GRAIN-INFESTING INSECTS IN WAREHOUSES AND FLOUR MILLS IN KASSALA PROVINCE OF THE REPUBLIC OF THE SUDAN

by

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INTRODUCTION

The Republic of the Sudan is an extensive country covering an area of nearly one million square miles of northern Africa (Plate I) with a population of less than 13 million (Sudan Almanac, 1963). It lies within the tropics between latitudes 22° N and 3° N (Ireland, 1948), and has an extreme range of climate and vegetation from desert conditions in the north to tropical forests in the south where rainfall is abundant. The country is divided into nine provinces, ranging in population from just more than half a million to more than two million.

Kassala Province (Plate II) is situated in the eastern part of the Sudan, extending from about latitude 23° N to latitude 12.5° N and from about longitude 33° E to about 30° E. As can be visualized from the map (Plate II), it is broad at the northern part, becoming narrower at its southern extremity, and has a total area of 134,450 square miles (Mackinnon, 1948). The population in the province increased from 421,978 in 1940 (Mackinnon, 1948) to 1,163,800 in 1963 (Sudan Almanac, 1963).

The inhabitants in the northern parts of Kassala Province are basically nomads, rearing camels and other small animals. They are continuously roaming in search of water and grazing areas. Some of them have settled and taken over agriculture; in fact, a more sedentary population is encountered as one proceeds southward.

Geographical Features of Kassala Province

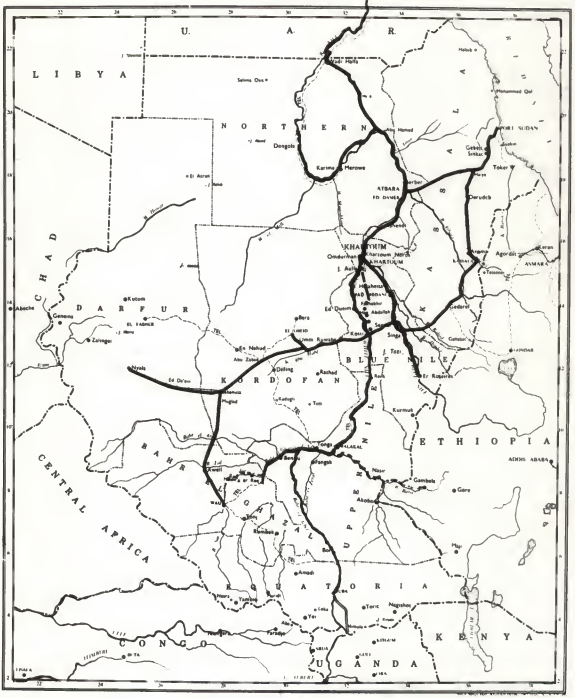
The northern part of the province is mainly desert. From the narrow coastal plain along the Red Sea shore, the land rises to a chain of mountains,

EXPLANATION OF PLATE I

Map of the Republic of the Sudan in the northern tropic of Africa.

PLATE I

SUDAN



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REFERENCE

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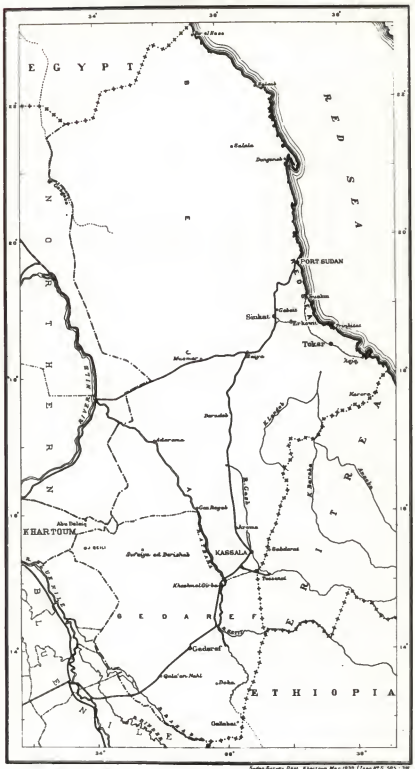
EXPLANATION OF PLATE II

Map of Kassala Province in the eastern part of the Republic of the Sudan.

PLATE II

KASSALA PROVINCE



the Red Sea Hills, which is a continuation from Egypt that merges into the Eritrean highlands (Mackinnon, 1948).

The river Atbara arises from Ethiopia (Plate II), and flows through the Butana plain until it reaches the Nile. The dam on this river at Khashmel Girba creates a new agricultural area that is currently cultivated by the people of Halfa district (Plate I). These people have been resettled in this area due to the installation of the High Dam of the United Arab Republic.

Two other seasonal rivers are found in the province, the Gash and the Baraka, both originating in Ethiopia. They form important inland deltas--Gash Delta north of Kassala town (Richard n.d.), and Tokar Delta in the eastern part of the province (Mackinnon, 1948).

Southern Kassala is a vast clay plain which is characterized by mechanized crop production in Gedaref District. This is an extensive area where several crops are produced under rain cultivation.

Port Sudan, the main sea port of the country, is located on the Red Sea in Kassala Province, about 850 miles south of Suez (March, 1948).

Climatological Data of Kassala Province

The rainfall in the northern part of Kassala Province is sparse and erratic and accounts for the fact that the region is mainly populated by the camel-owning nomads (Mackinnon, 1948). Along the Red Sea littoral zone and on the eastern slopes of the Red Sea Hills, the climate is profoundly modified by the maritime influence of the Red Sea. In this part, rain is possible at any time of the year, but most of it falls during the winter

(Ireland, 1948). The interior has a normal summer rainfall; places on the fringe, such as Sinkat Area (Plate II), may benefit from winter and summer rains (Mackinnon, 1948).

The summer rain in the middle part, including Butana, increases steadily from north to south with 200 mm (7.87 inches) at the northern head of Butana to 900 mm (35.43 inches) at the southern extremity.

The northern part has hot summers and cool winters, and the coastal plain has a high humidity during most of the year. The temperature is greatly modified by the elevation above sea level. Table 1 gives the elevation of selected towns in the province (Sudan Almanac, 1963). Sand storms are frequent in Tokar area, and to a lesser extent in Gash Delta.

Importance of Kassala Province

There are several factors contributing to the importance of Kassala Province. "Dura", a name applied to many varieties of Sorghum vulgare Priesner, is grown on large acreages in this area. The term "Dura", the staple food of the majority of the population (Jefferson, 1949), is extensively used in the literature (Burnett, 1948; Crowther, 1948; Joyce, 1952; March, 1948; Richards (n.d.); Wilson, 1948; and many others). It is calculated by the writer that in the 1961-1962 season more than 38% of the land planted to this crop in the Republic of Sudan was grown in Kassala Province (Agricultural Statistics, 1964). Dura is produced under rain cultivation in Gedaref District, and under flush irrigation in Gash and Tokar Deltas. Other crops, such as sesame, bulrush millet and cotton are also grown.

Table 1. Height above mean sea level (Alexandria) of selected towns in Kassala Province (Sudan Almanac, 1963, modified).

Station	Height		Remarks
	Metres	Feet*	
Port Sudan	8	26.2	The major sea port of the Sudan
Aroma	436	1,430.1	In Gash Delta
Khashmel Girba	461	1,512.1	In the new project of Khashmel Girba Scheme
Kassala town	495	1,623.6	The capital of the province; in Gash Delta
Gederef town	608	1,994.2	In the mechanized crop production area
Gebeit	799	2,620.7	In Sinkat Area, on the Red Sea Hills
Sinkat town	875	2,870.0	In Sinkat Area, on the Red Sea Hills
Summit	921	3,020.9	In Sinkat Area, on the Red Sea Hills
Erkawit	1,067	3,499.8	In Sinkat Area, on the Red Sea Hills

* 1 metre = 3.28 feet.

The installation of Khashmel Girba dam on Atbara river (Plate II) brought thousands of new settlers to the province. Kassala Province also enjoys the high altitude of Sinkat Area (Table 1) which is used as a summer resort by the sophisticated section of the population and by foreign tourists.

The general pattern of insect pests of stored grain may also be complicated by the presence of the only major sea port of the country in Kassala Province. Agricultural products and other items likely to harbor insects are not only coming from all over the country to Port Sudan, but also imported material has to pass through the port and the province.

REVIEW OF LITERATURE

Publications on the insect fauna of stored grain in the Sudan are few and scattered. Some writers dealt with specific insects while others treated phases of the problem. Only a few of the more important works in this field are covered here.

Bacon (1948) reported the occurrence of certain grain-infesting pests in the Sudan. He recorded Rhyzopertha dominica F., Sitophilus oryzae (L.), Sitotroga cerealella Oliv., Ephestia kuhniella Zell., Corcyra cephalonica Staint., Tribolium confusum Duv., as well as termites infesting sacks of stored grain sorghum.

A report was made by Joyce (1954) concerning the condition of grain held by the Ministry of Agriculture in the Central Rain land including Gedaref District in Kassala Province. He found that different varieties of sorghums contain different water content.

The susceptibility of different crops and of different varieties of the same crop to damage by stored-grain pests was noted by several writers. Bacon (1948) reported that while chickpea (Cicer arietinum Linnaeus) is susceptible to insect pests, the haricot bean (Phaseolus vulgaris Linnaeus) can be stored very well. Khalifa (1960) found that a variety of sorghum, locally known as Fitereta and known as Fetereta in the United States, harbored higher populations of insects than another variety "Mugud" in experimental underground pits in Gedaref area. He indicated that the reason for this is difficult to explain but it may be due to differences in the initial infestation, or to the different effect of the two varieties of Dura upon the fertility of insects. This same phenomenon was recorded by Darling

(1959) who stated that suitable Dura varieties should keep safely in underground pits. He also (Darling, 1951) observed that bulrush millet, also known as pearl millet (Pennisetum typhoideum (Burm.) Stapf and Hubbard) is not infested by Rhyzopertha dominica (Fabricius), and he attributed this to its small kernel size in which the insect is unable to develop.

George (1955) investigated the approximate length of the life cycle of Corcyra cephalonica Stainton under laboratory conditions in the Sudan. He found that the maximum life of the adult moth is 8 days in the absence of sesame seed, 9 days in the presence of seed, and 13 days in the presence of both seed and water, but that the moth cannot live for more than two weeks.

Khalifa and Badawy (1960) studied the systematics of Trogoderma and made a detailed study of the identity of this pest in the Sudan (Khalifa and Badawy, 1961). They concluded that the Sudanese Trogoderma is more closely related to Trogoderma granarium granarium Everts than to T. granarium afrum Priesner or to the hybrid between these subspecies.

Khalifa (1960) evaluated two methods of storage in the Sudan: open-air and underground storage. The former method is used in the drier part of the country. The investigation was conducted in Khartoum Province (Plate I). The underground grain storage which is widely used in Kassala Province is an ideal method for storage of sorghum in this area (Khalifa, 1960).

Perhaps the most thorough work on the grain storage problem in the Sudan was conducted by Darling (1951, 1954, 1959). His authoritative article on storage of food grain in the Sudan (Darling, 1954) outlined the problem in northern, central and southern Sudan. He considered the factors affecting

the incidence of insect pests in grain (Darling, 1951) and listed (Darling, 1959) the following six primary pests for the whole country in decreasing order of importance: Rhyzopertha dominica F., Trogoderma granarium Everts, Sitophilus oryzae (L.), Sitotroga cerealella Olivier, Corcyra cephalonica Staint., and Ephestia cautella Walk.

