STORED PRODUCTS ENTOMOLOGY IN CANADA

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HISTORY

Insects that infest stored grain and cereal products have posed problems in Canada since at least the 1850s. Probably the first record of a stored product insect in Canada was by Dupont on the granary weevil Calandra granaria (= Sitophilus granarius) (Linnaeus) from Cote de Beaupré, Quebec in 1857 (1). In 1884, James Fletcher found the pea weevil, Bruchus pisorum (Linnaeus) in Canadian seed collections, and by 1902, this species was estimated to cause losses of more than one million dollars annually (2). The consequence was a significant reduction of pea acreage in Canada. In 1889, Fletcher's discovery of the Mediterranean flour moth, Ephestia (= Anagasta) kuehniella Zeller was a first record of this species for North America. In 1916, Arthur Gibson noted it to be the most important pest during a national survey of flour mill insects. In 1898, the bean weevil, Acanthoscelides obtectus (Say) was recorded for the first time as a pest of stored beans in Canada (2).

In 1913, W.A. Ross used high temperature in a flour mill in Dundas, Ontario to control the Mediterranean flour moth. This was the first time that heat was used to control a stored product insect in Canada. In 1916, C.G. Hewitt served with C.J.S. Bethune, Ontario Agricultural College and E.M. Walker, University of Toronto on a committee appointed by the Royal Society of Canada to investigate the economic importance and control of insects infesting stored grain (3).

In 1919, E.H. Strickland, then employed by the Canadian government, studied the economic species of mites in grain stored in eastern terminal elevators and insect pests in flour mills and dried fruits. Gibson studied life histories and habits of several stored product pests. From 1924 to 1928, C.H. Curran assisted him and published a list of common stored pest species and a paper on the identification of adult months of stored products. In 1929, Gibson and C.R. Twinn published an illustrated bulletin entitled "Household Insects and Their Control", with revised editions appearing in 1931 and 1939 (4).

In 1931, grain was examined for insects in Canadian grain elevators. In 1932, Twinn found mites in terminal elevators at the lakehead cities of Fort William and Port Arthur, Ontario.

As the above reports indicate, there was no systematic or cohesive approach to stored product entomology in earlier years, and problems in this discipline were handled on an ad hoc basis by federal entomologists in field and orchard crops.

However, serious infestations of the hairy spider beetle, Ptinus villiger (Reitter) in western Canada led to the appointment of H.E. Gray in 1932 to investigate stored products insect problems on a continuing basis (2). A temporary laboratory was set up in Winnipeg to study the spider beetle problem and devise control measures. After two years, Gray was transferred to Ottawa.

In 1934, he surveyed flour mills in eastern Canada to examine flour shipments to Norway and the ships carrying the flour. The ships were not infested but most of the mills were. Cooperation between Canadian and Norwegian authorities and meetings on sanitation resulted in better conditions in Canadian mills. This policy and practice continued through the second world war. Also in 1934, Gray developed a standard inspection technique for grain-carrying ships (2). The technique was used in a program to inspect lakers and ocean-going grain vessels beginning with the outbreak of the war in 1939. To achieve this aim, inspectors of the Plant Protection Division of the Federal Department of Agriculture were trained in ship inspection. The program was so successful that it has continued and become standard practice at the Canadian lake and ocean ports for grain-carrying ships.

The necessity for long-term grain storage during the war years led to an increase in insect problems. In 1940, the Indian meal moth reached outbreak proportions in terminal elevators at several Georgian Bay ports. Grain was being stored in annexes and other temporary storage structures, some of them unsuitable for this purpose. Consequently, problems arose with the grain mite, Acarus siro Linnaeus and the rusty grain beetle, Cryptolestes ferrugineus (Stephens). B.N. Smallman, a grain inspector with the Board of Grain Commissioners, Winnipeg, in 1941 was seconded to the Entomology Division to investigate grain insect problems in the war-time storages under the Board's jurisdiction. The efforts of the stored product entomologists during the war contributed in large measure to the maintenance of sanitary grain storage facilities, thus ensuring supplies of insect-free, wholesome food for overseas shipment.

