THE DEVELOPMENT OF POPULATIONS OF RHIZOPERTHA DOMINICA, (FABRICIUS), SITOTROGA CEREALELLA (OLIVIER) AND SITOPHILUS SPECIES ON STORED SORGHUM AND MAIZE IN THREE CLIMATIC ZONES OF NIGERIA

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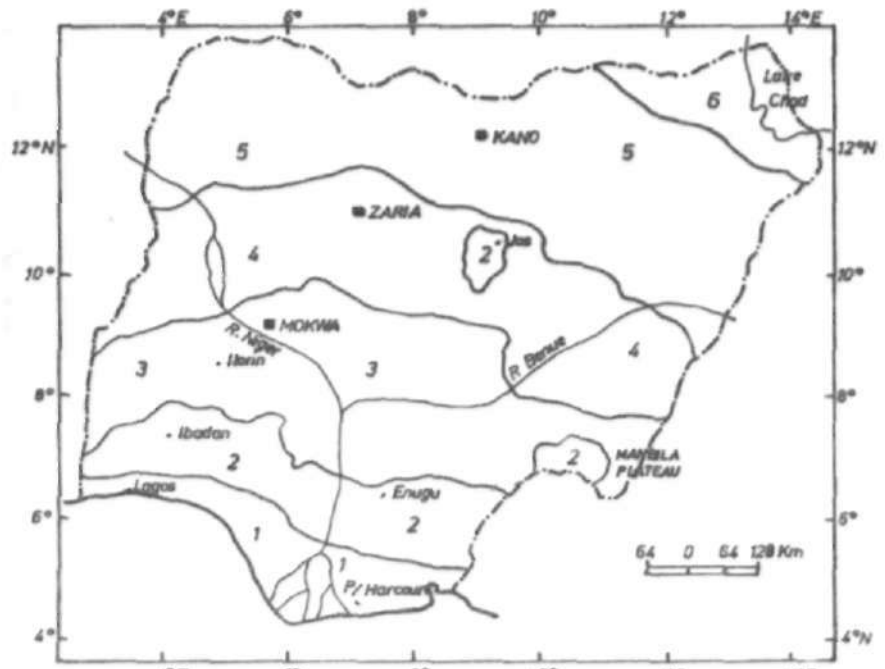
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1. INTRODUCTION

The pattern of agricultural production in Nigeria is dependent on rainfall distribution, a very important climatic variable. The rainfall distribution varies from 3,500mm a year along the coast to less than 500mm in the extreme north-eastern part of the country and is well reflected in the vegetational zones into which the country is divided (Fig. 1). The vegetation varies from the very wet coastal mangrove forest through rain-forest and savannah to the sahel savannah in the dry north-eastern part of Nigeria. Topography however disturbs this rainfall pattern in some places, such as around Jos and Mambila Plateau areas. In the Jos Plateau are for example, rainfall is about 2,000mm as compared with between 1,000 to 1,500mm in other areas in the same zone.

The production of maize and sorghum in Nigeria generally covers the forest and the savannah zones but the concentration of production in a specific locality depends on the local preferences of farmers and consumers. Sorghum (Sorghum vulgare pers.) is grown in the savannah zones of Nigeria and constitutes more than 40% of the total grain produced,

Fig. 1 NIGERIA : VEGETATION ZONES WITH ANNUAL RAINFALL RANGES



2500 - 3500 m/m	1	Mangrove Forest	1000 - 1500 m/m	4	Northern Guinea Savannah
2000 - 2500 m/m	2	Forest	500 - 1000 m/m	5	Sudan Savannah
1500 - 2000 m/m	3	Southern Guinea Savannah	200 - 350 m/m	6	Sahel "

Derived from KOWAL and KNABE, and HOPKINS.

making Nigeria the largest producer of sorghum in Africa (Table 1). Over 90% of this crop is grown in the Guinea and Sudan Savannah zones where the mean annual rainfall varies from 1,270mm to 500mm (Fajemisin, 1980). Consequently sorghum constitutes the most important stapple food of the people in the area. The grain is planted at the beginning of the rainy season (May/June) and is harvested towards the end of the year (November/ December). Harvesting coincides with the beginning of the dry season, so the dry harmattan winds help in drying the grain, reducing the grain moisture from about 25% at harvest to less than 12% at storage. At harvest, the dried heads are cut, bundled together and usually stored without threshing (Hays, 1975). About 70% of grain produced goes into storage for three to nine months.

Table 1: Maize and Sorghum Production in Nigeria, 1973 - 1979 (Metric Tonnes)

CROP	MEAN PRODUCTION 1973 - 1979	NIGERIA'S POSITION IN AFRICA*
MAIZE	1,318,400	4th.
SORGHUM	3,694,850	1st

*Out of an average of 30 countries

Source: Anon (1978, 1979)

Maize (Zea mays L.) on the other hand accounts for about 15% of Nigeria's total grain production and the country ranks fourth among producing countries in Africa (Anon 1978). Maize production covers the forest and the savannah zones but the bulk of its production and consumption is in the rainforest and the derived savannah zones. It is thus the most important cereal crop in the southern parts of Nigeria, where two crops may be grown in a year. In these zones, the main crop is planted in March/April and harvested in June/July while the late crop is planted in August/September and harvested in November/ December (Fajemisin, 1980). Only one maize crop is grown annually in the northern parts of the country where production is becoming increasingly important due to an increasing demand for the grain both for human consumption and for use in poultry feed. The setting up of a number of agricultural development projects in northern Nigeria recently has led to an increased production of this grain to meet these demands.

There are various methods of storing cereals in Nigeria. Giles (1964a) recorded five basic types of storage structures in the northern states and reported

that most of the crops are stored unthreshed in the earthenware or plant material bins. Caswell and Apeji (1977) described three main methods of storage of sorghum and millet in the northern states and pointed out that local farmers still store their produce in mud granaries (Hausa - rumbu) and that bundles of sorghum are only brought out for threshing when needed for food or for sale. Elder and Peters (1962) reported that in the southern states, maize is stored [illegible] bamboo cribs on the farms or simply hung (partly de-husked) from rafters of houses while cooperatives and government agencies usually store shelled maize in metal bins.

All the cereals produced in Nigeria are attacked by several pests in the field and in storage. Cornes (1964) compiled a list of insect pests associated with various stored products in southern Nigeria and some parts of the north while Giles (1965) recorded the stored product insects associated with sorghum in the northern part of Nigeria. The most important of these pests are insects belonging to the orders Coleoptera and Lepidoptera (Table 2). Among these

storage pests, some are reported to attack the grain from the field while others are known to be associated with grain only in storage. Mussidia sp. (Lepidoptera: Phycitidae) is recorded as a field pest of drying maize causing an initial damage of about 5% (Cornes and Rilley, 1962). Brachypeplus sp. (Coleoptera: Nitidulidae) is also recorded as a pest of drying sorghum in the field (Giles, 1965). These two insects are carried from the field to the store but do not continue to breed in storage, presumably because of reduced grain moisture. The most important insects attacking grains both in the field and in storage are Sitophilus spp. (Coleoptera: Curculionidae), Sitotroga cerealella (Oliv.) (Lepidoptera: Gelechiidae), Rhizopertha dominica (Fab) (Coleoptera: Bostrychidae) and Cryptolestes ugandae (Howe & Steel) (Coleoptera: Cucujidae) (Giles, 1965). Three insect pests regarded as the most important on whole grains of sorghum and maize in Nigeria are Sitophilus spp, Sitotroga cerealella and Rhizopertha dominica (Giles, 1965; Anon, 1976).

Giles (1964b) concluded from a market survey at Samaru, near Zaria, that insect damage to sorghum increases from May, reaching a peak of about 40% in August and then slowly declines to about 2% in January - February. Low grain moisture during the dry season was found to be responsible for the low level of damage recorded from January to May. From another market survey carried out in Kano by Halliday (1966), it was concluded that insect damage to sorghum was high[illegible] during [illegible] August/September when grain moisture was at its peak. He also suggested that the low level of damage (less than 1%) observed between December and April was due to the low grain moisture at this time. This made conditions unfavourable for insect pest development. Khare and Agrawal (1962) also reported that maximum damage to wheat and maize by Sitophilus oryzae (L.) and R. dominica (Fab.) in India occured when the relative humidity was between 64 and 75% (July-August). Caswell (in press) concluded, after sampling from 50 markets in the northern states of Nigeria, that maximum insect damage to sorghum of about 8% occured in October-November and declined to

below 2% between January and May. The results of the investigations reported above indicate that seasonal variation in moisture availability plays an important role in the incidence and damage to grains by these stored product pests. Thus, damage, which is directly related to the level of infestation by storage insects, was low during the dry season, when ambient relative humidity and grain moisture content were low, but rose steadily at the onset of the rainy season, reaching peaks at high ambient relative humidity. It follows therefore that moisture plays an important role in the development and activities of insect pests in stored grain.

Caswell (in press) reported that in Nigeria, Rhizopertha, Sitotroga and Sitophilus constituted about 80% of all insect pests found on stored sorghum and their incidence decreased from the Southern Guinea to Sudan Savannah zones. This observation suggested that the drier the area, the lower the incidence and damage to grains by these storage insects.

The purpose of this investigation is to:

(i) assess the validity of the suggestion that the drier the area, the lower the incidence and damage to grain by storage insects.

(ii) assess the effect of moisture on the population build-up of the three storage insects on sorghum and maize.

(iii) examine the effect of one species on another during their population build-up.

For the above investigation, samples of sorghum and maize were collected from three locations representing three climatic zones of Nigeria and a series of observations were carried out on these grain samples in the laboratory. Three insect genera were also cultured in the laboratory under controlled and ambient conditions to examine the role of moisture in the development and population build-up of the insects over a period of nine months. A brief study of the interactions among the species was also undertaken in the laboratory to examine the effect of each species on the other on stored grain.

TABLE 2: INSECT PESTS OF STORED SORGHUM AND MAIZE IN NIGERIA

COLEOPTERA	SORGHUM	MAIZE	REFERENCE
ANOBIIDAE Lasioderma serricorne (F)	a	c	Cornes 1964
BOSTRYCHIDAE Rhizopertha dominica (F)	a	a	"
CUCUJIDAE Cryptolestes ugandae (Steel & Howe)	b+	-	Giles 1965
C. pusillus (Schonnh.)	b	-	"
CURCULIONIDAE Sitophilus oryzae (L.)	a+	b	Cornes 1964
S. zeamais (Motsh.)	a	a+	"
DERMESTIDAE Attagenus gloriosae (F.)	c	-	Giles 1965
NITIDULIDAE Brachypeplus sp.	a+	a+	"
Carpophilus dimidiatus (F)	b	c	"
SILVANIDAE Ahasverus advena (Waltl)	b	b	"
Oryzaephilus mercator (Fauv)	a	b	Cornes 1964
O. surrinamensis (L)	b	b	"
TENEBRIONIDAE Palorus ratzeburgii (Wissm)	b	b	"
P. subdepressus (Woll.)	b	b	"
Tribolium castaneum (Hbst)	a	b	"
T. confusum (Duv.)	a	b	Giles 1965
LEPIDOPTERA			
GELECHIDAE Sitotroga cerealella (Oliv.)	a+	b	Cornes 1964
PHYCITIDAE Mussidia nigrivenella (Rag.)	-	a+	"

a - major pest
b - occassionally important
c - sometimes found
+ - attacks grain from field

2. REVIEW OF LITERATURE

The problems posed by stored product pests to food in general and to grains in particular have been well recorded by various scientists. Among the insect pests of stored produce, three that are pests of stored grains, and are of major importance to this review are; Rhizopertha dominica (Fab.) (Coleoptera: Bostrychidae), Sitotroga cerealella (Oliv.) (Lepidoptera: Gelechiidae) and Sitophilus spp. (Coleoptera: Curuculionidae). These insects are of world-wide distribution but are particularly abundant in the tropical and warm temperate regions where they breed continously and rapidly.

Potter (1935) reported that R. dominica probably originated from India or the Indian subregion and has spread all over the rest of the world. It survives throughout the year under natural conditions between latitudes 40°N and 40°S. R. dominica was considered a very important pest of stored grain in Argentina, India, United States and New South Wales (Australia) during and after the second world war and is still very important in most tropical countries on one grain or another.

Sitotroga cerealella also thrives well in the tropical and warm temperate regions and has a world-wide distribution. It has been reported to be able to tolerate temperatures of about 16°C, so it is found in the cold temperate regions as well (Howe, 1965). Three species of Sitophilus are relevant to this review; Sitophilus granarius (L.), S. zeamais (Mots.) and S. oryzae (L). S. granarius is more important in the cool temperate regions of the world and is usually not found infesting grains in tropical or subtropical regions. Little reference will therefore be made to this species. S. oryzae and S. zeamais were formerly known as the "small" and "large" strains of rice weevil Sitophilus (Calandra) oryzae respectively. The two species are more important as pests of stored grains in the tropics and warm temperate regions than in cool temperate regions.

Various workers have reported the occurence of one or the other of these insects on stored grains in various locations in the world. These include Kulash (1948) in North Carolina (U.S.A.), Howe (1952) in

Nigeria, Birch (1945) in Australia, Floyd et al. (1959) in Lousiana (U.S.A.), Khare and Agrawal (1962) in India and many others.

2.1 ENVIRONMENTAL FACTORS AFFECTING STORAGE INSECTS.

The activities of stored product insects are affected by environmental factors. It has been observed that oviposition, the rate of development, the degree of infestation of grains as well as the build-up of insect pest populations on grains, are affected by such factors as moisture, temperature, the food medium and the seasonal changes in climate. Of all these factors, the effects of moisture and temperature are closely interrelated and interacting and are the most important.

2.11 Moisture and Temperature

The interaction of temperature, relative humidity (r.h.) and moisture content of grain (m.c.) have very important effects on the activities of stored product insects. Such activities include oviposition, rate of development and the degree of infestation (Reddy, 1950).

2.111 Oviposition

Birch (1945c) reported that the lowest moisture content of wheat at which eggs were laid by S. oryzae was 10%. The rate of oviposition of R. dominica (F.) did not fall markedly in dry wheat until the moisture content was below 9% and the driest wheat on which eggs were laid was one with 8% moisture content. According

to Reddy (1950) the initial moisture content of grain, except at moistures below 10%, seems to have little affect on the oviposition of storage insects; he considered relative humidity and temperature to be the more important factors in this connection. Grain is hygroscopic and will eventually come into equilibrium with the surrounding relative humidity, regardless of its initial moisture content. This equilibrium is achieved either by absorbing more moisture when the ambient relative humidity is high or losing moisture when the ambient relative humidity is low. According to Reddy (1950) the maximum number of eggs were laid by S. oryzae at a relative humidity of 99%. This author further reported that though a very large number of eggs were laid at 84% r.h. by this insect; a relative humidity of 73% or less was unfavourable and no egg was laid at 30% r.h. The range of relative humidities favourable for egg laying and hatching by S. oryzae was given as 75% - 90% r.h. Howe (1952) reported that the oviposition rate of S. oryzae increased with relative humidity but that there was a critical point below which egg laying declined rapidly and mortality became high. For the same species, 30°C was found to

be the optimum temperature for egg laying and egg hatch with a range of 28°C to 32°C (Reddy 1950). Very few eggs were laid at 13°C or 35°C and none hatched at these temperatures.

No egg was laid by R. dominica at temperatures higher than 39°C but the maximum number of eggs was laid at 34°C in grain with moisture content of 14% (Birch 1945c). Grewal and Atwal (1969) reported that the the development, survival and fecundity of S. cerealella were more favoured at temperatures of 25-30°C and relative humidity of 80%. However, Hammad and Shenouda (1975) found that given a temperature of 27°C and relative humidities of 55%, 65% and 75%, S. cerealella laid the maximum number of eggs at 65% relative humidity. The lowest temperature at which S. cerealella oviposited on corn was found to be 16°C and the lowest relative humidity was 40% while the highest temperature and relative humidity were 32°C and 70% r.h. (Chesnut and Douglas, 1971). They also found that oviposition increased with higher humidities at all temperatures. It could thus be concluded that oviposition in these stored product insects is favoured by

temperatures of 25 - 34°C and relative humidities of between 60 and 99%. Temperatures and relative humidities outside these ranges will be unfavourable for egg deposition and egg hatch.

2.112 The rate of Development

Temperature, relative humidity and grain moisture content affect the rate of development of stored product insects. The larvae of insects which develop inside grains are affected in their development by grain moisture content more than by relative humidity (Prevett 1971).