MATERIAL AND METHODS

Objective of the Survey

During late February and early March, 1965, an ecological survey of grain-infesting insects was undertaken in Kassala Province. The objectives of the investigation were:

1. Identification of the different species of insect pests present in the storage facilities and flour mills of the province.
2. Study of the regional distribution of these pests in different parts of Kassala Province.
3. Evaluation of the different methods of storage and their relationship to the type of infestation.

Planning of the Survey

It was felt that this information was prerequisite to a general understanding of insect problems in warehouses and milling plants in the province. Accordingly, Kassala Province was divided into six regions representing different agricultural characteristics or types of storage practices in the area, or with other peculiarities. The following letters were designated to each region in alphabetical order:

A - Port Sudan, the sea port in the province.

B - Sinkat Area, with its high elevation above sea level.

C - Tokar Delta, representing the inland delta of Baraka river.

D - Gash Delta, representing the flush irrigation in Gash area.

E - Khashmel Girba District, a newly developed agricultural area.

F - Gedaref District, representing the mechanized crop production schemes under rain cultivation in the southern part of the province.

A questionnaire (Appendix) was designed with the aforementioned objectives in mind. To secure the cooperation of the property owners, the administrative staffs of the province were contacted and wide publicity was given to the survey.

Collection of Samples

One hundred eighteen collections were taken from the storage facilities and 44 from the milling plants of the province. Some 15 to 30 samples were from warehouses and 5 to 14 from flour mills. Due to transportation difficulty, only two samples were taken from Khashmel Girba area.

The procedure adopted was to secure one kilogram of grain or other stored products from different jute sacks and spilled commodities and then to collect the insects manually. Adult Lepidoptera were collected by randomly sampling the premises. Insects from each storage facility or flour mill were preserved in 60% alcohol and stored in one or two vials, or were wrapped in paper and packed in cotton wool. The collections were labelled with the alphabetical letter of the region and a number. The same letter-number label was recorded on the questionnaire to identify the sample for later investigation.

Samples were collected from 7:00 A.M. to 2:00 P.M. and from 3:00 P.M. to 5:00 P.M. between February 24 and March 3, and again between March 7 and March 11, 1965. Only one sample was taken from each warehouse or flour mill visited.

Identification of Insects

Identification of insect specimens was accomplished using a microscope or a 15X hand lens in good light. Both Hinton (1963) and a key prepared by Hinton and Corbet (1963) were used for identification of adult insects. Of great help was an authentically named collection presented to the writer from the Infestation Control Laboratory, Tolworth, Surrey, of the British Ministry of Agriculture, Fisheries and Food. A few immature stages of insects were reared in sorghum under room conditions and the adults were identified in the same way.

Confirmation of identification and/or identification of the majority of insects collected during the survey was secured through the cooperation of Mr. Awad Abdin Ali, Senior Entomologist in charge of the insect reference collection of the Research Station, Wad Medani, Sudan.

RESULTS

A list of the grain-infesting insects encountered in warehouses and flour mills in the six regions of Kassala Province, the information obtained from the questionnaires accompanying the survey, and other related information are presented according to area.

Port Sudan

This Red Sea port dates from 1905 (Mackinnon, 1948). It has a well protected harbor with a good natural anchorage (March, 1948). Most of the rainfall occurs during the winter (Ireland, 1948). The town plays a major role in the economy of the country since most of the Sudan's imports and exports pass through it (Barbour, 1961).

Both old and modern storage facilities of brick or concrete (Plate III, Fig. 2) are in use. There are adequate warehouse accommodations (March, 1948) for commodities intended for export as well as for receiving imported items. Some local traders use wooden structures (Plate III, Fig. 1) for storage of grain and other miscellaneous goods.

The storage buildings are for general use and two or more (usually more) of the following commodities may be found together some time during the year: sorghum, sesame, haricot bean, melon seeds, cotton seed and cotton seed cake, groundnuts (peanuts), together with imported rice, wheat and wheat flour. Several other agricultural products, such as gum arabic, may also be found in the same building.

Generally, stored products are held for a short period in these warehouses before they are exported, transported by rail to the interior of the country, or sold locally. The duration of storage varies from a few days to over a month, depending upon the availability of shipping space for exported commodities, and of rail wagons for imported goods. As a result, the quantity of merchandise passing through these warehouses is quite large and there is a continuous change in the nature of the material.

EXPLANATION OF PLATE III

Warehouses at Port Sudan

Fig. 1. Wooden bin used only by local traders.

Fig. 2. Brick warehouse used by importing and exporting firms.

Fig. 3. Government-owned terminal elevator under construction.

PLATE III

Fig. 1

Fig. 2

Fig. 3

The current storage is in jute sacks and mechanical handling of grain is not practiced; loading and unloading of stored products is done by manual laborers. In the new Government grain silo, still under construction (Plate III, Fig. 3), imported wheat and sorghum intended for export will be cleaned, dried, and weighed mechanically, and the grain will be stored in bulk. This terminal elevator will handle 70,000 tons of imported wheat and 300,000 tons of exported dura annually.

Twelve samples were taken from brick and concrete warehouses, 8 from wooden bins, and 10 from flour mills. The grain-infesting pests encountered are presented in Table 2. The concrete and brick buildings are grouped together. Milling plants, as in all other parts of the province, are small, offering their services to people in the area.

The incidence of storage insects in wooden bins is sometimes equal, but usually higher, than in brick and concrete buildings, and all pests recorded from the latter facilities are encountered in the wooden structures. Tenebroides mauritanicus (Linnaeus), Rhyzopertha dominica (Fabricius) and Trogoderma granarium Everts were especially abundant in wooden bins.

The relatively high occurrence of the following insects in all types of storage buildings is quite evident: Sitophilus oryzae (Linnaeus), Tribolium confusum Jacquelin duVal, Tribolium castaneum (Herbst), Oryzaephilus mercator (Fauvel), and Oryzaephilus surinamensis (Linnaeus).

Other species from warehouses in Port Sudan were: Sitotroga cerealella (Olivier), Corcyra cephalonica Stainton, Cryptolestes pusillus (Schönherr), Alphitobius diaperinus (Panzer), Latheticus oryzae Waterhouse, as well as Attagenus gloriosae (Fabricius), Bruchus spp. and Mesostenopa sp.

Table 2. Grain-infesting insects in warehouses and flour mills at Port Sudan.

Name of insect	Brick + concrete warehouses (No. of samples = 12)		Wooden bins (No. of samples = 8)		Flour mills (No. of samples = 10)	
	No. of infested samples	Percentage	No. of infested samples	Percentage	No. of infested samples	Percentage
Alphitobius diaperinus (Panzer)	1	8.3	2	25.0	1	10.0
Alphitophagus gloriosae (Fabricius)	3	25.0	2	25.0	1	10.0
Bruchus spp.	3	25.0	2	25.0	-	0.0
Corcyra cephalonica Stainton	2	16.7	2	25.0	1	10.0
Cryptolestes pusillus (Schönherr)	1	8.3	2	25.0	2	20.0
Latheticus oryzae Waterhouse	2	16.7	3	37.5	3	30.0
Mesostenopa sp.	2	16.7	3	37.5	-	0.0
Oryzaephilus mercator (Fauvel)	4	33.3	4	50.0	3	30.0
Oryzaephilus surinamensis (Linnaeus)	3	25.0	4	50.0	3	30.0
Rhyzopertha dominica (Fabricius)	2	16.7	6	75.0	3	30.0
Sitophilus oryzae (Linnaeus)	6	50.0	4	50.0	3	30.0
Sitotroga cerealella (Olivier)	2	16.7	2	25.0	1	10.0
Tenebroides mauritanicus (Linnaeus)	4	33.3	7	87.5	2	20.0
Tribolium castaneum (Herbst)	2	16.7	4	50.0	4	40.0
Tribolium confusum Jacquelin duVal	2	16.7	4	50.0	4	40.0
Trogoderma granarium Everts	5	41.7	6	75.0	3	30.0

Table 2 shows a higher infestation in wooden structures than in flour mills, but the results were inconsistent when the infestation in the flour mills was compared with concrete and brick warehouses, although it was generally higher in the storage buildings. However, Cryptolestes pusillus (Schönherr) and Latheticus oryzae Waterhouse infestations were higher in milling plants. Neither Mesostenopa sp. nor Bruchus spp. were found in flour mills in Port Sudan.

Sinkat Area

At the present time, Sinkat Area has neither agricultural nor other economic importance to Kassala Province. It was included in the survey because of its high altitude on the Red Sea Hills (Table 1). It is used as a recreational area but has some potentialities for development. The Horticultural Division of the Department of Agriculture is experimenting with some temperate fruits and vegetables to determine their suitabilities in this part of the Sudan.

The storage buildings in this area are of concrete (Plate IV) or mud (Plate V), and the capacity differs widely. Usually, they are small and general in type. Some are used for both storage and sales of different commodities.

The predominant product found in these stores is sorghum but wheat flour, tick bean (Vicia faba Linnaeus), various other food products and miscellaneous articles such as salt, sugar, dates, wood, cement, empty jute sacks, etc. are also found. The origin of the stored grain sorghum is either from Gedaref District, Gash Delta or Tokar Delta, and that of the wheat flour is from Port Sudan.

EXPLANATION OF PLATE IV

Concrete warehouses in Kassala Province used for storage of grain and other commodities.

Fig. 1. Small warehouse.

Fig. 2. Medium warehouse.

Fig. 3. Large warehouse.

PLATE IV

Fig. 1

Fig. 2

Fig. 3

EXPLANATION OF PLATE V

Mud warehouses in Kassala Province found in Sinkat District, Tokar Delta and Gash Delta.

Fig. 1. Small warehouse.

Fig. 2. Medium warehouse.

Fig. 3. Large warehouse.

PLATE V

Fig. 1

Fig. 2

Fig. 3

These products are intended for local sale to the indigenous population. The storage is continuous throughout the year in all facilities investigated. Flour mills also operate continuously in Sinkat Area.

Eight samples were taken from concrete warehouses, 17 from mud godowns, and 5 from flour mills. These were obtained from Gebeit, Sinkat town, Summit and Erkowit (Plate II). The insect species and numbers are shown in Table 3.

It will be noted from this table that for any particular insect, the percentage of infestation is higher in mud godowns than in concrete warehouses, but the difference generally was not great. Although Sitophilus oryzae (Linnaeus) infestations were nearly equal in both type of structures, there were considerable differences in each of the following insects: Latheticus oryzae Waterhouse, Oryzaephilus mercator (Fauvel), Oryzaephilus surinamensis (Linnaeus), Tribolium confusum Jacquelin duVal and Trogoderma granarium Everts.

There was a general tendency for higher infestations in flour mills than in mud godowns or concrete warehouses. However, some of the primary pests, such as Sitophilus oryzae (Linnaeus) and Tenebroides mauritanicus (Linnaeus), were found to be slightly more abundant in the storage buildings.

Other insects collected from the milling industries and warehouses were Alphitobius diaperinus (Panzer), Cryptolestes pusillus (Schönherr), Rhyzopertha dominica (Fabricius), Sitotroga cerealella (Olivier), Tribolium castaneum (Herbst) and several species of spider beetles (Ptinidae) including Gibbium scotias Fabricius.

Table 3. Grain-infesting insects in warehouses and flour mills in Sinkat Area.

