	Curculionidae
Corcyra cephalonica (Stainton)	Rice moth	Pyralidae
Cynaeus angustus (LeConte)	Larger black flour beetle	Tenebrionidae
Gnathocerus cornutus (F.)	Broadhorned flour beetle	Tenebrionidae
Lasioderma serricorne (F.)	Cigarette beetle	Anobiidae
Latheticus oryzae Waterhouse	Longheaded flour beetle	Tenebrionidae
Liposcelis spp.	Psocids	Liposcelidae
Palorus ratzeburgi (Wissmann)	Smalleyed flour beetle	Tenebrionidae
P. subdepressus (Wollaston)	Depressed flour beetle	Tenebrionidae
Prostephanus truncatus (Horn)	Larger grain borer	Bostrichidae
Ptinus villiger (Reitter)	Hairy spider beetle	Ptinidae
P. claviceps Panzer	Brown spider beetle	Ptinidae
Stegobium paniceum (L.)	Drugstore beetle	Anobiidae
Tenebrio molitor (L.)	Yellow mealworm	Tenebrionidae
T. obscurus (F.)	Dark mealworm	Tenebrionidae
Tribolium audax Halstead	American black flour beetle	Tenebrionidae
Trogoderma variabile Ballion	Warehouse beetle	Dermestidae
Typhaea stercorea (L.)	Hairy fungus beetle	Mycetophagidae

[a]Adapted from Cotton and Wilbur (1982).

24 species

A. Tropical humid climate
- a. Tropical wet
- b. Tropical dry

B. Subtropical climate
- a. Subtropical dry summer
- b. Subtropical humid

C. Dry climate
- a. Desert or arid
- b. Steppe or semiarid

D. Temperate climate
- a. Temperate oceanic
- b. Temperate continental

Early Records of Stored Product Insects

- Egyptian pyramids, 1345 B.C.
  - Red flour beetle.
- Israel, 700-900 B.C.
  - Granary weevil.
- Iron Age or Roman Period, 0-400 A.D.
  - Drug store beetle, Cadelle, Rusty grain beetle, Sawtoothed grain beetle, hairy fungus beetle, yellow and dark meal worms.
- Mid 1700s
  - Mentioned in literature.

Nutritional Ecology

- Includes all aspects of an organism's life.
  - Consumption, utilization, and allocation of food.
  - Interaction with the environment.
  - Selection on any of these components causes evolution of different life styles.

Stored Product Insects

- Over 100 species have been associated with stored grain. Based on their feeding habits, they can be classified as:
  - Seed-infesting species
  - Fungus-feeding species
  - Scavengers on dead plant materials
  - Scavengers on animal matter
  - Scavengers or semi-predators living under tree bark
  - Wood-borers and wood-scavengers
  - Scavengers in the nests of other insects
  - Predators and parasites

Seed-Infesting Species

- Infest seeds stored by humans and animals.
- Adapted to feeding on dry foods.
- Can infest seeds in the field and continue development in storage.
- Only a few species have this specialized feeding habit.
- Examples:
  - Angoumois grain moth
  - Bean weevils (Bruchids)
  - Weevils (Rice, granary, and maize)

Fungus-Feeding Species

- Many stored-product insects fit this category.
- Associated with old, damp, and moldy products.
- Lepidoptera
  - Tineidae (European grain moth)
  - Pyralidae (Indianmeal moth)
- Coleoptera
  - Cryptophagidae (*Cryptophagus* spp.)
  - Lathridiidae (Square-nosed fungus beetle)
  - Mycetophagidae (*Mycetophagus* spp.)
  - Tenebrionidae (Meal worms, *Tribolium* spp.)

Scavengers on Dead Plant Materials

- Rotting plant or grain materials.
- Examples:
  - Pyralid moths (Meal snout moth, *Pyralis farinalis*)

Scavengers on Dead Animal Matter

- Dermestid beetles
  - *Attagenus* spp.
  - *Trogoderma* spp.
  - *Dermestes* spp.

Scavengers or Semi-Predators Living Under Tree Bark

- Offers a protected environment.
- Presence of molds.
- Examples:
  - Trogositidae, Cadelle, *Tenebroides mauritanicus*
  - Cucujidae, Flat and rusty grain beetles, *Cryptolestes* spp.
  - Tenebrionidae, *Tribolium* spp.

Wood-Borers and Wood-Scavengers

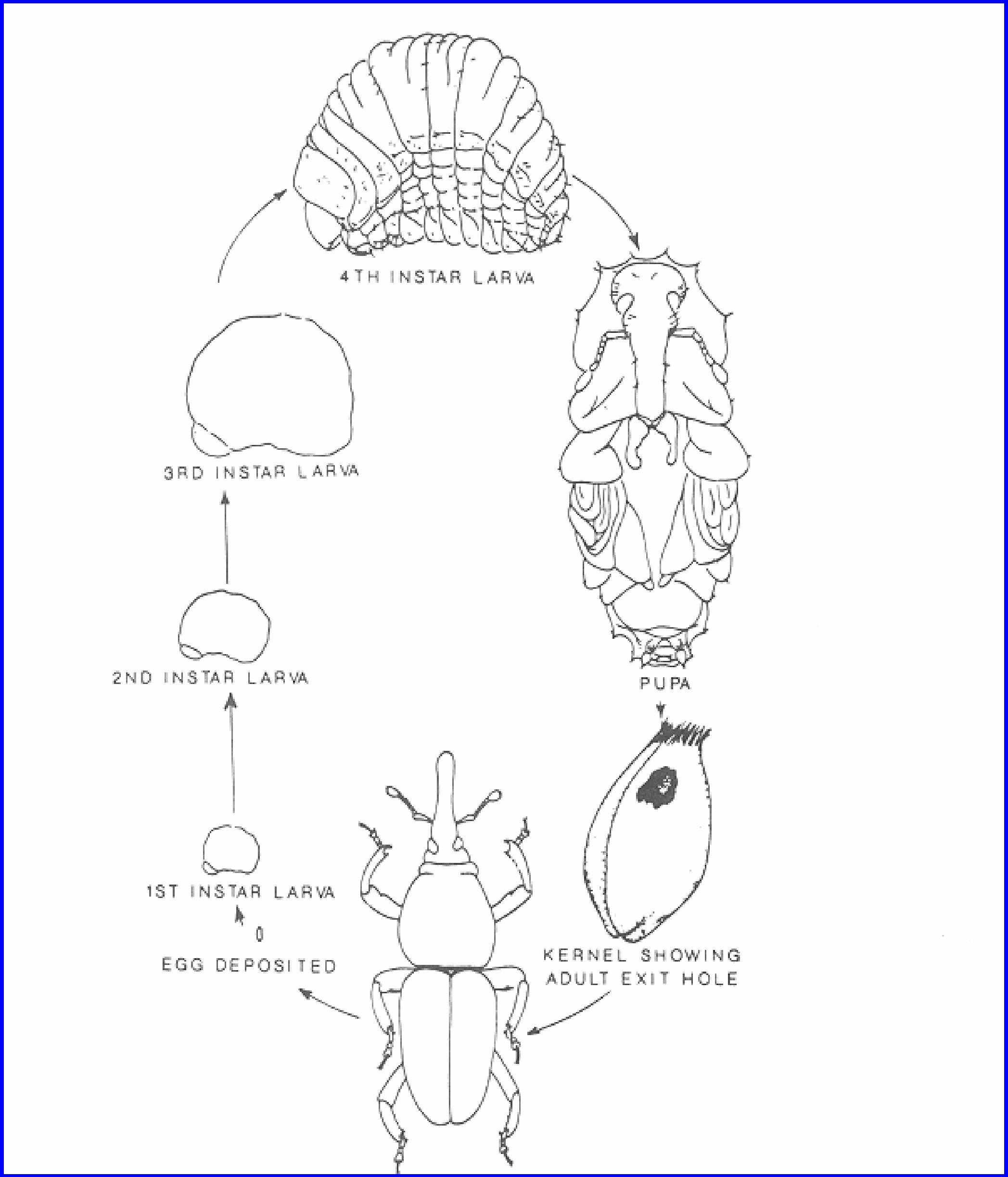
- Bore into living or dead wood.
- Examples:
  - Anobiidae (Drug store beetle, *Stegobium paniceum*)
  - Bostrichidae (Lesser grain borer, *Rhyzopertha dominica*; Larger grain borer, *Prostephanus truncatus*)

Scavengers in the Nests of Other Insects

- Nests of bees, wasps, ants, and birds.
- Examples:
  - Pyralidae (moths)
  - Ptinidae (Spider beetles)
  - Dermestidae (bird feathers)

Predators and Parasites

- Species of Hemiptera, Diptera, and Hymenoptera.
- These species attack stored product insects.
- Present in storage habitats.
- May regulate populations.


4TH INSTAR LARVA
3RD INSTAR LARVA
2ND INSTAR LARVA
1ST INSTAR LARVA
EGG DEPOSITED
PUPA
KERNEL SHOWING
ADULT EXIT HOLE

Feeding Habits

- Generalized feeding habits
  - Whole grain (Cereals)
  - Broken cracked damaged grains
  - Processed flour
  - Damp/moldy grain
  - Dried fruit
  - Nuts, pulses of high oil content
  - Spices

Table 10.1. Generalized Feeding Ranges of the Major Stored-Product Insect Pests of Cosmopolitan Importance

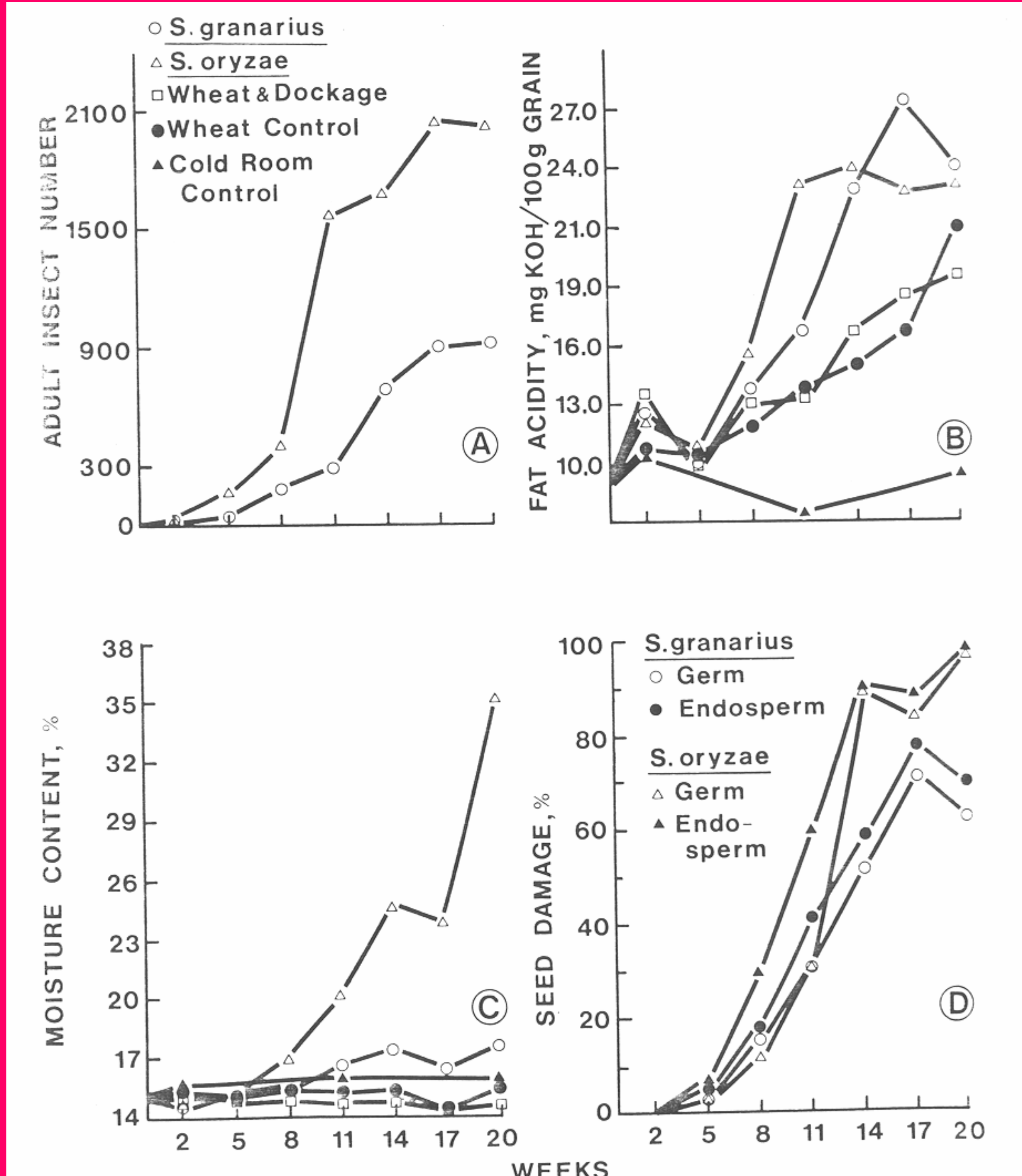
Food	Species	Feeding stage[a]	Common name
Whole, intact cereal grain	*Corcyra cephalonica*	L	Rice moth
	Cynaeus angustus	L, A	Larger black flour beetle
	Rhyzopertha dominica	L, A	Lesser grain borer
	Sitophilus oryzae	L, A	Rice weevil
	Sitophilus zeamais	L, A	Maize weevil
	Sitophilus granarius	L, A	Granary weevil
	Sitotroga cerealella	L	Angoumois grain moth
	Trogoderma granarium	L	Khapra beetle
Broken, cracked or damaged cereal grains	*Cryptolestes ferrugineus*	L, A	Rusty grain beetle
	Cryptolestes pusillus	L, A	Flat grain beetle
	Oryzaephilus surinamensis	L, A	Saw-toothed grain beetle
	Plodia interpunctella	L	Indianmeal moth
	Tribolium castaneum	L, A	Red flour beetle
	Trogoderma spp.	L	
Flour, processed foods	*Anagasta kuehniella*	L	Mediterranean flour moth
	Tribolium confusum	L, A	Confused flour beetle
	Tenebrio molitor	L	Yellow mealworm
Damp or moldy flour or grain	*Ahasverus advena*	L, A	Foreign grain beetle
	Pyralis farinalis	L	Meal moth
	Typhaea stercorea	L, A	Hairy fungus beetle
Dried fruit	*Cadra cautella*	L	Almond moth
	Ephestia elutella	L	Tobacco moth
	Cadra figuliella	L	Raisin moth
Nuts, cereal products of high oil content	*Oryzaephilus mercator*	L, A	Merchant grain beetle
Spices	*Lasioderma serricorne*	L	Cigarette beetle
	Stegobium paniceum	L	Drugstore beetle

Source: Compiled from Levinson and Levinson (1978) and USDA (1979).

