Chapter 11
Arthropods of Stored Cereals, Oilseeds, and Their Products in Canada: Artificial Ecosystems on Grasslands

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Abstract. Bulk grain is a dynamic, immature ecosystem with non-germinating seeds as "producers." Communities and populations of insects, mites, microflora, and occasionally vertebrates such as birds or rodents become associated with the seed, forming an integral part of the stored-grain ecosystem. Canada annually produces an average of 52 million tonnes of cereals. Most of this grain is stored on the farm, delivered to primary elevators, and finally moved by rail to terminal elevators on the coast or on the Great Lakes for sale abroad. There are 146 species of insects found in grain storage and cereal-processing facilities, but only 10–15 species occur frequently and most are beetles. Moths are often a problem in heated warehouses and terminal elevators in western and eastern Canada, especially from May through September. Climate, weather, and incoming grain condition dictate which species will become established and lead to major infestation. The diversity of insects and mites and levels of infestations in Canada are less than those in more moderate climates because Canada has a colder climate that limits the growth and population development of these species. Most farm-stored grain contains low levels of insects and mites, and they multiply and become a problem only during the warmer period after harvest. The most common insect pests in grain in western Canada are *Cryptolestes ferrugineus* and *Tribolium castaneum*, species that have very high rates of population increase (60- to 70-fold per month). *Sitophilus granarius* and *Plodia interpunctella* have greater cold hardiness than does *T. castaneum,* but they have rates of increase of only 15- to 30-fold per month. Insects found in processed products within heated flour mills, feed mills, warehouses, and distribution centres are not as limited by temperature and, as a consequence, moths, notably *P. interpunctella*, and dermestids and *Tribolium* spp. are more of a problem in these habitats. Mites no longer present major problems as a result of better grain-storage management practices.

Résumé. Le grain en vrac constitue un écosystème immature dynamique dont les graines sans pouvoir germinatif constituent les « producteurs ». Des communautés et populations d'insectes, d'acariens, de microflore et, à l'occasion, de vertébrés comme les oiseaux et les rongeurs peuvent s'associer à cet écosystème et en former une partie intégrante. Le Canada produit en moyenne chaque année 52 millions de tonnes de céréales qui sont en général entreposées à la ferme, livrées aux silos primaires et enfin transportées par rail aux silos terminaux sur la côte ou sur le bord des Grands Lacs pour être vendues à l'étranger. On trouve dans le grain entreposé et les installations de transformation des céréales 146 espèces d'insectes, mais seulement 10 à 15 — des coléoptères pour la plupart — se rencontrent fréquemment. Les lépidoptères posent souvent des problèmes dans les entrepôts et les silos terminaux chauffés de l'ouest et de l'est du Canada, surtout de mai à septembre. Le climat, les conditions

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atmosphériques et l'état du grain à l'arrivée déterminent lesquelles des espèces pourront s'établir et conduire à une infestation majeure. La diversité des insectes et des acariens et l'ampleur des infestations observées au Canada sont moindres que sous les climats plus modérés puisque le temps plus froid limite la croissance et le développement des populations de ces espèces. La plupart des céréales entreposées à la ferme contiennent peu d'insectes et d'acariens, et ces derniers n'arrivent à se multiplier et à devenir nuisibles qu'au cours de la période plus chaude qui suit la récolte. Les ravageurs les plus communs des céréales entreposées dans l'ouest du Canada sont le *Cryptolestes ferrugineus* et le *Tribolium castaneum*, deux espèces qui se reproduisent très rapidement (populations multipliées par 60 à 70 chaque mois). Le *Sitophilus granarius* et le *Plodia interpunctella* résistent mieux au froid que le *T. castaneum,* mais le facteur de multiplication de leurs populations n'est que de 15 à 30 par mois. Les insectes que l'on trouve dans les produits transformés dans les minoteries, les provenderies, les entrepôts et les centres de distribution chauffés ne sont pas limités par la température, et certaines espèces comme le lépidoptère *P. interpunctella*, certains dermestidés et plusieurs espèces de *Tribolium* posent plus de problèmes dans ces milieux. Les acariens ne présentent désormais plus de problèmes graves grâce à l'amélioration des pratiques de gestion du grain entreposé.

Introduction

Bulk grain is a dynamic, immature ecosystem with non-germinating seeds as “producers.” Communities and populations of insects, mites, microflora, and occasionally vertebrates such as birds or rodents become associated with the seed, forming an integral part of the stored-grain ecosystem (Sinha 1973). The populations interact with one another in a complex physicochemical environment (Calderon 1981). A bulk of grain is not a homogeneous environment, but contains gradients of oxygen, carbon dioxide, nitrogen, moisture (convection currents, bin leakage, different loads of grain), and temperature (insulating properties of a bulk). It also contains non-uniformly distributed quantities of dockage (weed seeds, chaff, and dust) and has distinct physical and biological properties. Qualitative and quantitative loss of grain during storage in such ecosystems may also depend on pre-storage factors, such as quantities of immature or frost-damaged seeds, harvesting and threshing methods, and grain drying. The losses should be reduced as grain proceeds through the various stages of transport and processing as the products become more valuable.

When left unmanaged, the stored-grain ecosystem will eventually mature, resulting in the spoilage of the grain. Increases in temperature and grain moisture content allow other organisms to thrive, which in turn leads to spoilage. The grain-storage ecosystem is different from other grassland ecosystems in that the environment is determined in large part by humans, whereas in other grassland habitats, such as pastures or annual crops, the temperature and humidity are not amenable to human control.

Stored-products entomology involves the study of insect and mite pests in a habitat with “unlimited food” (grain in bulk) and an environment with various gradients in temperature and moisture levels. Insect pests of stored grain are well adapted to dry, stored grain. They have short developmental periods and females can lay hundreds of eggs. Such insect populations have few effective biological controls, and competition with other species is limited unless the ecosystem is reaching maturity; they are well-protected from environmental extremes within a storage structure or in a heated building used for processing foods.

Insects and mites are a major cause of quantitative and qualitative loss to stored products throughout the world (Sinha and Wallace 1973). Therefore, the solution to infestations is not in merely controlling pests, but also in preventing infestations by considering the physical and engineering factors that combine to create the storage environment within which pests develop. To prevent pest outbreaks, a critical method that can be used in a storage environment, but can seldom be used against field-crop pests, is the manipulation of the environment in which the pests live. Mechanisms such as drying grain, cooling grain by aeration (with ambient or artificially chilled air), moving grain (physical disruption), or changing the size of storage structures (Banks 1976; Prevett 1990) may be considered as environmental manipulation that can be used to mitigate insect populations from becoming established and increasing.