H.H.J. Nesbitt was with Gray from 1936 to 1948 (2). In 1947, J.W. Arnold joined the Ottawa staff of the Stored Product Insect Unit (5). He, Nesbitt and Gray as head were the agricultural scientists. In addition, there were three technical support people and a stenographer. The laboratory was located in the basement of a downtown Ottawa building until 1948 when it was moved to the Science Service Building, Central Experimental Farm, which is now the old wing of the K.W. Neatby building. During 1948, Nesbitt collected mites in Nova Scotia, and Arnold inspected grain elevators and flour mills in the Vancouver area. Nesbitt resigned in the fall of 1948 to go into university teaching. J.H. Follwell joined the Ottawa staff in 1949, principally as an extension entomologist and then proceeded to Vancouver to establish a

laboratory there. He returned to Ottawa in 1952 and was succeeded in Vancouver by P. Zuk, formerly with the Plant Protection Division. About 1957, he reported through the Entomology Section of the Research Station in Vancouver but continued his work on stored products insects in terminal elevators in the Vancouver area.

After the war, Smallman and B. Berck, a chemist with the Grain Research Laboratory in Winnipeg, were transferred to the Entomology Division. The Winnipeg laboratory was re-established in 1946 with Smallman in charge. In the same year, F.L. Watters joined the staff as a senior agricultural assistant. In 1951, Smallman was transferred to the Entomology Research Institute in London, Ontario, and Watters became officer-in-charge of the Winnipeg laboratory. Support staff consisted of two technicians, G.A. Cox and R.A. Sellen, and a stenographer. The laboratory was located in the Dominion Public Building on south Main Street.

The most rapid expansion in stored product entomology occurred in the 1950s (see Appendix). S.R. Loschiavo joined the Ottawa laboratory in 1950 after spending seven months at the Winnipeg laboratory. In 1956, he was transferred to Winnipeg when it was decided that research in stored product entomology should be consolidated there. E.F. Cashman joined the Ottawa staff in 1951 but resigned in 1953 to study medicine. Follwell returned to Ottawa from Vancouver in 1952 and resigned a year later to enter private industry. D.B. Waddell who had come from the Science Service Laboratory in Summerland, B.C. went to Ottawa in 1953 after spending a few months at the Winnipeg laboratory. He spent two years with the stored product unit and then transferred to the Administration Unit. L.B. Smith joined the Ottawa group in 1955. After graduate studies in England from 1957 to 1960 he returned to his position which had been transferred to Winnipeg. When the stored product entomology program was moved to Winnipeg in 1956, Gray transferred to the Board of Grain Commissioners and became its first entomologist, but he remained in Ottawa.

During the years between 1948 and 1956, Gray's extensive travels on behalf of the Stored Products Insects Unit and FAO kept him away from Ottawa most of the time thus depriving the staff of firm continuous leadership and direction and a climate in which research could flourish. Despite this drawback, some excellent fundamental and applied work was conducted and published.

In 1957, the Winnipeg laboratory was moved to the newly established Research Station on the campus of the University of Manitoba. At the same time, the Field Crops Laboratory at Brandon moved to the same building where all federal entomological research in Manitoba was consolidated. R.D. Bird, who had been officer-in-charge at Brandon, was appointed head of the entomology section, including stored product entomology (6). The entomologists and cereal breeders, rust pathologists and quality control scientists who formerly had been part of the Dominion Rust Laboratory, together with support and administrative personnel, formed the staff of the Research Station under its first director, T. Johnson. At this time, the stored products

staff of professionals consisted of F.L. Watters, B. Berck, S.R. Loschiavo, and E.A.R. Liscombe who had joined the staff in 1956. The following year, R.N. Sinha was added to the professional staff. As mentioned earlier, Smith went to Winnipeg in 1960 to resume the position which had been transferred from Ottawa in 1956.

Liscombe resigned in 1965 to become the entomologist for the Board of Grain Commissioners in Winnipeg and was succeeded by P.S. Barker. The late H.A.H. Wallace, who had started with the Cereal Diseases Section at Winnipeg in 1938, was formally transferred to the crop protection group in 1964 when he continued collaborative work with Sinha and Mills until he retired in 1972. He continued working on fungi associated with stored grain for 10 years after his retirement.

In 1966, Bird retired and A.J. McGinnis, who was transferred from the Lethbridge Research Station, became head of the crop protection section which included the entomologists from the field crop laboratory at Brandon and the stored products entomologists from the amalgamated Ottawa and Winnipeg laboratories. J.T. Mills came in 1967 from Trinidad as a mycologist to succeed J.E. Machacek and became associated with the stored products entomologists. Mills began working full-time on storage mycology in 1974 and became officially a member of the stored products group in 1981. McGinnis left in 1972 to assume the directorship of the Vineland station. By this time, Watters had returned from a two-year tour of duty as a grain storage specialist with the Food and Agriculture Organization of the United Nations, and was appointed as head of the section. He held this position until his retirement at the end of 1981, at which time Loschiavo was appointed as section head.