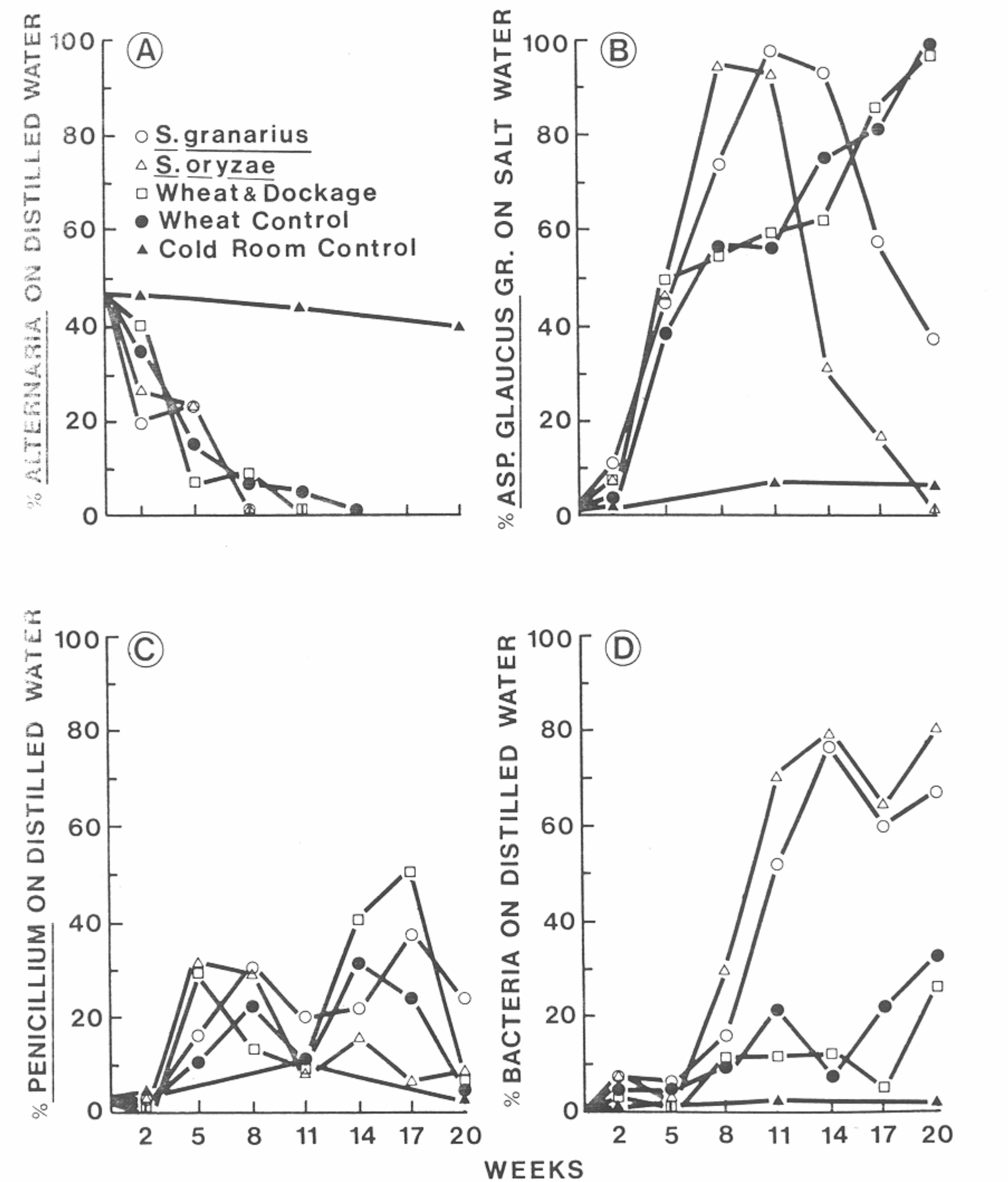
[a] Stage responsible for significant feeding damage. L, larvae; and A, adults.

Effects of Infestation

- Loss of weight (3-5%)
- Loss of nutrients
- Decrease in protein content
- Lowered palatability; allergic reactions
- Increase in fat acidity values
- Decreased germination
- Production of hot spots
- Contamination (body parts, excreta, secretions)
- Aesthetic damage



S. granarius
S. oryzae
Wheat & Dockage
Wheat Control
Cold Room Control
ADULT INSECT NUMBER
0
300
900
1500
2100
A
FAT ACIDITY, mg KOH/100g GRAIN
10.0
13.0
16.0
19.0
21.0
24.0
27.0
B
MOISTURE CONTENT, %
14
17
20
23
26
29
32
35
38
C
2
5
8
11
14
17
20
S.granarius
Germ
Endosperm
S. oryzae
Germ
Endo-sperm
SEED DAMAGE, %
0
20
40
60
80
100
D
2
5
8
11
14
17
20
WEEKS



A
B
C
D
% ALTERNARIA ON DISTILLED WATER
% ASP. GLAUCUS GR. ON SALT WATER
% PENICILLIUM ON DISTILLED WATER
% BACTERIA ON DISTILLED WATER
S. granarius
S. oryzae
Wheat & Dockage
Wheat Control
Cold Room Control
100
80
60
40
20
0
2
5
8
11
14
17
20
WEEKS

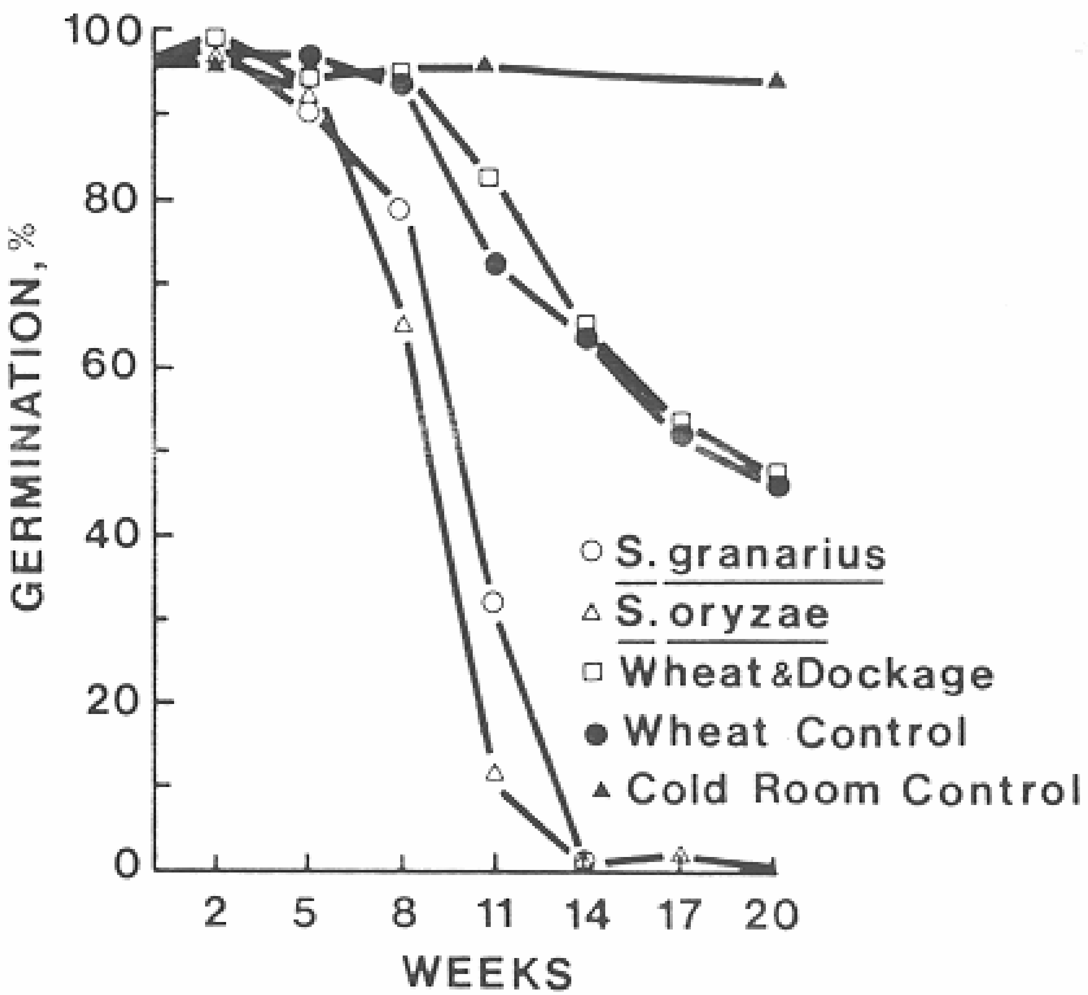


Fig. 2. Percentage of seed germination in weevil-infested and uninfested wheat plus dockage, and wheat control treatments incubated at 30°C and 70% RH.

Range of Tolerance for Temperature and Moisture

- Multiply rapidly when conditions are favorable.
  - Cold blooded
  - Temperatures, 8-41 ^{o}C
  - Optimum - 30^{o}C and 50-70% RH
  - Moistures 12-18% (40-80% RH)
- Survive unfavorable conditions
  - Diapause
  - Retrogressive development
  - Survive in hot spots
  - Survive in heated facilities or insulated refugia

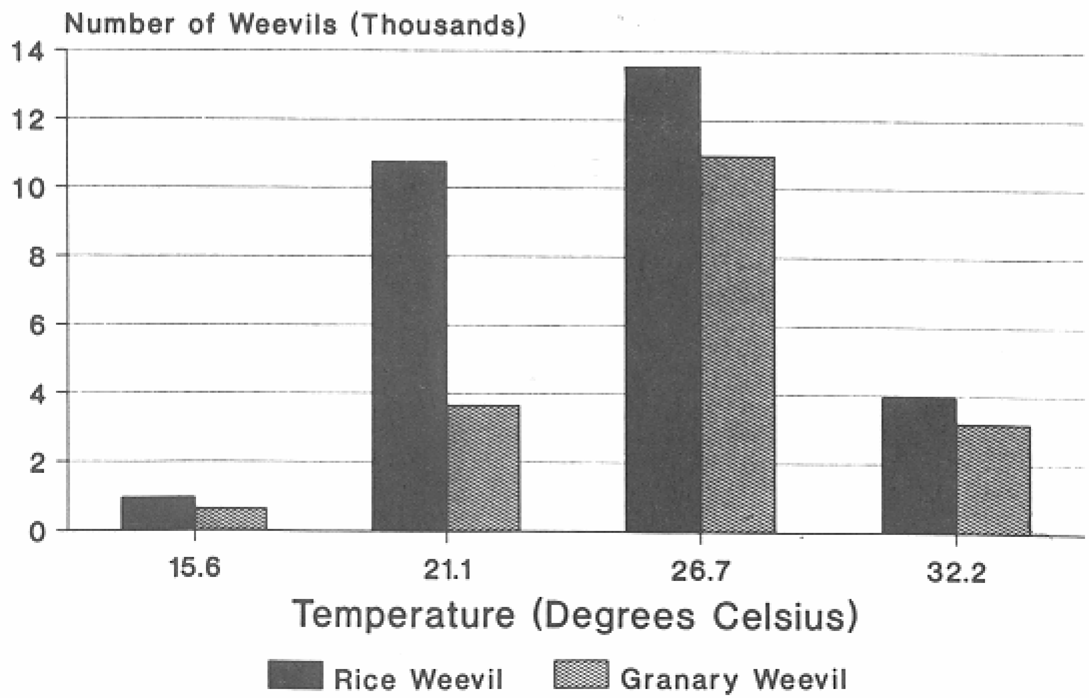


Fig. 25. Effects on insect development of moisture (at a constant temperature of 26.7°C; top) and temperature (at a constant 14% moisture; bottom).