Name of insect	Concrete warehouses (No. of samples = 8)		Mud godown (No. of samples = 17)		Flour mills (No. of samples = 5)	
	No. of infested samples	Percentage	No. of infested samples	Percentage	No. of infested samples	Percentage
Alphitobius diaperinus (Panzer)	1	12.5	3	17.6	1	20.0
Cryptolestes pusillus (Schönherr)	1	12.5	3	17.6	1	20.0
Latheticus oryzae Waterhouse	1	12.5	5	29.4	2	40.0
Oryzaephilus mercator (Fauvel)	1	12.5	5	29.4	1	20.0
Oryzaephilus surinamensis (Linnaeus)	1	12.5	5	29.4	1	20.0
Ptinidae	3	37.5	7	41.2	3	60.0
Rhyzopertha dominica (Fabricius)	1	12.5	4	23.5	1	20.0
Sitophilus oryzae (Linnaeus)	2	25.0	4	23.5	1	20.0
Sitotroga cerealella (Olivier)	1	12.5	4	23.5	1	20.0
Tenebroides mauritanicus (Linnaeus)	2	25.0	7	41.2	1	20.0
Tribolium castaneum (Herbst)	1	12.5	3	17.6	1	20.0
Tribolium confusum Jacquelin duVal	2	25.0	7	41.2	3	60.0
Trogoderma granarium Everts	2	25.0	7	41.2	2	40.0

Tokar Delta

The main area of this inland delta lies 100 miles south of Port Sudan. It is formed by the alluvial deposits laid down by the floods of the Baraka river (Mackinnon, 1948), and covers roughly 400,000 feddans or 415,200 acres (Sudan Almanac, 1963), but the cultivated area changes annually with the flood. The delta is in the form of an equilateral triangle with sides of 70 kilometres (about 44 miles).

The Baraka is a seasonal river originating from the Eritrean highlands. Even during a flood, the flow is discontinuous. It is characterized by a series of extremely viilent spates (flash floods) at irregular intervals; each spate may last for only a few hours or as much as 2 or 3 days (Sudan Almanac, 1963). During October to June or July, the river is dry (Mackinnon, 1948), but there is a light winter rain. The Baraka river carries a very high proportion of silt, and this, combined with its violence and irregularity, is the reason that large scale control works have not been built.

The delta produces a fine quality cotton and the best land is reserved for this crop. The inferior soils and the more lightly watered areas are usually sowed with sorghum and bulrush millet. The bulrush millet, known in the Sudan as "Dukhn", replaces sorghum as the principal cereal on light soil in Baraka Delta (Bacon, 1948).

The storage buildings in Tokar Delta are made predominantly of mud (Plate V). They are very small, general in nature, and belong to local traders.

The agricultural products in storage include: sorghum, bulrush millet, tick bean, cowpea, wheat, and wheat flour, together with various other items

such as sugar, salt and wood. The origin of these commodities is either Tokar Delta, Port Sudan, or Gedaref District.

The duration of storage of a particular item usually is not more than a month, depending upon supply and demand. However, storage is continuous because as soon as a commodity becomes short, it is replaced by another. Storage of all types of grain is in jute sacks, but there is always spilled grain and other products in the floor and cracks. Milling plants which operate continuously also have spilled food residues.

Twenty samples were taken from several villages in Tokar Delta, representing 15 mud warehouses, and 5 flour mills. The identified insects are shown in Table 4.

Insects recorded in Tokar Delta seemed to have cosmopolitan distribution in both warehouses and flour mills. There was a high infestation of Tribolium castaneum (Herbst), Tribolium confusum Jacquelin duVal, Trogoderma granarium Everts, Sitophilus oryzae (Linnaeus), and Sitotroga cerealella (Olivier).

The following insects also were collected from the delta: Tenebroides mauritanicus (Linnaeus), Rhyzopertha dominica (Fabricius), Oryzaephilus mercator (Fauvel), Oryzaephilus surinamensis (Linnaeus), Latheticus oryzae Waterhouse, Cryptolestes pusillus (Schönherr), Alphitobius diaperinus (Panzer), and Corcyra cephalonica Stainton. Several Bruchus spp. and Attagenus gloriosae (Fabricius) were reported from this area.

Gash Delta

Gash Delta consists mainly of alluvial soil deposited by the Gash river which rises in the Eritrean highlands. It has a total area of roughly 700,000

Table 4. Grain-infesting insects in warehouses and flour mills in Tokar Delta.

Name of insect	Mud warehouses (No. of samples = 15)		Flour mills (No. of samples = 5)	
	No. of infested samples	Percentage	No. of infested samples	Percentage
Alphitobius diaperinus (Panzer)	2	13.3	1	20.0
Attagenus gloriosae (Fabricius)	2	13.3	1	20.0
Bruchus spp.	4	26.7	1	20.0
Corcyra cephalonica Stainton	2	13.3	1	20.0
Cryptolestes pusillus (Schönherr)	3	20.0	1	20.0
Latheticus oryzae Waterhouse	4	26.7	2	40.0
Oryzaephilus mercator (Fauvel)	4	26.7	1	20.0
Oryzaephilus surinamensis (Linnaeus)	3	20.0	1	20.0
Rhyzopertha dominica (Fabricius)	3	20.0	1	20.0
Sitophilus oryzae (Linnaeus)	6	40.0	2	40.0
Sitotroga cerealella (Olivier)	7	46.7	2	40.0
Tenebroides mauritanicus (Linnaeus)	4	26.7	1	20.0
Tribolium casteneum (Herbst	10	66.7	3	60.0
Tribolium confusum Jacquelin duVal	6	40.0	2	40.0
Trogoderma granarium Everts	6	40.0	2	40.0

feddans (726,600 acres), of which about half is available for irrigation (Sudan Almanac, 1963). The Gash is a seasonal river that flows for about three months from July to September. The annual average rainfall for Kassala town (Table 1) is 327 millimetres (13 inches), but this figure decreases by at least one third as one proceeds northward through the delta (Mackinnon, 1948).

The main crops in the delta are cotton and sorghums. For a long time the local duras have been famed for their excellence. In general, they are large-grained, compact-headed sorghums of very good quality and they have different local names such as Aklumoi, Shebbat, Tawleeb, etc., enumerated by Richards (n. d.). Bacon (1948) noted that most of the excellent duras of Gash and Baraka Deltas belong to Sorghum vulgare Priesner variety subglabrescens Schweinf. et Aschers.

Warehouses in Gash area are usually small; the main stored product in all types of buildings is sorghum. In certain structures, sorghum flour, wheat, wheat flour, rice, and bulrush millet are present also. These godowns may store dates, dry okra (Hibiscus esculentus Linnaeus) and such commodities as charcoal, empty jute sacks, wood, and canned fruits intended for local sale. Some of the sorghum is exported to other parts of the country.

The storage facilities in the delta are basically of brick (Plate VI) or mud (Plate V). The insects collected from 17 brick warehouses and 13 mud godowns, as well as from 10 flour mills, are presented in Table 5.

Although there appeared to be a higher incidence of grain-infesting insects in mud buildings than in brick warehouses or in flour mills, the results were not consistent for certain insects and were inconclusive for others. It seemed probable, therefore, that insects listed in Table 5 were

EXPLANATION OF PLATE VI

Brick warehouses in Kassala Province used for storage of grain and/or miscellaneous food products.

Fig. 1. Small warehouse.

Fig. 2. Medium warehouse.

PLATE VI

Fig. 1

Fig. 2

Table 5. Grain-infesting insects in warehouses and flour mills in Gash Delta.

Name of insect	Brick warehouses (No. of samples = 17)		Mud godowns (No. of samples = 13)		Flour mills (No. of samples = 10)	
	No. of infested samples	Percentage	No. of infested samples	Percentage	No. of infested samples	Percentage
Alphitobius diaperinus (Panzer)	1	5.9	4	30.8	1	10.0
Attagenus gloriosae (Fabricius)	-	0	4	30.8	3	30.0
Bruchus spp.	5	29.4	3	23.1	1	10.0
Corcyra cephalonica Stainton	4	23.5	5	38.5	2	20.0
Cryptolestes pusillus (Schönherr)	3	17.6	3	23.1	2	20.0
Latheticus oryzae Waterhouse	3	17.6	4	30.8	3	30.0
Oryzaephilus mercator (Fauvel)	2	11.8	6	46.1	2	20.0
Oryzaephilus surinamensis (Linnaeus)	3	17.6	3	23.1	2	20.0
Ptinidae	3	17.6	4	30.8	2	20.0
Rhyzopertha dominica (Fabricius)	5	29.4	2	15.4	2	20.0
Sitophilus oryzae (Linnaeus)	6	35.3	6	46.1	3	30.0
Sitotroga cerealella (Olivier)	10	58.8	8	61.5	4	40.0
Tenebroides mauritanicus (Linnaeus)	2	11.8	2	15.4	1	10.0
Tribolium castaneum (Herbst)	8	47.1	5	38.5	5	50.0
Tribolium confusum Jacquelin duVal	5	29.4	4	30.8	4	40.0
Trogoderma granarium Everts	7	41.2	5	38.5	4	40.0

present in all storage facilities and milling plants. Alphitobius diaperinus (Panzer) was apparently dominant in mud godowns; Attagenus gloriosae (Fabricius) was not recorded from brick warehouses.

Sitotroga cerealella (Olivier) and Sitophilus oryzae (Linnaeus) were important in Gash Delta, as were Trogoderma granarium Everts, Tribolium castaneum (Herbst) and Tribolium confusum Jacquelin duVal.

Corcyra cephalonica Stainton, Oryzaephilus surinamensis (Linnaeus), Oryzaephilus mercator (Fauvel), Rhyzopertha dominica (Fabricius), Cryptolestes pusillus (Schonherr), Latheticus oryzae Waterhouse, and several Bruchus spp. including B. maculatus Fabricius were also of importance. Unidentified spider beetles (Ptinidae) were collected. Tenebroides mauritanicus (Linnaeus) was of minor importance in Gash district.

Stored Products in Relation to Insect Fauna in Warehouses in Gash Delta. Grain storage was continuous and in jute sacks. Of the 30 samples taken from warehouses, 20 were exclusively for dura; the other 10 samples were from buildings containing miscellaneous food products with or without sorghum. Insect fauna encountered in these two types of storage are summarized in Table 6. However, information from the questionnaire reveals that even in the exclusively dura warehouses, they may have been used for storage of various food commodities previously. Sitotroga cerealella (Olivier) was more plentiful in warehouses containing sorghum alone than in buildings having a variety of stored products.

Age of Warehouses in Relation to Insect Infestation in Gash Delta. To determine the effects of age of the building on insect infestation, warehouses in Gash Delta were divided into 3 age groups. The first group was built before 1949 and was made of mud; the second group was built between

Table 6. Grain-infesting insects collected from warehouses containing sorghum only and those taken from buildings having miscellaneous food products in Gash Delta.

Name of insect	Sorghum only (No. of samples = 20		Miscellaneous food products (No. of samples = 10)	
	No. of infested samples	Percentage	No. of infested samples	Percentage
Alphitobius diaperinus (Panzer)	3	15.0	2	20.0
Attagenus gloriosae (Fabricius)	2	10.0	2	20.0
Bruchus spp.	5	25.0	3	30.0
Corcyra cephalonica Stainton	6	30.0	3	30.0
Cryptolestes pusillus (Schonherr)	2	10.0	4	40.0
Latheticus oryzae Waterhouse	4	20.0	3	30.0
Oryzaephilus mercator (Fauvel)	5	25.0	3	30.0
Oryzaephilus surinamensis (Linnaeus)	4	20.0	2	20.0
Ptinidae	4	20.0	3	30.0
Rhyzopertha dominica (Fabricius)	5	25.0	2	20.0
Sitophilus oryzae (Linnaeus)	8	40.0	4	40.0
Sitotroga cerealella (Olivier)	14	70.0	4	40.0
Tenebroides mauritanicus (Linnaeus)	2	10.0	2	20.0
Tribolium castaneum (Herbst)	8	40.0	5	50.0
Tribolium confusum Jacquelin duVal	6	30.0	3	30.0
Trogoderma granarium Everts	8	40.0	4	40.0

1950 to 1960; the last group was erected since 1961. Five, 16, and 9 samples were taken, respectively, from each group; the grain-infesting insects collected from them are shown in Table 7.