In 1978, D. Abramson joined the stored products group as a mycotoxicologist. In 1981, N.D.G. White assumed the duties and responsibilities of Watter's position. A computer modeller, H. Kawamoto was hired to a two-year term position from 1989-1991, and P.G. Fields joined the stored-products group in 1988 to study the behavior and physiology of stored product insects, following the retirement of S.R. Loschiavo.

By 1983, each of the scientists in the crop protection section was working on one or more discipline areas of research dealing with stored cereals and oilseeds. In 1983, the name was changed to the Stored Products Section to more precisely reflect its mandate. In 1983, the professional staff consisted of Drs. Abramson, Barker, Loschiavo, Mills, Sinha, Smith and White (see Appendix). The technical staff was made up of J.M. Barron, R.J. Bell, C.J. Demianyk, G.H. Hamilton, R.W. Jenkins and T. Thorsteinson. L.B. Smith retired in 1986 and S.R. Loschiavo retired in 1987.

In 1989 the stored products group and integrated pest management entomologists at the Winnipeg Research Station were amalgamated into the Crop and Stored Products Section with the Crop Storage Project consisting of Drs. N.D.G. White (Project Leader), D. Abramson, P.S.

Barker, P.G. Fields, H. Kawamoto, J.T. Mills, and R.N. Sinha. Technical staff were J.M. Barron, R.J. Bell, C.J. Demianyk, R.W. Jenkins and D. Smith.

PAST AND CURRENT RESEARCH

The long distance separating the Ottawa Headquarters stored product laboratory from the major grain-growing regions of Canada influenced the type and direction of research that could be conducted. At Ottawa, most of the work was done in the laboratory although practical or mission-oriented research was included (5). Gray devoted himself almost entirely to extension work, visiting and inspecting many of the terminal elevators at both coasts, the Lakehead, the Georgian Bay ports, and the terminal elevators along the St. Lawrence seaway. He was instrumental in establishing inspection methods for flour mills and grain elevators and conducting, with the aid of his research staff, short refresher courses for inspectors in regulatory agencies of government. His familiarity with senior management in terminal elevators and mills helped to generate in the industry an appreciation of the importance of insect pests. In addition to doing extension work and attending to his administrative duties as head, Gray also undertook short-term field tests of fumigant effectiveness in areas of western Canada where outbreaks of the rusty grain beetle had occurred. Sometimes other research officers had to temporarily abandon their long-term laboratory projects to help in short-term control projects in the field. In fact, from 1947 to 1949, research officers could not devote their attention to long-term programs and had to limit their research to short-term projects such as effectiveness of inert dusts as grain protectants, toxic effects of various fumigants, and movements of flour beetles in flour, and granary weevils in wheat (5). The results appeared in laboratory reports and in-house reports of the Entomology Division.

Initially in 1947, Arnold compared the effectiveness of inert dusts as grain protectants, compared fumigant toxicity, and started a laboratory study of the movements of flour beetles in flour, and granary weevils in grain. He became interested in locating the site of action of fumigants in insects by histological methods. From 1949 to 1952, this project developed into a study of blood cell classification in the Mediterranean flour moth and the effect of fumigants on the different kinds of blood cells. Additionally, Arnold investigated the effectiveness of paradichlorobenzene and other insecticides (5). Nesbitt, one of the earliest members of the Ottawa laboratory, studied the biology and taxonomy of mites until his resignation in 1948 to teach at Carleton University. Follwell's primary work was to analyze conditions in Ontario mills and prescribe good housekeeping to help prevent or minimize insect infestations. He began a study of the biology of Laemophloeus (now Cryptolestes) in 1952 but this project was discontinued after his resignation.

Waddell's few months in Winnipeg in 1953 were spent primarily on surveys of insects in farm-stored grain during which he collected insects which he took to Ottawa in 1953 to organize and identify. He was unable to complete this work before he transferred to administration. He participated in some preliminary work on insect control in terminal elevators. During his two

years with the Ottawa laboratory between 1951 and 1953, Cashman found out that parental feeding had no effect on the rate of development of progeny of the confused flour beetle. He also helped evaluate insect-proof packaging for prepared food mixes and became involved in a study on the effect of the mechanical action of milling machinery on the development and reproduction of mill insects (5).