Stored-grain insects and mites are, for the most part, cosmopolitan (Freeman 1973). The arthropods come from a wide range of natural reservoirs (Linsley 1944), but can generally be classed as seed-infesting species, fungus-feeding species, scavengers, predators, or parasites (Linsley 1944; White 1995). Most stored-grain arthropods are thought to have originated in India or the Middle East and have been transported throughout the world by human movement of foods (Cotton 1956; Buckland 1981; Sinha and Watters 1985; Levinson and Levinson 1996). Stored-grain arthropods were not abundant in North America before the 19th century. *Tribolium confusum* Jacquelin du Val (Tenebrionidae) was first reported in the United States in 1893 (Metcalf *et al.* 1951) and *Cryptolestes turcicus* (Grouvelle) (Cucujidae) in 1882 (Lefkovitch 1962). *Tribolium destructor* Uyttenboogaart was first reported in western Canada (Alberta) in 1945 (MacNay 1950); *Palorus subdepressus* (Wollaston) (Tenebrionidae) in Manitoba (Canada) in 1974, arriving in maize shipped from the United States (Smith 1975); *Oryzaephilus mercator* (Fauvel) (Silvanidae) in Alberta (Canada) in 1925 (Loschiavo and Smith 1970); and *Cynaeus angustus* (LeConte) (Tenebrionidae) in Saskatchewan (Canada) in 1944 (CIPR 1952), having gradually spread from Mexico (Dunkel *et al.* 1982). All of these insects are common throughout the agricultural regions of Canada today. The main limitations to the spread of stored-grain insects are temperature and relative humidity (climate), the export and import of goods, and the regulatory diligence of importing countries. The importance of the last factor is demonstrated by the ability of North America and Australia to eradicate and then prevent the re-establishment of the Khapra beetle, *Trogoderma granarium* Everts (Dermestidae) (Banks 1977; Bousquet 1990).

Cereals in Storage

Canada annually produces an average of 30 million tonnes (Mt) of wheat, 12 Mt of barley, 3 Mt of oats, 7 Mt of maize, 5 Mt of canola, and 2 Mt of soybeans (Canadian Grain Commission 2007). Less significant crops include mixed grains, buckwheat, peas, beans, sunflower seed, lentils, flaxseed, and mustard seed. In the western Canadian grasslands, the longest period of seasonal storage occurs on the farm (Fig. 1A–C), where about 75% of total storage capacity is found. In most cases, grain is delivered throughout the year to primary elevators (Fig. 1D, E) by truck and transferred by railcar to terminal or transfer elevators for export or domestic use. Canada has a legally defined zero tolerance for live storage insects in stored grain (Canada Grain Act 1996).

Even in Canada, grain can be harvested warm (25 to 35 °C), and bulks of grain act as insulators, keeping central regions of a grain mass warm for long periods (Jayas *et al.* 1994). This insulation allows insects to feed and reproduce even when ambient temperatures are below 0 °C. Most storage insects cannot multiply below 20 °C (Howe 1965; Fields and White 1997) and will not fly at temperatures below 25 °C. Sinha (1963*a*) determined the number of months during which 14-t bulks of grain would remain above 20 °C across Canada if left unmanaged and demonstrated that, in most of the grain-growing area of western Canada, this would be three to four months. In western Canada, the southern half

Fig. 1. A, Corrugated metal bins are one of the most common farm grain storage units. Hopper bins (white) allow for easy unloading. B, Wooden bins are still used occasionally. C, There are many types of temporary storage units. D, Wooden elevators covered with metal sheathing were built from 1920 to 1960. E, High-throughput concrete elevators or inland terminals are quickly replacing the smaller wooden elevators.

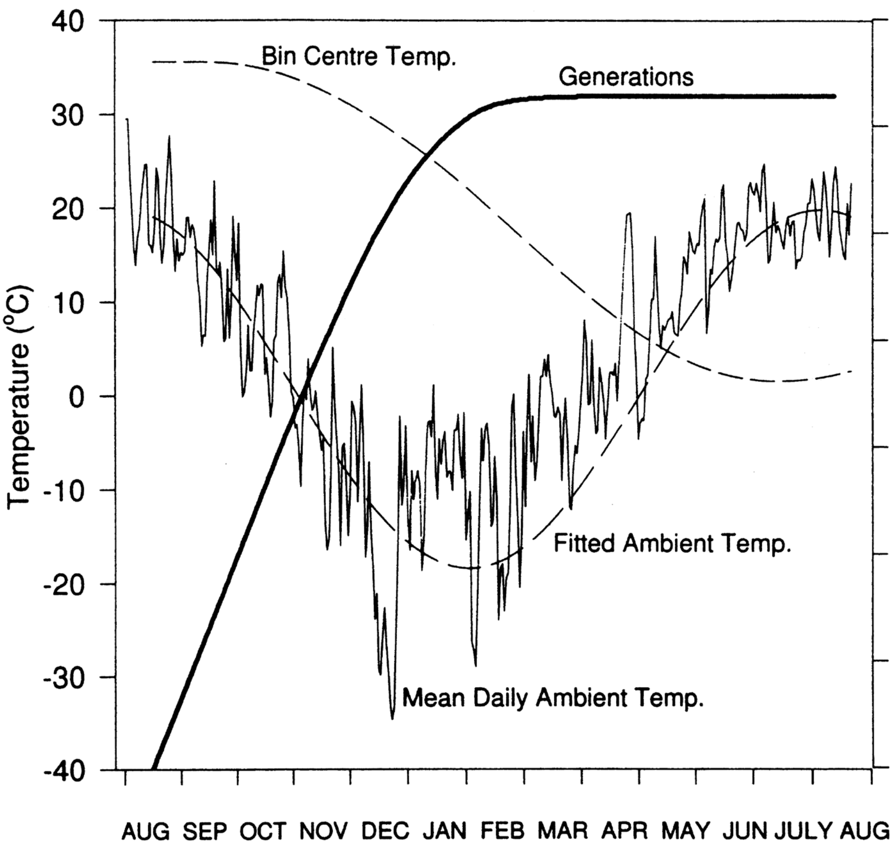

Fig. 2. Typical simulation of the number of completed generations of *Cryptolestes ferrugineus* based on ambient weather data and simulated grain bin temperatures.

of the grain-growing area is considered vulnerable to insect infestation even in these small bulks, which cool rapidly in the winter. The entire grain-growing area in eastern Canada, where temperatures are moderate, is vulnerable to most storage insects.

Computer simulations of grain temperatures in the centre of a 6-m diameter bulk of wheat in western Canada predicted a maximum of six generations of the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), between harvest in August and January when grain temperature falls below 20 °C (Woods *et al.* 1997) and reproduction ceases (Fig. 2). The same model also predicted large variations in infestations across the various crop districts of western Canada (Fig. 3). It predicted the locations where heavy infestations of *C. ferrugineus* would occur after an unusually hot harvest (from 1983 weather data), notably in the south between 49 and 50° latitude (Woods *et al.* 1997). Control of these insects, especially *C. ferrugineus*, which is very cold hardy, requires grain temperatures of −15 °C for two weeks or −5 °C for eight weeks (Fields 1992), and Smith (1995) demonstrated that aeration systems allow for the rapid and uniform cooling of bulk grains. The use of low temperatures can be an effective measure for grain handlers managing small grain bulks. Achieving temperatures of −5 °C or lower can be performed with relative ease, provided the grain bulk is not too large. In many cases, once grain is collected in the commercial system, the grain bulk is usually too large (>900 t) to be cooled without the addition of extremely large energy inputs.

The detailed life history and biology of many stored-product insects is well studied (Cotton and Wilbur 1982; Sinha and Watters 1985; Campbell *et al.* 1989; Bousquet 1990; Pedersen 1992; Rees 1996; Sedlacek *et al.* 1996).

Storage Structures

Stored-product insects are found in a large variety of structures, which in turn affects their population dynamics. Grain is initially stored in granaries on the farm. Most grain is stored either in corrugated metal granaries or in welded steel, hopper-bottom granaries (Fig. 1A).