Birch (1945 a and c) reported that the maximum and minimum temperatures for R. dominica survival was 38.6°C and 22°C respectively while the optimum temperature for development in wheat grain of 14% moisture content was 34°C. The moisture content of grain on which this insect was able to develop declined as the temperature increased from 18.2°C to 34°C but increased again as the temperature rose above 34°C. Prevett (1971) reported that at the optimum temperature development of R. dominica took about 28-30 days. This species could also tolerate a low relative humidity of about 30%

at that temperature. He found the optimum grain moisture content of rice for development to be 12.4%, slightly lower than the 14% reported for the same species on wheat by Birch (1945c). Thomson (1966) found that newly hatched larvae of R. dominica could not enter grain of less than 8% moisture content and reported that its life cycle lasted 30-35 days at 29°C and 75% relative humidity on sorghum of 12% moisture content. Pingale and Girish (1967) reported that R. dominica could breed in grain of 8% moisture content and the rate of development increased markedly when the grain moisture increased from 8% to 9%.

As the moisture content of maize grain increased from 14 to 17%, the developmental period of S. cerealella decreased by an average of 3 days (Warren, 1956). According to Prevett (1971) the life cycle of S. cerealella was completed in five weeks at 30°C on wheat and gave the optimum conditions for development as 26-30°C temperature and 70% relative humidity. The minimum relative humidity for the development of S. cerealella on rice was reported as 30% (Pingale and Girish, 1967).

Reddy (1950) reported that the optimum conditions for the development of S. oryzae were temperatures of

28-30°C, relative humidities of 75-90% and grain moisture content of 13.5-17.6%. He further observed that the development period of S. oryzae on wheat of 17.6% moisture content was 23 days at 30°C but this increased to 25 days at the higher temperature of 32°C and also to 31 days at the lower temperatures of 25 and 20°C. On wheat of 13.2% moisture content, the developmental period was 27 days at 30°C, 29 days at 32°C and 33 days at 25°C. This shows that at any given moisture content, the minimum developmental period was at 30°C. The lower limit of grain moisture content at which this insect could complete its development was given as 10% (Birch, 1945; Reddy, 1950). According to Howe (1952) the median period from oviposition to appearance of adults of S. oryzae on grains at 70% relative humidity were 110.2 days at 18°C and 40.3 days at 25°C. When the temperature was constant at 21°C, developmental period was 73.7 days at 50% r.h. and 47.8 days at 80% r.h. This is a further evidence that development of storage insects is affected by temperature and moisture.

2.113 Degree of Infestation and Population Build-up

The degree of infestation and the subsequent population build-up of storage insects are affected by grain moisture and temperature. Thus infestation by stored product insects increases with an increase in the moisture content of the substrate above 10% (Pingale & Girish, 1967).

Chalterji (1953) reported that the loss in weight and percentage damage to wheat grain, which are good indications of infestation, were significantly higher at 12% moisture content than at 8% or 5% when the grain was attacked by Rhizopertha, Sitotroga and Sitophilus. Giles (1964b) reported that infestation of sorghum seeds by insect pests was low during the dry season (Dec. - April) but increased sharply as the moisture content of grain increased from June to October/November. According to Reddy (1950) there was maximum infestation of wheat of moisture content of 13-17% at temperature of 30 C. Khochar and Gupta (1974) also found a relationship between temperature and susceptibility. They reported that a high level of infestation and greater weight loss of wheat, due to Rhizopertha, occured at 34°C than at temperatures

above or below this temperature. Also a high level of infestation and greater weight loss of wheat due to S. oryzae occured at 27.5°C. However the decrease in activity of the two insect species were less at 31°C and 25°C than at 37°C and 30°C respectively. Infestation and population build-up therefore increase at grain moisture in excess of 10% and at temperatures between 27°C and 34°C depending on the insect species involved. It could be concluded that for effective oviposition, larval development, infestation and subsequent population buil-up of insect pests of stored products temperatures should be between 25-34°C, relative humidities above 60% and the grain moisture content above 10% for most insect pests.

2.12 Food Medium

The type of food, its quality and quantity affect the development and grain infestation by storage insects. Some insects prefer one grain type to another and, grain type also affects larval development. Kapoor (1964) reported that the larval development of R. dominica

was faster in unhusked rice than in pearl millet and wheat but adults preferred wheat and barley to rice or maize as sources of food. According to Joubert (1966) the developmental period of S. cerealella was 19 days on sorghum of 12% m.c. stored at 28°C while on maize under the same conditions, the developmental period lasted 32 days. Mills and Wilbur (1967) also reported that the developmental period of S. cerealella maintained at 27°C, 70% r.h. and on grain with moisture content of 13.5%, was 37.9 days on wheat, 35.3 days on maize and 33 days on sorghum. Though the differences in the developmental periods reported by these authors for Sitotroga on sorghum were significantly different, the two observations showed that development was faster on sorghum than on maize under the same conditions. Ungsunantwiwat and Mills (1979) reported that when three species of Sitophilus were reared on wheat and sorghum, the developmental periods of their progeny were shorter on wheat than on sorghum. Even for the same grain, the quality of food affects the development of the insects. Khare and Mills (1968) reported that the developmental period of S. cerealella

in germ-drilled grains of wheat, sorghum and corn were respectively 32.5, 30.1 and 37.2 days while in endosperm-drilled grains, the developmental period on the three grain types were 49.4, 50.2 and 72.5 days respectively.

The quantity of food available can also affect the development of insects. Potter (1935) reported that the life cycle of R. dominica larva was prolonged in the absence of abundant food. The larva went through more moults and did not grow large in size. When food was given sparingly to a larva in its later stages, it died.

The physical and chemical natures of the food medium also affect the development of stored product insects. According to Reddy and Michelbacher (1953) the developmental period of S. oryzae was 30 days on raw wheat and 33 days on boiled wheat; however adults reared on boiled wheat were heavier than those on raw wheat probably due to a higher nutrient availability in the boiled wheat.

2.13 Time of the year

Seasonal changes during the year affect the development and the population build-up of stored product insects. Development is either delayed due

to low temperatures during the cold season and low relative humidities during the dry period or enhanced during warm moist periods. It has been observed that the period of maximum damage to stored grain is also the period of high insect population. Though differences have been found in the infestation and damage to grain at different times of the year, these differences are more related to changes in moisture and temperature at the given times rather than the time of the year per se. Thus Khare and Agrawal (1962) reported that the maximum damage to stored wheat and maize in India occured in July/August when there was maximum relative humidity. Khare (1964) reported that stored product insect populations at Jobner, India in 1961-62 reached their peaks in September, which also coincided with the period of maximum relative humidity. Both authors also reported that insect populations were generally low from December to June and that damage was low during this period. Low relative humidities characterised this period.

Giles (1964b) reported that in Nigeria insect populations remained at a low level in granary-stored

unthreshed sorghum until after June when the moisture content of the grain increased in the rainy season. The insect populations rose to a peak in November, two months after the maximum moisture content was reached but the numbers fell rapidly during the following dry season. According to Halliday (1966) in Kano, Nigeria, the maximum damage to sorghum occured in August/September when the moisture content of the grain was at the maximum. Caswell (in press) reported that R. dominica populations developed first in northern Nigeria, reaching a peak in July. S. cerealella populations reached a peak in August/September and Sitophilus populations increased reaching peaks in September and October/November. In all the above, it was observed that the insect populations were at their maximum when the relative humidity and ambient temperatures were high. As relative humidity and grain moisture decline, the populations of insects also decline reaching a minimum when the temperature is low in the cold dry season.

Shahjahan (1975) who reported that adult S. cerealella populations were high in farm storage areas in May-June and November - December in Bangladesh

related this to the storage condition since newly harvested Aman paddy was stored during November and the Boro paddy during May. These grains would also contain more moisture to encourage the rapid multiplication of the moths carried over from the old stock of grains. The minimum population was recorded in January and February during the cold weather. He thus concluded that the degree of infestation positively correlated with the moisture content of the rice varieties. In the investigations reported above, the authors did not mention temperature which interacts with moisture to reduce or enhance the incidence of the insects. It was also not mentioned if high mortality or migration was responsible for the minimum population of insects recorded during the cold dry season and laboratory investigations were not carried out to confirm the reasons advanced for the changes in the insect populations over the year.

2.2 GRAIN LOSS TO STORAGE INSECTS

Losses in growing crops may be compensated for by increased yield from surviving plants but losses after harvest are not recovered. Also infestation effects

on the field are often conspicous and can thus be dealt with promptly while in stored produce infestation may not be very conspicous but losses are real and can be estimated fairly accurately.

Damage to grains in storage and losses in weight are affected by such factors as the voracicousness of the insects attacking the grain, the stage of the insect, the general environmental conditions of the stored grain, the grain type and lenghth of storage, among others. Of the three insects under review here, R. dominica has been found to be the most voracious. According to Campbell and Sinha (1976) the damage caused by larvae of Cryptolestes ferrugineus (Steph.), R. dominica and S. granarius to individual wheat Kernels at 30°C and 70% relative humidity was 4,17 and 60% respectively. Adults of R. dominica also caused a greater weight loss and produced more frass than did those of S. granarius and C. ferrugineous. Cogburn (1977) concluded from an assessment of losses caused by S. oryzae, R. dominica and S. cerealella on varieties of rough rice over three generations that S. oryzae caused the least damage. He attributed this

to the presence of the few kernels with hull defect which could easily be penetrated by S. oryzae. The damage attributable to S. cerealella and R. dominica was found to be approximately equal. But S. cerealella developed faster and had more rapid population growth than R. dominica, thus, R. dominica caused greater damage between the two pests.

Loss in weight caused by S. oryzae in the course of its development was assessed by White (1953). He found that when S. oryzae was reared on wheat of 12.4% moisture content and at 26.7°C and 75% r.h., the loss in weight increased from the first to the fourth week after egg deposition and declined slightly in the fifth during pupation and adult emergence. The mean total loss in weight per infested kernel was 0.67, 2.36, 6.52, 13.59 and 20% after one, two, three, four and five weeks of larval development respectively. He concluded that 50% of the total loss in weight occured during the last 9.5 days of the developmental period and that 68% of the loss occured during the first 4 weeks of development when there was no outward evidence of infestation. This further shows that even where infestation is not conspicous in stored produce, damage can still occur.

When single kernels or samples of 20g and 250g of maize were infested with S. oryzae and then stored at 15.6°C, 21.1°C and 26.7°C, and relative humidity of 50%, Irabagon (1960) found that the total loss in weight was directly proportional to the number of weevils on the maize and was at a maximum when the temperature was 26.7°C in comparison with other temperatures. The insect caused 74.7% loss in weight in a single kernel and, 12.9% and 25.9% respectively in 20g and 250g samples.

Larval feeding of stored product insects not only causes loss in weight but also reduces germination of grains. According to Yadav et al. (1968) the feeding of the larvae of S. oryzae and R. dominica significantly reduced germinating ability of wheat seeds within 20 days and that of maize seeds within 15 days of exposure of the grains to the ovipositing females. With sorghum, all the germinating ability was lost within 15 days of exposure to females of either species. The germination ability of wheat, sorghum, maize, rice and barley seeds were affected within six days of exposure to the ovipositing females of S. cerealella and was completely lost within 18 days

of exposure to all seeds except maize. Mookherjee et al. (1969) concluded that rice was the most susceptible to larval damage by S. cerealella among five grain types. Considering the effect of infestation on the germination of seeds and, knowing that the peasant farmers in Nigeria hardly use any control measures for grain in storage, the question could arise as to how the farmers obtain the seeds for planting during the following season. It would appear that the seasonal variation in the climatic conditions over a year imposes a natural control on pest infestation and the time for rapid increase in stored product insects coincides with the time when the grains are in the field, hence the damage may not be high enough to result in a total loss of germination ability.

However, the length of the storage period would increase the infestation and the loss to the grains. The effect of the length of storage period on the level of damage and weight loss has been investigated by various workers. According to Floyd et.al. (1959) the percentage of corn kernel damaged by insects throughout Lousiana between 1955 and 1958 averaged about 10% at harvest. This increased during

storage to 17% in May and to more than 30% in July with Sitophilus being the principal pest involved. Damage caused by S. cerealeila was less than 2% of total damage at harvest but this increased to 16% when corn was stored until midsummer. Giles (1964a) reported that unthreshed sorghum stored undisturbed for nine months suffered a mean weight loss due to insects of about 8% but in some cases, about 25% of the crop was lost. A sample of a three-year-old threshed grain was found to have lost 37% of its original weight with as much as 78% of the grain damaged in some trials. He estimated that the yearly grain loss in Nigeria was 4% of all sorghum and millet produced although Caswell (in press) has recently estimated this to be 1.4%. Also Shahjahan (1974) reported that 3 - 12% of rice kernels were damaged over a period of 6 to 9 months in unhusked stored rice in Bangladesh. This brought about a total weight loss which ranged from 4.2 to 11.9% with a mean of 8.1%. He estimated an average weight loss to a single grain to be 56.3% while about 53.3% of each kernel was needed for complete larval development of S. cerealella.

It is necessary to point out here that there is no standardized methodology for the measurement of weight loss of grains due to insect activities. Thus individual scientists use methods most convenient to them and an estimate by one scientist may be doubled by another. Underestimation or overestimation of grain losses are therefore common.

2.3 INTERACTION BETWEEN STORAGE INSECT PESTS

Investigations involving single and mixed species populations in cultures over periods of time have been used in studies on interactions between species of stored product insects. No given population can continue to increase indefinitely, as mortality, caused by one or several factors, prevents the indefinite growth of such populations. This review examines the results of interactions between single and mixed species populations among stored product insects given limited resources.

The word 'Competition' has been used by various authors to describe the interaction between species and there has been a lot of controversy on the definition of the word as used by ecologists. Crombie (1947) defined competition as the demand,

typically at the same time, of more than one organism for the same resources of the environment in excess of immediate supply. He further stated that all organisms tend towards unlimited increase but meet with resistance from their physical and biological environment. He concluded that barring the effect of external factors, two species with identical needs and habbits can not survive in the same place if they compete for limited resources. Birch (1957) defined competition between animals as that which occurs when a number of animals (of the same or different species) utilise common resources, the supply of which is short; or if the resources are not in short supply, competition occurs when the animals seeking that resource nevertheless harm one or another in the process. According to Milne (1961) competition is the endearvour of two (or more) animals to gain the same particular thing or to gain the measure each wants from the supply of a thing when that supply is not sufficient for both (or all). Park (1962) recognised two components of competition: exploitation and interference. According to him exploitation occurs when organisms draw upon a particular

resource which is limited while interference operates when interactions between organisms affect their reproduction or survival. All the above definitions identify limited resources as the major cause of competition among animals. Some studies have been undertaken, using stored product insects, to show the effect of one species on the other when the insect populations were allowed to grow together. In such investigations, adult insects were introduced together on a limited food supply in a confined environment and the population growth observed. This growth is compared with the population growth in a single species culture.

Crombie (1944) reported that females of R. dominica and S. cerealella oviposit in environments suitable for the development of their respective larvae but the larvae themselves, during a period of migration in the first instar, choose the actual developmental site. Because of limited space, these larvae attack each other after encounters at random within the grain and the superflous individuals are either killed or forced to migrate. In such a competition, because of the greater success of R. dominica larvae over that of S. cerealella, S. cerealella was usually eliminated.

Crombie (1945) further found that either R. dominica or S. cerealella could coexist in the same medium with Oryzaephilus surinamensis (L.) because their larvae occupied different 'ecological niche'. While the larva of R. dominica or S. cerealella lived and fed inside the grain, that of O. surinamensis lived and fed outside the grain.

Predation of one species by another can confer an advantage to the predator when two species are competing in the same medium. According to Crombie (1946) in a mixed culture of Tribolium confusum (Duv) and O. surinamensis, T. confusum had an advantage because the adults and larvae could destroy both eggs and pupae of O. surinamensis while only adults of the latter could destroy the eggs of T. confusum and also to a lesser extent. When R. dominica was added to the mixed culture, it was found that the three species survived together on wheat. This was because R. dominica in the medium reduced the rate of predation of O. surinamensis pupae by T. confusum. Polnik (1963) also found that T. confusum eliminated Lathoticus oryzae (Waterh.) in a mixed culture of the two species. In analytical investigations, it was found that the fecundity of

L. oryzae was much lower than that of T. confusum. Thus the latter had an advantage of a higher population. Also the predation of eggs and pupae of L. oryzae by T. confusum, coupled with the cannibalism of L. oryzae of its young further contributed to the elimination of L. oryzae. According to Inuoye and Lerner (1965) T. confusum was eliminated in a mixed culture with Tribolium castaneum (Herbst.). The authors attributed the elimination not only to the high density which favoured T. castaneum, because of its high rate of oviposition and development, but also to the fact that T. castaneum tends to supply itself with essential nutrients by feeding on T. confusum.

Elimination of one of the competing species is not the only phenomenon that has been observed in mixed cultures of insect species. Thus Ciesielska (1971) observed a stimulation of devalopmental process of R. dominica when it was reared with O. surinamensis. Though he found that the developmental period of O. surinamensis was shorter when reared alone than when reared with R. dominica, mortality of both species was found to be lower in the mixed culture than in single cultures during the first three months. He thus

concluded that the displacement of an insect species occured not through an increase in its mortality but through a reduction in its rate of development. Phadke and Bhatia (1976) observed a mutual suppression of the populations of S. oryzae and R. dominica in a mixed culture. It was found that S. oryzae outnumbered R. dominica during the population growth and this was attributed to greater activity and faster rate of development in S. oryzae as compared with that of R. dominica. The population of S. oryzae or R. dominica were not as high as when they were reared alone.