From 1950 to 1956 in Ottawa, Loschiavo investigated the effectiveness of DDT to control flour mill insects, effects of sub-lethal exposures of flour beetles to fumigants, and insect food preferences in specially designed equipment. After transferring to Winnipeg he continued food preference studies, completed a life history - behavior study of a dermestid, Trogoderma parabile Beal (now T. variabile) and found a previously unknown coccidian pathogen of this species. After a year at the University of Wisconsin in 1961 he returned to Winnipeg where he developed a photometric method to study the chemosensory behavior of flour beetles. Individually or collaboratively he has investigated locomotory, feeding and reproductive behavior of rusty grain beetles on wheat and storage fungi, measured effects of disturbance on survival and reproduction, developed an escape-proof detection device for insects in grain and evaluated it in laboratory and field tests, developed a flour beetle assay to assess the nutritive value of cereals as feeds, measured growth effects of vitamins and fungi in insect diets, determined the distribution and economic importance of the merchant grain beetle, Oryzaephilus mercator Fauvel in Canada, conducted a survey of stored products insects in Hawaii, and helped to characterize triglycerides in wheat germ and the fungus Nigrospora sphaerica that elicit aggregation in flour beetles. He has evaluated antifeeding compounds, insect growth regulators, pheromones, and new insecticides potentially useful against stored products insects. He has been involved in a study of the effects on growth, development and reproduction of several species of stored grain insects reared on early and recent cultivars of canola seed. He has compiled and edited a departmental brochure on insects, molds and mites in farm-stored grain in western Canada. The stored product group contributed to the revised, updated version which remained current from 1983-1990 and was updated in 1990 with J. Mills acting as editor. Loschiavo was Section Head of the Stored Products Section from 1982 - 1984.

Watters' primary interest was in the physical and chemical control of stored products insects and biology. His research on physical control was concentrated on control of insects by high frequency electric fields and gamma radiation for the control of stored products insects, protection of packaged foods with silica gel, and the value of cotton and jute flour bags in reducing infestations by the hairy spider beetle. In his chemical control work, he evaluated synergistic mixtures of pyrethrins and piperonyl butoxide against flour mill insects, effectiveness of spot fumigants in flour mill equipment, effects of moisture content on residual toxicity and repellency of malathion, effectiveness of chlorinated hydrocarbon and organophosphorus insecticides against the hairy spider beetle, persistence and uptake of malathion and bromophos, toxicity and persistence of insecticides on building surfaces such as concrete, wood and metal, uptake of bromophos by stored rapeseed, and the use of organophosphorus insecticides for

controlling susceptible and malathion-resistant strains of the red flour beetle. In biology, Watters studied the effects of temperature on insecticidal toxicity, the locomotor activity of some species of stored products insects, and environmental factors influencing the development and rate of increase of the larger grain borer, Prostephanus truncatus (Horn) on stored maize.

In the early 1950s, Smallman, Watters and Berck were mainly concerned with the evaluation of new contact insecticides and fumigants for the control of insects in stored grain and flour mills, radio frequency sterilization, and the susceptibility of mill stocks to insect infestations. As officer-in-charge, Smallman created an atmosphere in which research could flourish. He not only stimulated and encourage his staff but also set example by his personal output of high quality research.

Berck as a chemist initially worked on developing methods to measure DDT and then measured losses in boxcars carrying flour as well as absorption and efflorescence of DDT deposited on wood. Later, he studied the factors that included fumigation, fumigant retention on treated shelled walnuts, and developed analytical methods to determine fumigants in air. He demonstrated that wheat acts as a chromatographic column toward several fumigants in the vapor phase and that carbon tetrachloride, when present in admixture, acts as an eluting agent. He measured the distribution and persistence of methyl bromide, ethylene dibromide, and carbon tetrachloride applied in grain fumigant mixtures and their sorption by cereal products. Berck retired in 1977.

Upon his arrival in Ottawa, Smith carried out several short-term projects including evaluation of pyrenone sprays to protect stored grain from the Indian meal moth, factors affecting population increase, and a description of a white-eyed strain of this species. After arriving in Winnipeg in 1960, Smith embarked on long-term research on the biology and population dynamics of stored products insects. His study of the intrinsic rate of increase of the rusty grain beetle has added to our knowledge of the biology of this serious pest of grain in western Canada. One of Smith's objectives was to determine cold tolerance levels for the ten most important species of stored grain insects. This study has enabled recommendations of temperatures and exposure times that will kill rusty grain beetles in stored grain. His finding that the flour beetle Tribolium madens, a new pest in Canada, can survive at -5°C for four weeks indicates that this insect can successfully overwinter in some parts of Canada. In a collaborative study of a history of infestation in a terminal elevator, it was shown that turning grain in winter controlled infestations of this species. Smith's mandate included a distribution study of insects in farm granaries in western Canada. His survey of boxcars loaded with grain in western Canada showed that almost half of them were infested with insects. His other research activities included the taxonomy of various species of insects associated with stored products.