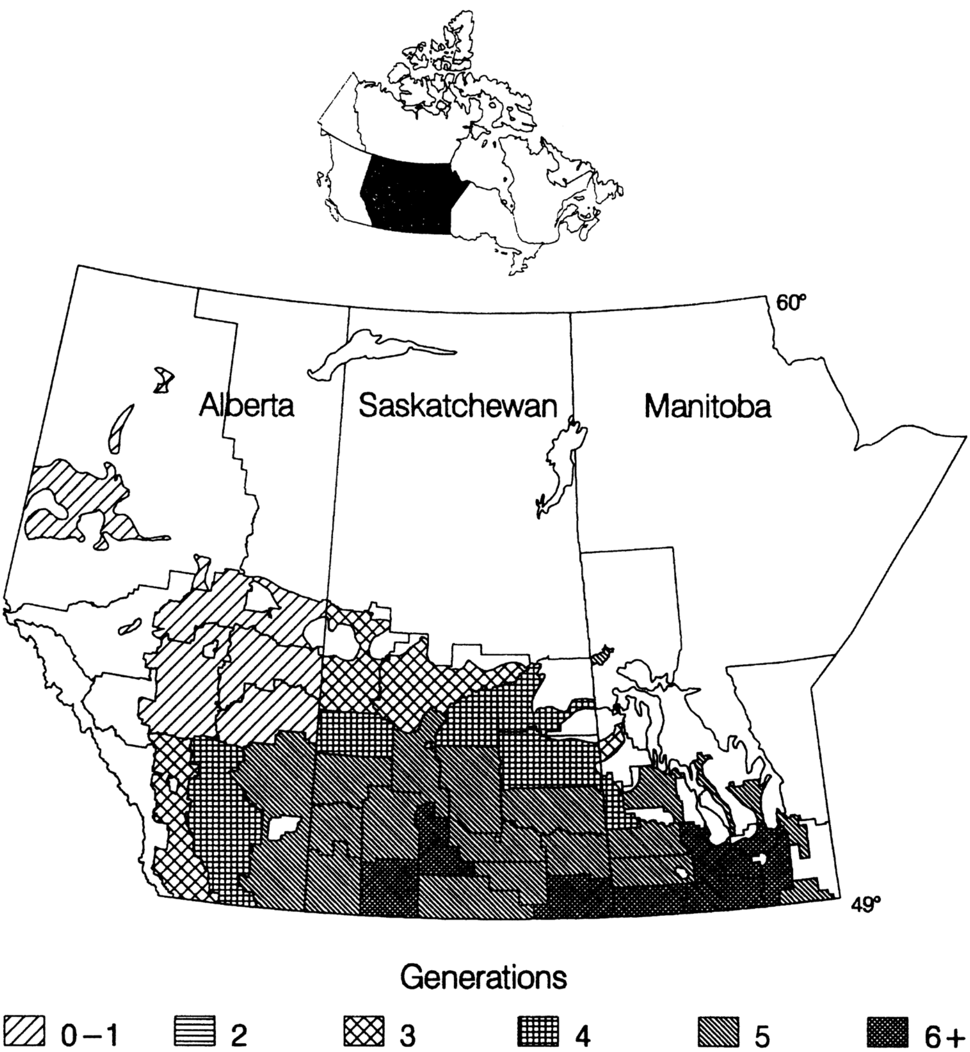

Fig. 3. Map indicating the simulated number of completed generations of *Cryptolestes ferrugineus* in 365 days for all crop districts in the prairie provinces of Canada in 1983, a year with high infestation levels. Unshaded areas are not used for agriculture.

The capacity of these granaries ranges from 10 t to over 400 t. Many granaries, especially those larger than 90 t, are equipped with aeration systems—fans, ducts, perforated floors, and vents—to force air through the grain. The same aeration system can be used to cool and dry the grain, depending on the amount of airflow. Aeration will bring grain temperature down to ambient air temperatures after three to seven days, depending on airflow, and will dry grain 1–2% after 7–21 days of aeration (Sinha *et al.* 1981). Some granaries do not have aeration, and the core temperatures of grain in this situation will remain considerably greater than that of grain in aerated storage (Fields and White 1997).

A small amount of grain is stored in wooden granaries (Fig. 1B) built prior to 1980. These granaries typically hold about 20 t, have no forced aeration, and cool quickly because the grain bulks are small. They are usually used only in years with a bumper harvest or for the storage of crops requiring identity preservation. There are also temporary storage structures made from plywood, metal, or plastic sheeting (Fig. 1C). Some producers simply drop the grain onto dry ground and cover it with a tarpaulin.

Grain bags are also being used for storing grain when storage granaries are unavailable. These harvest bags are somewhat different from silage or forage bags, are made of specialized polymers, and come in 60-, 75-, and 90-m lengths, with the bags typically holding approximately 3.5 t of wheat per metre. Extensive use of these bags has been made in South America and Australia, where claims of insect and mould control have been made through the achievement of natural hermetic conditions (Darby and Caddick 2007).

Grain remains on the farm for as little as a few weeks to more than a full year and most is rarely held for more than 10 months. Grain moves from the farm to a country elevator, an inland terminal, or directly to a terminal elevator. It moves from the farm by truck and then mainly by rail within Canada and the United States. About 80% of western Canadian grain is exported and most of it is moved to customers by ship from ports on the west and east coasts (Canadian Grain Commission 2007). Many primary elevators were built in the 1930s to the 1950s and are made of wood that is covered with metal sheeting (Fig. 1D). In these facilities, there is no aeration and grain residues in cracks in the wooden walls provide an ideal habitat for insects to multiply. This type of elevator typically contains 3,000–5,000 t of storage capacity. Many of these primary elevators have expanded their storage with large, metal corrugated or welded-steel bins for additional general storage, identity-preserved storage, or fumigation purposes, as grain stored in wooden silos cannot be fumigated effectively. Newer primary elevators, often termed inland terminals, are made of concrete and store 15,000 to over 60,000 t of grain (Fig. 1E). These facilities often source grain from large geographical regions (often over a 100-km radius) and bring grain in for just-in-time shipment of large volumes, often 5,000–10,000 t.

The terminal elevators, located at the ports, are also typically concrete structures with vertical silos. These facilities range in size, with storage capacities from 50,000 to over 450,000 t. Although concrete silos in terminal elevators offer fewer harbourages for insects than do wooden elevators, they often handle more grain and thus have larger and more complex insect infestation issues. The major complication associated with infestation within terminal elevators is that grain within these facilities is needed for shipments. Often, fumigated bulks are at least 1,000 t (one large bin at a terminal location) and if this grain is needed for the shipment, then demurrage charges of the vessel can be costly.

The remaining 20% of the grain is processed in Canada at flour and feed mills and is used to make a wide variety of cereal-based foods: bread, crackers, pasta, cookies, and breakfast cereals. All of these manufacturing plants have storage facilities for the raw grains and the processed products, and they have insect infestations within the processing equipment and the buildings. These buildings are heated throughout the winter and may use water in processing (pasta), which provides a much different habitat than that of unheated granaries and elevators, which only clean and sort the grain. As a consequence, these buildings have a different insect fauna (Sinha and Watters 1985).