Competition between S. cerealella and S. zeamais was investigated by Chesnut and Douglas (1971) in Mississippi (U.S.A.). In a field survey, an initial increase in the numbers of S. cerealella in comparison with S. zeamais was observed but the population of S. zeamais later increased rapidly surpassing that of S. cerealella. This was attributed to the shorter adult life (about one week) of S. cerealella. Thus S. cerealella which had a shorter developmental period and higher oviposition rate increased rapidly but was later eliminated. On the other hand, S. zeamais

with a longer adult life had its progeny continually added to the adult population giving it an advantage over its ecological homologue and S. cerealella was eventually eliminated after 6 - 8 generations. From their laboragory investigations, they also found that S. zeamais had an advantage over S. cerealella because the eggs of the latter were destroyed by mechanical damage caused by the weevils, thus limiting the number of female moths available for reproduction during the next generation. But Ayertey (1980) in his investigation on why S. zeamais eliminated S. cerealella from mixed cultures found that S. zeamais had only slight effects on the copulation, oviposition, egg or young larvae of S. cerealella. He concluded that the main cause of mortality to S. cerealella and the one which explained its elimination by S. zeamais in a mixed culture was the mortality of immature moths inside grains caused by the feeding of S. zeamais. The longer adult life of S. zeamais also made it possible for the moth to be exposed to the weevil for long periods when the two were present in the same environment. It could thus be inferred that it is the active stages of an insect (larvae and adults) that determine the outcome of two insect species bred in the same medium.

3. MATERIALS AND METHODS

3.1 SURVEY OF GRAIN INFESTATION AND DAMAGE

In the survey of grain infestation and damage in the three ecological zones of Nigeria, samples of maize and sorghum were collected monthly for nine months (October to June). These samples were obtained from markets located at Mokwa (Latitude 9°N.) representing the Southern Guinea Savannah, Zaria (Lat. 11°N.) which represents the Northern Guinea Savannah and Kano (Lat. 12°N) which represents the Sudan Savannah (Fig. 1). At each market, three samples each of sorghum and maize were purchased from different traders. Each sample, equivalent to a measure (Hausa-rebi mudu), weighed approximately one kilogram. The samples from each of the locations were brought to the laboratory where the following observations were made:

3.11 Assessment of grain infestation

Adult insects from each grain sample were sieved using a Griffin and George sieve, mesh sizes 10 and 30. The insects were separated into their various genera, counted and recorded. The grain samples were kept in jars in the laboratory for one month after which they were sieved again and any adults that emerged were identified, counted and added to

those obtained at the initial count. This procedure provided a record of insects contained in the sample at the time of purchase. The interval of one month may have excluded some insects which were in the egg stage at the time the grains were purchased but this was done to exclude the offspring of those that may have emerged soon after the grains were purchased from the markets.

3.12 Assessment of grain damage

To assess grain damage, 1,000 grain seeds were counted out of each sample and separated into whole (undamaged) or damaged seeds and the number in each category noted. The weights of the damaged or undamaged seeds were determined and recorded against their numbers. The weight loss was calculated from the unit weights of the damaged and undamaged grains in each category as follows:

$$\frac{\text{Unit weight of undamaged grain} - \text{Unit weight of damaged grain}}{\text{Unit weight of undamaged grain}} \times 100$$

3.13 Determination of moisture content

The oven method was used for the determination of moisture content of the grain samples (Hlynka and Robinson, 1954; Dixton, 1967). About 20g. of each sample was ground and subdivided equally into three aluminium tins with lids of known weights. Each tin containing the ground subsample was weighed on a Metler balance and, with its lid removed, transfered into a Gallenkamp ventilated oven maintained at 105°C where it was dry heated for four hours. The tins were removed after the dry heating, covered as quickly as possible with the lids, allowed to cool and then weighed again. The moisture content was calculated thus:-

$$\frac{\text{Weight of tin and contents before drying} - \text{Weight of tin and contents after drying}}{\text{Weight of Subsample}} \times 100$$

(where weight of the subsample is the initial weight of tin and contents minus weight of empty tin).

The final moisture content of each sample was the mean of the three subsamples. The moisture content of all samples obtained were determined in this manner.

3.2 LABORATORY STUDIES ON THE GROWTH OF INSECT PEST POPULATIONS

3.21 Source of food

In these studies, all the three populations of insects R. dominica, S. cerealella and Sitophilus sp. were bred in the laboratory. For this breeding, sorghum harvested in November/December 1978 was used. The sorghum grain (about 20kg) was first fumigated with phostoxin a few weeks after harvest and stored in a drum at the Institute for Agricultural Research, Samaru (near Zaria). Preliminary tests were carried out on the grains from May to July 1979 to assess the efficiency and effect of the fumigation. One hundred adults each of R. dominica, S. cerealella and Sitophilus obtained from stock cultures in the laboratory were introduced separately into a group of six jars (two jars to each genus), each containing 300g of sorghum and kept in the laboratory for three months. Another group of six jars, each with 300g sorghum grains but no insects were also kept for the same period. When the sorghum samples artificially

infested with insects were examined at the end of the three months, it was found that R. dominica had increased from a mean of 100 insects per jar to a mean of 327 adults, S. cerealella increased from a mean of 100 insects per jar to a mean of 613 adults and Sitophilus from a mean of 100 insects to a mean of 418 adults. The three insect species have therefore, within a period of three months, increased by a factor of 3, 6 and 4 respectively. Strong et al. (1967) in their breeding experiments involving these insects on wheat of 13% m.c. at 27°C and 60% r.h. reported that R. dominica increased by a calculated factor of three in eight weeks, S. cerealla by a factor of nine in five weeks and Sitophilus by a factor of two in six weeks. Consequently the growth of these populations on the sorghum grain was considered satisfactory and this sorghum was therefore used in all the breeding experiments. When the other set of jars that were not infested were sieved, no insects emerged from them. This shows that the fumigation was efficient in disinfecting the grain.

The treated sorghum was kept in a dessicator in the laboratory for one month, to allow a conditioning of the grain to the laboratory environment, after which the moisture content was determined according to the method described earlier, before it was used in the breeding experiments.

3.22 Containers

Dual purpose Kilner jars of various sizes viz; 250cc, 500cc and 750cc with screw tops were used for general insect rearing. Ventilation was provided by a 5cm - diameter screen opening in each top. To prevent the escape of the insects, each opening was covered with muslin fitted to 1.6 mm wire-mesh. The population growth experiments were carried out in 60cc bottles with screw tops. Three holes, each 1cm in diameter, were bored in each top to provide ventilation.

3.23 Insect Culturing

Rhizopertha, Sitotroga and Sitophilus species which had been maintained for about five years on sorghum in the laboratory at the Institute for

Agricultural Research, Samaru were subcultured in July 1979 on the conditioned sorghum to provide insects for the laboratory experiments. Culturing was done as follows: For Rhizopertha, one hundred adults selected randomly from the laboratory stock were placed on 300g sorghum in a 750cc dual purpose Kilner Jar in July. Five such jars were maintained until October when the insects were required for the experiments. For Sitophilus, five cultures were set up using same procedure as described for Rhizopertha above. For Sitotroga, one hundred adults picked randomly from the laboratory stock were added to 100g sorghum in a 500cc dual purpose Kilner jar. Seven such cultures were maintained initially but later, this was increased to ten, after the first generation of the insects had emerged.

3.24 Experimental Chambers

Two Humidity Cabinets (Towson and Mercer Ltd. of Croydon) were used. Each cabinet was made of fibre glass with two shelves and a door made of glass.

Externally, each measure 53cm in height, 40cm wide and 28cm deep. No heater was supplied with the cabinets to facilitate the control of temperature but humidity was controlled by the use of saturated salt solutions. To do this, salt solutions in beakers were placed in the dessicant tray of the cabinet and the following salt solutions in equilibrium with the given relative humidities were used (Peterson, 1934).

Cabinet A - Sodium Chloride = 76% ± 3 at 22°C.

Cabinet B - Calcium Nitrate = 55% ± 5 at 22°C.

Thermomethers and portable hygrometers were standardized with those used by the Meteorological section of the Institute for Agricultural Research and placed in each cabinet and, daily records of temperature and relative humidity were taken. Records of the ambient temperature and humidity in the laboratory were also taken using a Thermohygrograph with teperature and humidity ranges of 0 - 50°C and 0 - 100% with charts for 24h. recording. The 60cc bottles with screw tops containing grains and insects were kept on the two glass shelves together with the thermometers and the hygrometers.

3.25 Single and Mixed Species Cultures

There were two groups of experiments in which the population growth and the interaction of the three insect populations were observed.

Group A. - In the first group of experiments set up in October 1979, 25g of the conditioned sorghum were placed in each of twenty-four 60cc jars described above. Six replicates each, of the following three types of monocultures were set up.

1. Rhizopertha (R) Monoculture
2. Sitotroga (S1) "
3. Sitophilus (S2) "

The insects used in the experiments were not selected for age or sex but were picked randomly from the culture jars of each species.

Rhizopertha adults were sieved out of the stock culture and 20 insects, selected randomly were placed into each of the set of six 60cc jars containing 25 g sorghum. In each of another set of six jars, 20 adults of Sitophilus sieved out of its culture were introduced. A pooter was used to take out 20 adults of Sitotroga from its culture and kept in each of six test tubes. The test tubes containing the insects

were kept in a freezer for about one minute to keep the insects temporarily inactive and thus enhance their easy transfer from the test tubes into a third set of six experimental jars, also containing sorghum. Sitotroga is a very active but delicate insect to handle hence the special treatment. Three of each set of six jars with insects were kept in the first cabinet while the remaining three of each set were left outside the cabinet in the laboratory under ambient conditions. Daily records of temperature and humidity both in the cabinet and under the ambient conditions were kept.

Group B. - For the second group of experiments the same procedure was followed for the monocultures as in the first group but the number was increased and mixed cultures were set-up. Nine sets of jars were seeded with the three genera separately. For each genus three sets of jars were seeded with 10, 20 or 30 adults. Thus, there were three sets of six jars each of Rhizopertha, Sitotroga or Sitophilus with each set seeded initially with 10, 20 or 30 adults of each genus. The following types of mixed

cultures were also set up

Rhizopertha + Sitotroga (R + S1)

Rhizopertha + Sitophilus (R + S2)

Sitotroga + Sitophilus (S1 + S2)

Rhizopertha + Sitotroga + Sitophilus (R + S1 + S2)

Ten adults of Rhizopertha and 10 adults of Sitotroga were added to the tenth set of six jars. The eleventh and twelfth sets of six jars contained 10 adults each of Rhizopertha and Sitophilus or Sitotroga and Sitophilus. To the thirteenth set of six jars were added 10 adults each of Rhizopertha, Sitotroga and Sitophilus.

The different numbers of adults of each genus in the mixed cultures were duplicated in the monocultures so that the interaction of the populations in the mixed cultures could be evaluation against the same insect numbers in the monocultures.

Three of each set of six jars with insects were kept in the second cabinet while the remaining three of each set of jars were kept outside the cabinet in the laboratory. Portable thermometers and hygrometers were kept as before in these cabinets for daily records of temperature and humidity.

3.26 Assessment of insect population growth

One month after the start of these cultures and at monthly intervals, the adults were sieved out of the grain in each jar, counted and the live ones returned, with the grain weight topped up to the original 25g in each jar. This procedure was continued for nine months for the two groups of cultures. To monitor the change in grain moisture content, additional samples of sorghum with or without insects were kept in the cabinent and under ambient conditions and their moisture determined at intervals.

4. DESCRIPTION OF EXPERIMENTS AND RESULTS

4.1 INFESTATION OF AND DAMAGE TO SORGHUM AND MAIZE BY *RHIZOPERTHA*, *SITOTROGA* AND *SITOPHILUS* SPECIES IN THREE CLIMATIC ZONES OF NIGERIA.

4.11 Introduction

To a large extent, damage to stored produce is proportional to the infestation so that the higher the infestation level, the greater the damage. The degree of infestation and damage may depend on the ambient environment and it has been suggested that moisture is the most important factor in this context (Caswell, in press). In view of this, samples of maize and sorghum collected from three climatic zones in Nigeria were examined in the laboratory for infestation and damage. These locations, Mokwa, Zaria and Kano represent the Southern Guinea Savannah, Northern Guinea Savannah and Sudan Savannah zones respectively.

4.12 Methods

The samples of maize and sorghum, each weighing approximately 1 kg. and purchased from different traders from each of the locations, as described

earlier (see 3.1), were taken to the laboratory where the number of insects found and the number of damaged and undamaged grains from each grain category were recorded. The loss in weight of the damaged grains, was estimated as described earlier (see 3.12).

4.13 Results and Discussions

The mean numbers of adults found in the samples are given in Appendix Tables 1a and b. The grain damage and weight losses are given in Appendix Tables 2a and 2b. The moisture content of the grain samples collected from the three locations is given in Appendix Table 3.

There are two main features in the results of this investigation:

(i) Incidence and relative abundance of Rhizopertha, Sitotroga and Sitophilus on stored grains at the three climatic zones and

(ii) Damage to sorghum and maize seeds in the three climatic zones.

4.131 Incidence and relative abundance of Rhizopertha, Sitotroga and Sitophilus on stored grains at Mokwa, Zaria and Kano

Of all the insect pests found on the grain samples from the three locations, Rhizopertha, Sitotroga and Sitophilus species accounted for 57 - 84%.(Table 3). This is an indication that the three insect genera are the dominant pests of the two grain types at the three locations and confirms an earlier report by Caswell that the same genera formed about 80% of all the insects collected from samples of sorghum obtained from 50 locations in the northern states of Nigeria. The similarity in the levels of the three genera on sorghum and maize also shows their importance on maize included in this survey. Earlier work by Giles (1964b) showed that the main pests found on stored sorghum were Sitophilus and Sitotroga; Halliday (1966) reported that the main pests of stored sorghum and maize in Kano were Sitophilus and Rhizopertha. The three insect genera have therefore long been recognised as the

most important pests of stored sorghum and maize and this is confirmed by the present survey.

Changes in the total pest population with time on the two grains at the three locations followed the same general trend (Fig. 2). There was generally a decline in the pest populations from December to April on both grains followed by an increase from May. An increase in population was also observed in February and this was probably due to the emergence in storage of immature insect pests carried from the field at harvest. Sitophilus and Sitotroga are known to attack grains from the field (Giles, 1965). It is likely that the immature stages of these insects, carried into storage with grains in December, emerged in large numbers in February resulting in the high populations recorded for that month. In general, the total pest population closely followed the pattern of grain moisture content (Fig. 3). The insect populations were thus at a low level from January to April when the moisture content was low but increased from May as the grain moisture increased.

Fig. 2 Changes in the total pest population with time on stored sorghum and maize samples from Mokwa, Zaria and Kano.