Liscombe's work during his relatively short period in stored products entomology was on surveys and insect control in flour mills and warehouses. His survey of empty granaries

provided useful information on the kinds of mites and insects found in grain residues on the floor, cracks and crevices on floors and walls, and grain spillages. He also calculated milling losses due to infestation of wheat used for flour production. Liscombe resigned in 1965.

Barker, who succeeded Liscombe, assumed responsibility for research on the control of mites and beetles associated with stored products. As a prerequisite to the chemical control of mites, he conducted an extensive series of studies on the biology and life history of several species of mites. He then initiated research to develop economical and effective methods of fumigation against stored products insects. An important finding was that the fumigant phosphine generated from hydrogen phosphide gave poor control of mite eggs and hypopi as well as poor control of insect eggs. Barker's other main objectives were to determine the efficacy of fumigants and atmospheric gases such as carbon dioxide against adults and eggs of stored products insects, to establish rates of application of fumigants, and to evaluate synergists for use with insecticides.

Sinha's initial research was on the role of insects, mites and fungi in the heating of stored grain. Early in his career he devoted considerable time to studies of granary ecology of mites associated with stored grain. Later, in collaboration with associates, he elucidated the factors that contribute to the heating of grain in storage. He and his colleagues, including Prof. W.E. Muir, Department of Agricultural Engineering, University of Manitoba, have developed an ecosystem approach to the protection of cereals and oilseeds from post-harvest losses due to insects, mites and microflora. This approach is based on the premise that stored grain is a man-made ecological system in which deterioration of grain results from interactions among physical, chemical and biological variables. The storage ecology program includes studies on the inter-relationships of insects, mites and fungi in the aging and deterioration of stored cereal grains and oilseed, the measurement of abiotic and biotic variables in stored grain ecosystems, grain aeration, energy budgets for major stored grain insects and determination of moisture-temperature equilibrium curves and post-harvest pest infestation potential for cereal and oilseed cultivars.

Wallace collaborated with Sinha for several years elucidating the role of insects, mites and fungi in the heating of stored grain and the interrelationships of mites, insects, and fungi in the aging and deterioration of stored grain. In 1983, Sinha and F.L. Watters completed a monograph on insect pests of stored wheat and other cereals and their products in terminal elevators, flour mills and feed mills. The monograph is designed for use by the grain industry, regulatory agencies, researchers and students.

During his term as section head, McGinnis maintained an active interest in research. Because of his background in insect nutrition, he became interested in studies on the chemosensory behavior of stored products insects and collaborated with Loschiavo in this area. He and others found that triglycerides in wheat germ elevated aggregation responses in flour beetles. McGinnis also participated in the development of an insect bioassay to evaluate cereal grains as feeds.

Mills' work on fungi associated with stored grain led to a collaboration with Sinha in storage ecology. He initiated a project on the development, prediction and prevention of molds associated with loss of quality in stored cereals, oilseeds and their products. He has established the invasion route of storage fungi into mature canola seeds and has shown that specific fungal enzymes are involved. He has developed a fluorescence method for determining fungal growth within seed coat tissue. His recent and current research activities include studies of microflora in damp seed in swath and in storage, identification of mycotoxin-producing molds, establishment of safe storage limits for cereals and oilseeds, storability of frost-damaged canola seeds, evaluation of susceptibility of new cereal and oilseed cultivars to invasion by storage molds, and identification of molds in stored wheat treated with malathion. In 1989, he published a comprehensive manual on "Spoilage and Heating of Stored Agricultural Products". He served as Section Head of the Stored Products Section from 1984-1990.