Stored-Product Insects

In comparison to other parts of the world, Canada has relatively few stored-product insect infestations. This is mostly due to the temperate climate, which often does not allow for multiple generations per year and which can be used to manage insect population development. Lists of all stored-product insects reported from grain and its products in Canada are given in Sinha and Watters (1985), Campbell *et al.* (1989), Bousquet (1990), and White and Jayas (2003). There are 146 species listed, but only 10–15 species occur frequently and most are beetles. Moths are often a problem in heated warehouses and terminal elevators in western and eastern Canada, especially from May through September. Moths also occur on farms on the east and west coast and in eastern Canada, where the climate is milder. An additional 285 species of insects are found in stored grain in the United States (Gorham 1987). *Cryptolestes ferrugineus* (Fig. 4A) and *Tribolium castaneum* (Herbst) (Fig. 4B) are two of the most common insect pests in stored grain in western Canada (Sinha and Watters 1985). *Cryptolestes ferrugineus* feeds on broken grain, with preference for the germ. It can also complete its development solely on mould. It has a very

Fig. 4. A, *Cryptolestes ferrugineus*, the rusty grain beetle, and B, *Tribolium castaneum,* the red flour beetle, are two of the most common insect pests in stored grain in western Canada.

high rate of reproduction, capable of increasing 60-fold per month under ideal conditions (White *et al.* 1995*b*). This species is one of the most cold-tolerant insects found in stored grain (Fields 1992). Under the right temperature and moisture conditions, it can generate hotspots in the grain. *Tribolium castaneum* also feeds on broken grain and has a high rate of reproduction, 70-fold. However, it cannot withstand cold prairie winters (Fields and White 1997) but is present on farms every year, probably indicating dispersal from the more southerly United States.

Rhyzopertha dominica (Fabricius) (Bostrichidae) is abundant in western Canada (Fields *et al.* 1993), first being reported in Canada in 1894 (Potter 1935). It is virtually never detected in grain or in grain-handling facilities, presumably because of its slow rate of increase and the relatively rapid cooling of grain during the winter, which this species does not tolerate well. However, in 2007, it was encountered in grain more frequently by the Canadian Grain Commission. This species is typically a serious pest between 40° N latitude and 40° S latitude (Campbell *et al.* 1989). Gene flow and migration of *R. dominica* are widespread throughout North America, representative of its annual dispersal into Canada (Fields and Phillips 1994). This insect was firmly established in the southern United States by 1909 but became widespread during World War I, arriving in frequent shipments of Australian wheat (Schwardt 1933).

Farm Storage

Storage begins at the farm, and grain can be held on the farm for almost a year. Grain becomes infested in two ways: by insects flying into the grain or by insects already in the empty bin. Over 20 species associated with stored grain were collected in a flight trap (White *et al.* 1995*a*). The most common species captured were the fungivores *Atomaria* spp. (Cryptophagidae), *Melanophthalma* spp. (Lathridiidae), and *Cartodere constricta* (Gyllenhal) (Lathridiidae). One to three adults of the granivorous species, *C. ferrugineus,* were also caught flying. *Cryptolestes pusillus* (Schönherr) and *T. castaneum* were caught in several months for most years. The low frequency of these species does not reflect their common occurrence in granaries filled with cereals. Other less frequent granivores found were *Tenebroides mauritanicus* (L.) (Trogossitidae), *Alphitobius diaperinus* (Panzer) (Tenebrionidae), *Palorus subdepressus* (Wollaston), *Laemophloeus* sp. (Laemophloeidae), *Latheticus oryzae* Waterhouse (Tenebrionidae), *Gnathocerus cornutus* (Fabricius) (Tenebrionidae), *Attagenus* sp. (Dermestidae), and *Dermestes lardarius* L. (Dermestidae).

After grain has been emptied from a bin, the grain residues that remain often become infested. When newly harvested warm grain is placed in the bin, insects in the grain residues reinfest the new grain. Insects are found more frequently in empty bins in Saskatchewan, as there is a great deal more cereal production there than in Manitoba or Alberta (Tables 1 and 2). Intensive monoculture favours the presence and potential success of insects. Between 12 and 13 species of grain-feeding insects and 9 and 12 species of fungus-feeding insects have been found (Smith and Barker 1987). The most common grain-feeding insects are *Tribolium audax* Halstead, *C. ferrugineus*, *Tenebrio molitor* (L.) (Tenebrionidae), and *Ptinus villiger* (Reiter) (Ptinidae) (Table 1). The predominant fungus-feeding insects are *Monotoma* sp. (Monotomidae), *Lathridius minutus* (L.) (Lathridiidae), and *Cryptophagus varus* Woodroffe and Coombs (Cryptophagidae) (Table 2).

The main grain-feeding insects found in farm-stored grain in western Canada are *C. ferrugineus* and *T. castaneum* (Madrid *et al.* 1990) (Table 3; Fig. 4). These two insects have some of the highest rates of multiplication, 60- to 70-fold per month for stored-product insects (Howe 1965). These insects may be common in Canadian grain because it remains

Table 1. Number of samples collected from empty farm granaries in the prairie provinces infested with residual populations of stored grain insects (modified from Smith and Barker 1987).

Species	Occurrence in Samples (%)*		
	Manitoba	Saskatchewan	Alberta
Ahasverus advena (Waltl)	3	3	0.2
Attagenus unicolor (Brahm)	4	3	1
Cryptolestes ferrugineus (Stephens)	19	11	7
Cryptolestes pusillus (Schönherr)	1	0	0
Oryzaephilus surinamensis (L.)	1	0.4	0.2
Ptinus villiger (Reiter)	6	12	5
Pyralis farinalis L.	8	7	0.4
Tenebrio molitor (L.)	16	14	3
Tribolium audax Halstead	22	33	12
Tribolium castaneum (Herbst)	5	2	1
Tribolium confusum Jacquelin du Val	1	0	0

*Manitoba had 444 samples, Saskatchewan 762 samples, and Alberta 546 samples.

Table 2. Number of samples collected from empty farm granaries in the prairie provinces in which fungus-feeding insects were found (modified from Smith and Barker 1987).

Species	Occurrence in Samples (%)*		
	Manitoba	Saskatchewan	Alberta
Atomaria sp.	1	15	1
Cartodere constricta (Gyllenhal)	1	3	1
Corticaria serrata Paykull	0	18	26
Cryptophagus acutangulus Gyllenhal	1	11	3
Cryptophagus obsoletus Reitter	1	9	3
Cryptophagus varus Woodroffe and Coombs	4	31	12
Dienerella filiformis (Gyllenhal)	3	6	1
Enicmus fictus Fall	0	15	1
Lathridius minutus (L.)	13	38	19
Monotoma picipes Herbst	2	47	0.2
Mycetophagus quadriguttatus Müller	1	2	0.4

*Manitoba had 444 samples, Saskatchewan 762 samples, and Alberta 546 samples.

Table 3. Percentage of full-farm granaries in southern Manitoba infested by major taxa of insects and maximum numbers of insects captured per pitfall trap ($n = 16$ traps) in one week during three sampling periods in 1986–1987 (Madrid *et al.* 1990).