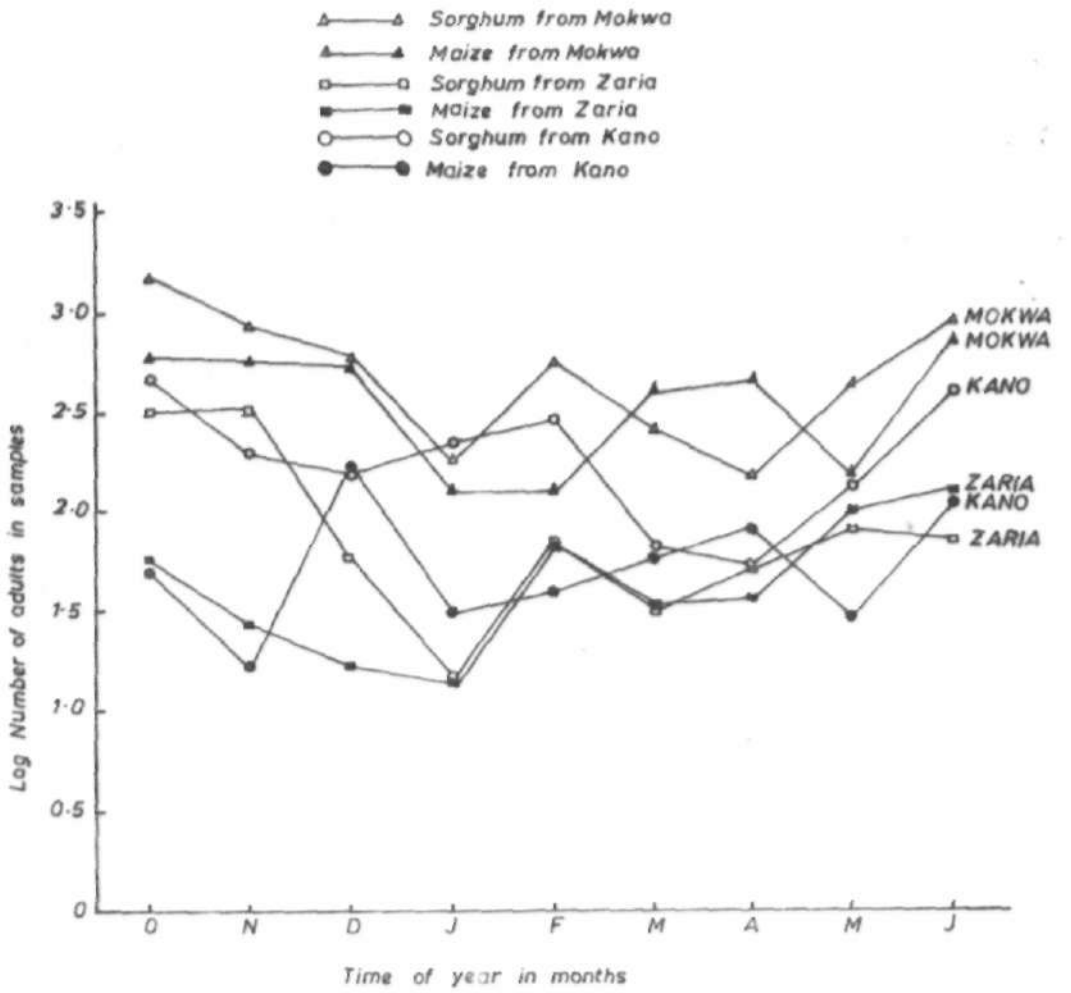

Sorghum from Mokwa
Maize from Mokwa
Sorghum from Zaria
Maize from Zaria
Sorghum from Kano
Maize from Kano
Log Number of adults in samples
3·5
3·0
2·5
2·0
1·5
1·0
0·5
0
MOKWA
MOKWA
KANO
ZARIA
KANO
ZARIA
O
N
D
J
F
M
A
M
J
Time of year in months

Fig. 3 Percent moisture content (m.c.) of maize and sorghum grains and total pest population (pest pop.) on these grains at Mokwa, Zaria and Kano.

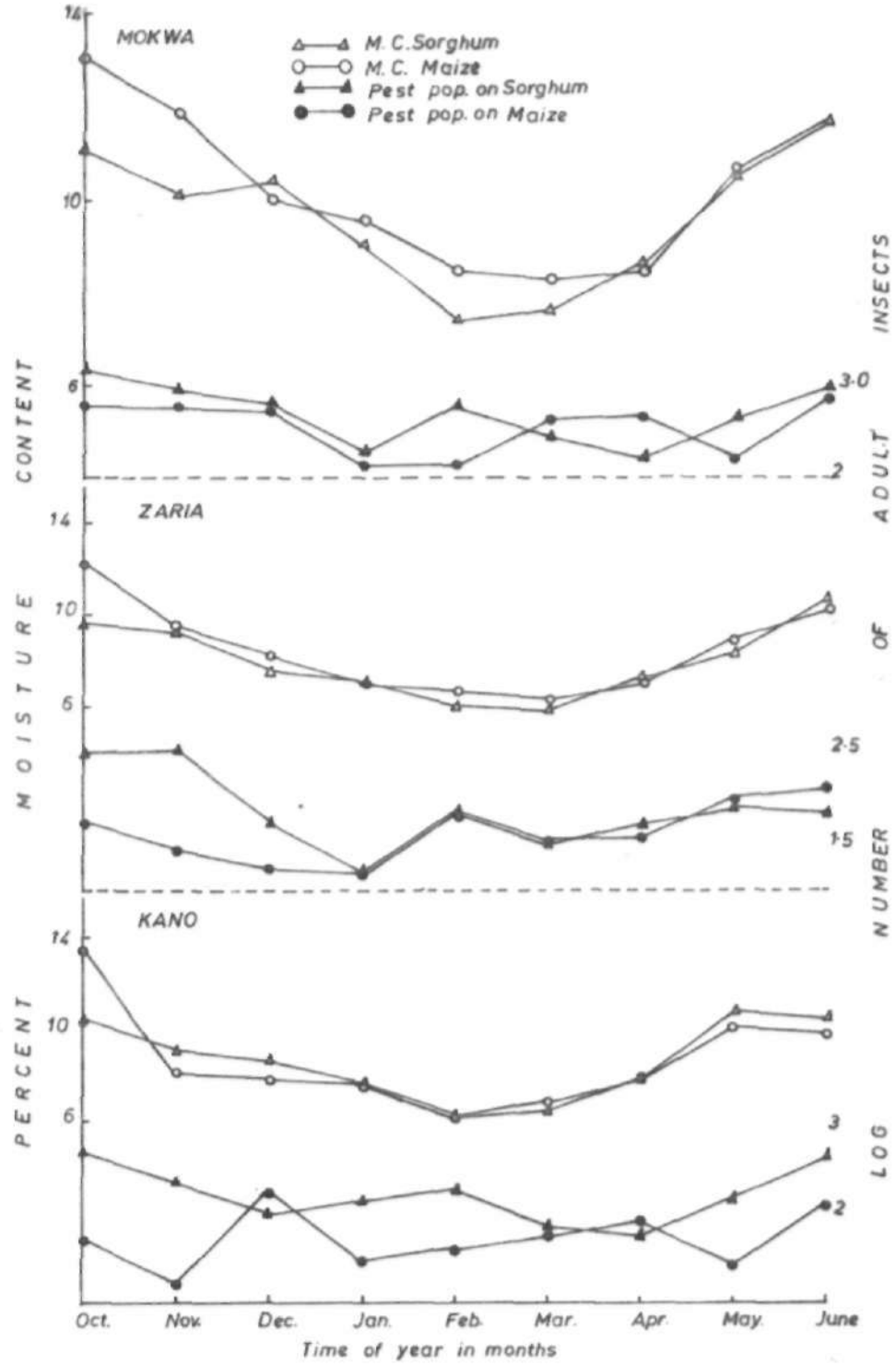

MOKWA
M.C.Sorghum
M.C. Maize
Pest pop. on Sorghum
Pest pop. on Maize
14
10
6
CONTENT
3·0
2
INSECTS
ADULT
ZARIA
14
10
6
MOISTURE
2·5
1·5
OF
NUMBER
KANO
14
10
6
PERCENT
3
2
LOG
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May.
June
Time of year in months

Fig 3

The total number of adult insects found at the three locations on sorghum showed that Rhizopertha and Sitophilus were lower in Kano and Zaria compared with that at Mokwa (Table 3). In an earlier work reported by Caswell, only the Sitophilus population was reduced in this latter zone. This shows the importance of Rhizopertha in the Southern Guinea Savannah Zone. The population of the three insect pests was also higher in Kano than in Zaria and this appears to be due to the generally higher grain moisture recorded from the Kano samples compared with that recorded at Zaria (Fig. 3).

Considering the three insect pests separately, the population of Rhizopertha on sorghum followed the same general pattern as the total pest population (Fig. 4). There was a low incidence of this pest from December to April. As the grains became drier, the population declined until April/May when the rains began and increased grain moisture. The dry weather, together with the low temperature, was therefore responsible for the low populations from December to April. An increase recorded in Kano during January and February was probably due to the

TABLE 3: TOTAL NO. OF INSECT PESTS COLLECTED FROM MAIZE AND SORGHUM SAMPLES FROM MOKWA, ZARIA AND KANO OVER A NINE-MONTH SAMPLING PERIOD

	MOKWA		ZARIA		KANO	
INSECTS PESTS	SORGHUM	MAIZE	SORGHUM	MAIZE	SORGHUM	MAIZE
Rhizopertha Sp.	1,446	17	210	31	529	52
Sitotroga sp.	242	637	302	40	336	31
Sitophilus spp.	2,741	2,455	236	190	401	283
Other	1,045	594	265	218	385	217
TOTAL	5,474	3,703	1,013	479	1,651	583

Note: 3 samples each weighing 1 kg. were obtained for each grain type for the nine months.

arrival there of newly harvested grain with a higher moisture content in November/December. Giles (1964b) reported an increase in insect development with the arrival of newly harvested sorghum into storage. At Mokwa the population of Rhizopertha began to increase from February and continued till the end of observation. This early rise in the pest population at Mokwa may be due to the earlier arrival of the rains in the Southern Guinea Savannah zone which probably resulted in an early increase in grain moisture. Also the moisture content of grains from Mokwa were high enough to support the continuous breeding of Rhizopertha (Fig. 3). Pingale and Girish (1967) reported that R. dominica could breed in grain of 8% moisture content and that the rate of development increased markedly when grain moisture content was increased from 8 to 9%.

The pattern of the population build-up of Sitotroga at the three locations differed from that shown by Rhizopertha (Fig. 5). There was a moderately high incidence of Sitotroga during the dry period (December - March). The rise recorded in December was probably due to a carry-over of field pests into

Fig. 4 Log. mean no. of adults of Rhizopertha obtained from sorghum samples at Mokwa, Zaria and Kano.

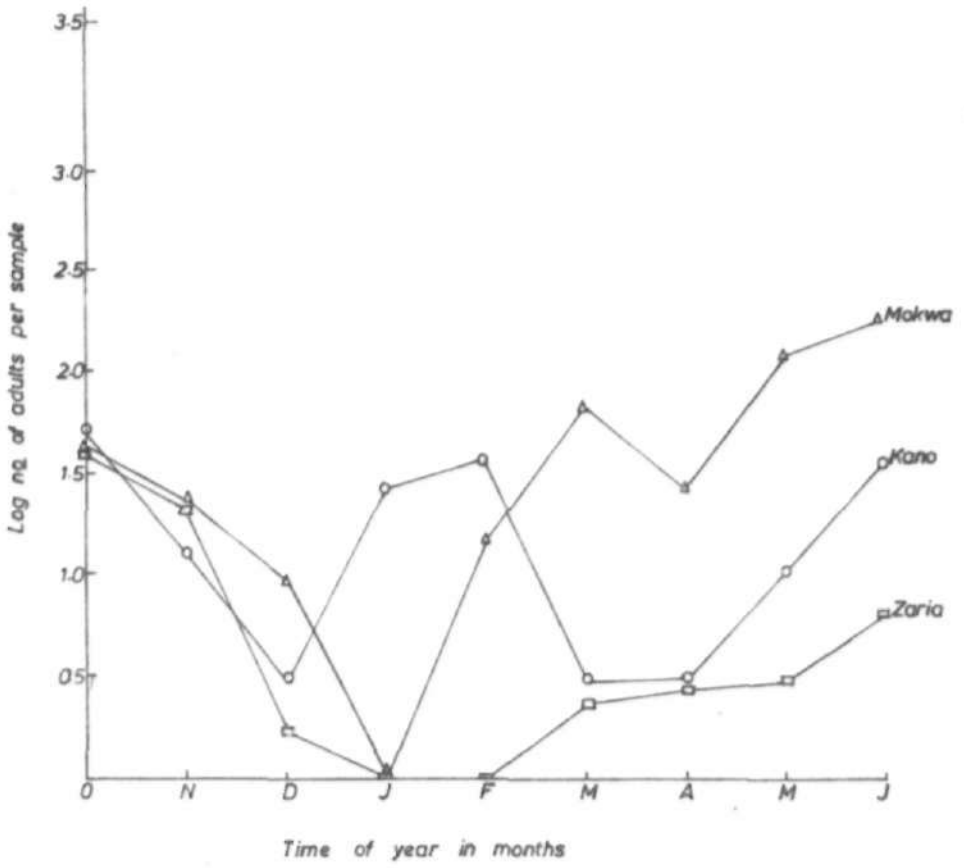
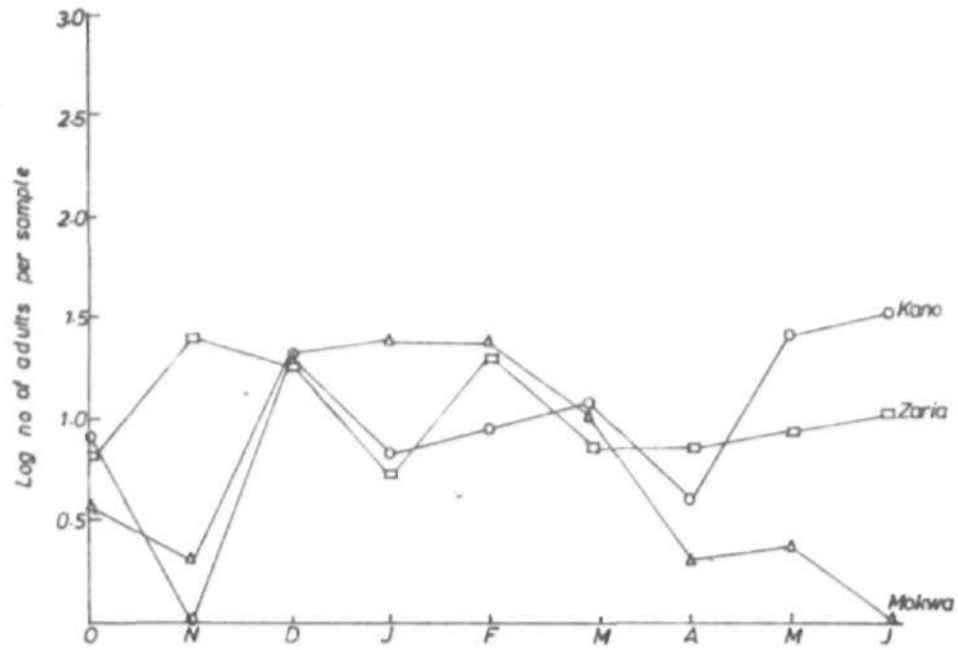

3·5
3·0
2·5
2·0
1·5
1·0
0·5
Log no. of adults per sample
Makwa
Kano
Zaria
O
N
D
J
F
M
A
M
J
Time of year in months

Fig 4

Fig. 5 Log. mean no. of adults of Sitotroga obtained from sorghum samples at Mokwa, Zaria and Kano.


Log no of adults per sample
3.0
2.5
2.0
1.5
1.0
0.5
O
N
D
J
F
M
A
M
J
Kano
Zaria
Mokwa
Time of year in months

F45

Fig. 6 L•g. mean no. of adults of Sitophilus and Sitotroga obtained from maize samples at Kano.

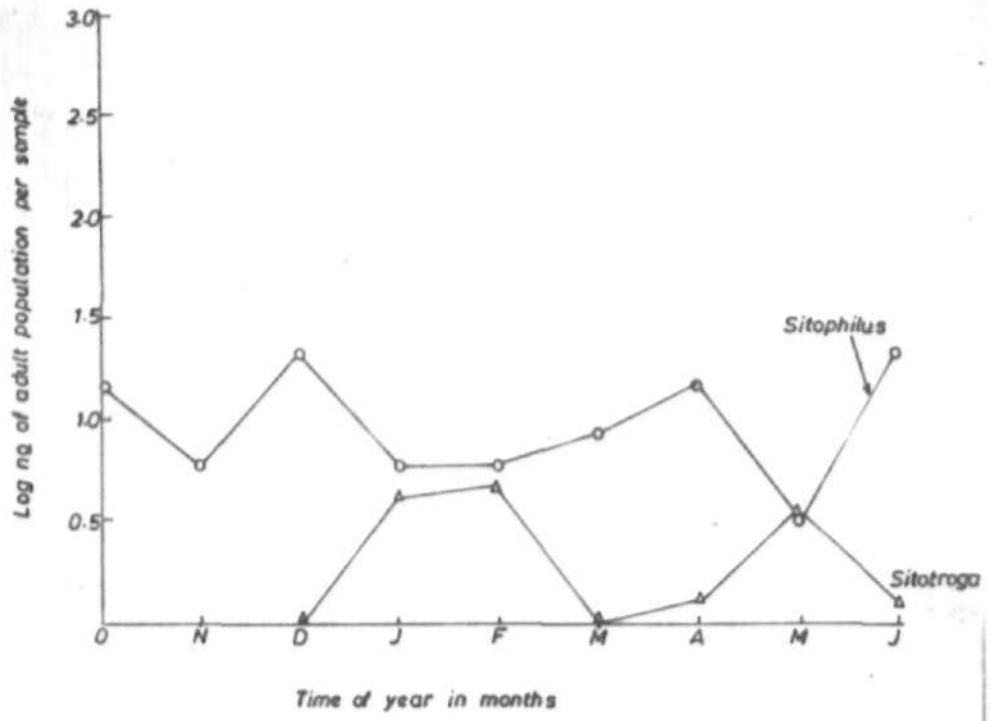
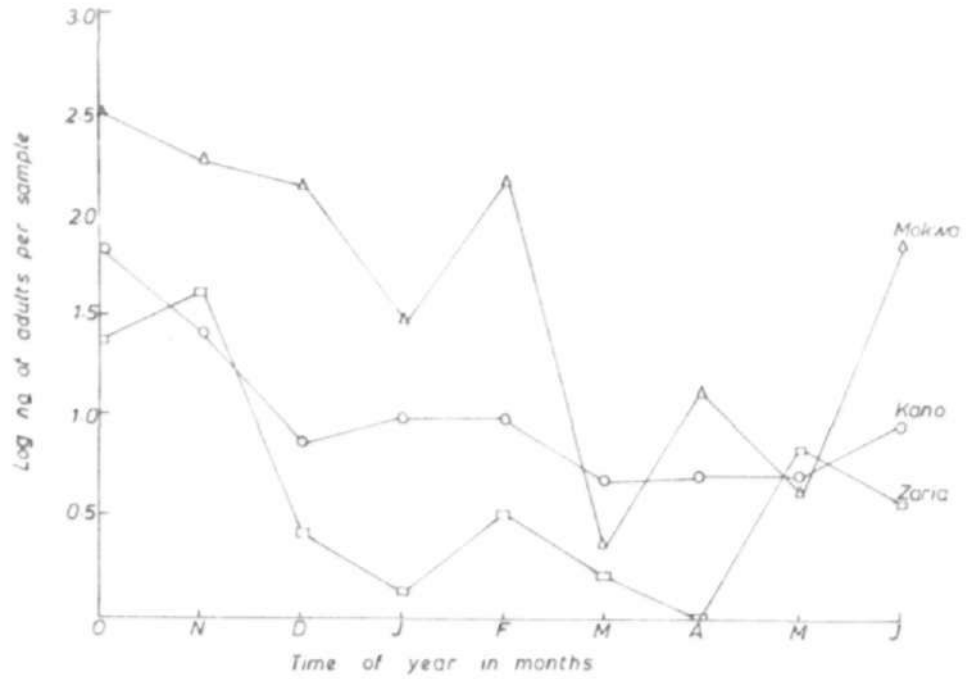

3.0
2.5
2.0
1.5
1.0
0.5
Log no of adult population per sample
Sitophilus
Sitotroga
O
N
D
J
F
M
A
M
J
Time of year in months

Fig. 7 Log. mean number of adults of Sitophilus obtained from sorghum samples at Mokwa, Zaria and Kano.