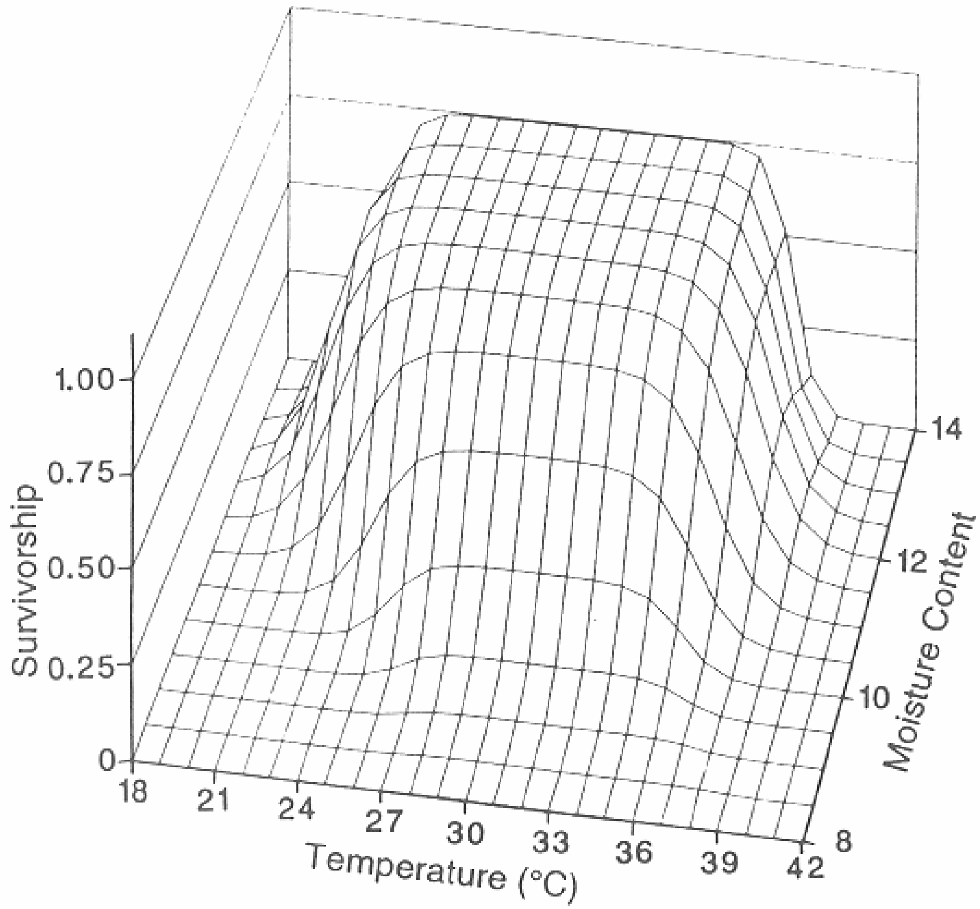


Figure 5 Effects of temperature and wheat moisture content on the survival of *R. dominica*. (Redrawn from Birch 1945.)

Table 1 Effects of Temperature on the Predicted Egg-to-Adult Development Times (in Days) of Stored-Product Insects[a]

Species	Temperature (°C)								
	17.5	20	22.5	25	27.5	30	32.5	35	37.5
Moths									
Ephestia kuehniella	—	69.1	56.0	46.5	40.6	39.2	—	—	—
Plodia interpunctella	150.9	99.3	67.3	48.1	37.9	34.9	38.4	49.1	—
Cadra cautella	108.9	76.7	57.1	45.3	38.3	34.4	32.5	31.8	—
Corcyra cephalonica	192.0	92.6	57.6	44.8	39.7	37.4	36.1	35.2	—
Ephestia calidella	94.2	62.7	43.6	32.9	28.2	28.7	34.2	45.8	—
Cadra figulilella	129.2	98.7	76.6	60.9	50.8	45.9	46.5	54.1	—
Average	135.0	83.2	59.7	46.4	39.3	36.7	37.5	46.1	—
Long-lived beetles									
Cryptolestes ferrugineus	—	—	53.4	37.0	28.1	23.2	20.6	19.0	18.2
Cryptolestes pusillus	—	—	53.1	45.1	38.5	32.9	28.4	25.1	24.5
Oryzaephilus surinamensis	—	—	48.5	36.4	27.9	22.4	19.8	20.8	27.0
Sitophilus oryzae	—	52.9	43.2	35.9	30.6	27.4	26.7	29.1	36.7
Tribolium castaneum	—	—	—	41.8	32.7	28.4	26.3	23.4	21.7
Tribolium confusum	—	—	56.2	44.6	35.6	28.5	23.0	20.0	34.1
Rhyzopertha dominica	—	—	—	58.8	49.9	42.4	36.1	31.0	—
Average	—	—	50.9	42.8	34.7	29.4	25.8	24.1	27.0
Short-lived beetles									
Acanthoscelides obtectus	82.0	60.4	45.4	35.7	30.2	28.9	—	—	—
Callosobruchus maculatus	167.4	72.5	42.0	31.5	27.3	25.3	23.9	22.8	21.9
Lasioderma serricorne		94.8	62.1	43.1	32.9	28.3	27.9	30.7	36.5
Stegobium paniceum	153.5	105.4	73.4	52.9	41.9	41.6	58.4	—	—
Average	134.3	83.3	55.7	40.8	33.1	31.0	36.7	26.8	29.2

[a]Predicted development times of moths and long-lived beetles are based on equations from Subramanyam and Hagstrum (1993) and Hagstrum and Milliken (1988), respectively. The same equation is used to predict the development times of short-lived beetles using data from Menusan (1934) for *A. obtectus*; from El-Sawaf (1956), Giga and Smith (1983), and Mookherjee and Chawla (1964) for *C. maculatus*; from Howe (1957) for *L. serricorne*; and from Lefkovitch (1967) and Momoi and Sadamori (1982) for *S. paniceum*.

Table 3 Effect of Insect Order and Moisture Content of Commodity on Percentage of Total Development Time Spent in Each Stage

	Stage		
Insect order	Egg	Larva	Pupa
High moisture content			
Moths	8	77	15
Beetles	15	66	19
Low moisture content			
Beetles	12	72	15

Source: Based on data from Hagstrum and Milliken (1988), and Subramanyam and Hagstrum (1993).

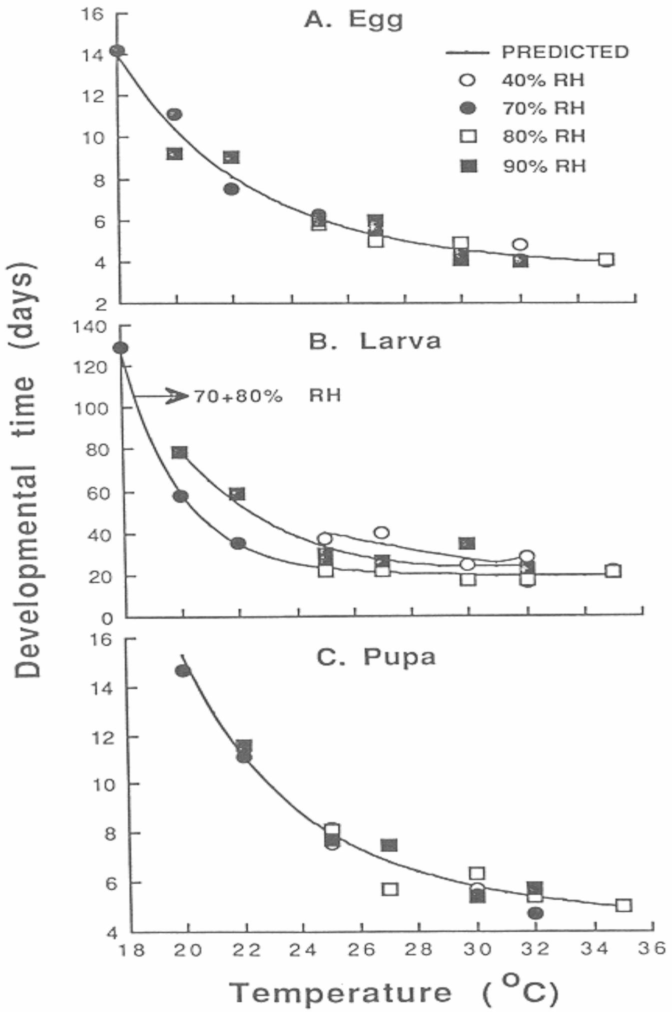
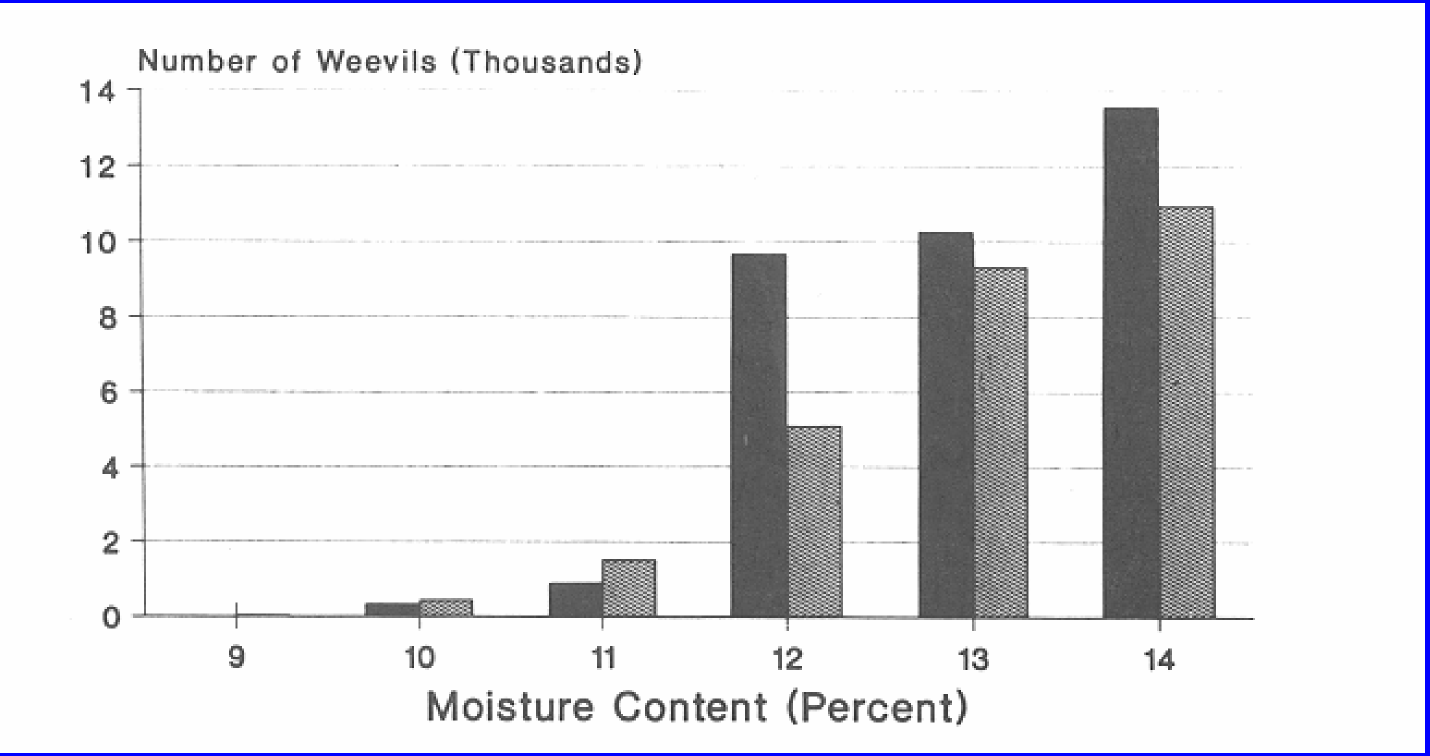


Figure 1. *Observed and predicted mean developmental times for egg (**A**), larval (**B**), and pupal (**C**) stages of* Prostephanus truncatus *reared at constant temperatures and relative humidities (RH). A single predicted line (see Table 1) described the data where differences between or among relative humidities were not significant* ($P > 0{\cdot}05$).


Number of Weevils (Thousands)
14
12
10
8
6
4
2
0
9
10
11
12
13
14
Moisture Content (Percent)

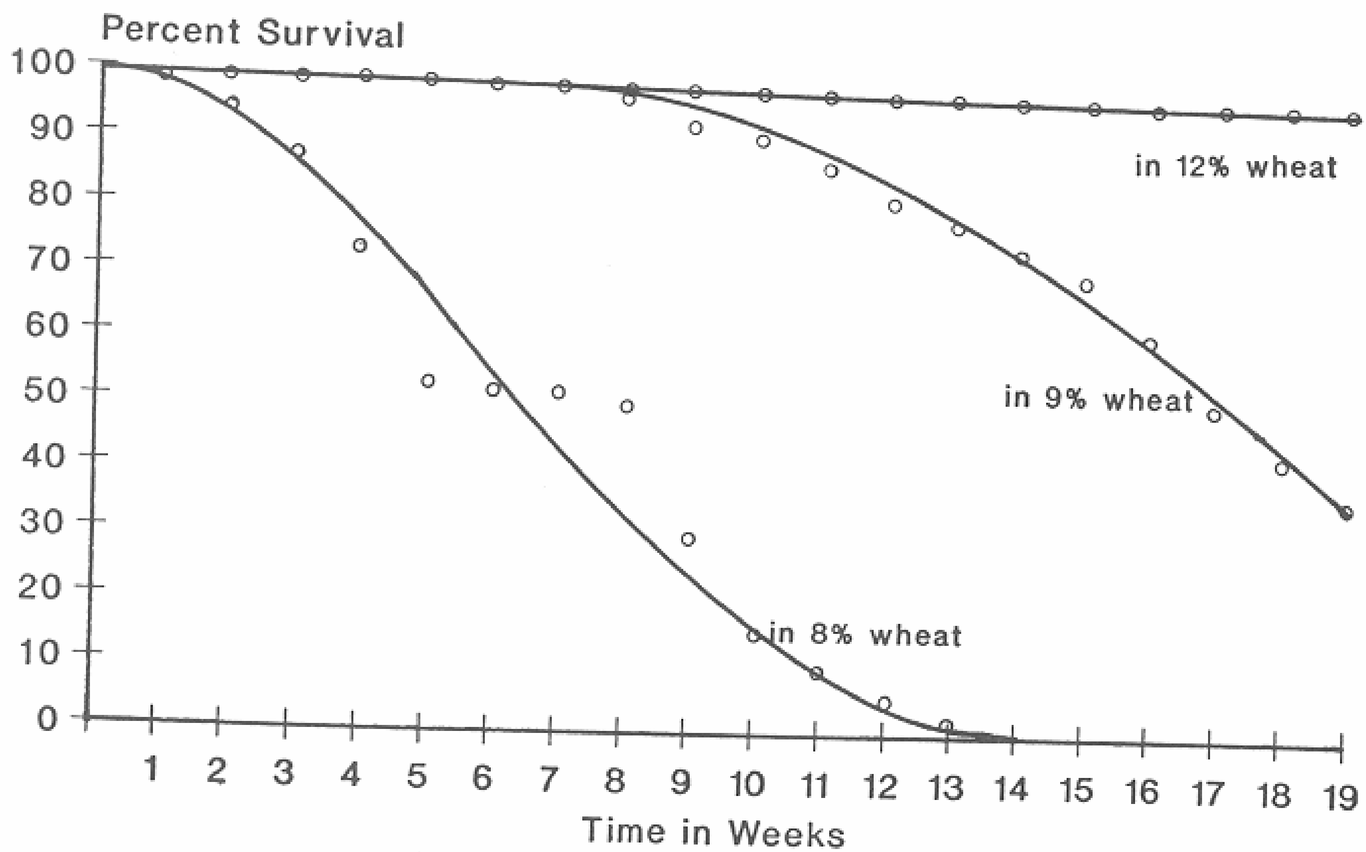


Fig. 27. Survival of confused flour beetle adults at 80°F in clean wheat of different moisture contents. (Reprinted, with permission, from Cotton et al, 1960)