Feeding Type	Species	% Infestation (Max. No. Insects Per Trap)		
		Fall 1986	Summer 1987	Fall 1987
Granivores	*Cryptolestes ferrugineus* (Stephens)	8a* (15)	13a (2)	46b (300)
	Tribolium castaneum (Herbst)	1a (1)	1a (1)	30b (100)
Fungivores	*Typhaea* sp.	1a (1)	16b (4)	39c (100)
	Cryptophagus sp.	5a (3)	23b (18)	6a (18)
	Ahasverus advena (Waltl)	9a (7)	7a (1)	46b (100)
	Cartodere constricta (Gyllenhal)	16a (1)	24a (67)	44b (57)
	Psocids	9a (100)	1b (100)	37b (100)
Predators and parasites		15a (13)	75c (4)	58b (100)

* Values within a row not followed by the same letter are significantly different ($P < 0.05$).

warm only briefly after harvest. In the United States, where grain is harvested in July and the fall weather is warmer, *Sitophilus oryzae* (L.) (Curculionidae) and *R. dominica* are much more common than in Canadian grain (Pedersen 1992). Of interest, *T. castaneum*, the second most common insect in farm-stored grain in Canada, was not observed west of Manitoba in the grain-growing areas before 1955 (MacNay 1955).

The community of fungus-feeding beetles found in full bins was similar to that found in empty bins and residues, but also included *Typhaea* sp. (Mycetophagidae) and psocids (Psocoptera). Many species have been identified in stored grain and its products, but are of secondary importance or infrequent occurrence. The presence of fungivorous insects may be indicative of quality problems within the grain bulk or simply the result of their seeking safe harborage as outside temperatures decrease in fall. Six species of psocids reported in Canadian cereals (Campbell *et al.* 1989) tended to feed on broken and shrivelled grain, weed seeds and fungi.

Railcars and Elevators

Grain is shipped by rail from the primary elevators in the prairies to the terminal elevators located at ports in Vancouver, Prince Rupert, Churchill, and Thunder Bay. Grain is sampled upon arrival at the ports and insects extracted by using Berlese funnels. The most common insects found in the samples are *C. ferrugineus* larvae. Typically, this species is discovered in the range of 1–4% of cereal samples inspected from over 60,000 samples tested from railcar unloading at terminals annually (Fig. 5); discoveries are mostly made between May and November. The variation within the year is probably due to the build up of populations

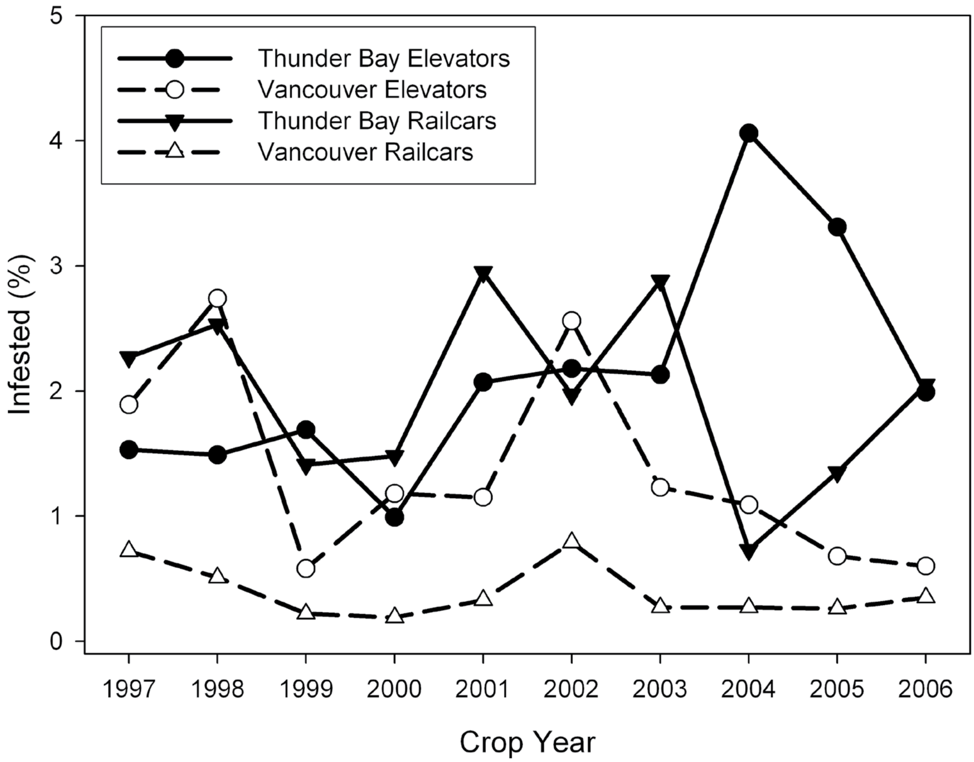

Fig. 5. Infestation of railcars and terminal elevators from 1997 to 2006. Berlese funnels were used to extract insects from grain. Most insects were *Cryptolestes* spp. larvae.

Table 4. Frequency of occurrence and rank of 10 most common arthropods in terminal grain elevators in Canada from 1969 to 1981 (Sinha and Watters 1985).

Rank	Species	Occurrence in Reports (%)*
1	*Tenebrio molitor* (L.)	17
2	*Nemapogon granella* L.	14
3	*Attagenus* spp.	10
4	*Cryptolestes ferrugineus* (Stephens)	7
5	Mites	5
6	*Sitophilus granarius* (L.)	5
7	*Cryptolestes pusillus* (Schönherr)	3
8	*Sitophilus oryzae* (L.)	3
9	*Pyralis farinalis* L.	3
10	*Tenebroides mauritanicus* (L.)	3

*Total number of reports is from 1,095 samples; 52% of reports indicated infestation.

Table 5. Frequency of occurrence (% of reports) of the most common arthropods in terminal grain elevators located in Thunder Bay and Vancouver from 1999 to 2007.*

Order	Insect	Occurrence in Reports (%)	
		Vancouver	Thunder Bay
Coleoptera	*Tenebrio molitor* (L.)	75	82
	Cryptolestes spp.**	39	15
	Tribolium castaneum (Herbst)	14	9
	Sitophilus granarius (L.)	9	0
	Trogoderma spp.	0	64
	Attagenus and *Dermestes* spp.	7	48
	Carpophilus spp.	0	18
	cryptophagid spp.	50	45
	lathridid spp.	0	25
	ptinid spp.	2	18
Lepidoptera	*Nemapogon granella* L.	0	76
	Haplotinea ditella (Pierce Metcalfe and Diakonoff)	0	33
	Hofmannophila pseudospretella (Stainton)	86	0
	Endrosis sarcitrella (L.)	42	0

*Mites, in low or high numbers, are discovered in virtually all samples. Fly larvae are distributed equally, being discovered in approximately 40% of the reports. Early instar immatures are not identified to species unless they are suspected of being a primary insect pest.

**Mainly C. ferrugineus, but some Cryptolestes pusillius.

in grain. Variation among years is probably due to the level of degree-day buildup over the growing season. Hot, dry years are more favourable to the occurrence of more generations per year than are years when extreme winter temperatures cause higher levels of mortality or when temperatures over the growing season are not conducive for multiple generations (and therefore larger populations) to develop (Woods *et al.* 1997) (Fig. 2).

In Vancouver, a strong positive relationship has been observed between the infestation in railcars and infestation discovered in elevator bins ($R^2 = 0.79$, $P < 0.007$; Fig. 5), which may indicate that the main source of infestation in Vancouver elevators is grain delivered to the elevators. In the eastern region, however, no correlation occurs between infestations in railcars and infestations in elevators ($R^2 = 0.25$, $P < 0.599$; Fig. 5), indicating that the main locus for infestations may be local rather than from grain delivered to Thunder Bay. More detailed studies are required to elucidate the factors causing infestations in terminal elevators.