3.0
2.5
2.0
1.5
1.0
0.5
Log na of adults per sample
Makao
Kano
Zaria
O
N
D
J
F
M
A
M
J
Time of year in months

storage which continued to breed because the insect could tolerate the low temperature (about 22°C) and relative humidity conditions (between 35 - 45%) prevailing during this period. Howe (1965) reported that the minimum relative humidity for Sitotroga development was 30% and the lowest temperature for its development was 16°C. This shows that the low relative humidity during December - March was higher than the minimum required for Sitotroga development. Also the probable reduction in the population of its competitor (especially Sitophilus) due to this dry weather condition may have enabled Sitotroga to increase its population (Fig 6).

The development of the Sitophilus population was similar to that of Rhizopertha with a decline from December to April. The increase of the population in February was, like Sitotroga, also probably caused by a carry-over of the pest from the field to storage (Fig. 7).

Apart from Sitotroga, the Mokwa samples yielded the largest numbers of Sitophilus and Rhizopertha and also showed an earlier increase in these populations than at the other locations. This is attributable to

the higher moisture content of the grains from Mokwa. Also the population of insects in Kano was higher than that obtained from grains from Zaria and this also appears to be due to the higher grain moisture at Kano (Fig. 3) (see 4.2). Earlier work by Caswell (in press) showed that Rhizopertha reached a peak population in June in the Mokwa area, July in Zaria and August in Kano. Although the survey reported here did not cover these months, the trends shown in Figure 4 appear to lead to a similar conclusion.

The results obtained for Sitotroga at Mokwa in the present survey do not confirm Caswell's observations on this population. Caswell reported that Sitotroga population reached its peak in June at Mokwa but this population died out during that month in the present survey (Fig. 5). This was probably caused by the high population of Rhizopertha and Sitophilus which, between them, eliminated Sitotroga. Crombie (1944) found that Rhizopertha had an edge over Sitotroga when they were in the same culture and Chesnut and Douglas (1971) reported that Sitophilus would eliminate Sitotroga whenever the two are in the same culture.

The observations made on Sitophilus population in this survey are similar to Caswell's except that, like Rhizopertha, no observations could be made on when this species reached peak populations because the survey did not cover the peak period reported by Caswell (in press).

An analysis of the survey data showed that on sorghum, the insect population at Mokwa was significantly higher than those at Zaria or Kano ($P < .01$), the latter two not being significantly different from each other (Table 4). A comparison of the populations recorded each month showed that the populations in October were significantly higher than the populations during the other month ($P < .05$). No other significant differences were obtained between all other periods. This suggests that the maximum population of the pests may have been reached before or about October when real differences could be detected. A comparison of the three genera showed a significant difference between Sitophilus and Sitotroga populations but no significant differences were detected between Rhizopertha and Sitophilus or between Rhizopertha and Sitotroga.

Table 4: Mean numbers of adults by site, genus and Period for sorghum samples with their Least Significant Differences (L.S.D.).

Site	Genus	Period
50.7 - Mokwa	26.98 - Rhizopertha	63.5 - October
9.4 - Zaria	10.86 - Sitotroga	39.3 - November
15.3 - Kano	41.70 - Sitophilus	20.8 - December
	20.93 - Others	8.9 - January
		22.9 - February
		10.0 - March
		6.6 - April
		18.2 - May
		35.8 - June
L.S.D. = 21.8	L.S.D. = 25.3	L.S.D. = 37.9

On maize, the incidence of Rhizopertha on samples from the three locations was low (Fig. 8). Except for a single high incidence in December at Kano, the population of this insect was generally low throughout the survey. This is an indication of preference for sorghum by this insect over maize (compare Figs. 3 and 7).

On maize, Sitotroga was more dominant at Mokwa than at the more northern regions (Fig. 9) and shows its importance on maize in this zone. A comparison of the incidence of Sitophilus on maize at the three locations shows that the largest numbers were from the Mokwa samples (Fig. 10). This also shows that Sitophilus is more important on maize in the south than in the more northern zone. Cornes and Rilley (1961) reported that the principal insect pest found in their survey of small scale storage cribs of maize in western Nigeria was S. zeamais and that the population began to decline after it had reached a maximum in December.

The small reduction in the population of Sitophilus during January/February could be attributed to the low temperature and relative humidity at this time.

Fig. 8 Log. mean number of adults of Rhizopertha obtained from maize samples at Mokwa, Zaria and Kano.

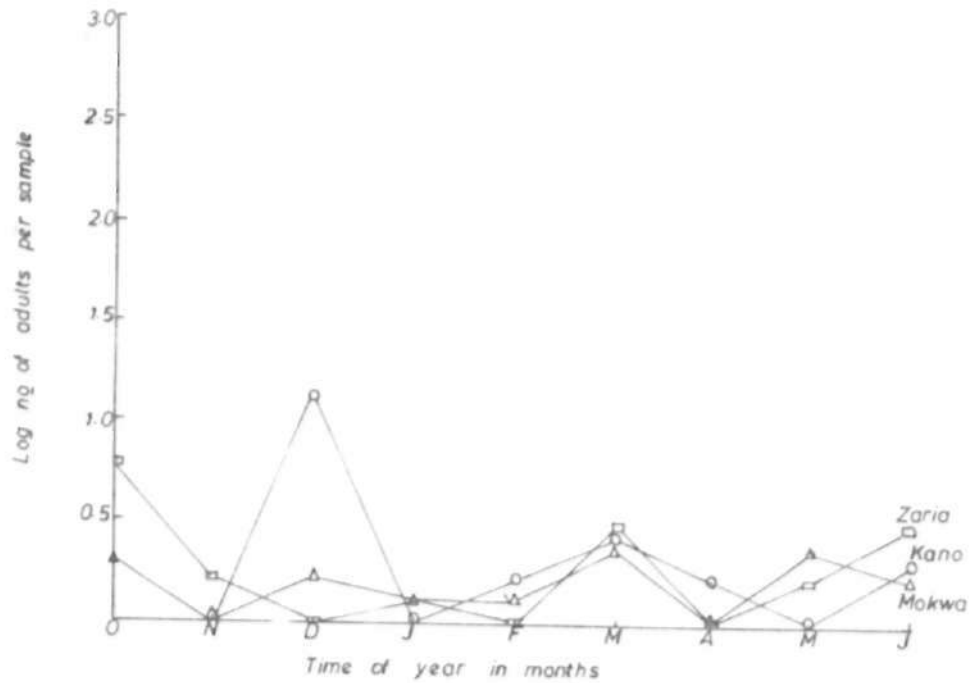

Log no of adults per sample
3.0
2.5
2.0
1.5
1.0
0.5
0
N
D
J
F
M
A
M
J
Zaria
Kano
Mokwa
Time of year in months

Fig. 9 Log. mean number of adults of Sitotroga obtained from maize samples at Mokwa, Zaria and Kano.

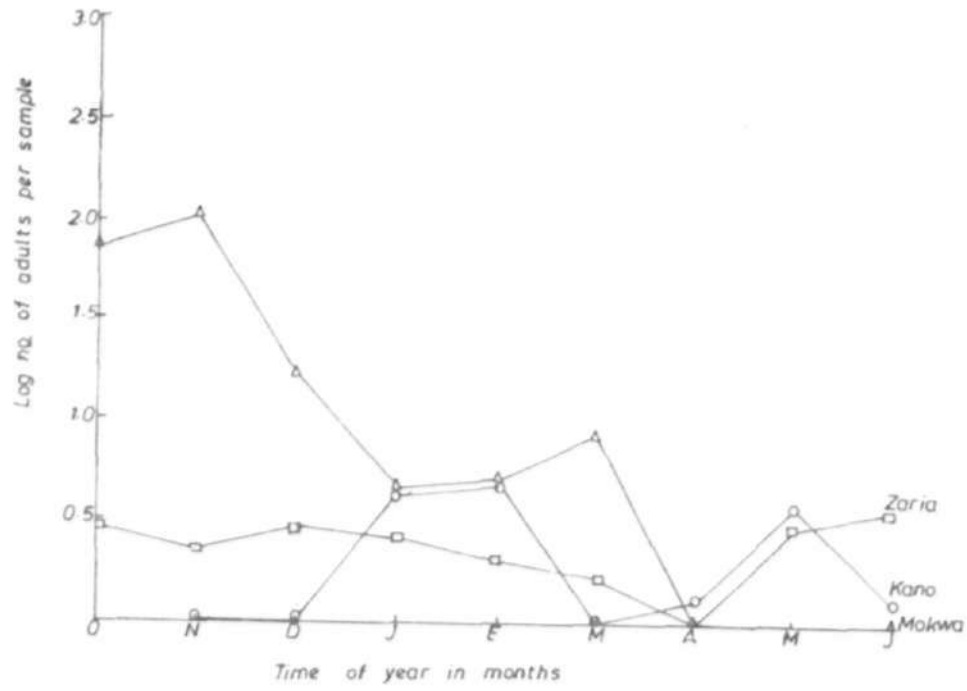
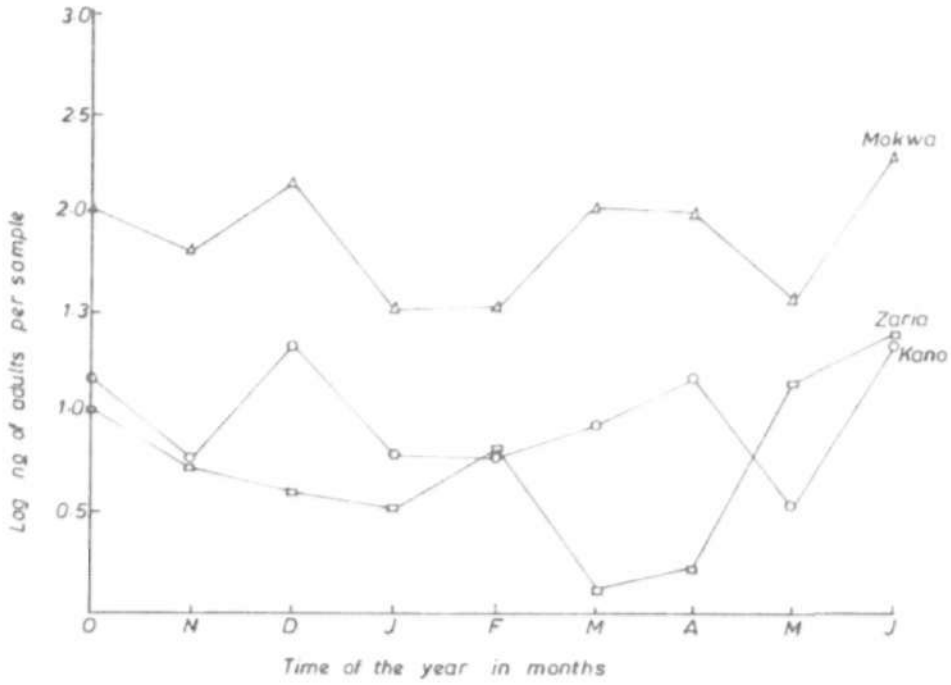

3.0
2.5
2.0
1.5
1.0
0.5
0
Log no. of adults per sample
N
D
J
F
M
A
M
J
Zaria
Kano
Mokwa
Time of year in months

Fig. 10 Log. mean number of adults of Sitophilus obtained from maize samples at Mokwa, Zaria and Kano.


3·0
2·5
2·0
1·3
1·0
0·5
Log no of adults per sample
Makwa
Zaria
Kano
O
N
D
J
F
M
A
M
J
Time of the year in months

Howe (1965) reported that the insect will not develop at humidities below 60% while a temperature of less than 25°C would prolong its developmental period (Reddy, 1950).

It would appear therefore that the low moisture during December to March, together with the low temperature of these months were responsible for the low growth during this period. It is worth noting that the population of Sitotroga during January to March was high and suggests that it may have taken advantage of the reduction in the population of its competitors during the period. At all locations and on both grains, fluctuations in the population of Sitotroga were related to an increase in the population of the other pests, where a decline in the Sitotroga population corresponded with a rise in the population of Rhizopertha or Sitophilus (Fig. 6). Ayertey (1980) reported that Sitotroga was eliminated by S. zeamais when the two species were cultured together and he attributed this to the mortality of immature moths inside grains caused by the feeding of S. zeamais. Thus an increase in the population of Sitophilus in nature

would result in the decline of Sitotroga where they are both present.

A statistical analysis of the results shows that on maize, the insect population at Mokwa was significantly higher than that at Zaria or Kano ($P < .01$); the latter two were not significantly different from each other (Table 5). Differences in population levels between months were not significant and differences in the incidence of the three species on maize showed that significantly more Sitophilus were present than any of the other two genera. The populations of Rhizopertha and Sitotroga were not significantly different from each other.

It could thus be concluded that in all cases, the insect populations on the two grains were higher at Mokwa than at Kano or Zaria and this could be related to moisture availability. The moisture content of grains from Mokwa was higher than at Kano or Zaria. Also the rainy season starts earlier in the Southern Guinea area (Mokwa) than in the more northern zones (Zaria or Kano) hence pest population development starts much earlier in the south. Thus Sitophilus population, though not significantly higher than that of

Table 5: Mean numbers of adults by site, genus and period for maize samples with their Least Significant Difference (L.S.D.).

Site	Genus	Period
34.3 - Mokwa	1.2 - Rhizopertha	19.6 October
4.4 - Zaria	8.7 - Sitotroga	16.7 November
5.4 - Kano	36.1 - Sitophilus	20.4 December
	12.6 - Others	4.8 January
		6.5 February
		13.8 March
		15.8 April
		7.8 May
		27.1 June
L.S.D. = 15.04	L.S.D. = 26.04	L.S.D. = 17.36

Rhizopertha on sorghum, remained a dominant pest of this grain. On maize, it is the most important pest.

4.131 Insect pest damage to stored sorghum and maize seeds at Mokwa, Zaria and Kano

The insect pest damage to grain samples collected from the Mokwa, Zaria and Kano markets and the calculated weight losses are shown in Appendix Tables 2a and 2b.

4.1321 Damage and weight loss in stored sorghum seeds at the three locations.

The damage to sorghum seeds was high (7-10%) at the beginning of the investigation in October at all the three locations. This level declined from November and remained low (1-3%) until April (Fig. 11). This pattern corresponded with the insect infestation recorded at these locations. The low level of damage from December to April confirmed the report of Giles (1964b) that grain damage during the dry season was less than 3% in the Samaru (Zaria) area. A high damage level recorded in Kano during the month of January also corresponded with a high incidence of Rhizopertha

Fig. 11 Percent damage and weight loss to sorghum grains at Mokwa, Zaria and Kano.