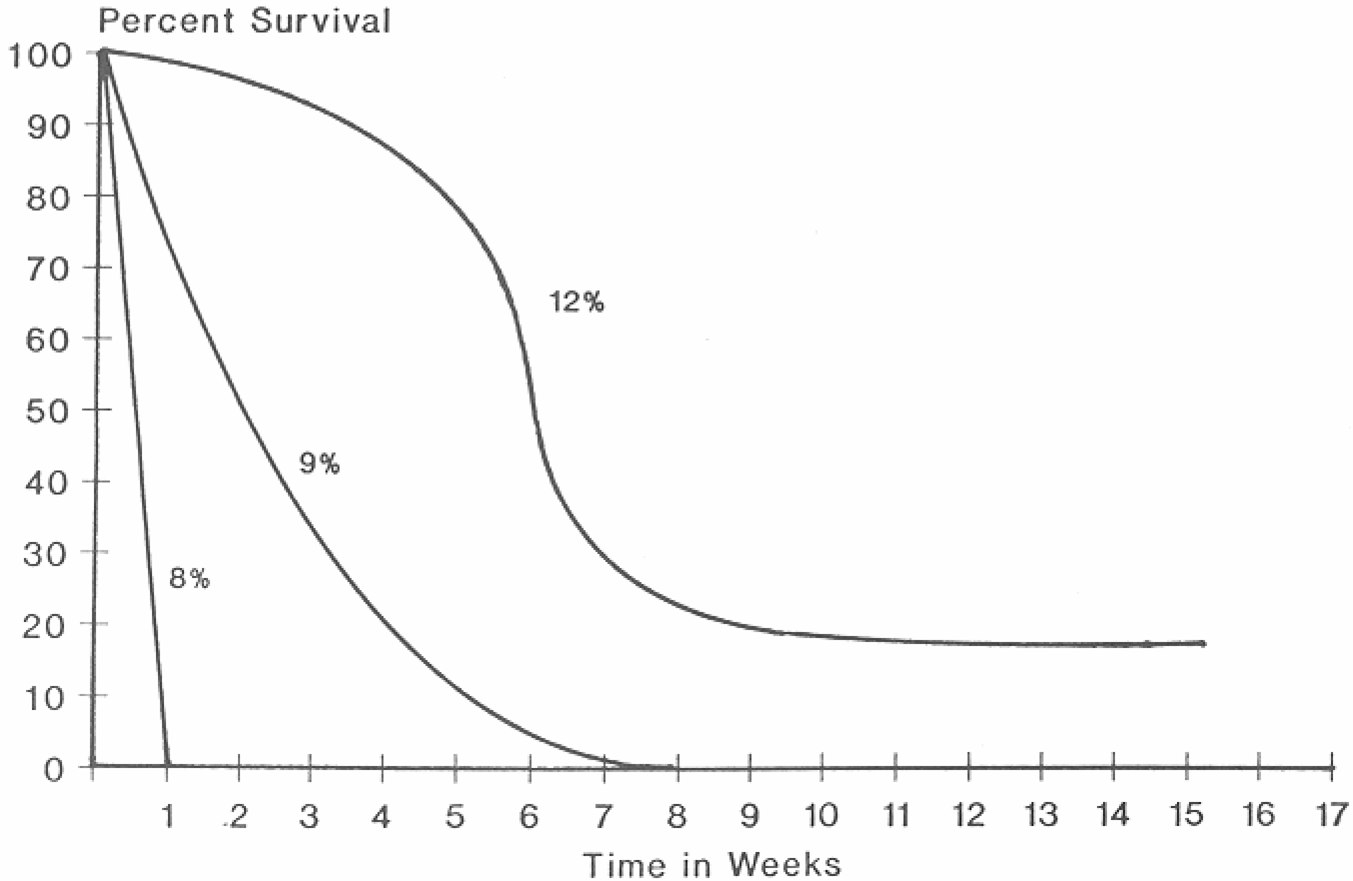


Fig. 26. Survival of rice weevil adults at 85° F in wheat of different moisture contents. (Reprinted, with permission, from Cotton et al, 1960)

Climatic plasticity index (I_p) values for species of stored-product insects

I_p	Species	I_p	Species
700	*Tribolium castaneum*	172.5	*Sitophilus granarius*
600	*Anagasta kuehniella*	165	*Ephestia elutella*
575	*Cadra cautella*	150	*Cryptolestes ugandae*
570	*Cryptolestes ferrugineus*	131	*Trogoderma granarium*
570	*Tribolium confusum*	110	*Corcyra cephalonica*
550	*Callosobruchus maculatus*	105	*Cryptolestes capensis*
550	*Sitotroga cerealella*	105	*Cryptolestes pusilloides*
550	*Carpophilus hemipterus*	100	*Cryptolestes pusillus*
500	*Oryzaephilus surinamensis*	95	*Latheticus oryzae*
475	*Cryptolestes turcicus*	67.5	*Stegobium paniceum*
360	*Dermestes maculatus*	42	*Gibbium aequinoctiale*
360	*Araecerus fasciculatus*	42	*Caryedon serratus*
330	*Plodia interpunctella*	42	*Ptinus ocellus*
330	*Endrosis sarcitrella*	24	*Mezium affine*
315	*Callosobruchus chinensis*	23	*Ptinus fur*
285	*Dermestes frischii*	21	*Stethomezium squamosum*
275	*Acanthoscelides obtectus*	21	*Niptus hololeucus*
275	*Sitophilus oryzae*	19	*Hofmannophila pseudospretella*
250	*Necrobia rufipes*		
230	*Callosobruchus rhodesianus*	15	*Trigonogenius globulum*
230	*Cadra calidella*	15	*Pseudeurostus hilleri*
210	*Oryzaephilus mercator*	10	*Ptinus clavipes*
200	*Lasioderma serricorne*	9.5	*Ptinus sexpunctatus*
190	*Zabrotes subfasciatus*	9	*Tipnus unicolor*
180	*Gnatocerus cornutus*	5	*Ptinus pusillus*

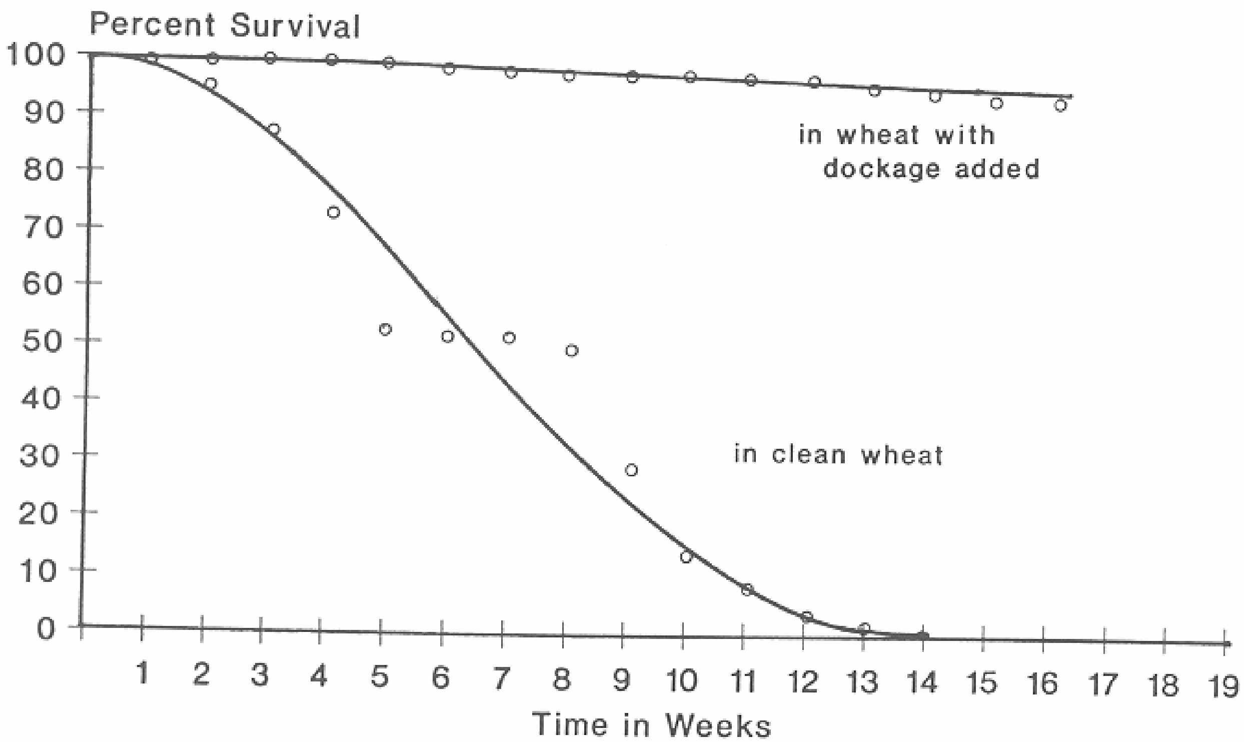


Fig. 28. Survival of confused flour beetle adults in 8% moisture wheat as affected by dockage. (Reprinted, with permission, from Cotton et al, 1960)

Table 2 Development Time from Egg to Adult and Progeny Production of *S. granarius* on Five Types of Grain at 27.5°C and 75% Relative Humidity

	Development Time (Days)			Progeny Production per 20 Weevils/4 Days		
Grain	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: Based upon data from Schwartz and Burkholder (1991).

Table 4 Oviposition, Survival, and Population Growth of *C. cautella* on 48 Peanuts Distributed among 1–24 Locations.

Number of peanuts per location	Number of eggs per peanut	Number of larvae per peanut	Population growth rate per generation
2	15.6	0.61	2.9
4	17.3	0.87	4.3
8	14.8	0.95	5.3
16	14.4	1.10	6.1
48	9.4	1.23	7.4

Source: Based on data from Hagstrum (1984).

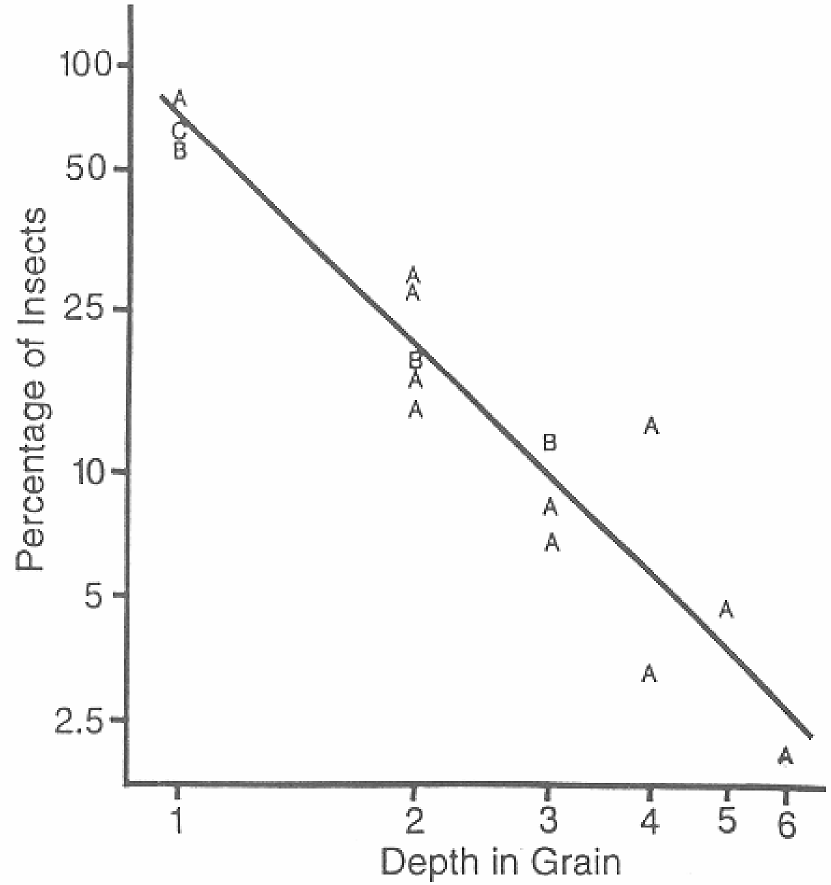


Figure 17 Logarithmic decrease in the percentage of *C. ferrugineus* population in successive 0.75 m layers of wheat. A, B, and C indicate data point for one, two, or three bins, respectively. (Reprinted from Hagstrum 1989.)