The first age group exhibited a deteriorated condition and harbored a high population of all insects recorded from the area. The same insects were found, but to a lesser degree, in the other two groups. The structures in both of these were made of mud (Plate V) or brick (Plate VI), and the percentage of infestation in them was similar for any particular insect.

Khashmel Girba District

Until recently, the middle zone of Kassala Province, including the region known as Butana, was described as a featureless plain (Mackinnon, 1948). The new Khashmel Girba Dam provides necessary water for the irrigation of 500,000 feddens (519,000 acres) of land on the western side of the Atbara river (Sudan Almanac, 1963). It is used as a settlement for, and is cultivated by Halfa people, whose land in the northern border of the Sudan is permanently flooded by the High Dam waters of the United Arab Republic. A variety of crops are produced in this part of Kassala Province.

Two government-owned concrete warehouses used for general storage were sampled. These buildings stored cotton seed and groundnuts (peanuts) to be used as seed, and also held fertilizers and insecticides. They had been stacked for about one year and had been dusted with BHC.

The following insects were identified in these samples: Oryzaephilus mercator (Fauvel), Tribolium castaneum (Herbst), and Trogoderma granarium Everts.

Table 7. Age of warehouses in relation to insect infestation in Gash Delta.

Name of insect	Before 1949 (No. of samples = 5)		1950-1960 (No. of samples = 16)		1961-1965 (No. of samples = 9)	
	No. of infested samples	Percentage	No. of infested samples	Percentage	No. of infested samples	Percentage
Alphitobius diaperinus (Panzer)	2	40.0	2	12.5	1	11.1
Attagenus gloriosae (Fabricius)	1	20.0	2	12.5	1	11.1
Bruchus spp.	2	40.0	4	25.0	2	22.2
Corcyra cephalonica Stainton	2	40.0	5	31.3	2	22.2
Cryptolestes pusillus (Schönherr)	3	60.0	2	12.5	1	11.0
Latheticus oryzae Waterhouse	2	40.0	4	25.0	1	11.1
Oryzaephilus mercator (Fauvel)	2	40.0	4	25.0	2	22.2
Oryzaephilus surinamensis (Linnaeus)	2	40.0	3	18.8	1	11.1
Ptinidae	2	40.0	3	18.8	1	11.1
Rhyzopertha dominica (Fabricius)	2	40.0	3	18.8	2	22.2
Sitophilus oryzae (Linnaeus)	4	80.0	5	31.3	3	33.3
Sitotroga cerealella (Olivier)	4	80.0	10	62.5	4	44.4
Tenebroides mauritanicus (Linnaeus)	1	20.0	2	12.5	1	11.1
Tribolium castaneum (Herbst)	3	60.0	6	37.5	4	44.4
Tribolium confusum Jacquelin duVal	2	40.0	4	25.0	3	33.3
Trogoderma granarium Everts	3	60.0	7	43.8	2	22.2

Gedaref District

Gedaref District is a vast plain with a reliable rainfall especially in the southern part, so its potential for crop production is great. The climate is characterized by a rainy season occurring from June to mid-October and followed by a dry season of 7 to 9 months (Joyce, 1952). The area is sparsely populated due to a shortage of drinking water. Consequently, some of the agricultural operations are mechanized to secure efficient utilization of these plains.

The Mechanized Crop Production Schemes form part of Gedaref District. Its relative proximity to Port Sudan enhances the site value of its exportable production (Mackinnon, 1943) and stimulates interest in private farms in the District. The land is vested in the state and an individual only has cultivation rights over the land he is using (Jefferson, 1949).

The richness of the soil and the reliability of rain are such that this area is the chief granary of the Sudan (Barbour, 1961). Sorghum and sesame (Sesamum orientale Linnaeus) are the main crops, although cotton has lately become important. Of all the land planted to sorghum in the Sudan, 27.7% was found in Gedaref area; of that planted to sesame, 14.2% was grown in this District in the 1961-1962 season (Agricultural Statistics, 1964). This is understandable since sorghum is basic in the diet of the people (Bacon, 1948; Burnett, 1948; Jefferson, 1949) and sesame is the main source of vegetable oil (Sudan Almanac, 1963). Thus there is a considerable shipment of both sorghum and sesame from Gedaref District to other parts of the Sudan, and a growing export of both of these crops to other countries.

It was noted by Bacon (1948) that Aphanus littoralis Distant, known in the area as "kaok," feeds on the sesame capsules in the field and on

seeds on the stalks before threshing. It attacks sorghum grain on the threshing floor in the same way (Bacon, 1948).

The storage buildings in this area usually belong to the scheme owners operating in the District. They are made of concrete (Plate IV), brick (Plate VI), or corrugated iron (Plate VII).

The grain in these structures is stored in jute sacks. An important and unique method of storage is in underground pits, generally known as "matmura" (Plate VIII). The local cultivator traditionally stores his grain in these pits (Darling, 1954) (Plate VIII, Fig. 1). The pits are dug in soil of fairly close texture and with good natural drainage (Plate VIII, Fig. 2). They are filled with dry bulk grain sorghum on top of which is placed a layer of threshed heads. The top 9 inches are filled with earth, which is continued for about a foot above the ground level (Plate VIII, Fig. 3) in order that rain water may run off (Burnett, 1948). The maximum capacity is about 25 tons of sorghum (1,000 bushels) but it may be smaller (Darling, 1959).

Unfortunately, only one sample was taken from a newly laid matmura and this was free from insect infestation. In the tabulation this sample was disregarded. Fourteen other samples were taken from flour mills, 16 from corrugated iron warehouses, and 10 from brick and concrete buildings. The brick and concrete structures are treated as one category since there were no substantial differences between them (Table 8).

The infestation in corrugated iron warehouses seemed to be consistently higher than in brick and concrete buildings. The only exception was for Oryzaephilus mercator (Fauvel) and may have been due to sampling errors. Rhyzopertha dominica (Fabricius), Sitophilus oryzae (Linnaeus)

EXPLANATION OF PLATE VII

Corrugated-iron warehouses in Gedaref District used mainly for storage of sorghum and sesame.

Fig. 1. Small warehouse.

Fig. 2. Medium warehouse.

Fig. 3. Large warehouse.

PLATE VII

Fig. 1

Fig. 2

Fig. 3

EXPLANATION OF PLATE VIII

Underground pits, or "matmura", a traditional method for storage of grain sorghum in Gedaref District.

Fig. 1. Small privately-owned underground pit.

Fig. 2. Government-owned underground pit under construction.

Fig. 3. Closed underground pit.

PLATE VIII

Fig. 1

Fig. 2

Fig. 3

and Cryptolestes pusillus (Schönherr) infestations were predominant in corrugated iron warehouses.

Other insects reported from the area in all types of storage facilities were: Sitotroga cerealella (Olivier), Alphitobius diaperinus (Panzer), Tribolium castaneum (Herbst), Tribolium confusum Jacquelin duVal and Tenebroides mauritanicus (Linnaeus). Besides these, Corcyra cephalonica Stainton, Oryzaephilus surinamensis (Linnaeus), Latheticus oryzae Waterhouse, Attagenus gloriosae (Fabricius), and Mesostenopa sp. were also collected from warehouses.

All samples from flour mills were infested, and all insect species encountered in the storage facilities were also found in the mills. The following insects were of importance in the milling plants: Tribolium castaneum (Herbst), T. confusum Jacquelin duVal, Sitotroga cerealella (Olivier), Alphitobius diaperinus (Panzer) and Latheticus oryzae Waterhouse.

Aphanus littoralis Distant was recorded in large numbers in both flour mills and warehouses. Other species listed in Table 8 were of general distribution in both mills and storage facilities.

Type of Operation of Warehouses in Relation to Insect Infestation in Gedaref District. From the questionnaire, it was found that the scheme operators kept the sorghum and sesame grain for less than a year, until transportation was available, or until the market price was suitable. Such storage structures are referred to as "seasonal." Some local traders and other agents kept the grain for two or more years and the building is considered to be in "continuous" storage. In the latter category, the new crop is introduced as the crop of the previous season is disposed of but there is always a substantial amount of overlapping material. Grain-infesting insects

Table 8. Grain-infesting insects in warehouses and flour mills in Gedaref District.

Name of insect	Brick + concrete warehouses (No. of samples = 10)		Corrugated-iron warehouses (No. of samples = 16)		Flour mills (No. of samples = 14)	
	No. of infested samples	Percentage	No. of infested samples	Percentage	No. of infested samples	Percentage
Alphitobius diaperinus (Panzer)	4	40.0	7	43.8	5	35.7
Aphanus littoralis Distant	5	50.0	10	62.5	8	57.1
Attagenus gloriosae (Fabricius)	3	30.0	5	31.3	3	21.4
Corcyra cephalonica Stainton	2	20.0	4	25.0	2	14.3
Cryptolestes pusillus (Schönherr)	1	10.0	4	25.0	3	21.4
Latheticus oryzae Waterhouse	2	20.0	5	31.3	5	35.7
Mesostenopa sp.	3	30.0	5	31.3	1	7.1
Oryzaephilus mercator (Fauvel)	3	30.0	3	18.8	4	28.6
Oryzaephilus surinamensis (Linnaeus)	2	20.0	5	31.3	3	21.4
Rhyzopertha dominica (Fabricius)	1	10.0	7	43.8	3	21.4
Sitophilus oryzae (Linnaeus)	3	30.0	10	62.5	4	28.6
Sitotroga cerealella (Olivier)	5	50.0	10	62.5	6	42.9
Tenebroides mauritanicus (Linnaeus)	3	30.0	6	37.5	5	35.7
Tribolium castaneum (Herbst)	3	30.0	7	43.8	7	50.0
Tribolium confusum Jacquelin duVal	3	30.0	5	31.3	7	50.0

in these two systems are presented in Table 9. There was a consistently higher incidence of insects in all the buildings where the operation was continuous, as compared with those where the grain was kept temporarily, but for certain insects the differences were not great.

Stored Products in Relation to Insect Fauna in Warehouses in Gedaref District. At the time of sampling, some warehouses contained sesame only, others sorghum, and still others had both crops in the same buildings. Insects from these three categories are shown in Table 10.

The percentage of infestation in warehouses containing both sesame and sorghum was usually higher than those in which either of these crops was stored alone. However, Aphanus littoralis Distant was more abundant in buildings in which sesame is stored by itself but the difference was not great. On the other hand, Sitophilus oryzae (Linnaeus) was slightly more abundant in sorghum stores than those containing both sorghum and sesame, but it was dominant when compared with warehouses having sesame only. The incidence of Sitotroga cerealella (Olivier) was about the same in storage facilities containing sorghum only, as in those with both sorghum and sesame, but it was about five times higher in dura than in sesame buildings.

Comparing the infestation in the godowns in which only sorghum was stored with those that had sesame alone, the results were not consistent for most other insects. Tenebroides mauritanicus (Linnaeus), Tribolium castaneum (Herbst), and Tribolium confusum Jacquelin duVal were apparently more important in dura stores. These insects, as well as Sitotroga cerealella (Olivier), were recorded to lesser degree in sesame stores. On

Table 9. Grain-infesting insects in "seasonal" and "continuous" warehouses in Gedaref District.