Abramson, as a mycotoxicologist, has focused on mycotoxin-producing fungi and mycotoxins in cereal grains, oilseeds and feeds. He has collaborated with Mills and Sinha to determine ecological causes of mycotoxin production in moist cereals and to develop analytical methods for early detection of grain deterioration. Abramson and Mills have investigated conditions affecting toxin production using cultures of toxigenic fungal strains obtained from samples of cereals and oilseeds in western Canada. In collaboration with veterinarians and provincial governments in western Canada, Abramson documents suspected mycotoxicoses in western Canada and assays feeds for mycotoxins. He also checks the incidence of mycotoxins in tough and straight-grade export grain, in collaboration with the Canadian Grain Commission.

White is interested in the control of stored products insects with contact insecticides and protectants as well as physical controls and insecticide resistance. His program includes evaluating the effectiveness of chemicals in stored grain and storage structures. His primary areas of interest are: the degradation of contact insecticides in cereals and oilseeds, uptake of insecticides into cereals from different surfaces, monitoring of resistance in insects and the effects of resistance on biology. He is measuring the impact of various insecticides on stored-grain ecosystems, degradation rates of new insecticides, for example, pirimiphos-methyl, chlorpyrifos-methyl, and synthetic pyrethroids on cereals and residual activity of insecticides. In collaboration with Prof. D.S. Jayas, Dept. of Agricultural Engineering, University of Manitoba, he is studying controlled atmosphere storage of grain and suitable storage conditions to avoid pest infestations.

Kawamoto joined the stored products group as a post-doctoral fellow studying the application of computer models to predict processes in stored grain ecosystems and to effectively manage stored grain. In 1989 he was hired by the government of Canada on a term contract and produced models of population dynamics of the rusty grain beetle; common mite species; and the integration of these models into an ecosystem model to predict pest infestations. He has also developed a model to predict grain moisture content and temperature at harvest across the Canadian prairies for any particular year, based on temperature and precipitation.

Fields joined the stored products group as an eco-physiologist. His main interests include the cold-hardiness of stored-product insects and improved methods to use low temperature to control pests; insect trapping behavior; and pheromone studies. In 1990, using pheromone-baited flight traps, he was the first person to detect large numbers of the lesser grain borer, Rhyzopertha dominica (F.) in western Canada.

This historical account of stored product entomology in Canada would not be complete without reference to the related work at London, Ontario and Winnipeg. The late H.A.U. Monro at London, worked on standard and atmospheric fumigation of stored commodities in the early 1940s and later on the prevention and control of insect pests in cargo ships. His research included studies on selection of methyl bromide-resistant granary weevils, low temperature fumigation, and insect respiration at reduced pressures. Probably, his most significant contribution from a practical standpoint was the FAO sponsored publication entitled "Manual of Fumigation for Insect Control" dealing with several aspects of fumigation to preserve food. It is a useful guide to those engaged in fumigant application.

E.J. Bond worked closely with Monro during the late 1950s and early 1960s on the toxicity of fumigants to the cadelle, Tenebroides mauritanicus (Linnaeus). Bond became involved in basic studies on the effect of some fumigants on the activity and respiration of certain insects with fumigants at low temperatures or in atmospheres of carbon dioxide, and toxicity of mixtures of fumigants. Since 1980, he has been investigating the sorption of fumigants by various stages of the red flour beetle, and the effects of mixtures of phosphine and carbon dioxide. He completely revised Monro's manual on fumigation in 1984 and it is currently the main reference book on fumigation world-wide. Following Bond's retirement, stored products research was terminated in London by 1990.

The other Canadian entomologists concerned with stored products insects are those under the jurisdiction of the Canadian Grain Commission. The position was created in 1956 and the first appointee was H.E. Gray who held the position until 1965. E.A.R. Liscombe, who had been with the Winnipeg stored product insect group until that time, succeeded Gray and held the position until 1969. He was succeeded by A.G. Rudd from 1969 to 1974. J. van Loon was appointed in 1974 and still holds this position (1990). The Commission entomologist's mandate is to minimize infestations in Canadian grain intended for export. His responsibility to minimize insect infestations begins at the primary elevator and continues during transit to and storage at the terminal elevators until the grain is loaded onto ships. The entomologist tries to influence good maintenance of grain on farms by establishing a harmonious working relationship with the grain companies. The commission's entomologist works in close cooperation with the stored products entomologists in the Research Branch.

In 1985, Y. Bousquet at the Biosystematics Research Centre of Agriculture Canada in Ottawa began a taxonomic manual including distribution and known biology of stored products beetles

in Canada. In 1990 the manual "Beetles associated with stored products in Canada: An identification guide" was published.