Reproductive Rates and Population Characteristics

- Beetles - long-lived
  - Mate and lay eggs throughout adult life
- Moths - short-lived
  - Mate a few times and lay eggs within 1 week.
- High reproductive rates.
- Dispersal.

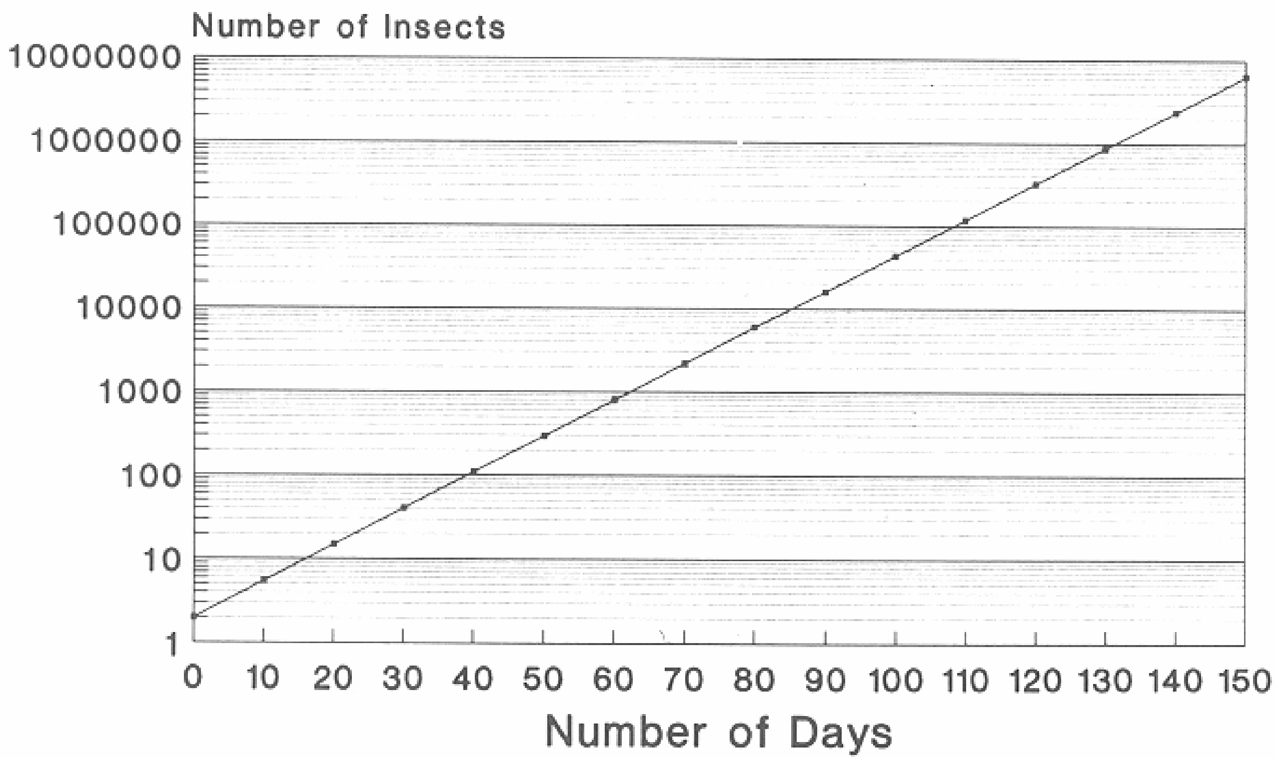


Fig. 3. The intrinsic rate of population increase for *Tribolium castaneum* at 28.5°C and 65% rh. (Data from Leslie and Park, 1949)

Table 12.2

Bionomics of moth pests of stored products

Species	Temperature (°C)			Relative Humidity (%)		Duration of life cycle (days)[a]	Maximum rate of increase per lunar month[b]	References
	Minimum for population increase	Optimum for develop-ment	Maximum for develop-ment	Minimum for population increase	Optimum for develop-ment			
Corcyra cephalonica	18	30	35–37	30	80	25	15	*(38, 55)*
Ephestia cautella	17	30	37	20	75	28	60	*(9, 22, 55, 63)*
Ephestia elutella	10–12	25	30	20	70	40	15	*(9, 55)*
Ephestia figulilella	15	30	36	30	70	40	20	*(34)*
Ephestia kuehniella	8–12	25	28	0	70	40	50	*(9, 37, 55, 56)*
Plodia interpunctella	18	30	35	20	75	25	60	*(9, 55, 63)*
Sitotroga cerealella	16	30	35–37	30	75	30	50	*(19, 55)*

[a] At optimum temperature and humidity on good food.
[b] Maximum rate of increase in numbers that can be expected over a 28-day period under ideal conditions, starting from a population with all life stages present.

Adult Survival in the Absence of Food

- Adults of some beetles can live for several years.
- Examples:
  - In ship holds
  - In empty facilities

Morphological Adaptations

- Small size.
- Flattened shape of many beetles. (Cucujidae) helps them hide in cracks and crevices.
- Easily overlooked.
- Need special tools to detect them.

Factors Affecting Growth

- Food quantity and quality.
  - Quantity is abundant.
  - Quality-better than natural sources.
  - Least important factor in regulating populations
- Temperature and humidity.
  - Most important factors.
  - Determine abundance and distribution.

Species that Develop Best at High Temperatures

- Optimum 30-34 C
- *Trogoderma granarium* (Khapra beetle)
- *Oryzaephilus surinamensis* (Sawtoothed grain beetle)
- *Tribolium castaneum* (Red flour beetle)

Species that Develop Best at Moderate Temperatures

- Optimum, 24-27 C
- *Ephestia kuehniella* (Mediterranean flour moth)
- *Sitotrogra cerealella* (Angoumois grain moth)
- *Sitophilus granarius* (Granary weevil)

Effects of Humidity

- Equilibrium moisture content of grain.
- Insects populations do better on grain moistures of 12% and above.

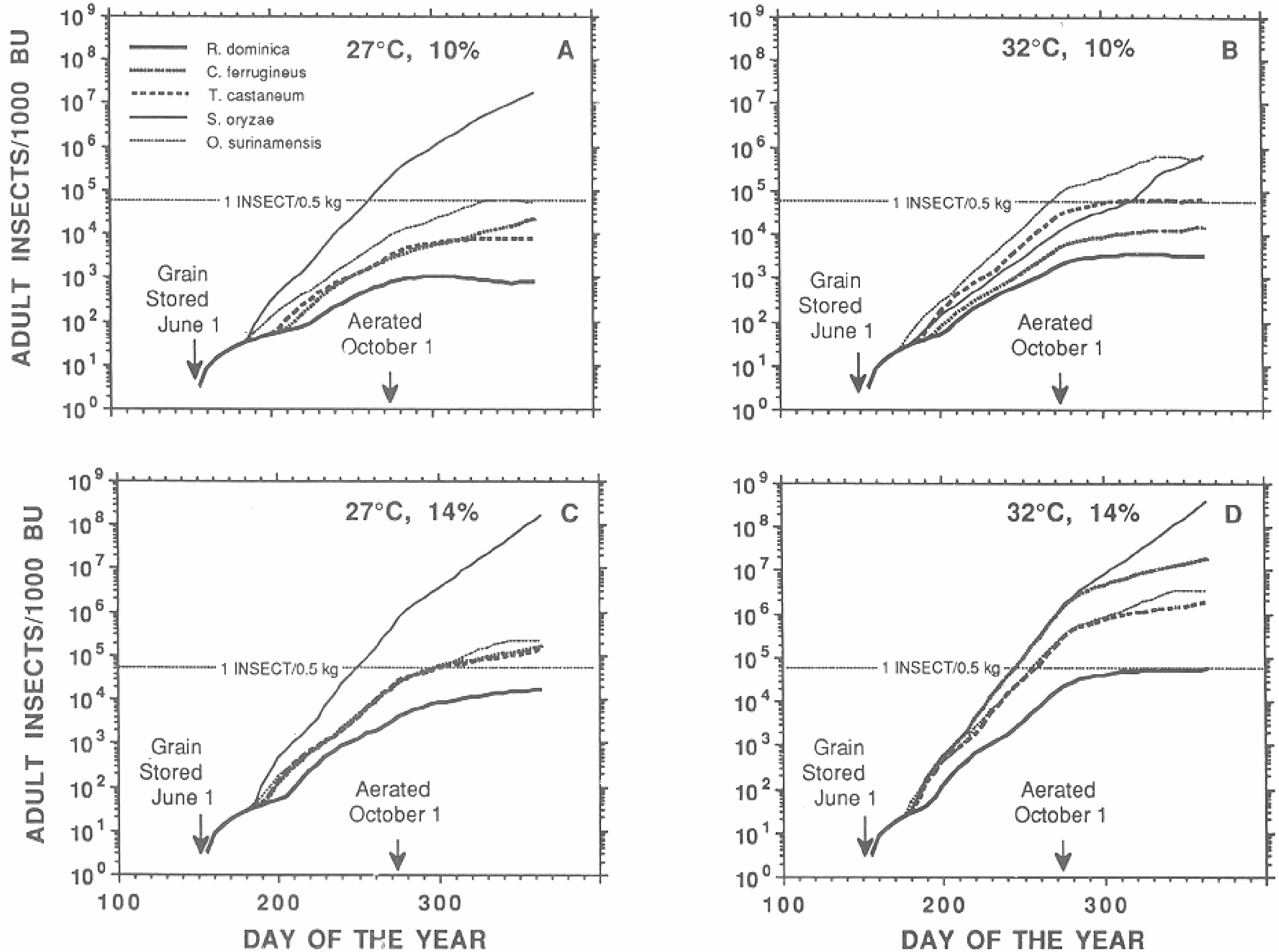


Figure 3. Predicted effects of initial temperatures and percentage of grain moistures of A) 27°C and 10 percent, B) 32°C and 10 percent, C) 27°C and 14 percent, and D) 32°C and 14 percent on the population of growth of five species of stored-grain insects with grain aeration completed on October 1. (Source: Hagstrum and Flinn, 1990.)

Food Finding in Insects

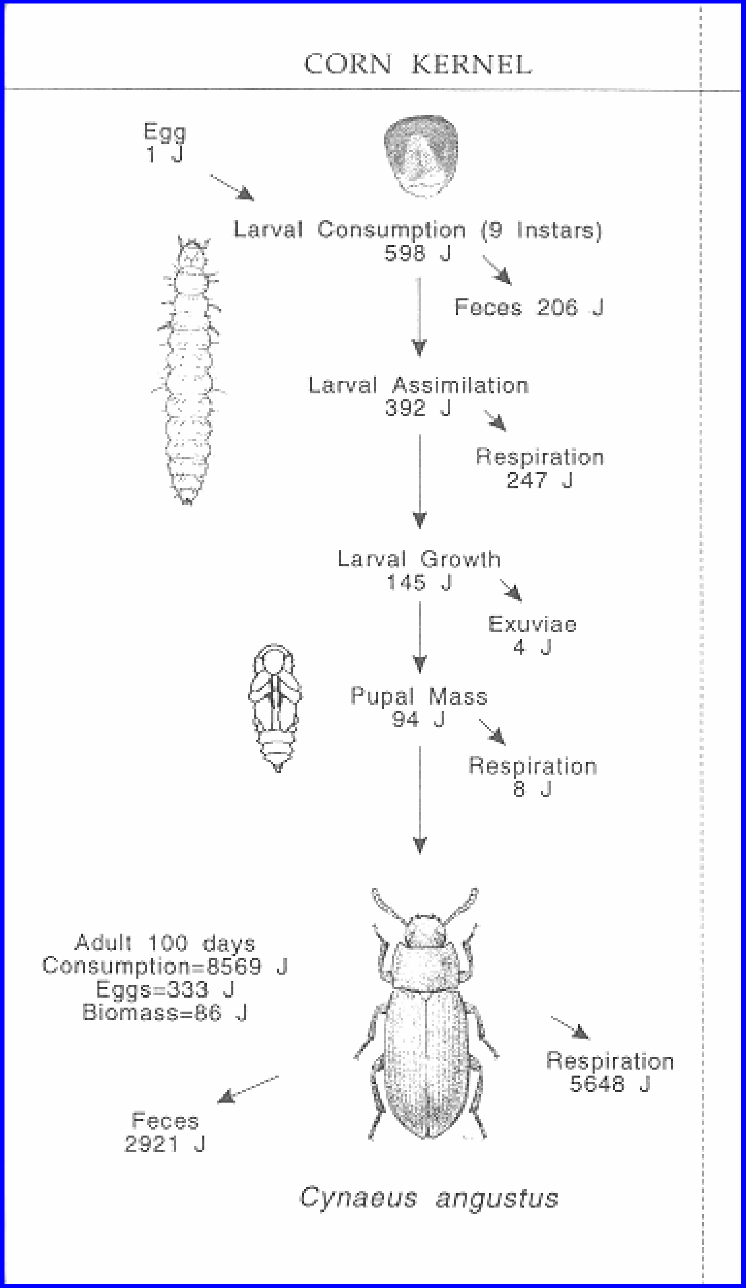
- Volatiles from grains.
- Extracts of wheat or tobacco resulted in a 7-fold increase in oviposition in the cigarette beetle, *Lasioderma serricorne*.
- Extracts of rice brans stimulate oviposition in *Sitophilus oryzae* (Rice weevil).

Food Attractants

- Lipid oxidation products result in adult aggregation on foods (broken kernels!).
- Concentration of fatty acids is important.
- Stored wheat is more attractive than fresh wheat to *Sitophilus granarius*.
- Sucrose, fructose, glucose, and maltose stimulate feeding in *Plodia interpunctella* (Indianmeal moth) larvae.
- Maltose - feeding stimulant for the *Tribolium confusum* (Confused flour beetle).
- Amylopectin for *Sitphilus oryzae* (Rice weevil).