Name of insect	"Seasonal" warehouses (No. of samples = 11)		"Continuous" warehouses (No. of samples = 15)	
	No. of infested samples	Percentage	No. of infested samples	Percentage
Alphitobius diaperinus (Panzer)	4	36.4	7	46.7
Aphanus littoralis Distant	6	54.5	9	60.0
Attagenus gloriosae (Fabricius)	3	27.3	5	33.3
Corcyra cephalonica Stainton	2	18.2	4	26.7
Cryptolestes pusillus (Schönherr)	2	18.2	3	20.0
Latheticus oryzae Waterhouse	2	18.2	5	33.3
Mesostenopa sp.	3	27.3	5	33.3
Oryzaephilus mercator (Fauvel)	2	18.2	4	26.7
Oryzaephilus surinamensis (Linnaeus)	2	18.2	5	33.3
Rhyzopertha dominica (Fabricius)	3	27.3	5	33.3
Sitophilus oryzae (Linnaeus)	5	45.5	8	53.3
Sitotroga cerealella (Olivier)	5	45.5	10	66.7
Tenebroides mauritanicus (Linnaeus)	3	27.3	6	40.0
Tribolium castaneum (Herbst)	4	36.4	6	40.0
Tribolium confusum Jacquelin duVal	3	27.3	5	33.3

Table 10. Grain-infesting insects collected from warehouses containing sesame only, sorghum only, and sesame plus sorghum in Gedaref District.

Name of insect	Sesame only (No. of samples = 7)		Sorghum only (No. of samples = 10)		Sesame + sorghum (No. of samples = 9)	
	No. of infested samples	Percentage	No. of infested samples	Percentage	No. of infested samples	Percentage
Alphitobius diaperinus (Panzer)	3	42.9	4	40.0	4	44.4
Aphanus littoralis Distant	5	71.4	4	40.0	6	66.7
Attagenus gloriosae (Fabricius)	2	28.6	3	30.0	3	33.3
Corcyra cephalonica Stainton	2	28.6	1	10.0	3	33.3
Cryptolestes pusillus (Schönherr)	1	14.3	1	10.0	3	33.3
Latheticus oryzae Waterhouse	1	14.3	3	30.0	3	33.3
Mesostenopa sp.	2	28.6	2	20.0	4	44.4
Oryzaephilus mercator (Fauvel)	1	14.3	2	20.0	3	33.3
Oryzaephilus surinamensis (Linnaeus)	2	28.6	2	20.0	3	33.3
Rhyzopertha dominica (Fabricius)	2	28.6	3	30.0	3	33.3
Sitophilus oryzae (Linnaeus)	2	28.6	6	60.0	5	55.6
Sitotroga cerealella (Olivier)	1	14.3	7	70.0	7	77.8
Tenebroides mauritanicus (Linnaeus)	1	14.3	4	40.0	4	44.4
Tribolium castaneum (Herbst)	1	14.3	4	40.0	5	55.6
Tribolium confusum Jacquelin duVal	1	14.3	3	30.0	4	44.4

the other hand, the infestations of Corcyra cephalonica Stainton were more abundant in sesame warehouses than in sorghum godowns.

Regional Distribution of Insect Fauna in Warehouses in Kassala Province

Insect pests collected from warehouses of each of the five major regions in Kassala Province are expressed as a percentage of the infested samples to the total samples taken from a particular area (Table 11). Since the number of samples from Khashmel Girba District was small, this area was not included in this table. Similarly, the over-all infestation for the whole province is summarized in Table 13; therefore, this region was not included.

With the exception of one underground pit in Gedaref District, all storage facilities examined during the current survey harbored some insects of stored grain. The following major pests were found throughout the province (Table 11): Cryptolestes pusillus (Schönherr), Oryzaephilus mercator (Fauvel), Oryzaephilus surinamensis (Linnaeus), Rhyzopertha dominica (Fabricius), Sitophilus oryzae (Linnaeus), Sitotroga cerealella (Olivier), Tenebroides mauritanicus (Linnaeus), Tribolium castaneum (Herbst), and Tribolium confusum Jacquelin duVal. Other species in the province were Alphitobius diaperinus (Panzer) and Latheticus oryzae Waterhouse.

Trogoderma granarium Everts was reported from warehouses in all regions of the province except from Gedaref District. Corcyra cephalonica Stainton was not recorded from Sinkat Area, although it was found in other parts of Kassala Province. Attagenus gloriosae (Fabricius) had a similar distribution as Corcyra cephalonica Stainton.

Several species of spider beetles (Ptinidae), including Gibbium scotias Fabricius were taken only from Sinkat Area and Gash Delta, but were not encountered in other parts of the province.

Table 11. Regional distribution of insect fauna in warehouses in Kassala Province.

Name of insect	Port Sudan (No. of samples = 20)		Sinkat Area (No. of samples = 25)	
	No. of infested samples	Percentage	No. of infested samples	Percentage
Alphitobius diaperinus (Panzer)	3	15.0	4	16.0
Aphanus littoralis Distant	-	0.0	-	0.0
Attagenus gloriosae (Fabricius)	5	25.0	-	0.0
Bruchus spp.	5	25.0	-	0.0
Corcyra cephalonica Stainton	4	20.0	-	0.0
Cryptolestes pusillus (Schönherr)	3	15.0	4	16.0
Latheticus oryzae Waterhouse	5	25.0	6	24.0
Mesotenopa sp.	5	25.0	-	0.0
Oryzaephilus mercator (Fauvel)	8	40.0	6	24.0
Oryzaephilus surinamensis (Linnaeus)	7	35.0	6	24.0
Ptinidae	-	0.0	10	40.0
Rhyzopertha dominica (Fabricius)	8	40.0	5	20.0
Sitophilus oryzae (Linnaeus)	10	50.0	6	24.0
Sitotroga cerealella (Olivier)	4	20.0	5	20.0
Tenebroides mauritanicus (Linnaeus)	11	55.0	9	36.0
Tribolium castaneum (Herbst)	6	30.0	4	16.0
Tribolium confusum Jacquelin duVal	6	30.0	9	36.0
Trogoderma granarium Everts	11	55.0	9	36.0

Tokar Delta (No. of samples = 15)		Gash Delta (No. of samples = 30)		Gedaref District (No. of samples = 26)	
No. of infested samples	Percentage	No. of infested samples	Percentage	No. of infested samples	Percentage
2	13.3	5	16.7	11	42.3
-	0.0	-	0.0	15	57.7
2	13.3	4	13.3	8	30.8
4	26.7	8	26.7	-	0.0
2	13.3	9	30.0	6	23.1
3	20.0	6	20.0	5	19.2
4	26.7	7	23.3	7	26.9
-	0.0	-	0.0	8	30.8
4	26.7	8	26.7	6	23.1
3	20.0	6	20.0	7	26.9
-	0.0	7	23.3	-	0.0
3	20.0	7	23.3	8	30.8
6	40.0	12	40.0	13	50.0
7	46.7	18	60.0	15	57.7
4	26.7	4	13.3	9	34.6
10	66.7	13	43.3	10	38.5
6	40.0	9	30.0	8	30.8
6	40.0	12	40.0	-	0.0

Table 12. Regional distribution of insect fauna in flour mills in Kassala Province.

Name of insect	Port Sudan (No. of samples = 10)		Sinkat Area (No. of samples = 5)	
	No. of infested samples	Percentage	No. of infested samples	Percentage
Alphitobius diaperinus (Panzer)	1	10.0	1	20.0
Aphanus littoralis Distant	-	0.0	-	0.0
Attagenus gloriosae (Fabricius)	1	10.0	-	0.0
Bruchus spp.	-	0.0	-	0.0
Corcyra cephalonica Stainton	1	10.0	-	0.0
Cryptolestes pusillus (Schönherr)	2	20.0	1	20.0
Latheticus oryzae Waterhouse	3	30.0	2	40.0
Mesostenopa sp.	-	0.0	-	0.0
Oryzaephilus mercator (Fauvel)	3	30.0	1	20.0
Oryzaephilus surinamensis (Linnæus)	3	30.0	1	20.0
Ptinidae	-	0.0	3	60.0
Rhyzopertha dominica (Fabricius)	3	30.0	1	20.0
Sitophilus oryzae (Linnaeus)	3	30.0	1	20.0
Sitotroga cerealella (Olivier)	1	10.0	1	20.0
Tenebroides mauritanicus (Linnaeus)	2	20.0	1	20.0
Tribolium castaneum (Herbst)	4	40.0	1	20.0
Tribolium confusum Jacquelin duVal	4	40.0	3	60.0
Trogoderma granarium Everts	3	30.0	2	40.0

Tokar Delta (No. of samples = 5)		Gash Delta (No. of samples = 10)		Gedaref District (No. of samples = 14)	
No. of infested samples	Percentage	No. of infested samples	Percentage	No. of infested samples	Percentage
1	20.0	1	10.0	5	35.7
-	0.0	-	0.0	8	57.1
1	20.0	3	30.0	3	21.4
1	20.0	1	10.0	-	0.0
1	20.0	2	20.0	2	14.3
1	20.0	2	20.0	3	21.4
2	40.0	3	30.0	5	35.7
-	0.0	-	0.0	1	7.1
1	20.0	2	20.0	4	28.6
1	20.0	2	20.0	3	21.4
-	0.0	2	20.0	-	0.0
1	20.0	2	20.0	3	21.4
2	40.0	3	30.0	4	28.6
2	40.0	4	40.0	6	42.9
1	20.0	1	10.0	5	35.7
3	60.0	5	50.0	7	50.0
2	40.0	4	40.0	7	50.0
2	40.0	4	40.0	-	0.0

Table 13. Summary of grain-infesting insects in warehouses and flour mills in Kassala Province.

Name of insect	Warehouses (No. of samples =116)		Flour mills (No. of samples = 44)	
	No. of infested samples	Percentage	No. of infested samples	Percentage
Alphitobius diaperinus (Panzer)	25	21.6	9	20.5
Aphanus littoralis Distant	15	12.9	8	18.2
Attagenus gloriosae (Fabricius)	19	16.4	8	18.2
Bruchus spp.	17	14.7	2	4.5
Corcyra cephalonica Stainton	21	18.1	6	13.6
Cryptolestes pusillus (Schönherr)	21	18.1	9	20.5
Latheticus oryzae Waterhouse	29	25.0	15	34.1
Mesostenopa sp.	13	11.2	1	2.3
Oryzaephilus mercator (Fauvel)	32	27.6	11	25.0
Oryzaephilus surinamensis (Linnaeus)	29	25.0	10	22.7
Ptinidae	17	14.7	5	11.4
Rhyzopertha dominica (Fabricius)	31	26.7	10	22.7
Sitophilus oryzae (Linnaeus)	47	40.5	13	29.5
Sitotroga cerealella (Olivier)	49	42.2	14	31.8
Tenebroides mauritanicus (Linnaeus)	37	31.9	10	22.7
Tribolium castaneum (Herbst)	43	37.1	20	45.5
Tribolium confusum Jacquelin duVal	38	32.8	20	45.4
Trogoderma granarium Everts	38	32.8	11	25.0

Some Bruchus spp., including B. maculatus Fabricius, were sampled from Gash and Tokar Deltas, and from some godowns in Port Sudan, but the genus was not encountered from milling plants in this town (Table 12), nor in other regions of the province.

Mesostenopa sp. (Tenebrionidae) was found in fairly large number in warehouses in both Gedaref District and Port Sudan (Table 11), and from one flour mill in Gedaref Area (Table 12).

The "sesame seed bug" (Aphanus littoralis Distant) was recorded in large numbers in the storage facilities of Gedaref District only (Table 11).

Regional Distribution of Insect Fauna in Flour Mills in Kassala Province

Flour mills in Kassala Province were small. They were operated locally throughout the year and offered their service to people in the vicinity of the plant. Individual customers brought a basketful or a sack of grain sorghum for milling, and the flour was taken later during the day.