OBJECTIVE AND RESEARCH RESPONSIBILITY IN THE 1990s

Presently, the broad objective of the stored products group is to do research in grain storage ecology, stored product entomology and mycology and mycotoxicology as a basis for developing effective control recommendations for reducing losses from insect and mite infestations, and storage fungi in cereal grains, oilseeds and their products during post harvest storage, transportation and processing.

Areas of research responsibility includes farm granaries, primary elevators, rail cars, terminal elevators, ships, feed mills, processing plants including flour mills, warehouses, retail stores, and homes in all parts of Canada. Although the Winnipeg-based group technically has a national responsibility, resource limitations preclude regular programs in all geographical areas of Canada. It has concentrated instead on solving immediate problems of local or regional importance, for example, with the brown house moth and white-shouldered house moth in west coast terminals, or outbreaks of the rusty grain beetle in farm granaries in the prairie provinces. Occasionally, one or more members of the group works collaboratively with Inspectors from the Plant Products Division or Canadian Grain Commission, Agriculture Canada to solve insect problems in terminal elevators or grain vessels in ports on the Great Lakes, St. Lawrence Seaway, and the Maritimes. The seven scientists in the group collaborate with each other in solving grain storage problems, and with other station or University colleagues in different disciplines, for example, cereal breeding, plant pathology, botany, pesticide residue analysis, agricultural engineering, and veterinary medicine. Some of the group are adjunct or honorary professors at the University of Manitoba. Some train graduate students or give lectures in various university departments.

IMPACT OF RESEARCH

The early work in stored product entomology developed with the need for insect control. This pragmatic approach provided information that was immediately usable. Also, it contributed to a knowledge of the types of problems likely to be encountered in the field and how to solve them. In Gray's time, stored product entomology provided a useful service to the grain industry and to regulatory agencies of government concerned with the quality of our export cereals and cereal products. The accumulated information enabled the group to make recommendations on stored product insect prevention and control in flour mills and elevators. The training courses provided by the stored products research entomologists in the early 1950s were significant contributions to better recognition of pest species and a more uniform method of inspection by regulatory inspectors concerned with grain quality. Similar courses were provided for inspection personnel concerned with insect contamination of food from a human health standpoint. In the

years since the 1950s, there has been considerable expansion in research on stored products insects. The added components of microflora and mycotoxins have allowed greater diversity in the research program as has extensive collaboration with agricultural engineers. In recent years, scientists in the group have had considerable impact in the agricultural industry, for example:

- Knowledge of the specific role of insects, mites and microflora and their interrelations is contributing to protection and improved quality of stored grain and oilseeds. These data are used by the grain industry to improve keeping quality during storage, and by the Canadian Wheat Board (our grain marketing agency in Canada) to increase export sales.

- Economical aeration units which can lower moisture content of rapeseed by 2% and temperature by 15 to 20 $^{\circ}$C are being increasingly used by grain producers in western Canada.

- The ecosystem and energy budget concepts have enabled the agricultural industry to assess qualitative and quantitative losses of food energy in stored grains and oilseeds.

- The canola, canola meal, and wheat charts for predicting storability of canola, canola meal, and wheat at different temperatures and moisture contents will enable producers and processors to plan sales at the time of optimal prices within the storability period.

- Analytical methods for determining the presence and quantity of mycotoxins in grain will provide a means of early detection in grain to be sold domestically or for export. They have been used to confirm cases of suspected mycotoxicoses in poultry, swine, and cattle. This information has aided provincial veterinarians.

- A one-year project to trace the history of an infestation in a terminal elevator bin has led to recommendations by the Canadian Grain Commission that turning grain in winter is the most effective means of controlling insects.

- The flour beetle assay used to evaluate cereal lines for feed quality is being used by some barley breeders for screening lines. The assay showed a correlation between larval development and lysine content in barley lines. It may be useful to animal scientists. It is an economical, quick method to compliment traditional feeding trials.

- Recommendations on the safe and effective use of insecticides and modified atmospheres in farm granaries, primary and terminal elevators, boxcars, warehouses, and ships has provided the grain industry and regulatory agencies with guidelines for the prevention and control of infestations.

FUTURE RESEARCH

Most of the past work in stored product entomology arose from a recognized need to control insects that infest food and fiber. It was of a practical problem-solving nature. As a result, much information was gathered that was put to immediate use. But more knowledge is necessary to provide a basis for more effective long-term control. Practical knowledge is needed to solve the on-site problems of grain producers and those involved with the processing of stored grains and their products. Fundamental research is needed to improve our basic knowledge of insect biology, ecology and behavior within the framework of the Canadian environment, to enable us to make recommendations for the prevention and control of insect infestations on a long-term basis.