Food Utilization

- *Sitophilus oryzae* (Rice weevil) larvae grow faster on pelletized ground maize than intact maize kernels.
- Nutrient distribution affects growth rates and assimilation of nutrients.
- Temperature increases consumption rate, but consumed food is not efficiently utilized.


CORN KERNEL
Egg
1 J
Larval Consumption (9 Instars)
598 J
Feces 206 J
Larval Assimilation
392 J
Respiration
247 J
Larval Growth
145 J
Exuviae
4 J
Pupal Mass
94 J
Respiration
8 J
Adult 100 days
Consumption=8569 J
Eggs=333 J
Biomass=86 J
Respiration
5648 J
Feces
2921 J
Cynaeus angustus

Energy Loss

- Wheat - 1 kernel (34 mg) - 752 J
- *T. castaneum* Dev 237 J As adult 3111 J
- *C. ferrugineus* Dev 35 J As adult 311 J
- *S. granarius* Dev 345 J As adult 1193
- *S. oryzae* Dev 130 J As adult 300 J
- *R. dominica* Dev 33 (88) J As adult 414 (2646)
- *E. cautella* Dev 605 J As adult (does not feed)

Energy Loss

- Corn -1 kernel (225 mg) - 4537 J
- *Cynaeus angustus* - Larger black flour beetle
  - Dev. 598 J As adult 8569 J
- *Prostephanus truncatus* - Larger Grain borer
  - Dev. 252 (547) J As adult 4210 (21,383) J
- *P. interpunctella* - Indianmeal moth
  - Dev. 657 J As adult (does not feed)

Storage Mites

- Order: Acarina
- Suborder: Astigmata
- Saprophagus, fungivorous, graminivorous
- Families: Acaridae, Glyciphagidae, Chrotoglyphidae, Carpoglyphidae, and Pyroglyphidae.
- Size: Body length varies from 365 - 1200 micrometers.
- Pale in color, soft-bodied.

Brief Development

- Eggs
- Protonymph (6 legs)
- Duetonymph (hypopus) - dispersal/survival
- Tritonymph (8 legs)
- Adult

Table 11.1. Species of Astigmata Most Frequently Found in Surveys of Stored Products or Foodstuffs by Investigators from Different Countries

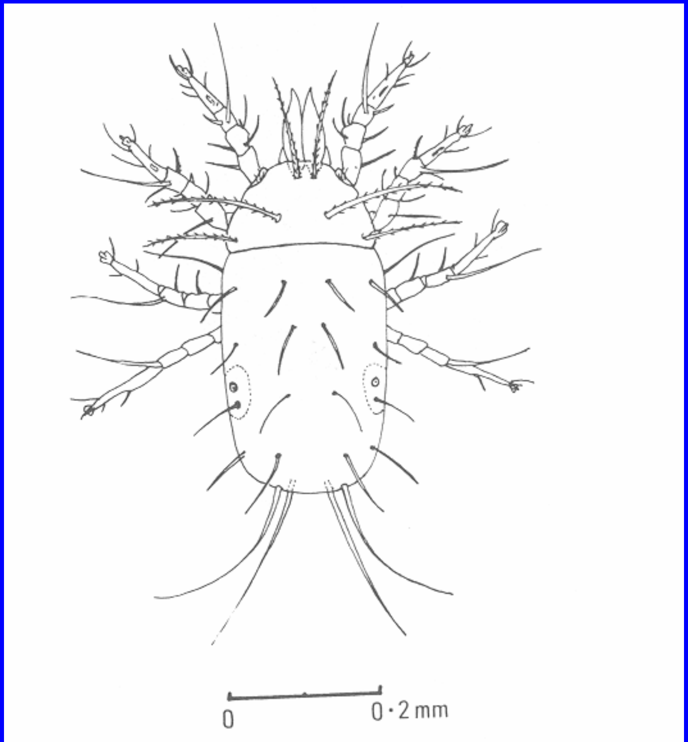
Species[a]	Food; class of product	References[b]
ACARIDAE		
Acarus siro	Cereal, legume, seed, bulb, proteinaceous food, hay/field	1–10
Acarus farris	Cereal, legume	4–8
Acarus immobilis	Cereal	6–8
Tyrophagus putrescentiae	Cereal, legume, seed, fruit and vegetable, proteinaceous food, sweet or starchy, bulb, hay/field	1–7, 9, 10
Tyrophagus longior	Cereal, legume, fruit and vegetable, proteinaceous food, sweet or starchy, bulb, hay/field	1, 3–8, 10
Tyrophagus similis (= *oudemansi* = *dimidiatus*)	Cereal, fruit and vegetable, proteinaceous food	2, 4, 7, 10
Tyrophagus palmarum	Cereal, seed, fruit and vegetable, proteinaceous food, hay/field	1, 5–8, 10
Tyrolichus casei (= *Tyrophagus casei*)	Cereal, legume, seed, proteinaceous food, hay/field	1, 2, 4–6, 10
Aleuroglyphus ovatus	Cereal	2, 3, 9, 10
Lardoglyphus konoi	Proteinaceous/high fat foods	4, 10
Caloglyphus berlesei	Cereal, fruit and vegetable, proteinaceous food, sweet or starchy, fungi	2–4, 7, 8, 10
Caloglyphus mycophagus	Fruit and vegetable, fungi	4, 6, 10
Rhizoglyphus robini (= *echinopus*)	Cereal, bulb, hay/field	1, 2, 4, 6, 7, 10
GLYCYPHAGIDAE		
Lepidoglyphus destructor (= *Glycyphagus destructor*)	Cereal, legume, seed, proteinaceous food, fruit and vegetable, fungi	1–10
Glycyphagus domesticus	Cereal, legume, seed, proteinaceous food, hay/field	1–3, 5–8
Blomia freemani	Cereal, fruit and vegetable, hay/field	1, 6, 10
Gohieria fusca	Cereal, legume, seed, proteinaceous food, fungi	2, 3, 5–10
CHORTOGLYPHIDAE		
Chortoglyphus arcuatus	Cereal, legume, seed, fruit and vegetable	2, 3, 5–10
CARPOGLYPHIDAE		
Carpoglyphus lactis	Cereal, legume, fruit and vegetable, proteinaceous food	4, 5, 10
PYROGLYPHIDAE		
Dermatophagoides farinae	Cereal	5

[a] Classification follows that of Hughes (1976) and Krantz (1978).
[b] Legend: 1, Griffiths (1960) (England); 2, Krantz (1961) (USA); 3, Sinha (1963) (Canada); 4, Champ (1966) (Australia); 5, Zdarkova (1967) (Czechoslovakia); 6, Cusack et al. (1975) (Ireland); 7, Griffiths et al. (1976) (England); 8, Jeffrey (1976) (Scotland); 9, Pagliarini (1979) (Yugoslavia); 10, Tseng (1979) (Taiwan).

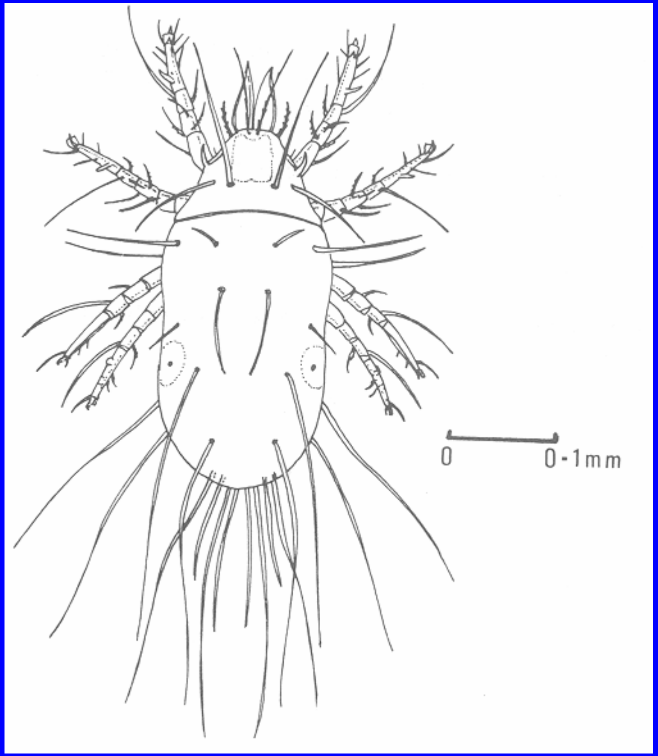
Table 11.2. Relative Humidity (RH) and Moisture Content (MC) Limits and Optima for Survival and Reproduction of Feeding, and Critical Equilibrium Activities (CEA) of Fasting, Astigmatid Mites at 25°C

Species (references)	Fasting CEA	Approximate feeding limits (Lower–optimum–upper)	
		% RH	% MC
Caloglyphus rodriguezi (Rodriguez, unpublished)	~0.97	95–97–ND[a]	ND–ND–ND
Acarus siro (Solomon, 1946; Cunnington, 1965, 1976; Knulle, 1965)	0.70	67–90–ND	13–ND–ND
Tyrophagus putrescentiae (Rivard, 1959; Cunnington, 1969; Sasa et al., 1970; Cutcher, 1973)	~0.84	65–90–ND	14–16–18
Aleuroglyphus ovatus (Matsumoto, 1963; Sasa et al., 1970)	ND	69–85–95	12–14–18
Glycyphagus destructor (Matsumoto, 1963; Stratil et al., 1980)	ND	69–88–94	ND–ND–ND
Lardoglyphus konoi (Matsumoto, 1968)	ND	71–82–ND	ND–ND–ND
Dermatophagoides pteronyssinus (Arlian, 1977)	0.73	ND–ND–ND	ND–ND–ND
Dermatophagoides farinae (Sasa et al., 1970; Waki and Matsumoto, 1973; Arlian and Veselica, 1981)	~0.57	41–60–76	10–25–35

[a] Not determined.



Flour mite, *Acarus siro*



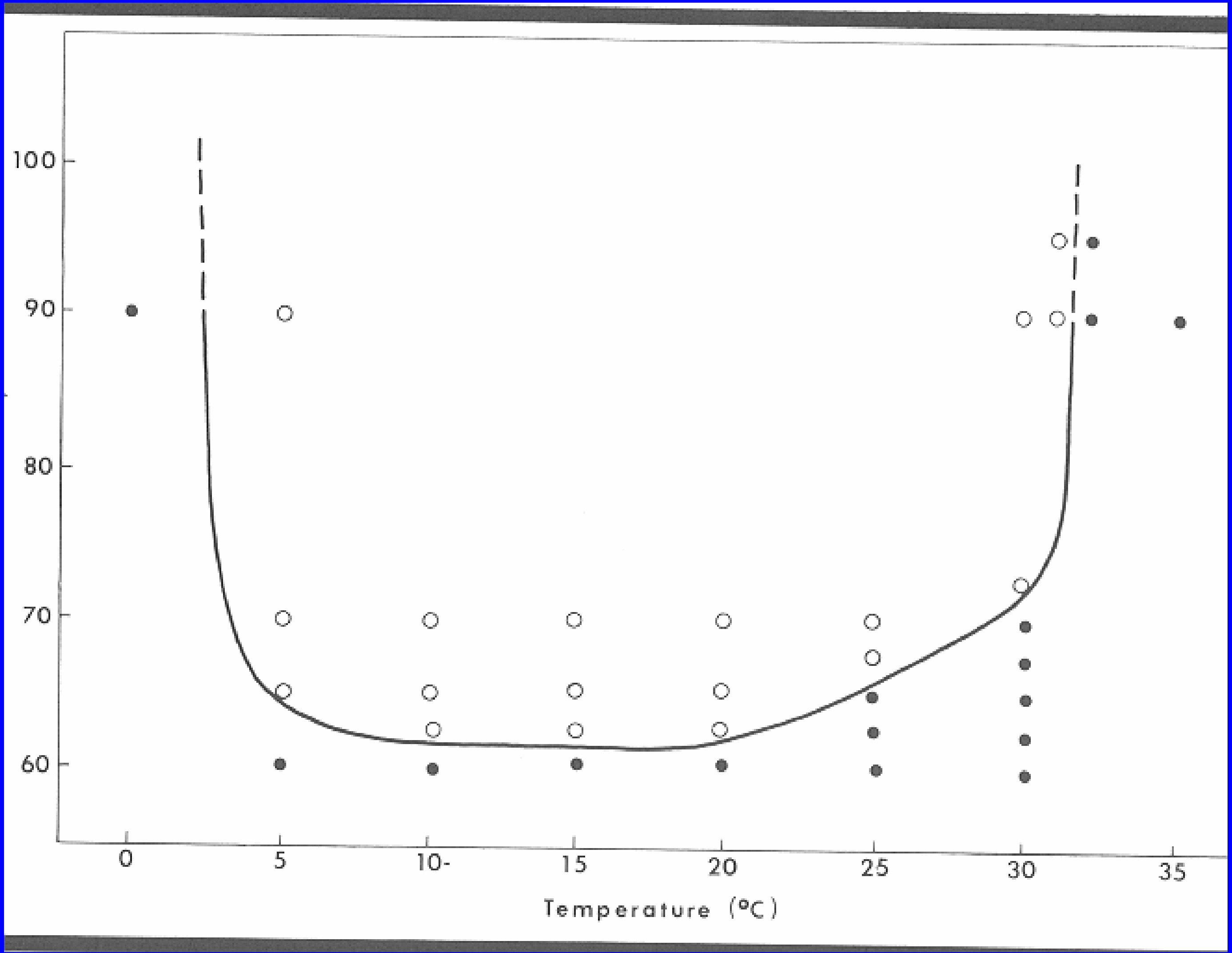
Cheese or bacon mite
Tyrophagus putrescentiae