These mills were made of corrugated iron, brick or concrete (Plate IX and X). Some of them were so poorly constructed (Plate IX) that they offered no protection from rain, dust, or insects (Plate IX, Fig. 1). Others had a leaky roof (Plate IX, Fig. 2), and still others were so old and without maintenance that they provided optimum conditions for multiplication of insect pests (Plate IX, Fig. 3).

However, comparatively new milling plants (Plate X) are arising, especially in big towns, to meet the hygienic demands of the urban population. These are being made of corrugated iron (Plate X, Fig. 1), of brick (Plate X, Fig. 2), or other building material. A high degree of sanitation is usually maintained as there is increasing competition between the operators.

EXPLANATION OF PLATE IX

Old flour mills in Kassala Province.

Fig. 1. Mill of corrugated iron.

Fig. 2. Mill of brick.

Fig. 3. Mill of concrete.

PLATE IX

Fig. 1

Fig. 2

Fig. 3

EXPLANATION OF PLATE X

Comparatively new flour mills in Kassala Province.

Fig. 1. Mill of corrugated iron.

Fig. 2. Mill of brick.

PLATE X

Fig. 1

Fig. 2

Insect pests encountered in the milling industries in the different regions of Kassala Province are reported in Table 12; the over-all infestation is summarized in Table 13. In both tables, Khashmel Girba area is not included.

All mills investigated during the survey contained some infestation. Most of the major pests were collected from each of the five regions (Table 12). These included: Sitophilus oryzae (Linnaeus), Rhyzopertha dominica (Fabricius), Oryzaephilus surinamensis (Linnaeus), Oryzaephilus mercator (Fauvel), Tribolium confusum Jacquelin duVal, Tribolium castaneum (Herbst), Tenebroides mauritanicus (Linnaeus), Cryptolestes pusillus (Schönherr), and Sitotroga cerealella (Olivier). Latheticus oryzae Waterhouse and Alphitobius diapernus (Panzer) were also cosmopolitan in distribution.

The prevalence of Trogoderma granarium Everts in the northern parts of the province, and its absence only in Gedaref District farther south (Table 12), is in general agreement with the findings in the storage buildings (Table 11).

Corcyra cephalonica Stainton and Attagenus gloriosae (Fabricius) were collected from milling plants in Tokar and Gash Deltas, as well as from Gedaref District and Port Sudan town, but were not found in Sinkat Area (Table 12).

Several specimens of spider beetles (Ptinidae), including Gibbium scotias Fabricius, were collected from Sinkat Area; they were also reported from Gash Delta (Table 12), but were absent from other parts of the province.

Some Bruchus spp., including B. maculatus Fabricius, were encountered in the flour mills of the two deltas of Gash and Barka, but were not found in

other parts (Table 12), although this genus was collected from the storage facilities of these same areas and from Port Sudan (Table 11).

Mesostenopa sp. (Tenebrionidae) was taken from one milling plant in Gedaref District only (Table 12) but was found in fairly large numbers in warehouses both in Gedaref Area and Port Sudan (Table 11).

As in the storage buildings (Table 11), Aphanus littoralis Distant was taken only from Gedaref Area and not from any of the other samples from the flour mills of the province (Table 12).

Miscellaneous Insects Collected During the Survey

Besides Bruchus spp., other members of seed weevils (Bruchidae) may have been present in the province. Pachymerus (Caryedon) fuscus Goeze was taken from some warehouses in Gash Delta.

Although only the lesser meal worm was cosmopolitan in distribution, other species of Alphitobius did occur in the province. Alphitobius laevigatus (Fabricius) was collected from Gedaref District in both flour mills and storage buildings. Two other Dermestidae identified as Anthrenus sp. and Dermestes sp. were recorded from a few warehouses and milling plants throughout Kassala Province.

Three members of the family Tenebrionidae were collected from certain storage facilities. Mesostena laevicollis Sol. occurred only in warehouses in Tokar Delta. Blaps mucronata Latereille and Gonocephalum sp. were collected only once in Gash Delta and can be considered as incidental pests.

Another incidental insect reported from warehouses of the same delta was the house and field cricket (Gryllus ignobilis Wlk.). Gryllus sp. was also encountered in warehouses and flour mills in Gedaref Area.

Blatella sp. was taken from one godown in Gedaref District. Another species belonging to the same family was the surinam cockroach (Leucophaca surinamensis Linnaeus) collected from Khashmel Girba District.

Termites (Isoptera) were taken from several warehouses in Sinkat Area. They were usually, but not always, associated with wooden material in the stores.

Spiders were occasionally sampled in large numbers from flour mills and storage facilities in Sinkat Area and Gash Delta.

Parasites and Predators

A number of species of Hymenoptera and Diptera were recorded from several warehouses and flour mills throughout the province, but their parasitic status was not investigated. However, in Sinkat Area some specimens of Angoumois grain moth were highly infested with a parasitic larvae. From the same area, Micro bracon sp. (Hymenoptera: Braconidae) was collected. On the other hand, Coranus pullesens Germ. (Hemiptera: Reduviidae) was taken in very large numbers from the milling plants and storage buildings in Gedaref Area only.

DISCUSSION

Major Grain-infesting Insects in Warehouses of Kassala Province

The most prevalent insect pests of stored grain in warehouses, listed according to their over-all importance (Table 13) were: Angoumois grain moth (Sitotroga cerealella (Olivier)), rice weevil (Sitophilus oryzae (Linnaeus)), red flour beetle (Tribolium castaneum (Herbst)), confused flour beetle (Tribolium confusum Jacquelin duVal), khapra beetle (Trogoderma granarium Everts), cadelle

(Tenebroides mauritanicus (Linnaeus)), merchant beetle (Oryzaephilus mercator (Fauvel)), lesser grain borer (Rhyzopertha dominica (Fabricius)), saw-toothed grain beetle (Oryzaephilus surinamensis (Linnaeus)), long-headed flour beetle (Latheticus oryzae Waterhouse), lesser meal worm (Alphitobius diaperinus (Panzer), flat grain beetle (Cryptolestes pusillus (Schonherr)), and rice moth (Corcyra cephalonica Stainton).

Angoumois grain moth was especially important in the agricultural areas of Gedaref District, Gash Delta, and Tokar Delta (Table 11). Darling (1959) observed that this moth confines its attack mainly to sorghum in the field in central and southern Sudan. Wilbur (1962) reported that field infestations by this pest and certain other species create annual problems in the southern parts of the United States of America and that combine harvesting has greatly reduced or eliminated field infestations in wheat. Experiments are being conducted in Gedaref Area to introduce a combine sorghum to solve the problem of laborer shortage. This may also reduce or eliminate field infestation in this district.

The importance of the rice weevil in Port Sudan was reported by Darling (1951) who indicated that this insect is a major pest in this city which has an annual mean relative humidity of 55% and where air-dry grain has a mean moisture content of about 11-12%. Wilbur (1962) noted that this weevil is better adapted to southerly regions in the United States of America where they frequently fly to the field of grain and oviposit in the developing kernel. Darling (1954) recorded this insect as having attacked ripening grain in the field in central Sudan. The abundance of this pest in warehouses throughout the province was substantiated by the current survey. Even in Sinkat Area, it was collected in fairly large numbers (Table 11).

The red flour beetle and confused flour beetle were equally abundant at Port Sudan. In the two deltas of the province and in Gedaref District, the red flour beetle was dominant. At the high altitute (Table 1) of Sinkat Area, however, the confused flour beetle was more abundant (Table 11).

The khapra beetle was an important pest in Kassala Province. Its absence in the samples obtained from Gedaref Area (Table 11) may be questionable, since it was found in large numbers in all other regions including Khashmel Girba District. Darling (1959) showed that this insect causes serious losses in the dry northern half of the Sudan but is of negligible importance farther south. However, Khalifa (1960) reported one live and no dead insects identified as Trogoderma from a sample taken from an experimental underground pit in Gedaref District. At Port Sudan, the khapra beetle was apparently a predominant pest in wooden bins (Table 2).

The cadelle was similarly dominant in wooden structures at Port Sudan (Table 2), but occurred in large numbers throughout the province. It was of less importance in Gash Delta (Table 11).

Nearly one fourth of the warehouses investigated during the survey harbored merchant beetles in all regions except that at Port Sudan the incidence was even greater (Table 11), particularly in wooden godowns (Table 2). This pest was recorded in large numbers in mud warehouses in Sinkat Area (Table 3), Tokar Delta (Table 4), and Gash Delta (Table 5), and in concrete buildings in Gedaref District (Table 8). It was also noted in samples from Khashmel Girba area.

The saw-toothed grain beetle had a distribution and occurrence more or less similar to the merchant beetle (Table 11) except that it seemed to be more abundant in corrugated-iron warehouses in Gedaref District (Table 8).

The distribution of lesser grain borers was similar to that of cadelle in that both occurred in large numbers in all storage facilities of the province (Table 11), and in that both were abundant in wooden structures at Port Sudan (Table 2).

The long-headed flour beetle was a predominant pest in mud godowns of Sinkat Area (Table 3), Tokar Delta (Table 4), and Gash Delta (Table 5), as well as in wooden bins at Port Sudan (Table 2) and in corrugated iron warehouses of Gedaref District (Table 8). Its over-all distribution was about the same in the five regions of the province (Table 11).

The incidence of the lesser meal worm was exceptionally high in Gedaref Area, but it occurred in moderate numbers in other parts of Kassala Province also (Table 11).

The flat grain beetle was of equal importance in all five regions (Table 11).

The rice moth was collected in large numbers from Gash Delta and from Gedaref District where it seemed to be of more importance in sesame stores. It also occurred in Tokar Delta and at Port Sudan but had not been encountered in Sinkat Area.

Other species of interest from the province included Attagenus gloriosae (Fabricius) that had not been reported from warehouses (Table 11) or flour mills (Table 12) in Sinkat Area but was found in other parts of Kassala Province. Willcocks (1922, 1925) recorded it in Egypt from grain damaged by insects and in mill debris where it probably fed on remains of insects. It had also been reported by Zacher (1940) in barley malt from the same country.

Mesostenopa sp. (Tenebrionidae) were found in fairly large numbers in warehouses in both Gedaref District and Port Sudan (Table 11), and in one

flour mill in Gedaref Area (Table 12). Little is known about this genus and it is probably of little importance in grain storage. The species M. picea Kraatz, however, was reported by Howe (1952) to occur occasionally in quite large numbers in groundnut storage in northern Nigeria.

Several specimens of spider beetles (Ptinidae) including Gibbium scotias Fabricius and probably other members of this family, were collected from Sinkat Area (Table 3) where the high elevation of the Red Sea Hills (Table 1) and the low winter temperature permit their abundance. Cotton (1956) noted that they are more often reported from the extreme northern states of the United States of America where they frequent warehouses. They were also taken from Gash Delta (Table 5) but their presence was usually associated with damp, cool conditions. However, they were absent from other parts of the province in both warehouses (Table 11) and flour mills (Table 12).

Aphanus littoralis Distant (Hemiptera: Lygaeidae) is a major field pest in Gedaref District and was collected in large numbers in this area but was never seen in all other samples taken from warehouses of the province (Table 11). Mallmaire (1954) found that the lygaeid Aphanus sordidus Fabricius, in Dakar, attacked groundnuts both in the field and when stored in heaps after harvest. It was also recorded by Cancela Da Fonseca (1955) as associated with groundnuts stored out of doors in unprotected mounds in Portuguese Guinea. It was considered by China (Corby, 1947) that A. littoralis Distant may prove to be synonymous with A. sordidus Fabricius although this has not been confirmed. Mackie (1944) found the latter species to attack shelled groundnuts (peanuts) stored in bulk in eastern Nigeria but appeared to cause little damage to groundnuts in bags. This may explain the absence of A. littoralis

Distant from other parts of Kassala Province since the usual method of storage was in jute sacks.