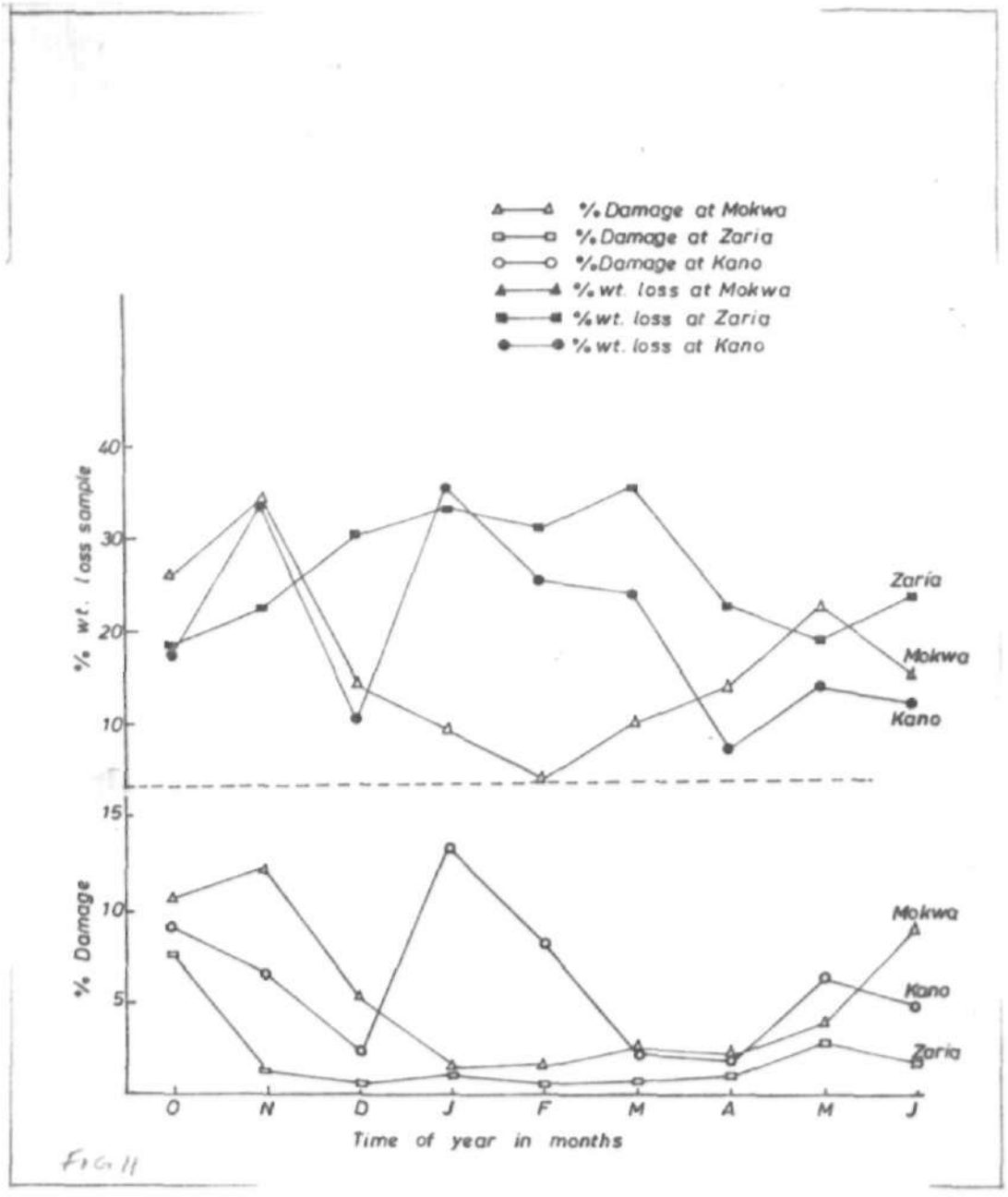

% Damage at Mokwa
% Damage at Zaria
% Damage at Kano
% wt. loss at Mokwa
% wt. loss at Zaria
% wt. loss at Kano
% wt. loss sample
40
30
20
10
Zaria
Mokwa
Kano
15
10
5
% Damage
Mokwa
Kano
Zaria
O
N
D
J
F
M
A
M
J
Time of year in months

FIG II

during this month and showed that this insect may be responsible for much of the damage recorded on these grains. Earlier work at Kano (Halliday, 1966) showed a slight increase in sorghum damage in January/February but the maximum damage was recorded in August/September, a period not covered by the present survey. The maximum damage to sorghum recorded in this survey occured in October in Zaria. Giles (1964b) reported that the maximum damage to sorghum was reached in August and Caswell reported a similar damage level in September/October in the same area. The position of the damage level in Zaria in October in this survey is suggestive that the maximum damage could have occured about that period.

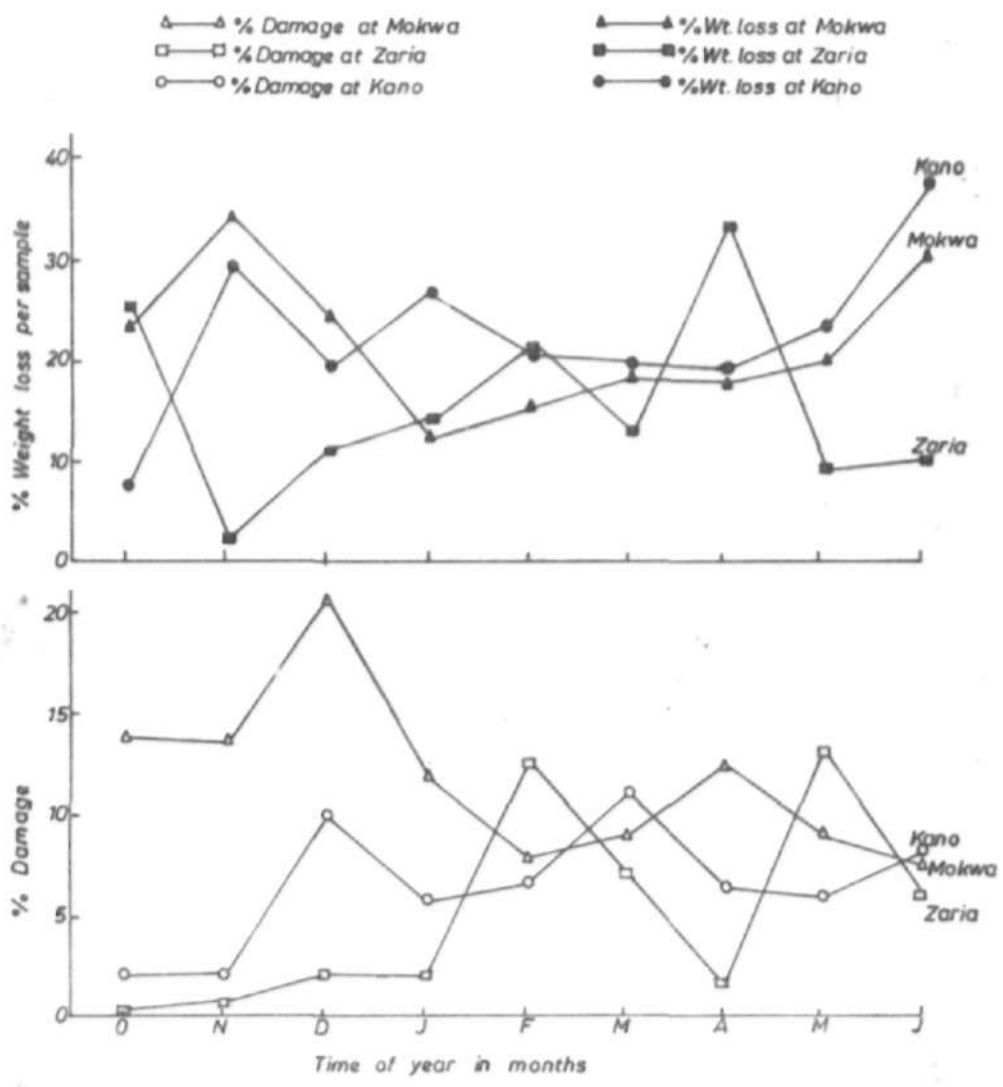
The grain weight losses at the three locations did not follow the same trend. While the loss in weight of sorghum grain from Mokwa and Kano followed the general pattern of the damage, that of Zaria was different. At Mokwa, weight loss was low from December to April and was at a maximum in November and a minimum in February. Weight loss in grain from Kano was at the maximum

level in January. These corresponded with the damage levels recorded at these locations. The weight loss in grains from Zaria on the other hand started to increase from the beginning of the observations, reaching a maximum in March. Damage was however low during this period. This shows that the few grains infested were badly damaged. Since Sitotroga was the major pest recorded at Zaria during these months, the increased weight loss may be attributed to this pest, especially when two or more of its larvae developed in the same grain. At Kano, the combined feeding of Sitotroga larvae and Rhizopertha larvae and adults, (high from December to February) was probably responsible for the maximum damage and weight losses recorded in January at this location. Pingale and Girish (1967) reported that Sitotroga and Rhizopertha can tolerate a relative humidity as low as 30% hence the low relative humidity of December to February (35 - 45%) will not affect the activities of these two insects.

4.1322 Damage and weight loss in stored maize seeds at the three locations.

The damage to maize grains at the three locations, did not follow a common trend. At all location, it was low at the beginning of the survey and started to increase in November, reaching a maximum in December at Mokwa, March at Kano and in May at Zaria (Fig. 12). At Zaria, the level of damage remained below 2% for the first four months of observation and suggests that infestation from the field was probably low during harvest in September/October. At Kano, damage increased after the second month of observation suggesting grain infestation from the field. Damage to maize was relatively high throughout in Mokwa (7 - 20%) which corresponded with the high level of infestation of the grain by Sitophilus at this location. The very high level of damage recorded in December at Mokwa and Kano is attributable to the relatively high incidence of Rhizopertha, Sitotroga and Sitophilus at these locations while the relatively high level of damage at Zaria in February and Kano in March is attributable to Rhizopertha and Sitotroga. The maximum damage to maize at Kano was

Fig. 12 Percent damage and weight loss to maize grains at Mokwa, Zaria and Kano.


% Damage at Mokwa
% Damage at Zaria
% Damage at Kano
% Wt. loss at Mokwa
% Wt. loss at Zaria
% Wt. loss at Kano
% Weight loss per sample
40
30
20
10
0
Kano
Mokwa
Zaria
% Damage
20
15
10
5
0
O
N
D
J
F
M
A
M
J
Time of year in months

about 11% and occured in March but an earlier work by Halliday (1966) in Kano showed that the maximum damage was 5% and occured in May which he attributed to a long period of storage and high grain moisture.

The grain weight losses fluctuated like the damage but the peaks did not coincide. At Mokwa weight loss increased to a peak in November and then declined to a low level until May. At Zaria the loss in weight reached a minimum in November before increasing again (just like the damage level). That for Kano increased in November and remained above a 15% level during the period of observation. It is interesting to note that on maize a high weight loss preceeded a high damage level. This is contrary to what was observed for sorghum in which high weight losses corresponded with high damage levels. Since maize grains are larger than sorghum grains it is possible that food contained in maize grain could support more larvae developing in them than in sorghum grain. The feeding of those larvae will result in higher weight loss and when these larvae eventually emerge as adults, more grains would be attacked either by these adults or by the

larvae that hatched from the eggs laid by them, and this could result in high damage level.

The maximum damage levels recorded for sorghum and maize were 13 and 21% respectively. However the maximum weight loss in the two grain types were about the same. This shows that the sorghum grains were more severely damaged than the maize grains. It also shows that Sitophilus which was dominant on maize was not as destructive as Rhizopertha on sorghum.

4.2 INVESTIGATIONS INTO THE ROLE OF MOISTURE IN THE BUILD-UP OF POPULATIONS OF RHIZOPERTHA, SITOTROGA AND SITOPHILUS ON STORED GRAINS IN NORTHERN NIGERIA

4.21 Introduction

As a follow-up to the survey work, experiments were conducted to observe the growth of populations of Rhizopertha, Sitotroga and Sitophilus under ambient and humidity-controlled environments, with relative humidity regulated by using saturated salt solutions.

It has been suggested that moisture is the most important factor determining insect infestation and damage to grains. The moisture content of grains in an environment is related to the relative humidity in that environment because grains, being hygroscopic, absorb moisture from or lose it to the environment until the grain moisture is in equilibrium with the relative humidity. Hence the lower the relative humidity of an environment, the lower the moisture content of grains stored in that environment. Relative humidity was therefore used to alter the grain moisture in this investigation.

4.22 Method

Cultures of each of the three species were separately set-up in 60 cc jars, each containing 25 g sorghum. Each culture jar was seeded with 20 adults of the appropriate insect. The sex ratio of each of the populations was assumed to be unity. There were six jars of each genus separately cultured and three of these were kept in humidity cabinets while the remaining three were left on a bench in the laboratory under ambient conditions. Monthly records of adult insects in each jar were kept as described earlier (see 3.2).

4.23 Results and Discussions

The monthly population growth of the insects is given in Appendix Table 4. The records of relative humidity and temperature, as well as the 3-4 monthly moisture determinations of grain from the two environments are in Appendix Tables 5a and 5b. The main feature to be considered in this experiment is the effect of moisture on the growth of each pest population.

4.231 The growth of populations of Rhizopertha under humidity-controlled or ambient laboratory conditions

The monthly examination of the culture jars showed that adult Rhizopertha began to emerge from both groups of cultures two months after they were set up. Throughout the period of observation, more adults were recorded on grain kept in the humidity-controlled environment than on those kept under ambient conditions but significant differences were not detected until after March, six months after the beginning of the cultures (Fig. 13). There was a rapid increase in the Rhizopertha population under the humidity-controlled condition from March till the end of the observation, while the population under the ambient conditions declined until May. Since no adult Rhizopertha emerged under both environmental conditions in the culture jars until the second count, 60 days after the culture was set up, it could be deduced that the life cycle of the insects introduced on grain of 11% moisture content, at a mean temperature of 27°C and relative humidity of 60 - 70% was more than 30 days and suggests that both the lower grain moisture and relative humidity were responsible for the prolonged developmental period. Thomson (1966) reported that the

Fig. 13 Population growth of 20 adults of Rhizopertha on 25 g. sorghum under humidity-controlled and ambient laboratory conditions.

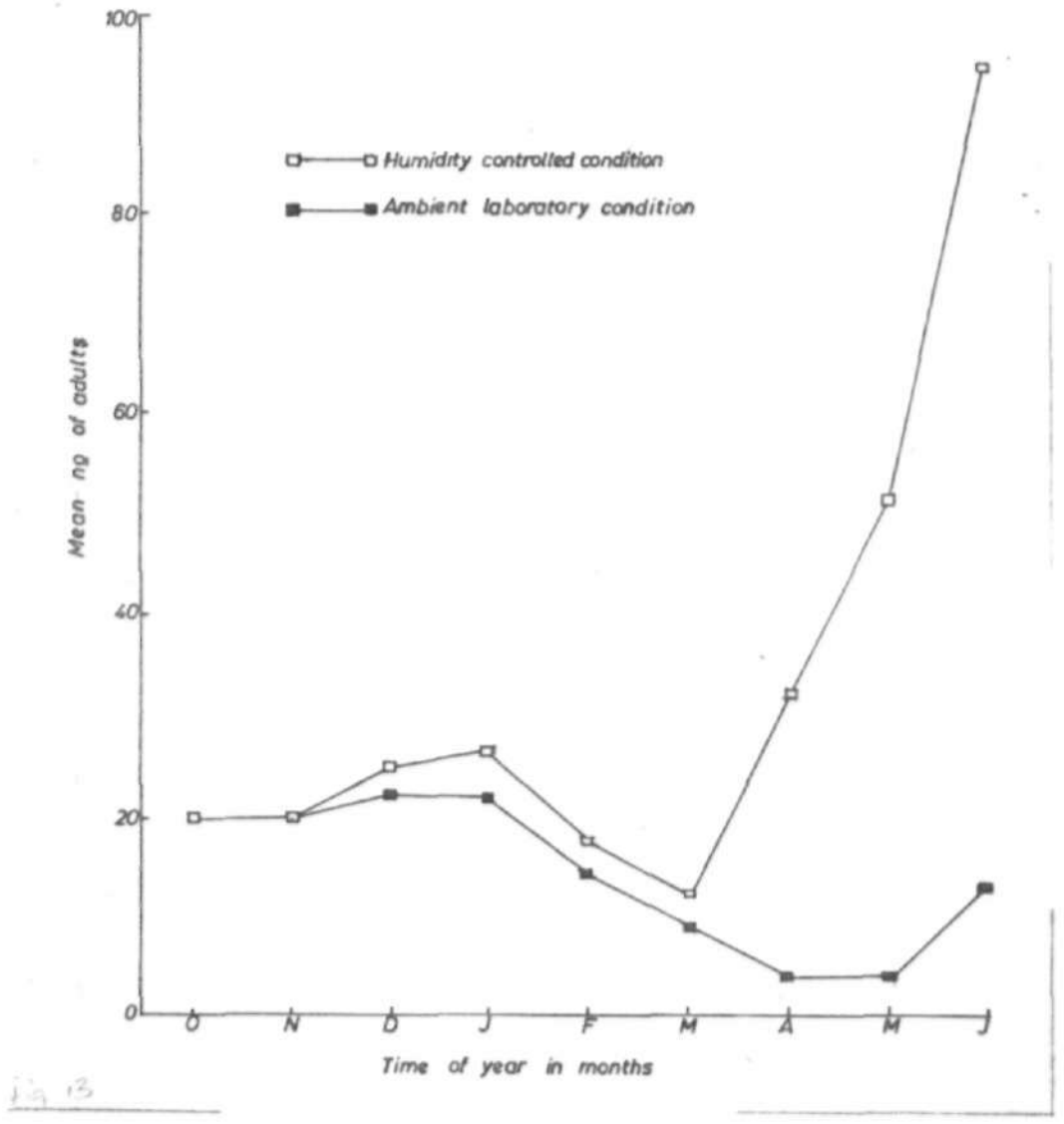

Humidity controlled condition
Ambient laboratory condition
Mean no of adults
100
80
60
40
20
0
O
N
D
J
F
M
A
M
J
Time of year in months