Table 6.7

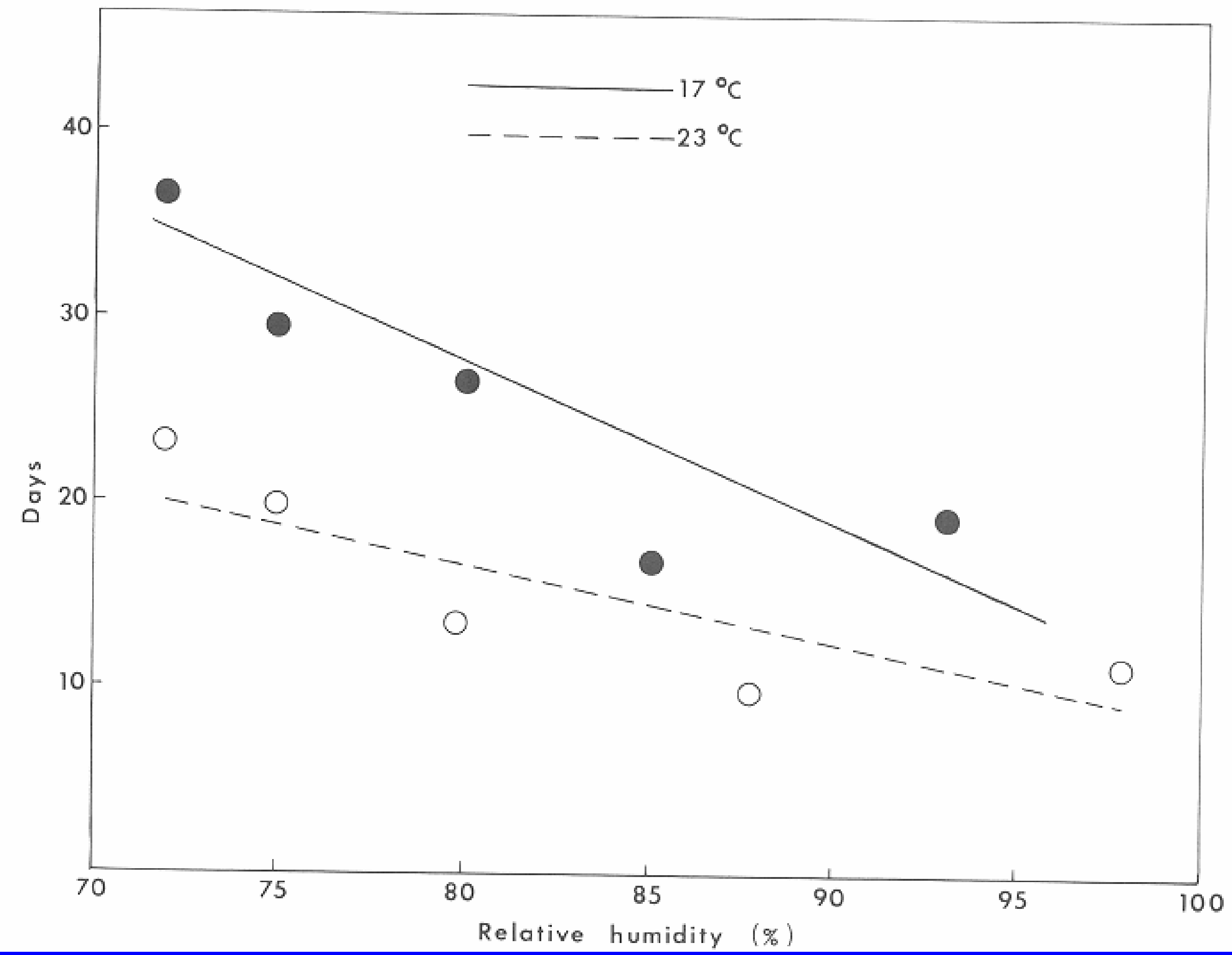
Ecological parameters for some important stored-product mites

Species	Physical limits: Temperature (°C) Range	Temperature (°C) Optimum	Relative humidity (%) Minimum	Relative humidity (%) Optimum	Results under optimum conditions: Fecundity (number of eggs/female)	Develop-mental time (days)	Longevity (days)	R_o	r_m	Sex ratio (males: females)
Acarus										
farris	3–31	20	74	89	137	10	19	32.9	0.176	—
siro	2.5–31	20	63	80	230	9	30	—	—	47:53
Aeroglyphus robustus	—	30	—	75	12	90	—	2.5	0.03	—
Aleuroglyphus ovatus	—	25	—	75	60	16	—	—	—	—
Caloglyphus										
anomalus	?–34	23	—	98	738	9.5	30	—	—	—
berlesei	16–35	27	—	95	588	8	24	192	0.375	50:50
Carpoglyphus lactis[a]	3–35	20	60	80	278	10	20	118	—	45:55
Cheyletus eruditus[a]	8–31	20	56	80	71	17	35	—	—	0:100
Glycyphagus domesticus	—	22	—	—	135	22	31	32	0.097	50:50
Lardoglyphus konoi	—	30	75	82	—	8	—	—	—	—
Lepidoglyphus destructor	3–34	25	62	90	150	27	—	—	—	—
Rhizoglyphus echinopus	3–31	25	86	90	600	8	35	336	0.162	40:60
Thyreophagus entomophagus[a]	3–32	20	75	85	156	16	47	—	—	49:51
Tyrophagus putrescentiae[a]	8.5–36	25	69	85	500	10	62	30	0.210	45:55

[a]Duration of starvation (days) is 29 for *Carpoglyphus lactis*, 69 for *Cheyletus eruditis* and *Thyreophagus entomophagus*, and 60 for *Tyrophagus putrescentiae*.



100
90
80
70
60
0
5
10-
15
20
25
30
35
Temperature (°C)



17 °C
23 °C
Days
40
30
20
10
70
75
80
85
90
95
100
Relative humidity (%)

Effects of temperature and relative humidity on *Tyrophagus putrescentiae*

Temperature (°C)	10			15–18			20–22			25			30		
Relative humidity (%)	70	80	95	70	80	95	70	80	95	70	80	95	70	80	95
Fecundity (eggs/female)															
Wheat germ	2	88	33	43	234	260	76	310	327	36	317	306	42	102	383
Developmental time for one generation (days)															
Wheat germ	—	130	76	—	75	—	50	32	26	—	—	16	—	18	47
Cottonseed	55	53	76	—	37	38	23	21	17	—	20	14	14	12	11
Mortality (%)															
Wheat germ	—	—	98	—	—	90	—	—	48	—	—	38	—	—	57
Longevity (days)															
Wheat germ	62	125	159	80	85	81	75	64	52	53	80	53	53	39	36
Powdered milk	—	—	—	—	—	—	—	75	—	—	—	—	—	—	—
Rolled oats	—	—	—	—	—	—	—	25	—	—	—	—	—	—	—
R_0															
Yeast	—	—	—	—	—	—	—	—	119	—	—	113	—	—	204
r_m															
Yeast	—	—	—	—	—	—	—	—	0.15	—	—	0.2	—	—	0.26
λ															
Yeast	—	—	—	—	—	—	—	—	0.17	—	—	1.22	—	—	1.30
Dried plums	—	—	—	—	—	—	—	—	—	—	1.1	—	—	—	—

Food Habits

- Feed on fungi.
- Disseminate fungi to clean grain.
- Can reproduce on seed-borne fungi.
- Mycotoxins kill mites.
- Ochratoxin is toxic to *T. putrescentiae* larvae.
- *A. siro* prefers germ of wheat and multiplies rapidly, but cannot penetrate intact kernels.
- Lecithin stimulates reproduction
- Casein, amino acids, wheat germ containing diets are excellent diets for mites.

Metabolic Inhibitors

- Additives (2%)
  - Calcium and sodium propionate
  - Potassium sorbate
- 0.55 of propionic, caproic, caprylic, and capric acids are inhibitory.
- Best strategy: Moisture management.

Management

- Sanitation
- Aeration
- Physical Methods
- Chemical Methods

Table 2 Response of Stored-Product Insect Pests to Temperature.

Zone	Temperature range (°C)	Effects
Lethal	> 62	Death in less than 1 min
	50–62	Death in less than 1 h
	45–50	Death in less than 1 d
	35–42	Populations die out, mobile insects seek cooler environment
Suboptimum	35	Maximum temperature for reproduction
	32–35	Slow population increase
Optimum	25–32	Maximum rate of population increase
Suboptimum	13–25	Slow population increase
Lethal	5–13	Slowly lethal
	3–5	Movement ceases
	−10 – −5	Death in weeks, or months if acclimated
	−25 – −15	Death in less than 1 h

Source: adapted from Fields (1992)

Table 1. Maximum moisture contents for aerated grain storage.

Grain Type and Storage Time	Maximum Moisture Content for Safe Storage (Percent Wet Basis)		
	South	Central	North
Shelled corn and sorghum			
Sold as #2 grain by spring	14	15	15
Stored 6 to 12 months	13	14	14
Stored more than 1 year	12	13	13
Soybeans sold by spring	13	14	14
Stored 6 to 12 months	12	12	13
Stored more than 1 year	11	11	12
Wheat, oats, barley, rice			
Stored up to 6 months	12	13	14
Stored 6 to 12 months	11	12	13
Stored more than 1 year	10	11	12
Sunflower			
Stored up to 6 months	10	10	10
Stored 6 to 12 months	9	9	9
Stored more than 1 year	8	8	8
Flaxseed			
Stored up to 6 months	9	9	9
Stored more than 6 months	7	7	7
Edible beans			
Stored up to 6 months	14	15	15
Stored 6 to 12 months	12	13	14
Stored more than 1 year	10	11	12

Values for good quality, clean grain and aerated storage.

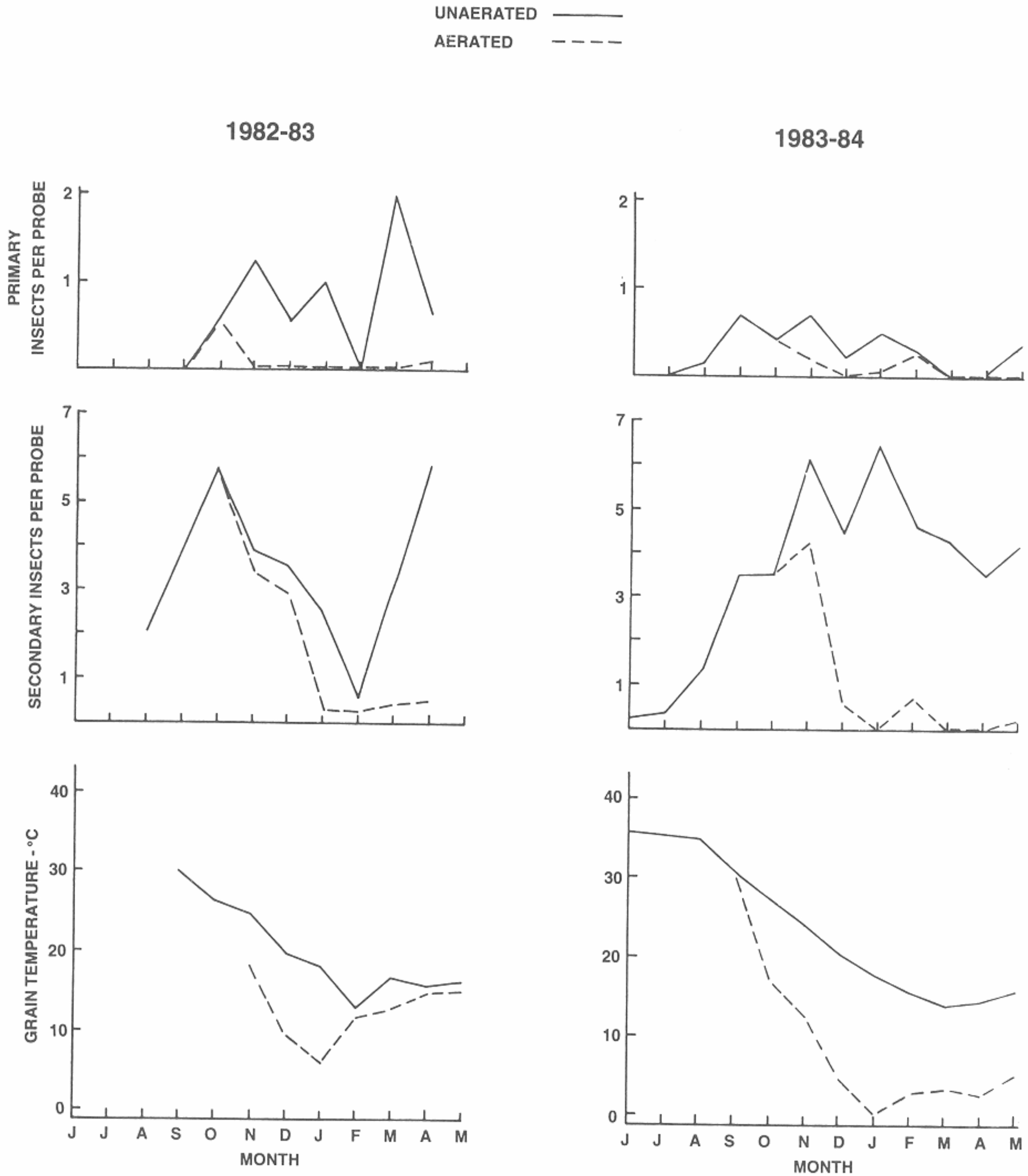

UNAERATED
AERATED
1982-83
1983-84
PRIMARY INSECTS PER PROBE
SECONDARY INSECTS PER PROBE
GRAIN TEMPERATURE - °C
J J A S O N D J F M A M
MONTH
J J A S O N D J F M A M
MONTH

Table 3. Recommended minimum airflow rates for aeration.