Effect of Building Material of Warehouses on Insect Infestation

A proper assessment of the different storage facilities in Kassala Province and the effect of their structure on extent of infestation by insect pests of stored grain was difficult to make since a complex of interacting factors may be involved, such as location of the building and previous control measures. At Port Sudan, for example, neglected and dirty stores and badly infested commercial plant products frequently are treated by fumigation or fogging. This is done by teams of the Plant Quarantine Service, Plant Protection Division at the owner's expense whether or not such treatment is requested. Warehouse operators may clean the building by sweeping, but the frequency of such cleaning differed widely. Dusting the floor with BHC was occasionally practiced.

The incidence of grain-infesting insects in mud godowns and in concrete buildings in Sinkat Area (Table 3) are similar. The long-headed flour beetle, merchant beetle, saw-toothed grain beetle, confused flour beetle, and khapra beetle infestations predominated in mud stores. The reason for the higher incidence of insects in the mud warehouses was probably due, at least in part, to the poor sanitary conditions in these buildings.

In Gedaref District the lesser grain borer, rice weevil, and flat grain beetle were more abundant in corrugated-iron buildings than in concrete and brick warehouses (Table 8). Wilbur and Halazon (1965) indicated that migration from infested sources may occur since these insects are capable of sustained flight, and that they may be in the air in abundance around infested granaries.

Although this phenomenon was not observed during the survey, it was noted that a large number of storage facilities made of corrugated iron were not insect proof (Plate VII).

At Port Sudan cadelle, lesser grain borer, and khapra beetle were especially abundant in wooden bins (Table 2). It is probable that these insects established themselves by tunneling in the wooden structures. As was indicated by Wilbur (1962), their holes provide hiding places for other species and lodging places for nutritious dust, and the presence of these tunnels prevents thorough cleaning of grain residue from the granaries. This may explain the tendency for higher infestation in this type of storage facility (Table 2).

Infestation in underground pits or matmura (Plate VIII) has not been investigated. However, Darling (1959) indicated that insect attack is confined to the peripheral grain and that rain or insect damage does not go more than 20 centimetres (8 inches) into the grain. Suitable varieties of sorghum, when buried with care, should keep safely in pits for up to three years and possibly longer (Darling, 1959), and can be stored safely for a maximum of 5 years after which sorghum loses its viability (Khalifa, 1960). Among other insects reported by Khalifa (1960) in experimental pits in Gedaref Area, are the following: Tribolium, Latheticus, Rhyzopertha and Laemophloeus (=Cryptolestes).

Darling (1954) indicated that the dura is buried shortly after harvesting and threshing in the dry season when the relative humidity is below 30% and when the grain water content is about 7-8%. He estimated that the loss, during 18 months in storage, did not exceed 2% by weight of the entire bulk, and it may be appreciably less.

Effect of the Nature of Stored Products on Insect Infestation

Various commodities are stored together in the warehouses in Kassala Province. The presence of one type of grain in certain buildings reflects the situation at the time of sampling rather than the usual practice. As a result, insect pests of stored products have a wide variety of foods. The presence of spilled grain and of other stored materials, although unsuitable for insect attack, provides pockets of infestation and harborage.

In Gash Delta, sorghum may be the only stored material, or it may be found with other products in the same building. Although one may expect to find a consistent difference in the incidence of grain-infesting insects in these two systems, the results did not show this (Table 6). This is natural considering the nature of the storage practices.

It is worthy to note that in Gash Delta the percentage of infestation by the Angoumois grain moth was higher in warehouses containing sorghum alone than in buildings storing miscellaneous food products (Table 6). This was also observed in Gedaref District where the moth was particularly abundant in dura storage facilities (Table 10). Furthermore, most of the miscellaneous insects not recorded in Table 6 in Gash Delta but mentioned elsewhere (p. 58), were collected from warehouses containing a wide variety of stored products.

The cadelle, rice weevil, red flour beetle, and confused flour beetle seemed to be important in sorghum stores in Gedaref District (Table 10). Whether this difference is due to food preferences of some of these insects, or to other factors, has not been determined.

On the other hand, the rice moth, known also in the Sudan as the sesame seed moth (George, 1955), is nearly three times as abundant in sesame stores

as in sorghum godowns in Gedaref Area. It is likely that food preference is involved in this case, but further investigation is needed.

Aphanus littoralis Distant, referred to by Bacon (1948) as the sesame seed bug, was a serious pest in Gedaref District and was also more prevalent in buildings in which sesame was stored by itself (Table 10). The species Aphanus sordidus Fabricius was reported by Corby (1947) in stored groundnuts (peanuts) in Nigeria and by Kasargode and Deshpande (1920) from India, attacking groundnuts and sesame in the field. It was carried into storage.

Thus, in Gedaref District, although there was a general tendency for higher percentages of infestation in buildings where both sorghum and sesame were stored together, the results were not conclusive for certain pests and were inconsistent for others (Table 10). In warehouses where either of these crops was stored by itself, the results also were inconsistent and seemed to have depended more upon the insect species involved than upon the nature of stored products. They may also have been affected by the previous use of the building.

It appears, therefore, that the division shown in Table 10 may be arbitrary, and that it may be premature to recommend keeping sorghum and sesame in separate warehouses in Gedaref Area. There was a preliminary indication to this effect. If this product separation did result in a better sanitation rating, the economics of the problem should then be considered.

Darling (1951) noted that bulrush millet, locally known in the Sudan as "dukhn", has small seeds, and that it is unlikely that lesser grain borer, rice weevil and Angoumois grain moth will breed extensively in this grain. He observed that dukhn remained free from attack by lesser grain borer even

though this pest may be present in large numbers in neighboring consignments of sorghum. This same phenomenon was recorded in Tokar Delta during this survey, but factors other than grain size, such as food preference and nature of the seed coat, may also be involved.

Effect of Duration of Storage on Insect Infestation

Storage buildings in Kassala Province usually operate continuously, resulting in the presence of one or more commodities for insect maintenance and reproduction throughout the year. The duration of storage for a particular item is variable depending upon such factors as demand and availability of transportation facilities, but generally there are some stored products in the warehouse suitable for insect attack.

In Gedaref Area, certain warehouses were used only for a few months each year so that new crops are stored in buildings that have been empty. There appears to be a correlation between the extent of infestation and the duration of storage in this district. This survey indicated that insects were more prevalent in all types of storage buildings where the operation was continuous compared to those where the grain was kept for a short period. For certain species the difference was not great (Table 9).

It was found that even in the seasonal warehouses, an odd sack or two of grain might be present, and there was usually spilled grain from the previous season on the floor and in cracks and crevices. This may explain the fact that all insects reported in the continuous storage facilities were also recorded in the seasonal type, and that certain pests compare favorably in numbers in both systems (Table 9). The presence of other material such as empty new and old jute sacks may also be a factor. This survey points to the

advisability of not storing grain for more than one season in Gedaref area under the prevalent storage practices. Underground pits may be an exception (Darling, 1954, 1959; Khalifa, 1960).

Effect of the Age of Warehouses on Insect Infestation

Some of the storage facilities in the province are old and without adequate maintenance so that they offer an optimum opportunity for insect multiplication and rat infestation. Other warehouses, although comparatively new, harbored a large population of grain-infesting insects.

This problem was investigated in Gash Delta. Storage buildings were divided into three groups according to their age (Table 7). The presence of all insects reported from this delta in the three categories, irrespective of age, and the tendency for the infestation to level out suggests that these pests are cosmopolitan in the area. The presence of these insects even in comparatively new storage buildings indicates that any warehouse built in the future may eventually be infested unless drastic measures are taken.

This may be true for other regions in Kassala Province and has practical importance because of the new Government silos at Port Sudan (Plate III, Fig. 3), and in Gedaref District which are designed to handle large amounts of grain.

Major Grain-infesting Insects in Flour Mills of Kassala Province

Insect pests in milling plants listed in decreasing order of importance for the whole province (Table 13) were red flour beetle, confused flour beetle, long-headed flour beetle, Angoumois grain moth, rice weevil, khapra

beetle, merchant beetle, saw-toothed grain beetle, lesser grain borer, cadelle, flat grain beetle and lesser meal worm.

As in warehouses (Table 11), the infestations of red flour beetle were either equal to, or greater than, the confused flour beetle in flour mills of all the regions investigated except at Sinkat Area where the latter was dominant (Table 12). Wilbur (1962) reported that these two species are believed to be equally abundant in flour mills in central states of the United States of America and that north of this region the confused flour beetle is considered to be the dominant species while in the south it is the red flour beetle.

The long-headed flour beetle was an important pest in the milling industries of Kassala Province and occurred in large numbers in all regions (Table 12).

Although the Angoumois grain moth was the most important insect pest in warehouses, it ranks fourth in importance in the milling plants (Table 13). However, its distribution was similar to that in the storage buildings (Table 11) in that it tended to be abundant in Tokar Delta, Gash Delta, and Gedaref District (Table 12).

The rice weevil seemed to be of great importance in Tokar Delta, of importance in both Gash Delta and Port Sudan, of less importance in Gedaref area, and occurred in Sinkat District (Table 12). This insect was apparently well established in the flour mills.

The khapra beetle is of equal importance in all regions except in Gedaref District where it was not recorded during this survey (Table 12).

The merchant beetle and saw-toothed grain beetle are present in equal numbers (Table 12). These species seemed to be cosmopolitan in the flour mills of Kassala Province.

The lesser grain borer was of comparatively greater importance in flour mills at Port Sudan (Table 12) where it also ranked high in storage infestations (Table 11), particularly in wooden structures (Table 2). It was also recorded in large numbers in the flour industries in other parts of the province (Table 12).

The incidence of the cadelle was about equal for Port Sudan, Sinkat Area, and Tokar Delta. It was extensive in Gedaref District but seemed to be of less importance in Gash Delta (Table 12).

The flat grain beetle was slightly more important in flour mills than in warehouses (Table 13). It was uniformly distributed in about 20% of the milling plants of the five regions (Table 12).

The lesser meal worm predominated in Gedaref Area but also was recorded from mills in other parts of Kassala Province (Table 12).

Another insect of interest recorded from the milling industry is the rice moth (Corcyra cephalonica Stainton). As in warehouses (Table 11), this insect was not collected from the milling plants in Sinkat Area (Table 12). Darling (1959) noted that this pest occurred only in southern Sudan. It was reported by Cotton (1956) that this moth is rarely found in flour mills but is a common pest of rough rice in southern United States of America.

As indicated earlier, the presence of Aphanus littoralis Distant in Gedaref area only is understandable considering the fact that it is a major field pest in the Mechanized Crop Production Schemes. There are two explanations for the occurrence of these insects in the flour mills in this area (Table 12). They may have been brought with the incoming grain and stayed in the building during the milling operations or they may have been migrating and sought shelter during the dry season. It is more likely that the latter

possibility is correct since the grain is usually cleaned by the customer before it is sent to the mill. It is the practice of the housewife to wash the grain with water and then spread it in the sun to dry, clean it by hand sieve, or turn it manually by hand to pick large bits of chaff, weeds, and conspicuous insects from the grain. Corby (1947) noted that during the day nymphs and adults were found either inside the building or outside, but at night they were scattered thickly on the ground and vegetation searching for moisture.

It is suggested that once any insect is established in the flour mill, it will continue to stay indefinitely under the present practice. The floor is customarily swept in the early morning and occasionally during the working hours, but there is usually spilled grain and flour for insect survival and reproduction, especially in old mills (Plate IX). This may explain why all flour mills investigated contained some infestation, and why some of the major pests of stored grain were prevalent throughout the province (Table 12). The presence of certain secondary storage pests (Table 13) can be explained by the nature of available products.