Fig 13

life cycle of Rhizopertha lasted 30 - 35 days in sorghum of 12% moisture content at 29°C and 75% relative humidity. The optimum temperature for the development of Rhizopertha is recorded as 34°C and the developmental period increases as the temperature is decreased to a minimum at 18°C (Birch, 1945; Khare and Agrwal, 1967). Prevett (1971) also reported that at the optimum temperature of 34°C, the development of Rhizopertha took about 28 - 30 days. Temperature may therefore have contributed to the prolonged developmental period in this investigation. The decline in the populations of Rhizopertha from January to March under the two experimental conditions may also be due to a decrease in temperature during the period. Temperatures under the two conditions during this period ranged from 22°C to 25°C. As temperatures increased to 28°C in March, the population of the insects in the humidity-controlled cabinet increased rapidly. The further decline in population of the insects under the ambient laboratory conditions was due to the lower relative humidity resulting in low grain moisture. The ambient relative humidity from December to April was less than 45%

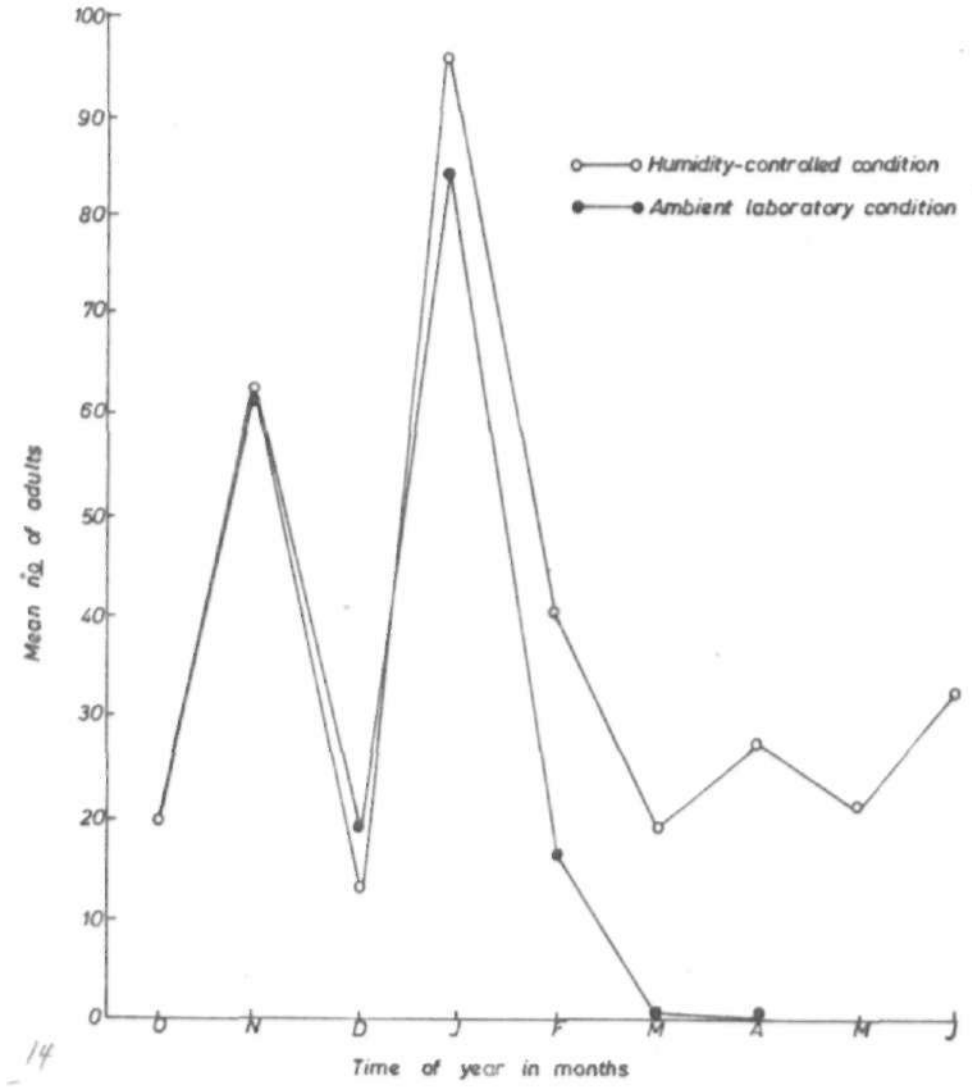
resulting in a grain moisture content of 5.9% in February. When the relative humidity increased to 75% from May, this population began to increase. It could thus be concluded that moisture was mainly responsible for the high differences in the population growth of the insects in the two environments from March to the end of the observation.

Prevett (1971) reported that Rhizopertha could tolerate a relative humidity of about 30% at a temperature of 34°C and, Pingale and Girish (1967) found that Rhizopertha could breed in grain of 8% moisture content. Furthermore Birch (1945) found that the minimum temperature for the survival of Rhizopertha was 22°C. Rhizopertha can thus survive at a humidity of 30%, grain moisture content of 8% and a temperature of 22°C. The weather condition from December to April in Nigeria did not fall below those given above and this explains the survival of this insect under these adverse conditions.

4.232 The growth of populations of Sitotroga under humidity-controlled or ambient laboratory conditions

No major differences in the populations of Sitotroga were observed under the two environmental

Fig. 14 Population growth of 20 adults of Sitotroga on 25 g. sorghum under humidity-controlled and ambient laboratory conditions.


Humidity-controlled condition
Ambient laboratory condition
Mean no. of adults
100
90
80
70
60
50
40
30
20
10
0
O
N
D
J
F
M
A
M
J
Time of year in months

conditions until February, five months after the start of the cultures. After this period, the Sitotroga population under the humidity-controlled condition was significantly more than that under the ambient conditions and this continued until the end of the observation in June (Fig. 14). The moisture content of the grain under the ambient condition was less than 6% in February/March and the low population recorded for this pest in March and its subsequent elimination in April can be attributed to the low grain moisture. The higher moisture level (about 12% in February) was responsible for the survival of the Sitotroga population under the humidity-controlled condition. The life cycle of Sitotroga in this experiment was less than 30 days since new adults emerged under both conditions at the first census. This conforms with work by previous workers (Crombie, 1944; Mills and Wilbur 1967). The sorghum grain used had a moisture content of 11% at a temperature of about 27°C and relative humidity of 60 - 70%. Crombie (1943) reported that the developmental period of Sitotroga kept at 30°C and 70% relative humidity ranged from

30 to 40 days with an average of 32 days and, Mills and Wilbur (1967) found that adults of Sitotroga emerged after 33.1 days on sorghum.

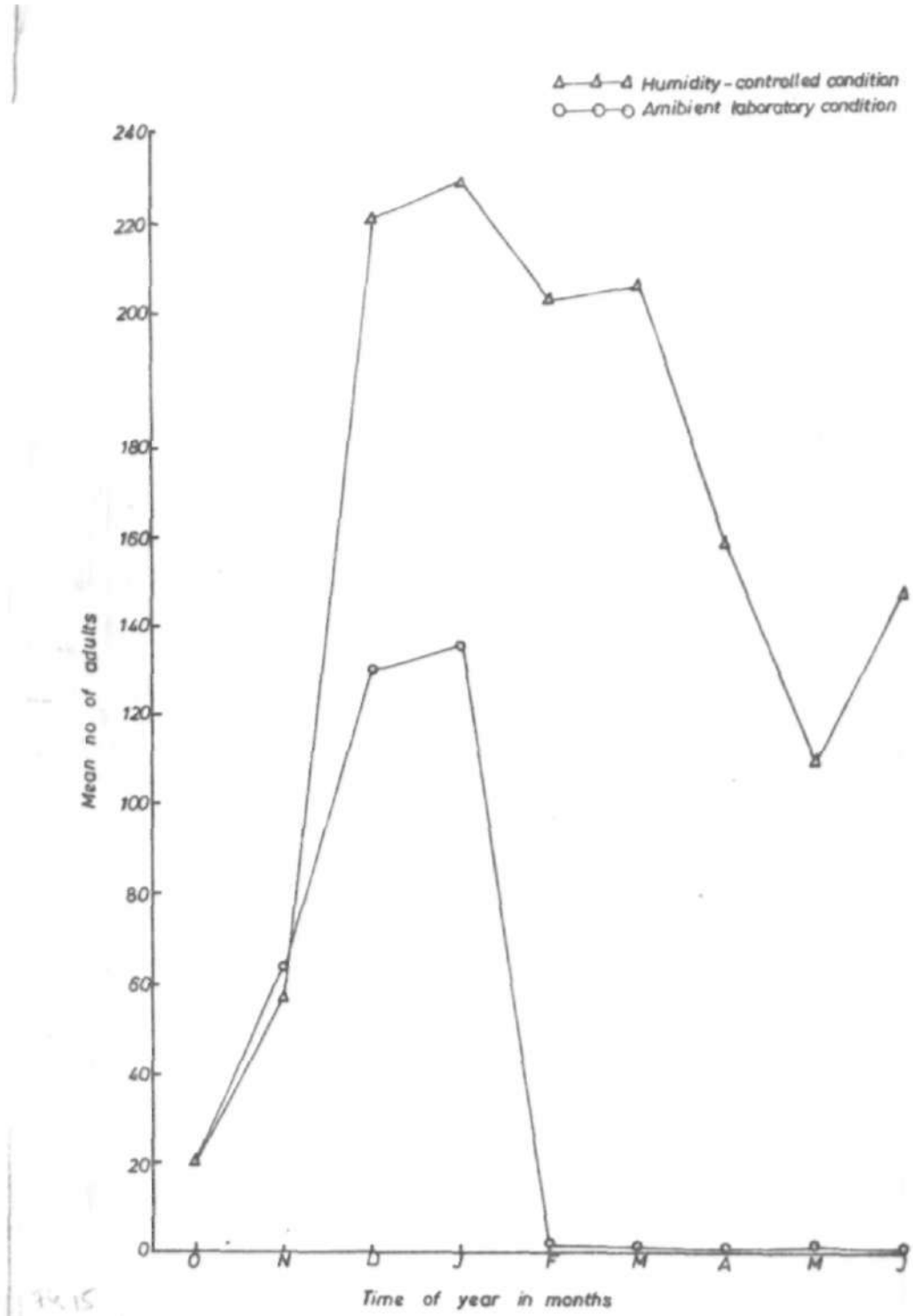
The maximum population under both conditions was recorded in January, one of the coldest months in northern Nigeria, with a room temperature of about 23°C and confirms the tolerance of this species of low temperatures. Howe (1965) reported that Sitotroga could tolerate temperatures of about 16°C. The minimum relative humidity for its development has been given as 30% (Pingale and Girish, 1967) and the minimum obtained in this investigation did not fall below this level. It is thus concluded that moisture was responsible for the continual growth of this insect in the humidity-controlled experiment but grain moisture of less than 6% had an adverse effect on the survival of Sitotroga placed under the ambient conditions. It is worth noting that the population of this insect during November to February was higher than that of February-June even under the humidity-controlled environment. This is probably due to a loss of eggs and newly emerged larvae from the culture medium during the monthly sieving to separate adults from the grain.

Such a gradual removal with frass would reduce the subsequent number of females available for egg laying.

4.233 The growth of populations of Sitophilus under humidity-controlled or ambient laboratory conditions.

The differences in the population growth of Sitophilus under the two environmental conditions became significant from December (three months after the start of the experiment) and continued until the end of the observation (Fig. 15). The maximum population under the two conditions was recorded in January after which the population under the ambient laboratory condition declined steeply and Sitophilus placed under the ambient conditions was eliminated in March, six months after the beginning of the experiment. On the other hand the Sitophilus population under the humidity-controlled condition continued, with a slight decline recorded in January. The moisture content of grain under the ambient laboratory condition was about 6% in February/March and the relative humidity was about 30%. This low moisture was responsible for the high mortality of Sitophilus under the ambient conditions in February and its elimination in March. The lower limit of grain moisture at which Sitophilus could complete development has been recorded as 10% (Birch, 1945;

Fig. 15 Population growth of 20 adults of Sitophilus on 25 g. sorghum under humidity-controlled and ambient laboratory conditions.


Δ—Δ—Δ Humidity - controlled condition
○—○—○ Ambient laboratory condition
Mean no of adults
240
220
200
180
160
140
120
100
80
60
40
20
0
O
N
D
J
F
M
A
M
J
Time of year in months

Reddy, 1950). Howe (1965) also found that Sitophilus would not develop at humidities less than 60%.

The increase in the insect population in the culture jars during the first count under both condition was an indication that the life cycle of Sitophilus on sorghum grain of 11% moisture content, at an average temperature of 27% and relative humidity rarge of 65 - 75% was less than 30 days. Reddy (1950) found that the optimum conditions for the development of Sitophilus were temperatures of 28 - 30°C, relative humidities of 75 - 90% and grain moisture content of 13.5 - 17.6%. He observed that the development period of this insect on wheat of 17.6% moisture content was 23 days at 30°C but this increased to 31 days at a lower temperature of 25°C.

The small increase in the Sitophilus populations observed from December to January under both conditions and the slight decrease in population under the humidity-controlled environment between January and February was probably due to the low temperature (about 22°C) of these periods. The decline observed from March to May in the population of Sitophilus under the humidity-controlled conditions could be attributed to such

factors as overcrowding or old age.

It can be concluded that the high population of Sitophilus recorded under the humidity-controlled environment was due to the high relative humidity and grain moisture which favoured the continuous breeding of this insect. The reduced grain moisture from January to April, was responsible for the low populations reported in many surveys carried out in northern Nigeria during this period (Giles, 1964b; Halliday, 1966; Caswell, 1979).

4.3 THE EFFECT OF ONE INSECT POPULATION ON ANOTHER IN THE DEVELOPMENT OF POPULATIONS OF RHIZOPERTHA, SITOTROGA AND SITOPHILUS IN A HUMIDITY-CONTROLLED OR AMBIENT LABORATORY CONDITIONS.

4.31 Introduction

Generally two or more insect species are simultaneously found in association with stored grains. Common among such pests are R. dominica, S. cerealella, Sitophilus and Tribolium species. In the market samples collected from the three climatic zones (see 4.1), more than two insect genera were found in various proportions in each sample. At high insect density, the insect species will encounter one another and interact. The incidence of the three genera in varying proportions at different times and at the three ecological zones found in the market surveys may well be due to this interaction. The possible effect of one species on another during the population growth was investigated under humidity controlled and ambient conditions using mixed cultures of Rhizopertha, Sitotroga and Sitophilus. Single species cultures served as controls.

4.32 Method

All cultures were run in 60cc jars, each containing 25 g. of sorghum as described earlier (see 3.24).

Mixed cultures of Rhizopertha, Sitotroga and Sitophilus containing ten adults of each genus in various combinations (see 3.25) were set-up. There were six replicates of each mixed culture and three of these were placed in the humidity-controlled cabinet while the remaining three were left on a bench in the laboratory under ambient conditions. Counts of adult insects were made a month after the beginning of the experiment and continued monthly for nine months.

4.33 Results and Discussions

The mean monthly population growth of the single and the mixed cultures each initially seeded with ten adult insects are given in appendices 6 and 7.

4.331 Effect on Rhizopertha, of populations of Sitotroga and Sitophilus

The growth of the Rhizopertha population in the single and mixed cultures under the humidity-controlled or ambient laboratory conditions followed the same trend (Fig. 16a and 16b). No major increases were recorded until after about six months. This is attributed to the low temperatures recorded during this period.

Fig. 16a Mean monthly population growth of Rhizopertha on 25 g. sorghum in single and mixed cultures with Sitotroga and Sitophilus in a humidity-controlled environment.