Terminal grain elevators have been regularly sampled for over 50 years (Sinha and Watters 1985), and the insects found from 1969 to 1981 (Sinha and Watters 1985) (Table 4) are very

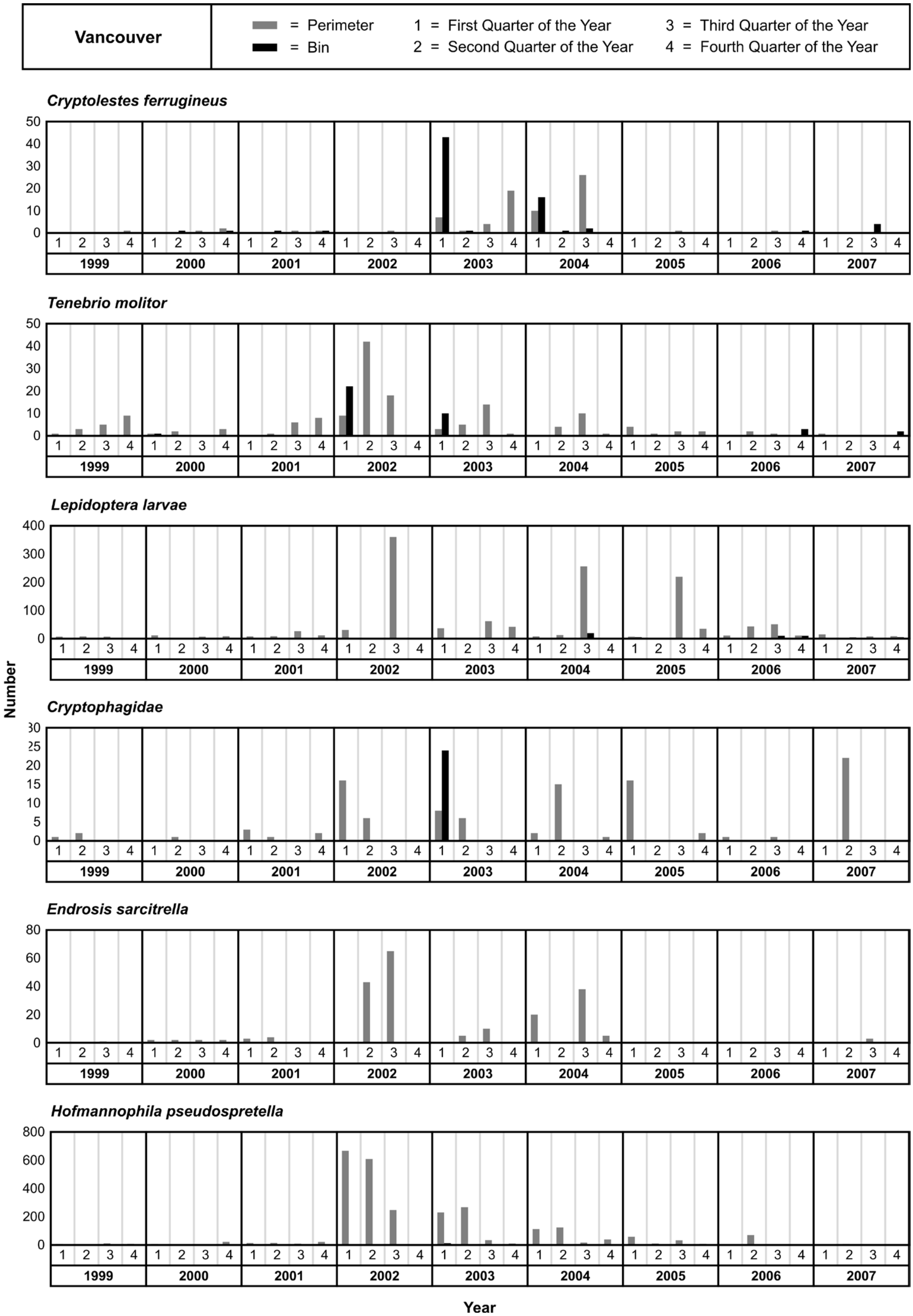

Fig. 6. Insects found in bins or in an elevator in Vancouver (perimeter) grouped by quarter from 1999 to 2007. Samples of grain or debris taken from the operating area of the terminal and grain within bins were collected and insects extracted by using Berlese funnels.