Crop	Moisture Content	Cfm/Bu. Range
Shelled Corn, Sorghum	14 percent and below	1/10 to 1/4
	15 to 16 percent	1/4 to 1/2
	18 percent +	1/2 to 1
Wheat, Oats, Barley, Rice	13 percent and below	1/10 to 1/4
	14 to 16 percent	1/4 to 1/2
	17 percent +	1/2 to 1
Soybeans	10 to 11 percent	1/10 to 1/4
	12 to 13 percent	1/4 to 1/2
	14 percent maximum	1/2 to 1
Sunflowers	8 to 9 percent	1/10 to 1/4
	10 to 11 percent	1/4 to 1/2
	12 to 13 percent	1/2 to 1

Source: Stored Grain Management Handbook, Kansas State University.

Table 6. Airflow rate, Cfm/bu. vs. cooling time.

	Low Aeration		Medium Aeration				High Aeration		
Cfm/Bu.	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
	Hours*								
Summer	180	90	45	30	24	18	15	12	9
Fall	240	120	60	40	30	25	20	15	12
Winter/ Spring	300	150	75	50	40	30	25	20	15

* Assumes clean grain at safe storage moisture. Grain that is peaked and has foreign material concentrated under the fill point(s), cooling may require 50 percent additional time or more.

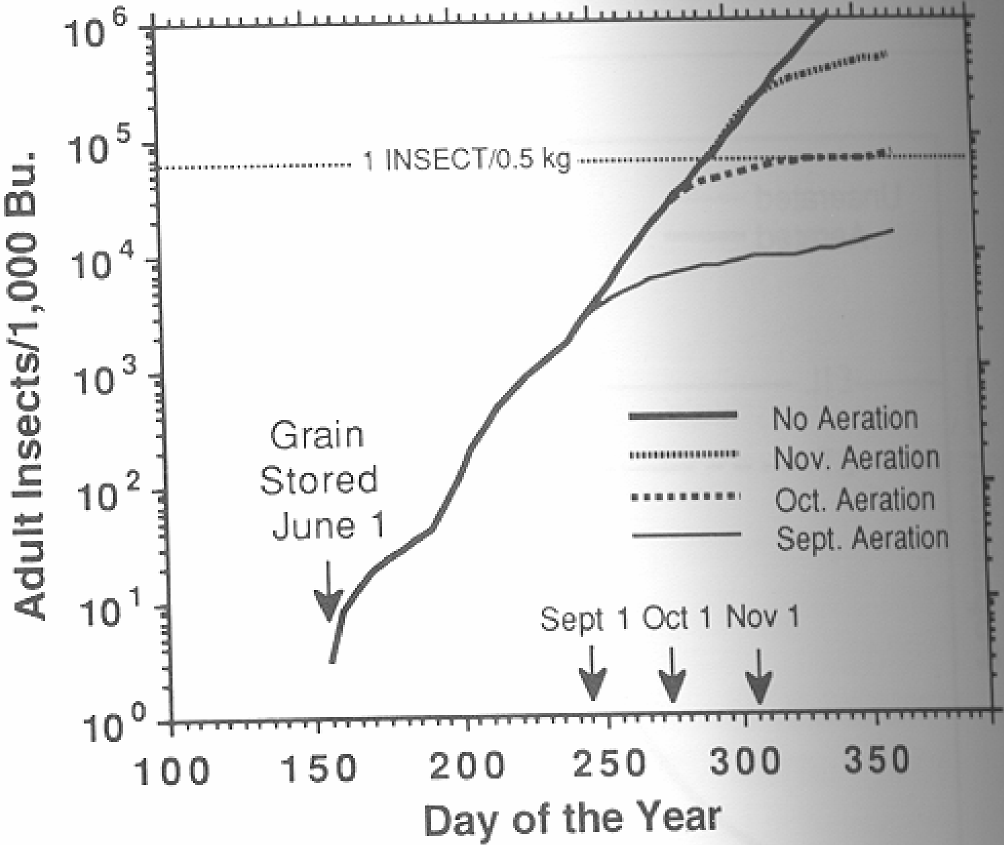
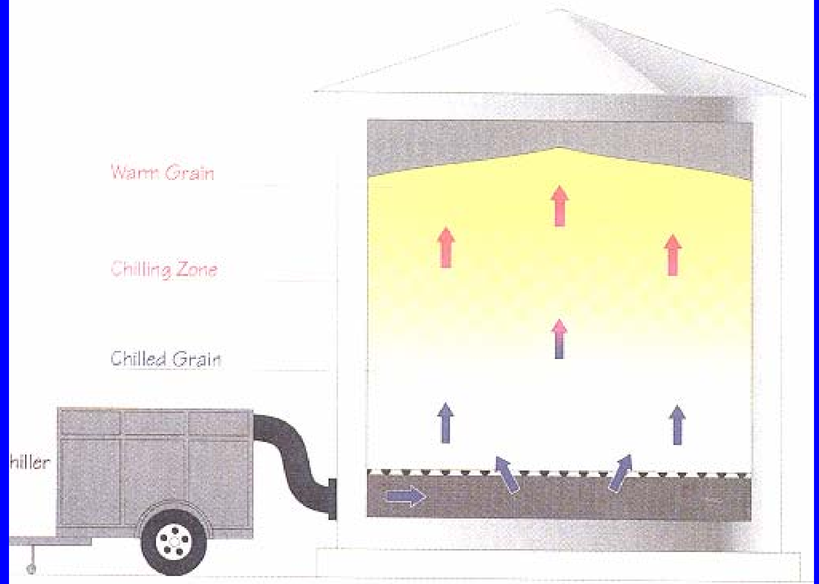
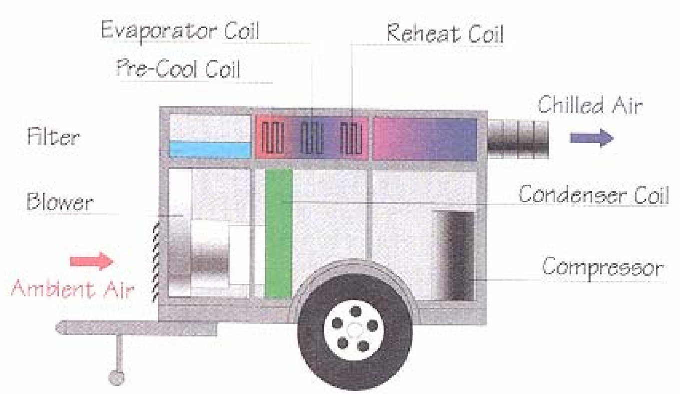


Figure 4. Time of aeration and growth of lesser grain borer populations on wheat stored at 32°C and 14 percent moisture content. (Redrawn from Flinn and Hagstrum, 1990a.)



Chilled Aeration and Conditioning Process

1a.



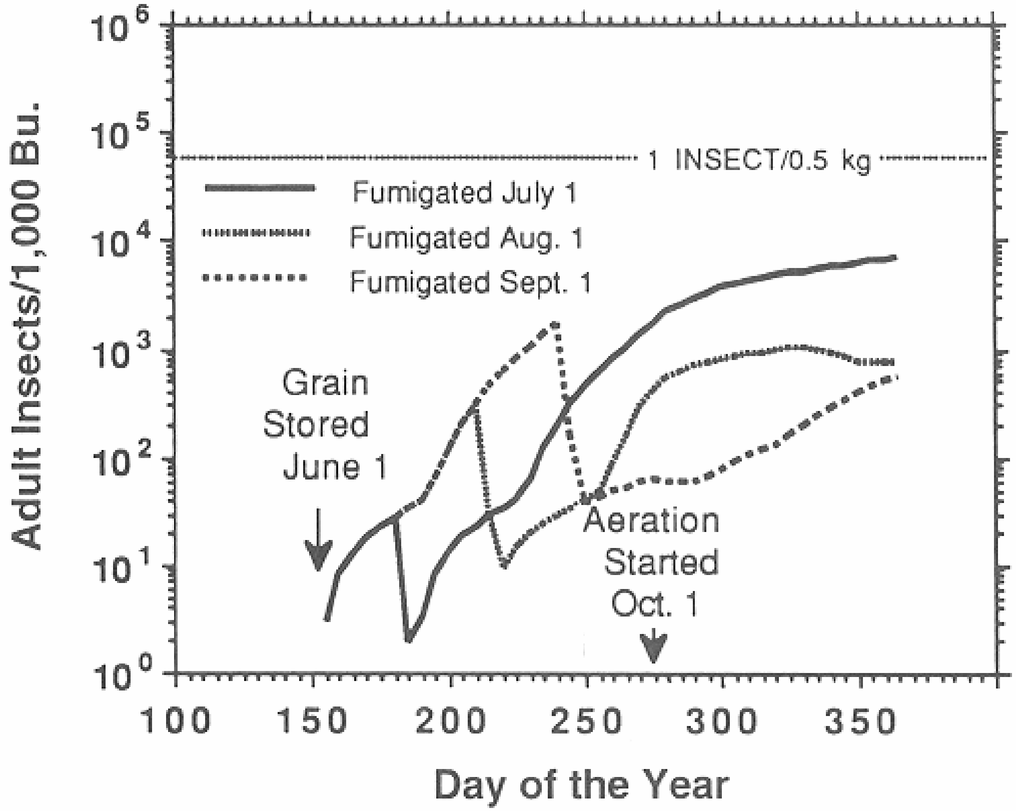


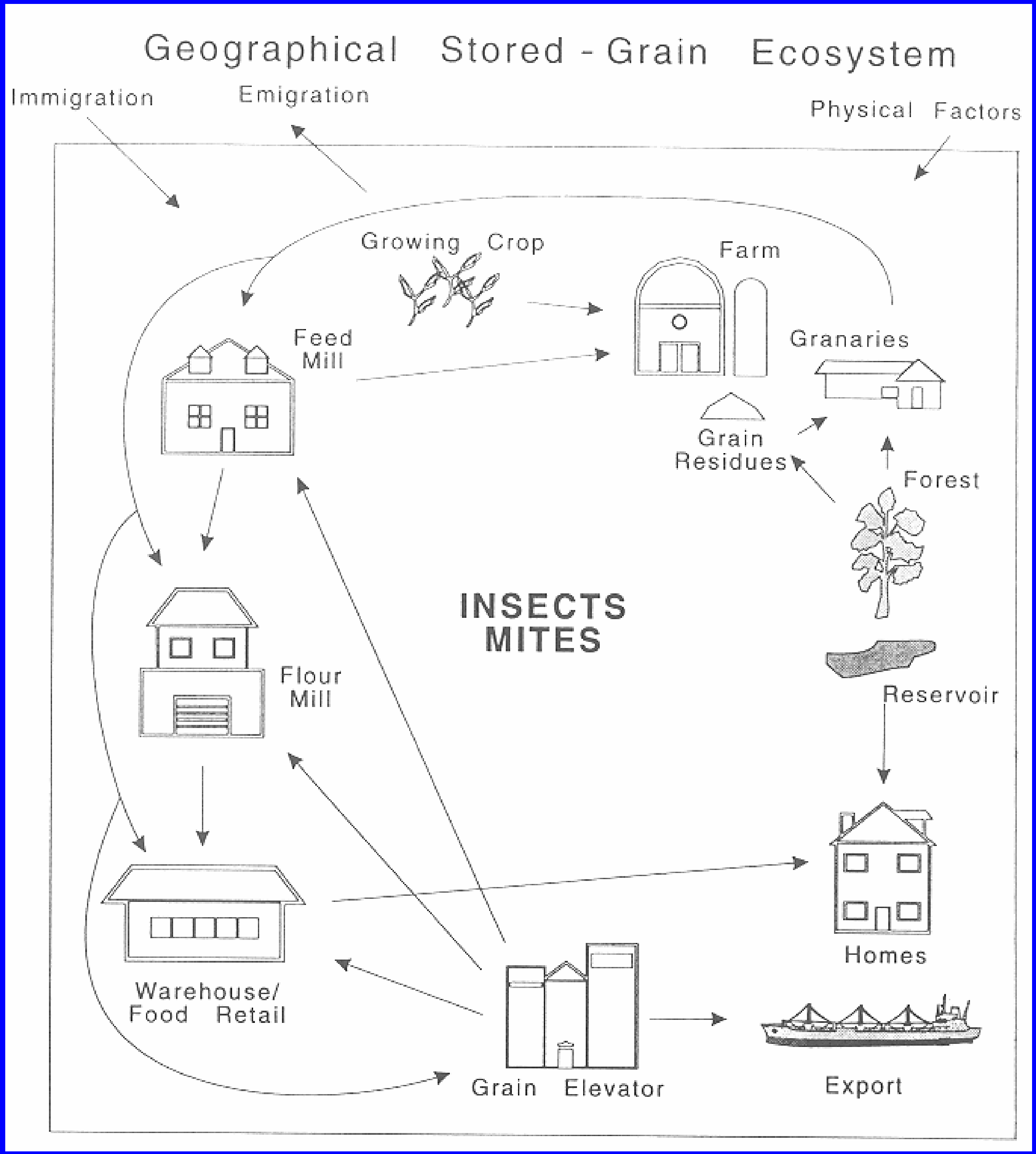
Figure 6. Time of fumigation and growth of lesser grain borer populations on wheat stored at 32°C and 14 percent moisture content. (Redrawn from Flinn and Hagstrum, 1990a.)

Residual Products

- Tempo

Monitoring Pest Populations

- Traps for insects in grain.
- Traps for insects in feed mills.


Geographical Stored - Grain Ecosystem
Immigration
Emigration
Physical Factors
Growing Crop
Farm
Feed Mill
Granaries
Grain Residues
Forest
INSECTS MITES
Flour Mill
Reservoir
Homes
Warehouse/ Food Retail
Grain Elevator
Export