Surveys of granaries, primary elevators, and food-processing establishments should be conducted regularly to provide more precise information on the kind, incidence, distribution and habits in situ of stored products insects. The use of monitoring devices and sampling techniques will enable us to evaluate the potential economic importance of domestic pests and those of recent introduction which may become established in Canada as the result of changing storage practices. Species such as the rice weevil, Sitophilus oryzae (Linnaeus), the American black flour beetle, Tribolium audax Halstead, and a similar European species, Tribolium madens (Charpentier) have been found in Canada in recent years. The highly destructive lesser grain borer, Rhyzopertha dominica has spread in the U.S.A. to infest grain in the most northern counties in the states along the Canadian border (7) and has been found in pheromone-baited flight traps across the Canadian prairies in 1990. These reports should concern us and should stimulate support for research on species hitherto considered exotic.

Ecology and control studies must be conducted on a long-term basis in grain elevators and flour mills. To do this, we must be prepared to compensate producers and industry people who allow the use of their premises and facilities for any losses sustained during the experiments. Otherwise, we are obliged to do trial and error field research which produces only fragmented information. The long-term use of such premises will allow us to do adequately designed experiments on chemical control in different seasons to determine optimal concentrations and methods of application and effects on different stages of insects, effects of combinations of insecticides in different formulations and longevity of residues.

More biological studies are necessary not only to determine optimal conditions for development but from an ecological standpoint, to determine cause of population growth and development, intra- and inter-specific relationships, distribution, and behavior. Although we have considerable knowledge of the ecology of major pests like the rusty grain beetle, flour beetle, and some other grain beetles, we are ignorant of many other species, particularly those of recent introduction.

Fundamental research that has little obvious or immediate practical application should not be ignored in stored product entomology even though under present budgetary constraints it does not enjoy a high priority. Stored products insects are ideal for such studies because they can be reared economically in large numbers on a year-round basis. They are suited to studies in toxicology and the physiology of nutrition, respiration, reproduction, behavior and diapause.

With a more thorough and systematic knowledge of biology, storage ecology, population dynamics, behavior, and control, we should be able to more effectively manage our post-harvest production and minimize losses due to insects, mites and microflora in the future. The importance of a discipline concerned with the preservation of food and its quality should not be minimized. We cannot afford to take our daily bread for granted.

ACKNOWLEDGEMENTS

The author thanks Drs. D. Abramson, P.S. Barker, J.T. Mills, R.N. Sinha, L.B. Smith, and N.D.G. White for their useful suggestions.

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APPENDIX

PROFESSIONAL STORED-PRODUCT WORKERS IN CANADA

Name	Year started in Stored Products	Location
Abramson, David	1978	Winnipeg
Arnold, J.W.[1]	1947	Ottawa
Barker, Philip S.	1965	Winnipeg
Berck, Ben	1946	Winnipeg
Bond, Ed. J.[1]	1950s	London
Bousquet, Y.	1980s	Ottawa
Cashman, E.F.[2]	1951	Ottawa
Fields, Paul G.	1988	Winnipeg
Follwell, J.W.[3]	1949	Ottawa
	1950	Vancouver
	1952	Ottawa
Gray, H.E.[3]	1932	Ottawa
Kawamoto, Hitoshi	1989	Winnipeg
Liscombe, E.A.R. (Ray)[2]	1956	Winnipeg
Loschiavo, Sam R.	1949	Winnipeg
	1950	Ottawa
	1956	Winnipeg
McGillis, A.J. (Bud)[1]	1966	Winnipeg
Mills, John T.	1967	Winnipeg
Monro, H.A.U.[3]	1940s	London
Nesbitt, H.H.J.[2]	1936	Ottawa
Rudd, A.G.	1957	Winnipeg
Sinha, Ron N.	1957	Winnipeg
Smallman, Beverly N.[1]	1941	Winnipeg

Smith, Lawrie B.[3]	1955	Ottawa
	1960	Winnipeg
Van Loon, John	1974	Winnipeg
Waddell, D.B.[2]	1953	Winnipeg
	1953	Ottawa
Wallace, H.A.H.[3]	1964	Winnipeg
Watters, Fred L.[1]	1946	Winnipeg
White, Noel D.G.	1981	Winnipeg
Zuk, P.[1]	1952	Vancouver

[1]Retired
[2]Resigned
[3]Deceased