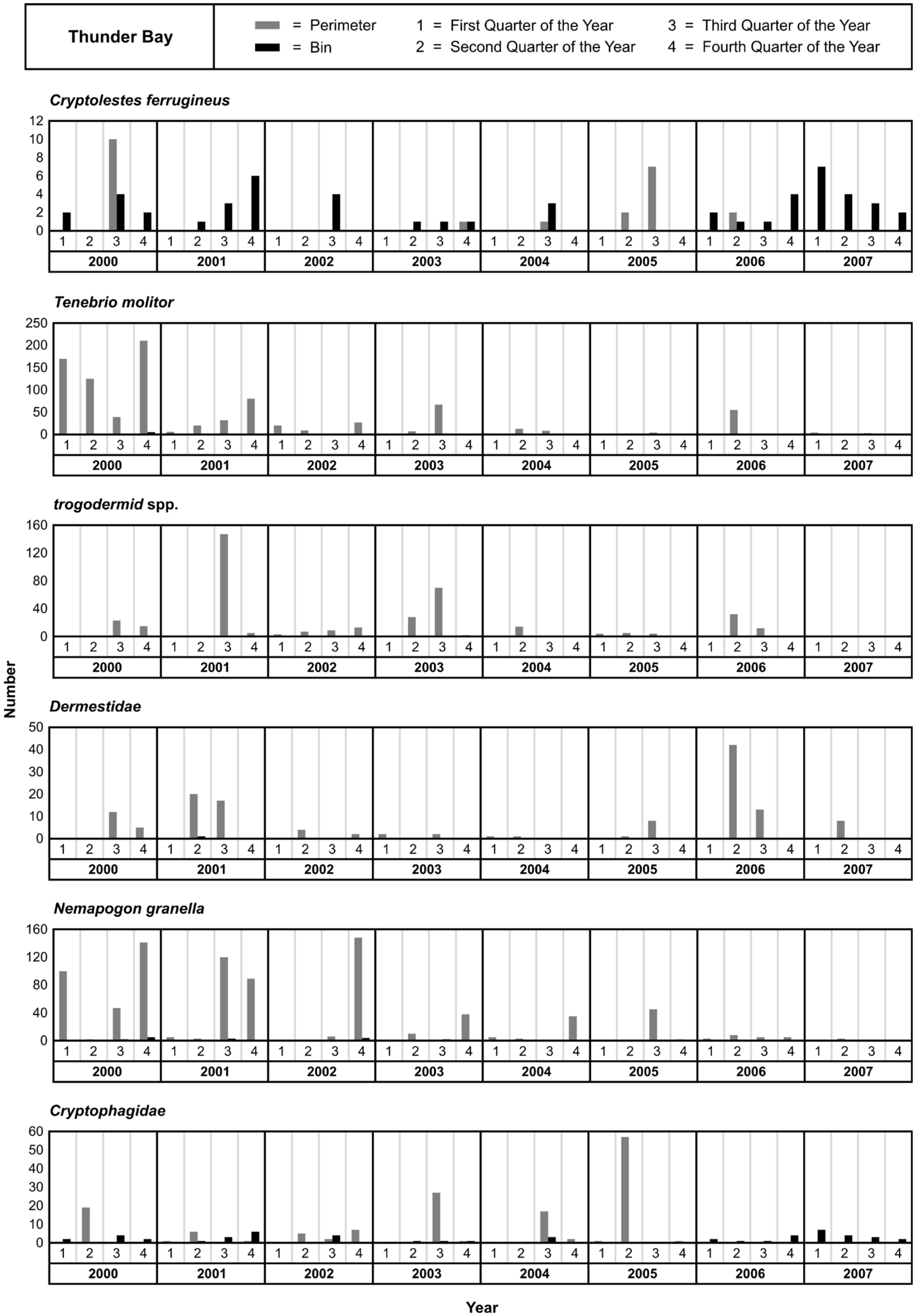

Fig. 7. Insects found in bins or in an elevator in Thunder Bay (perimeter) grouped by quarter from 2000 to 2007. Samples of grain or debris taken from the operating area of the terminal and grain within bins were collected and insects extracted by using Berlese funnels.

similar to what was found in 1999–2007 (Table 5). In Thunder Bay, *T. molitor* was the most common beetle discovered (82% of beetles), followed by, in order of frequency, *Trogoderma* spp., *Attagenus* and *Dermestes* spp., and cryptophagid spp. In Vancouver, the most frequent discovery of beetles was also *T. molitor,* followed by cryptophagid spp. and *Cryptolestes* spp. Moth discoveries in Thunder Bay are almost exclusively *Nemapogan granella* (L.) (Tineidae) (76% of reports), whereas in Vancouver, *Hofmannophila pseudospretella* (Stainton) (Oecophoridae) and *Endrosis sarcitrella* (L.) (Oecophoridae) were the dominant moth discoveries at 86% and 42% of occurrences, respectively. Insects are reported more now (Table 5) than they were 25 years ago (Table 4). This may be due to differences in reporting or sampling or to insects being more common now than they were 25 years ago.

Insect populations vary over time and space. This variation is seen for stored-product insects in terminal elevators (Figs. 6 and 7). Grain elevators are typically inspected several times per year to ensure that primary insect pests are not becoming established and thus threatening infestation of export shipments. During each inspection, samples of grain and/or debris from the operating area of the terminal and within bins are collected. Insects common to both Thunder Bay and Vancouver include *C. ferrugineus, T. molitor*, and various Cryptophagidae. Trogodermids (exclusively *Trogoderma inclusum* (LeConte), *T. glabrum* (Herbst), and *T. variable* Ballion) and other Dermestidae (exclusively *Attagenus unicolor* (Brahm), *Dermestes lardarius,* and *D. maculates* DeGeer) have been found in the Thunder Bay elevator examined, but not in the Vancouver facility.

In addition, moths differ between the facilities in Vancouver and Thunder Bay. *Nemapogon granella* L. is the only moth species found in Thunder Bay, whereas *E. sarcitrella* and *H. pseudospretella* are found in Vancouver terminals. Other species of arthropods such as psocids, mites, and springtails have been discovered in both locations but were not recorded. Within the working area (perimeter) of the terminals, *T. molitor* is the most common beetle found in both elevators, followed by cryptophagid beetles. Within bins, *C. ferrugineus* is most common in both terminals, followed by cryptophagids in Thunder Bay and *T. molitor* in Vancouver.

Differences in the species found in the Vancouver terminal compared with the Thunder Bay terminal are likely caused by several factors: variations in climate, Vancouver being much more temperate than Thunder Bay; grain sourcing, Vancouver typically receiving grain from the western prairies and Thunder Bay receiving most of its grain from the eastern prairies; and any differences between grain management, frequency, and effectiveness of cleaning and pest control.

Differences in species composition and frequency within terminal elevators over the years are most likely due to regional climate and the forces that impact the population's growth such as the species of insects that are originally present, the natural enemies of insects, previous management of insects, and grain management. Within bins, the climate and management strategies used to clean and treat grain are the most important factors in determining how quickly and to what extent a pest population develops.

Processing Facilities

The flour beetles, *T. castaneum* and *T. confusum,* are the most common insects found in flour mills (Table 6) and feed mills (Table 7). Some insects, such as *T. castaneum*, *Sitophilus granarius* (L.), *T. molitor,* and *Cryptolestes* spp. found on the farm and in grain elevators, are also found in processing facilities. The major insect found in processing facilities, but not commonly found in bulk grain, is *T. confusum.* It cannot fly and it is relatively cold susceptible, which may be contributing factors to its absence in bulk grain. However, *S.*

Table 6. Frequency of occurrence and rank of 10 most common insects in flour mills in Canada from 1969 to 1981 (Sinha and Watters 1985).

Rank	Insect	Occurrence in Reports (%)*
1	*Tribolium castaneum* (Herbst)	25
2	*Tribolium confusum* Jacquelin du Val	20
3	*Tribolium* spp.	7
4	*Attagenus* spp.	5
5	*Sitophilus granarius* (L.)	4
6	*Gibbium psylloides* (Czenpinski)	3
7	*Tenebrio molitor* (L.)	3
8	*Cryptolestes pusillus* (Schönherr)	3
9	*Cryptolestes ferrugineus* (Stephens)	3
10	*Tenebroides mauritanicus* (L.)	3

*Total number of samples is 1,019; 69% of reports indicated infestation.

Table 7. Frequency of occurrence and rank of 10 most common insects in feed mills in Canada from 1969 to 1981 (Sinha and Watters 1985).

Rank	Insect	Occurrence in Reports (%)*
1	*Tribolium castaneum* (Herbst)	14
2	*Tribolium confusum* Jacquelin du Val	13
3	*Attagenus* spp.	12
4	*Nemapogon granella* L.	6
5	*Cryptolestes ferrugineus* (Stephens)	6
6	*Tenebrio molitor* (L.)	6
7	*Oryzaephilus surinamensis* (L.)	5
8	*Plodia interpunctella* (Hübner)	4
9	*Tribolium* spp.	4
10	*Tenebroides mauritanicus* (L.)	3

*Total number of reports from 413 samples; 55% of reports indicated infestation.

granarius also cannot fly and is regularly found in bulk grain in elevators; thus, flightlessness does not preclude a pest from being in bulk grain. *Oryzaephilus surinamensis* (L.) and *Plodia interpunctella* (Hübner) (Phycitidae) tend to be found in processed products, dry animal foods and warehouses.

Mites

Mites have been associated with stored grains and other foods for many years; however, their destructive role has been overshadowed by those of insect pests and fungi (Sinha 1979). As early as 1880, the grain mite, *Acarus siro* L. (Acaridae), was reported to multiply on cheese and flour in Ontario (Sinha 1979). Ten additional species, including *Cheyletus eruditus* (Schrank) (Cheyletidae), *Carpoglyphus lactis* (L.) (Carpoglyphidae), and *Rhizoglyphus* spp. (Acaridae), were reported to infest foods such as whole wheat, flour, barley seed, dried fruits, ham, cheese, and sugar (Jarvis 1909). Because of the close proximity of household bulk foods to human inhabitants, these infestations of both mites and insects have been more noticeable than have those occurring in outside storage structures.