Parasites and Predators

Although some hymenopterous and dipterous specimens were taken from warehouses and flour mills in the province, their parasitic status is not known. Darling (1959) mentioned several taxonomic groups associated with grain-infesting insects in the Sudan. He reported Pteromalidae (Hymenoptera) in the south of the Sudan, found with Sitophilus oryzae (Linnaeus) and other pests. The members of this family are known to be parasitic on a wide variety of hosts, and the adult of many species feeds on the body fluids of the host

which exude from the puncture made by the parasite's ovipositor (Borror and DeLong, 1964).

Darling (1959) reported several unidentified predaceous fly larvae of the family Scenopinidae (Diptera) from heavily infested dura in southern Sudan. Borror and DeLong (1964) indicated that the larvae of Scenopinus fenestralis (Linnaeus) feed on the larvae of carpet beetles, and that the larvae of other species occur in decaying wood and fungi.

Unidentified predaceous bugs of the family Anthocoridae (Hemiptera) were noted by Darling (1959) to be common in heavily infested grain. These small bugs, known as flower or minute pirate bugs, feed on small insects and insect eggs (Borror and DeLong, 1964). Another group reported by Darling (1959) in a similar situation are some unidentified pseudoscorpions (Arachnida: Chelonethida). Borror and DeLong (1964) indicated that the members of Pseudoscorpionida or book scorpion often cling to and are carried about by large insects, and that they feed chiefly on small insects.

During the survey, several specimens of parasitic Hymenoptera identified as Macrobracon sp. (Braconidae) were collected from Sinkat Area. In the same warehouses and flour mills of this district, some specimens of Angoumois grain moth were found to be highly infested with parasitic larvae.

Gryllus sp. had been encountered occasionally in warehouses and flour mills in Gedaref Area. It was observed by Corby (1947) that G. domesticus Linnaeus fed on the eggs and active stages of Aphanus littoralis Distant and that it may have given some control.

Coranus pullescens Germ. (Hemiptera: Reduviidae) was sampled in great numbers in Gedaref District. The members of the genus Coranus are predatory

and normally are found in the field. However, Risbec (1950) reported the nymphs of Coranus pullidus Rt. feeding upon the nymphs of Aphanus sordidus Fabricius. From the current study, there appeared to be a relationship between the presence of Aphanus littoralis Distant (Hemiptera: Lygaeidae) and the occurrence of Coranus pullescens Germ. in the storage facilities and flour mills. It is likely that this assassin bug is a predator on Aphanus littoralis Distant and probably on other insects as well. Neither of these species have been reported from other parts of Kassala Province during the survey.

SUMMARY

An ecological survey of grain-infesting insects in warehouses and flour mills was undertaken in Kassala Province of the Sudan during February and March, 1965. The objectives of the study were to identify insect pests present in these facilities, to determine their general distribution, and to evaluate any relationship between insect species and numbers and the different storage methods. A total of 118 and 44 samples were taken, respectively, from the different warehouses and flour mills.

The most prevalent pests in warehouses, listed in decreasing order or importance for the province, were: Sitotroga cerealella (Olivier), Sitophilus oryzae (Linnaeus), Tribolium castaneum (Herbst), T. confusum Jacquelin duVal, Trogoderma granarium Everts, Tenebroides mauritanicus (Linnaeus), Oryzaephilus mercator (Fauvel), Rhyzopertha dominica (Fabricius), Oryzaephilus surinamensis (Linnaeus), Latheticus oryzae Waterhouse, Alphitobius diaperinus (Panzer), Cryptolestes pusillus (Schönherr), and Corcyra cephalonica Stainton.

The most important species in the flour mills, similarly listed, were: Tribolium castaneum (Herbst), T. confusum Jacquelin duVal, Latheticus oryzae

Waterhouse, Sitotroga cerealella (Olivier), Sitophilus oryzae (Linnaeus), Trogoderma granarium Everts, Oryzaephilus mercator (Fauvel), O. surinamensis (Linnaeus), Rhyzopertha dominica (Fabricius), Cryptolestes pusillus (Schönherr), and Alphitobius diaperinus (Panzer).

Other species collected from the province included Attagenus gloriosae (Fabricius), Mesostenopa sp., Bruchus spp., including B. maculatus Fabricius, and several unidentified Ptinidae including Gibbium scotias Fabricius. Aphanus littoralis Distant (Hem.: Lygaeidae) was encountered in large numbers only in southern Kassala, where it was also a major field pest.

Studies of the effect of building materials on insect infestation, showed a high incidence of insects in mud godowns which was probably due to low sanitary conditions in these stores. Rhyzopertha dominica (Fabricius), Sitophilus oryzae (Linnaeus), and Cryptolestes pusillus (Schönherr) predominated in corrugated iron buildings which were not insect proof. The incidence of Tenebroides mauritanicus (Linnaeus), Rhyzopertha dominica (Fabricius), and Trogoderma granarium Everts was especially high in wooden bins. Infestation in underground pits was not investigated but published works on this problem are discussed.

Studies of the effect of the nature of stored products on insect population revealed inconsistent results since warehouses in the province are usually general in nature. However, Sitotroga cerealella (Olivier), Tenebroides mauritanicus (Linnaeus), Sitophilus oryzae (Linnaeus), Tribolium castaneum (Herbst), and T. confusum Jacquelin duVal were more important in sorghum stores compared with buildings containing sesame in southern Kassala, while Corcyra cephalonica Stainton and Aphanus littoralis Distant predominated in the latter facilities. There is a preliminary indication of the advisability

of keeping these two crops in separate buildings but the economic aspects of this problem should be taken into account.

Seasonal warehouses in Gedaref area, in the south of the province, harbored fewer insects than in continuous storage but the difference was not great. The presence of an odd sack or two of grain, spilled commodities, or old jute sacks, in the seasonal system, contributed to this phenomenon. Nevertheless, the advisability of not keeping the grain for more than one season, under the prevalent storage practice, has been practically substantiated by the current survey.

The age of the building seems to bear no relation to the incidence of stored pests in Kassala Province. The presence of all insects reported from the area in all categories irrespective of age, and the tendency for the infestation to level out suggests that these pests were cosmopolitan in distribution, and that any insect-free warehouse will eventually be infested by them unless drastic measures are taken. This has a practical value because of the new Government grain silos erected in Gedaref District and Port Sudan.

Parasites and predators were not fully investigated although several hymenopterous and dipterous specimens were collected. Microbracon sp. was taken from Sinkat Area on the Red Sea Hills where several specimens of Sitotroga cerealella (Olivier) were also found to be highly infested with parasitic larvae. Coranus pallescens Germ. (Hem.: Reduviidae) was found in great numbers associated with Aphanus littoralis Distant in flour mills and warehouses of Gedaref District, but both species were not encountered from other parts of Kassala Province.

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VITA

Abdelazim R. Khalil, son of Mr. and Mrs. Rodwan Khalil, was born January 1, 1934 at Port Sudan, the Republic of the Sudan. He attended Wadi Seidna Secondary School, Omdurman, from which he was graduated in 1953.

After passing the Oversea School Certificate Examination, University of Cambridge, in December, 1953, he enrolled in the University of Khartoum, Sudan, and received his B. Sc. from the Faculty of Agriculture in March, 1960.

In July, 1960 he joined the Plant Protection Division of the Department of Agriculture of the Sudan in which he is still working. His responsibilities include: participation in the Desert Locust control, making of pest survey and supervising the plant protection work. Most of the time he is in charge of all the Plant Protection operations in Kassala Province.

In August, 1961 he visited the United States for one year under the sponsorship of the U. S. Agency for International Development. He enrolled in Kansas State University, Manhattan, Kansas, specializing in grain storage and marketing.

In May, 1963 he was awarded a fellowship from the Food and Agriculture Organization of the United Nations to attend a course in grain storage conducted in U. S. S. R. During a period of three months, he visited several research institutes in Moscow, Krasnodar, Armavir, Novorossisk, and Leningrad.

In September, 1964 he visited England for a period of another three months to attend a course about the technology of grain storage entomology and rodent control under the sponsorship of the Department of Technical Cooperation (The British Council), conducted at Tolworth, Surrey, Infestation

Control Laboratory, of the Ministry of Agriculture, Fisheries and Food.

In September, 1965 he again came to the United States under the sponsorship of the U. S. Agency for International Development. He entered Kansas State University to study toward a Master of Science degree in Entomology.

He is a member of the Agricultural Society of the Sudan, the Kansas Entomological Society, and the Entomological Society of America.

APPENDIX

SURVEY OF PESTS OF STORED GRAIN AND MILLS IN KASSALA PROVINCE

Date of sampling _____ Hour _____
Weather condition _____
Name of the godown owner _____
Location of the warehouse or mill _____

Description of the building site _____

Description of the building material _____
Volume of the building _____
The first date on which the building is used as storage facilities _____

History of previous use _____
Does the owner do any maintenance to the building? _____
Type of maintenance _____
Kind of crops stored _____
Date of arrival of crop at the godown _____
Other material stored in the warehouse _____
Quantity of material stored _____
Methods of storage (sacks, bulk, etc.) _____
Average duration of the storage _____
Is the storage structure used seasonal or continuous? _____

Does storage of grains overlap? _____
Origin of the grain _____
Transportation methods to the building _____

Intended destination of the crop _____
Transportation methods practiced, if any _____

Remarks _____

Pests found (for laboratory use) _____

GRAIN-INFESTING INSECTS IN WAREHOUSES AND FLOUR MILLS IN KASSALA PROVINCE OF THE REPUBLIC OF THE SUDAN

by

ABDELAZIM RODWAN KHALIL

B. Sc., University of Khartoum, 1960

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

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MASTER OF SCIENCE

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1967

A survey was conducted to identify the grain-infesting insects in warehouses and flour mills in Kassala Province of the Sudan, to determine their distribution, and to evaluate the storage practices. A total of 152 samples were taken in February and March, 1965.

In warehouses, the most prevalent pests were (1) Sitotroga cerealella (Olivier), (2) Sitophilus oryzae (Linnaeus), (3) Tribolium castaneum (Herbst), (4) T. confusum Jacquelin duVal, (5) Trogoderma granarium Everts, (6) Tenebroides mauritanicus (Linnaeus), (7) Oryzaephilus mercator (Fauvel), (8) Rhyzopertha dominica (Fabricius), (9) Oryzaephilus surinamensis (Linnaeus), (10) Latheticus oryzae Waterhouse, (11) Alphitobius diaperinus (Panzer), (12) Cryptolestes pusillus (Schonherr), and (13) Corcyra cephalonica Stainton, listed in order of importance. These same pests were collected from the flour mills but they ranked differently. Attagenus gloriosae Fabricius, Aphanus littoralis Distant, Bruchus spp., Mesostenopa sp. and several unidentified Ptinidae were occasionally encountered in the province.

There was a high incidence of insects in mud stores, probably as the result of poor sanitary conditions. Corrugated-iron warehouses were not insect-proof and harbored higher populations of Rhyzopertha dominica (Fabricius), Sitophilus oryzae (Linnaeus), and Cryptolestes pusillus (Schonherr). There was a general, higher incidence of storage pests in wooden bins but the following were particularly abundant in these stores: Tenebroides mauritanicus (Linnaeus), Rhyzopertha dominica (Fabricius), and Trogoderma granarium Everts. Published works about underground pits, an important method of storage, are also discussed.

There is some indication that it is not advisable to keep sorghum grain and sesame grain in the same building but the economic aspect has to be