Another common species, *Lepidoglyphus* (*Glycyphagus*) *destructor* (Schrank) (Glycyphagidae), began appearing in grain elevators at Fort William (Thunder Bay), Ontario, in 1919 (Sinha 1979). *Lepidoglyphus destructor* was well-established in farm granaries and elevators throughout the prairie provinces during 1939–1942 (McLaine 1943), when up to 75% of local granaries were infested (Sinha 1963*b*). Smallman (1942) reported five common species of mites in western Canadian stored grain: *A. siro*, *L. destructor*, *Glycyphagus domesticus* (DeGeer), *C. eruditus*, and *Parasitus* spp. (Parasitidae). Ryan (1943) found *L. destructor* to be the most common mite species during inspections of large government elevators in Montreal, Quebec, during 1940–1943. Grain was being stored for extended periods during World War II and this necessity resulted in large stocks of surplus grain, which provided favourable harbourages for mites and insect pests (Loschiavo 1990). After the war, many grain-importing countries began to develop inspection systems

Table 8. Number of stored-product mite species recorded in Canada from 1873 to 1960 (Sinha 1963*b*).

Location	Number of Mite Species
British Columbia	14
Alberta	21
Saskatchewan	41
Manitoba	39
Prairie provinces combined	65
Ontario	34
Quebec	18
Atlantic provinces	18
Total species recorded	90

Table 9. Stored-product mites occurring in the prairie provinces listed in order of frequency in published and museum records, with their respective ecological niche (after Sinha 1963*b*).

Species	Feeding Type		
	Primary, Directly on Grain	**Secondary, on Fungi or Scavenger**	**Predator or Parasite, on Other Mites or Insects**
Lepidoglyphus destructor (Schrank)	x	x	
Acarus siro L.	x		
Cheyletus eruditus (Schrank)			x
Androlaelaps (*Haemolaelaps*) *casalis* (Berlese)			x
Tarsonemus spp.		x	
Tydeus interruptus Sig Thor		x	x
Haemogamasus pontiger Berlese			x
Parasitus spp.			x
Pergamasus spp.			x
Androlaelaps (*Haemolaelaps*) spp.			x
Bdella longicornis (L.)			x
Caloglyphus spp.		x	
Blattisocius (*Melichares*) *tarsalis* (Berlese)			x
Blattisocius (*Melichares*) *keegani* (Fox)			x

for quality assurance of imported grain and other food products, and so Canadian grain shipments came under more rigorous inspection (Sinha 1964*a*). At the same time, more attention within Canada was given to the quality of stored grain, aimed at maintaining our reputation as providers of high-quality cereal products for export. Surveys of bulk grain and empty granaries collected 90 species; some were predaceous and others were mycophagous (Sinha 1963*b*) (Table 8). Saskatchewan had the most diverse fauna with 41 species, followed by Manitoba with 39; the three prairie provinces combined (Alberta, Saskatchewan, and Manitoba) had a total of 65 of the 90 species (the same species occurred in different regions).

The highest frequencies of stored-product mites are for two primary grain feeders, *L. destructor* and *A. siro*, and the two predators known to feed on them, *C. eruditus* and *Androlaelaps* (*Haemolaelaps*) *casalis* (Berlese) (Laelapidae) (Sinha 1979) (Table 9). In 1981, a Manitoba survey was conducted to determine the occurrence of stored-product mites in empty farm-bin sweeping/residues and spills. Seventy-six farms were visited and a total of 431 bins sampled between 8 July and 20 August 1981. One hundred forty-one bins had previously held wheat, 122 barley, 52 oat, 43 rapeseed, 13 sunflower, 5 each durum wheat and corn/chop, and 7 miscellaneous grains; 17 samples were from various spilled grain found outside and near bins. Nearly 95% of samples contained one or more species of mites. The four top-ranking mite species were found to be the same two primary grain feeders and two predators recorded historically (Table 9), albeit the predators *Androlaelaps* (*Haemolaelaps*) spp. and *C. eruditus* occurred more frequently than did the grain feeders *A. siro* and *L. destructor* (CJD, unpublished) (Table 10).

A similar survey of 207 farm bins in Saskatchewan in 1982 showed an 82% occurrence for the predators *Androlaelaps* spp. and *Blattasocius* spp. (Ascidae) (combined), 72% occurrence for *Acarus* spp., and 52% occurrence for *C. eruditus* (CJD, unpublished). The presence of *Aeroglyphus robustus* (Banks) (Glycyphagidae) (Table 10) reflects its recent appearance in the historical record. Its first occurrence was reported by Sinha *et al.* (1962) from a 9,000-t wheat bulk stored seven years in an aircraft hangar in Yorkton, Saskatchewan.

Lepidoglyphus destructor and *A. siro* are the two most common mite pest species associated with grain stored on the farm or in primary elevators in western Canada (Sinha

Table 10. Percentage of empty farm bins and spills containing stored-product mites in Manitoba in 1981 (CJD, unpublished).

Species	Occurrence (%)
Androlaelaps spp.	80
Cheyletus eruditus (Schrank)	55
Acarus spp.	47
Lepidoglyphus destructor (Schrank)	40
Tydeidae spp.	16
Aeroglyphus robustus (Banks)	14
Tarsonemus spp.	<1
No mites	5

1963*b*). Their presence in large numbers can make grain and its products unacceptable and unpalatable for human or animal consumption. In additional, human allergic sensitivities can occur to mite bodies and excreta within grain dust (Revsbech and Andersen 1987). *Lepidoglyphus destructor* cannot chew through the hard parts of seeds, preferring instead to feed on grain dust, broken kernels, and the field fungus *Alternaria alternata* (Fries) Keissler (Dematiaceae). Akimov (in Sinha 1979) has suggested that the digestive system and enzymes of *L. destructor* are adapted to assimilating small particles. Chronic occurrence by this species is linked with seasonal temperatures, and periodic outbreaks tend to be linked with the abundance of *A. alternata* (Sinha and Wallace 1973). In contrast, acarid mites such as *A. siro* have mouthparts that can penetrate grain kernels, causing internal seed changes. *Acarus siro* prefers to feed on the seed germ, and its digestive and enzyme systems enable it to assimilate hard particles. Economically, it is the most important mite pest of stored grain in Canada (Sinha 1963*b*). Periodic outbreaks can occur every few years unaffected by grain aging (Sinha and Wallace 1973). Both species can form a hypopal stage, which does not feed and can be resistant to unfavourable conditions such as desiccation (Griffiths 1964). Sinha (1964*b*) reported their survival at temperatures of −18 °C. The hypopus of *L. destructor* is inactive, whereas that of *A. siro* is mobile, which may serve as a means of dispersal in adverse conditions (Hughes 1976) or to avoid predation. Predators such as *A. casalis* and *C. eruditus* appear to be dependent on the densities of prey populations within the bin, usually following a similar population growth and crash as that of the prey, but somewhat delayed (Sinha 1963*b*; Sinha and Wallace 1973).

Generally, mites are no longer a major problem in grain storage because of better management of grain temperature and moisture content. Problems can develop through poor storage management or breakdown in handling equipment or structures that allow deterioration of the product to occur; a leaking roof or open hatch may allow water to enter, resulting in localized seed sprouting, fungal growth, and heating.

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