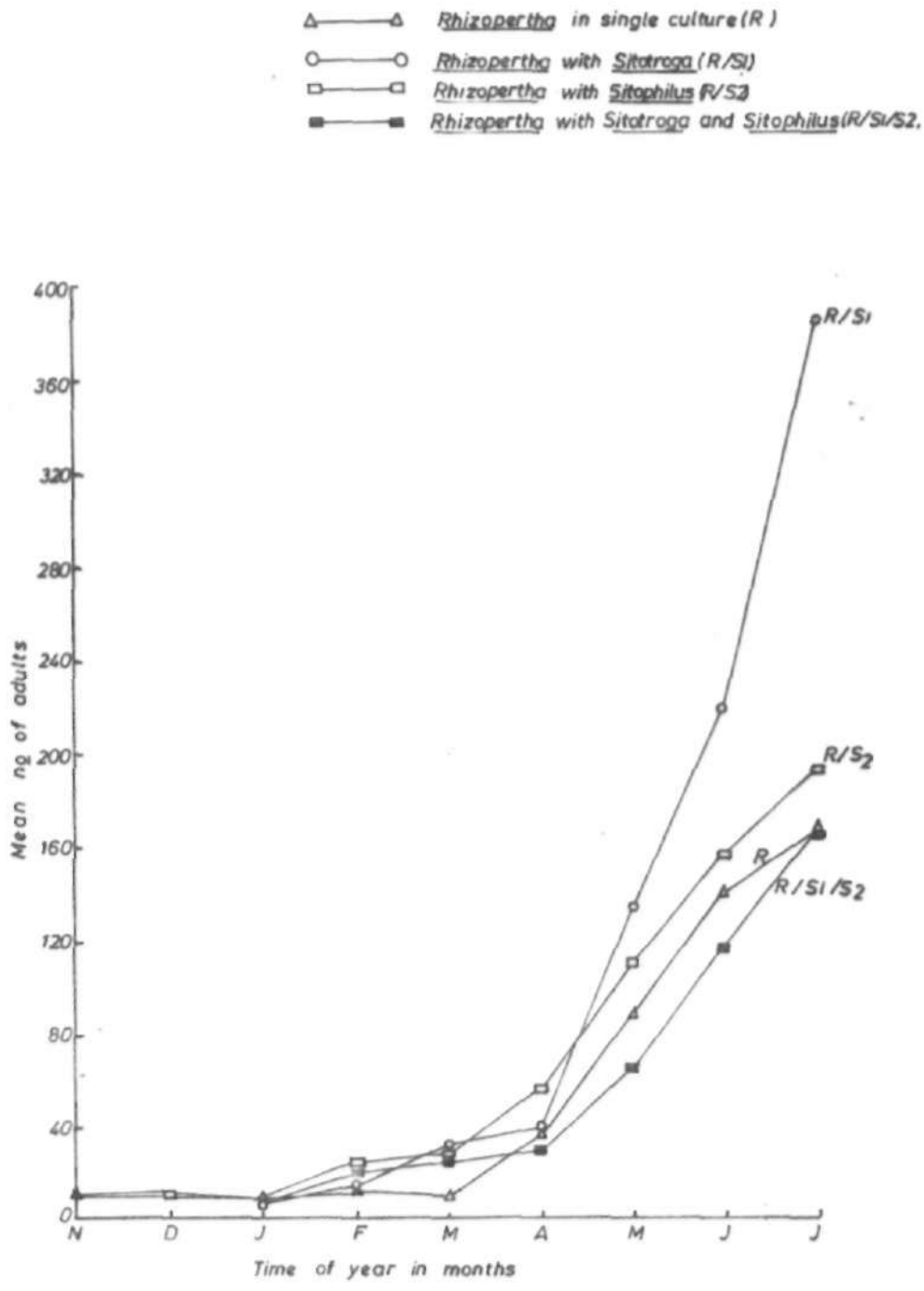
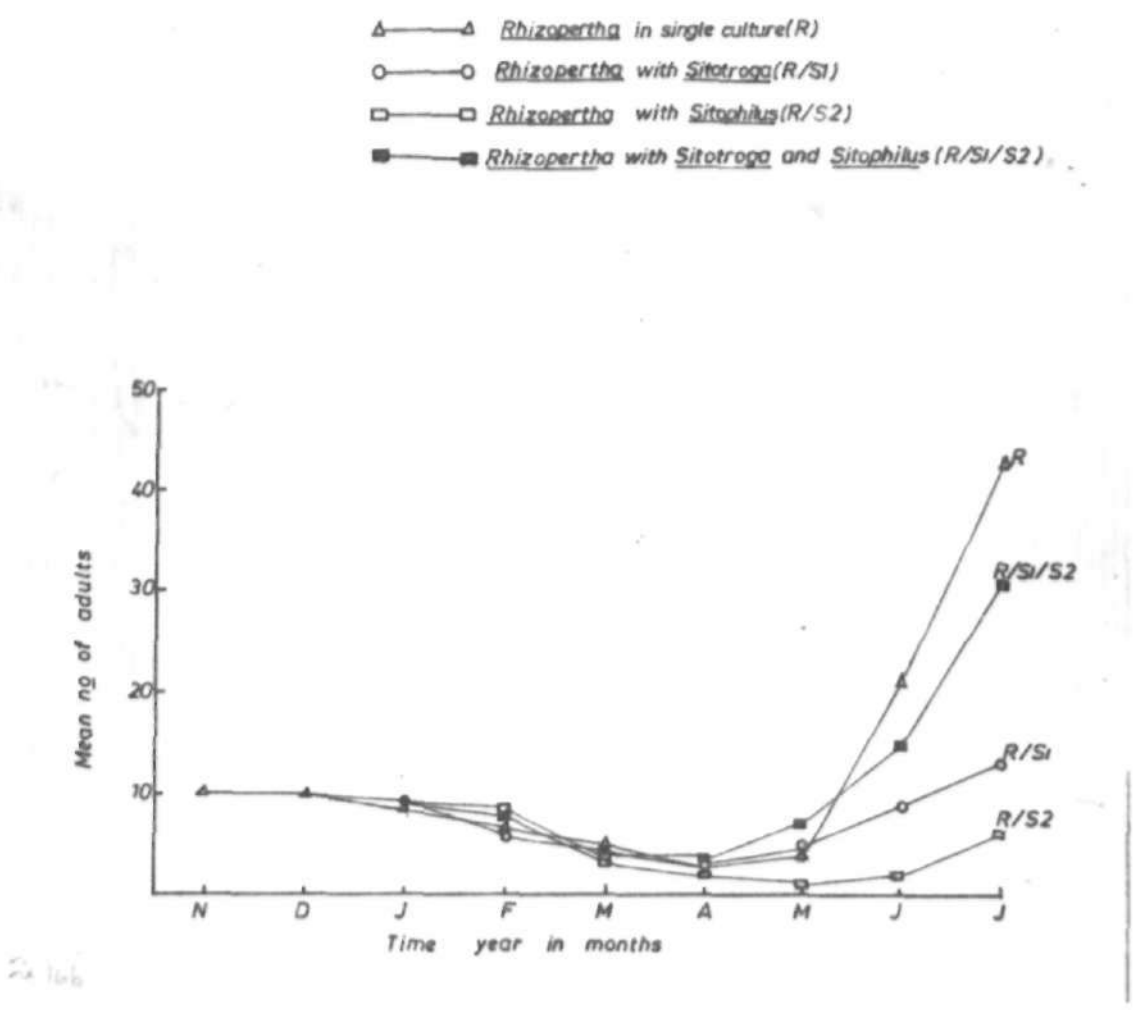

Rhizopertha in single culture (R)
Rhizopertha with Sitotroga (R/Si)
Rhizopertha with Sitophilus (R/S2)
Rhizopertha with Sitotroga and Sitophilus (R/Si/S2)
Mean number of adults
400
360
320
280
240
200
160
120
80
40
0
N
D
J
F
M
A
M
J
J
Time of year in months
R/Si
R/S2
R
R/Si/S2

Fig. 16b Mean monthly population growth of Rhizopertha on 25 g. sorghum in single and mixed cultures with Sitotroga and Sitophilus under ambient laboratory conditions.


Rhizopertha in single culture(R)
Rhizopertha with Sitotroga(R/S1)
Rhizopertha with Sitophilus(R/S2)
Rhizopertha with Sitotroga and Sitophilus (R/S1/S2)
Mean no of adults
50
40
30
20
10
N
D
J
F
M
A
M
J
J
Time year in months
R
R/S1/S2
R/S1
R/S2

In the humidity-controlled environment, the greatest increase in the Rhizopertha population occured when this pest was cultured with Sitotroga and was higher than when the beetle was cultured alone. An examination of the Sitotroga population in a mixed culture with Rhizopertha also shows that the initial slow rate of Rhizopertha corresponded with a rapid growth in the moth population. The major increase in the Rhizopertha population occured when temperatures increased and the moth was also eliminated from the mixed cultures (compare figs. 16a and 17a). This suggests that temperatures and Sitotroga depressed the Rhizopertha growth initially but once the moth was eliminated and temperatures also increased, Rhizopertha was able to compensate for it's initial drop in population in the subsequent months. The lower population levels reached by the single species culture of Rhizopertha when temperatures improved suggests that in the mixed culture, greater grain damage by Sitotroga larvae may have improved grain entry by Rhizopertha larvae.

Under ambient laboratory conditions, Rhizopertha appeared to have been similarly depressed initially

by temperature and Sitotroga but the beetle was unable to compensate for this in subsequent months probably because of the generally unfavourable ambient conditions. The lower moth population obtained here also suggest that fewer grains were damaged by Sitotroga larvae which could improve grain entry by Rhizopertha larvae (Figs. 16b and 17b).

When Rhizopertha was cultured together with Sitophilus, the population of Rhizopertha in this medium was higher than when it was cultured alone. An examination of the Sitophilus population in mixed cultures with Rhizopertha also showed that an initial slow rate of Rhizopertha growth corresponded with a rapid increase in the Sitophilus population. The major increase in the Rhizopertha population occured when the Sitophilus population began to decline and temperature had increased (compare Figs 16a and 18a). This also suggests that Sitophilus and temperature depressed Rhizopertha population growth initially but once the Sitophilus population started to decline and temperatures increased, Rhizopertha was able to compensate for this initial drop in its population in the subsequent months.

Damaged grains by Sitophilus may have improved grain entry by Rhizopertha larvae in these mixed cultures also. In an earlier work, Bhatia and Phardke (1976) found that Sitophilus suppressed Rhizopertha when the two pests were cultured together.

Under the ambient laboratory conditions, Rhizopertha was similarly depressed initially by temperature and Sitophilus but Rhizopertha was unable to compensate for this in subsequent months. The population of Rhizopertha was low here and remained so after Sitophilus had died out probably because very few grains were damaged which could have enhanced grain penetration by Rhizopertha larvae (compare figs. 16b and 18b).

In the humidity-controlled environment, the population of Rhizopertha in mixed culture with Sitotroga and Sitophilus was lower than when it was cultured alone. An examination of the populations of Sitotroga and Sitophilus in mixed culture with Rhizopertha shows that the initial slow rate of Rhizopertha growth also corresponded with the rapid increase in the populations of the other two pests. An increase in the population of Rhizopertha occured when Sitotroga was eliminated, the Sitophilus population declined and temperatures

increased (compare figs. 16a, 17a and 18a). This suggests that the two pests and temperature depressed the Rhizopertha population. Despite the presence of damaged grains, due to the combined feeding of Sitotroga larvae and Sitophilus, Rhizopertha could not compensate for its initial drop in population in the subsequent months. This was probably because the joint effect of the two insects was more than when Rhizopertha was cultured with only one insect population.

Under the ambient laboratory conditions, Rhizopertha seemed to have been similarly depressed initially by temperature, Sitotroga and Sitophilus but it did better than when it was mixed with only one of the pests (compare figs. 16b, 17b and 18b). The initial depression however did not allow the population to rise to the same levels attained by Rhizopertha when cultured alone.

4.332 Effect on Sitotroga of populations of Rhizopertha and Sitophilus

The growth of the Sitotroga population in the single and mixed cultures under the humidity-controlled or ambient laboratory conditions followed

the same trend (figs. 17a and 17b). Major increases were recorded during 2 - 5 months of the start of the cultures. This could be attributed to its tolerance of low temperatures (Howe, 1965).

In the humidity-controlled environment, the greatest increase in the Sitotroga population occured when this pest was cultured with Rhizopertha and was higher than when the moth was cultured alone. An examination of the mixed culture of Rhizopertha and Sitotroga showed that the initial increase in the moth population corresponded with a slow growth of the Rhizopertha population. This increase in the Sitotroga population occured when both temperature and Rhizopertha population were low but when these increased, Sitotroga was eliminated (compare figs. 17a and 16a). This suggests that Sitotroga took advantage of the initial low temperature and low population of Rhizopertha but once temperatures increased and the population of Rhizopertha increased, the moth was unable to compete with the beetle. The feeding of Rhizopertha on grains in the medium would help Sitotroga larvae to have easy access to damaged grains. This may have led to the high population growth of this insect in this medium.

Fig. 17a Mean monthly population growth of Sitotroga on 25 g. sorghum in single and mixed cultures with Rhizopertha and Sitophilus under humidity-controlled conditions for nine months.

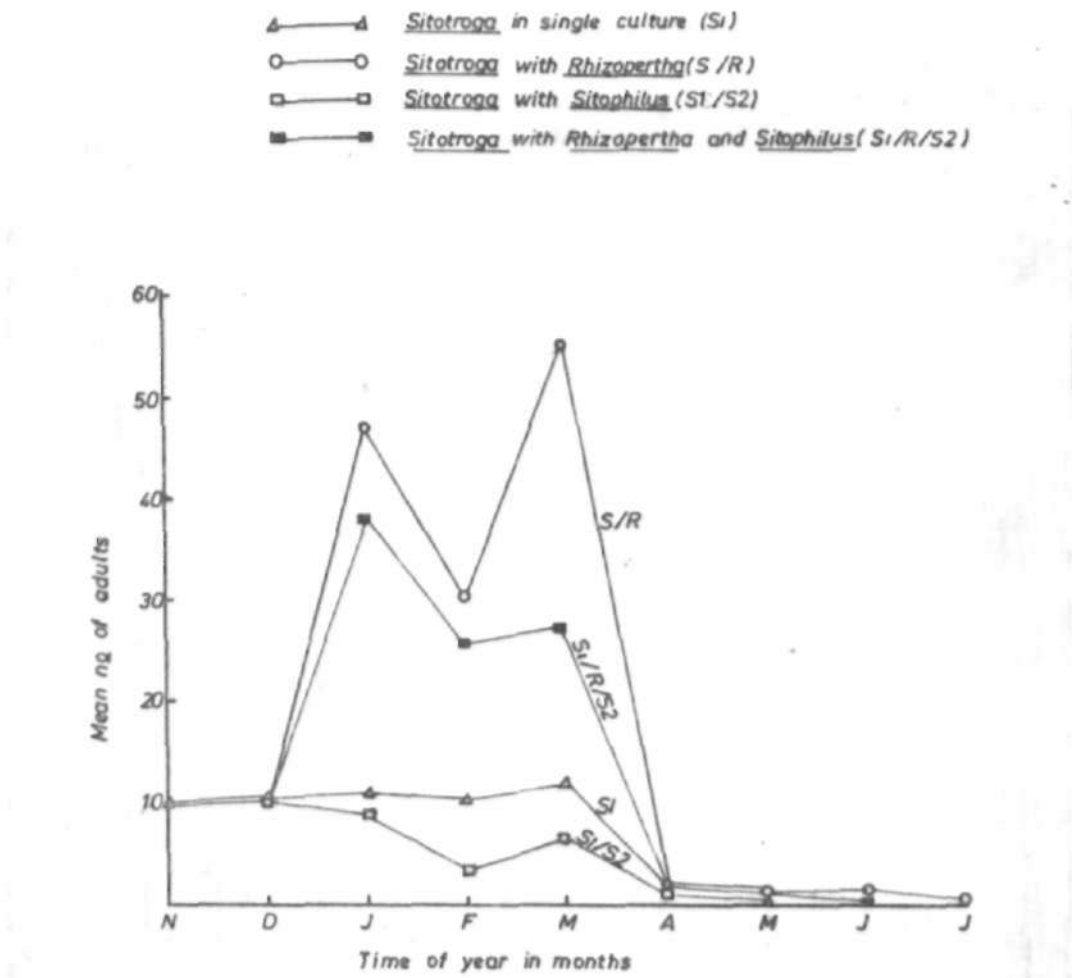

Sitotroga in single culture (S1)
Sitotroga with Rhizopertha (S/R)
Sitotroga with Sitophilus (S1/S2)
Sitotroga with Rhizopertha and Sitophilus (S1/R/S2)
Mean no. of adults
60
50
40
30
20
10
S/R
S1/R/S2
S1
S1/S2
N
D
J
F
M
A
M
J
J
Time of year in months

Fig. 17b Mean monthly population growth of Sitotroga on 25 g. sorghum in single and mixed cultures with Rhizopertha and Sitophilus under ambient laboratory conditions.

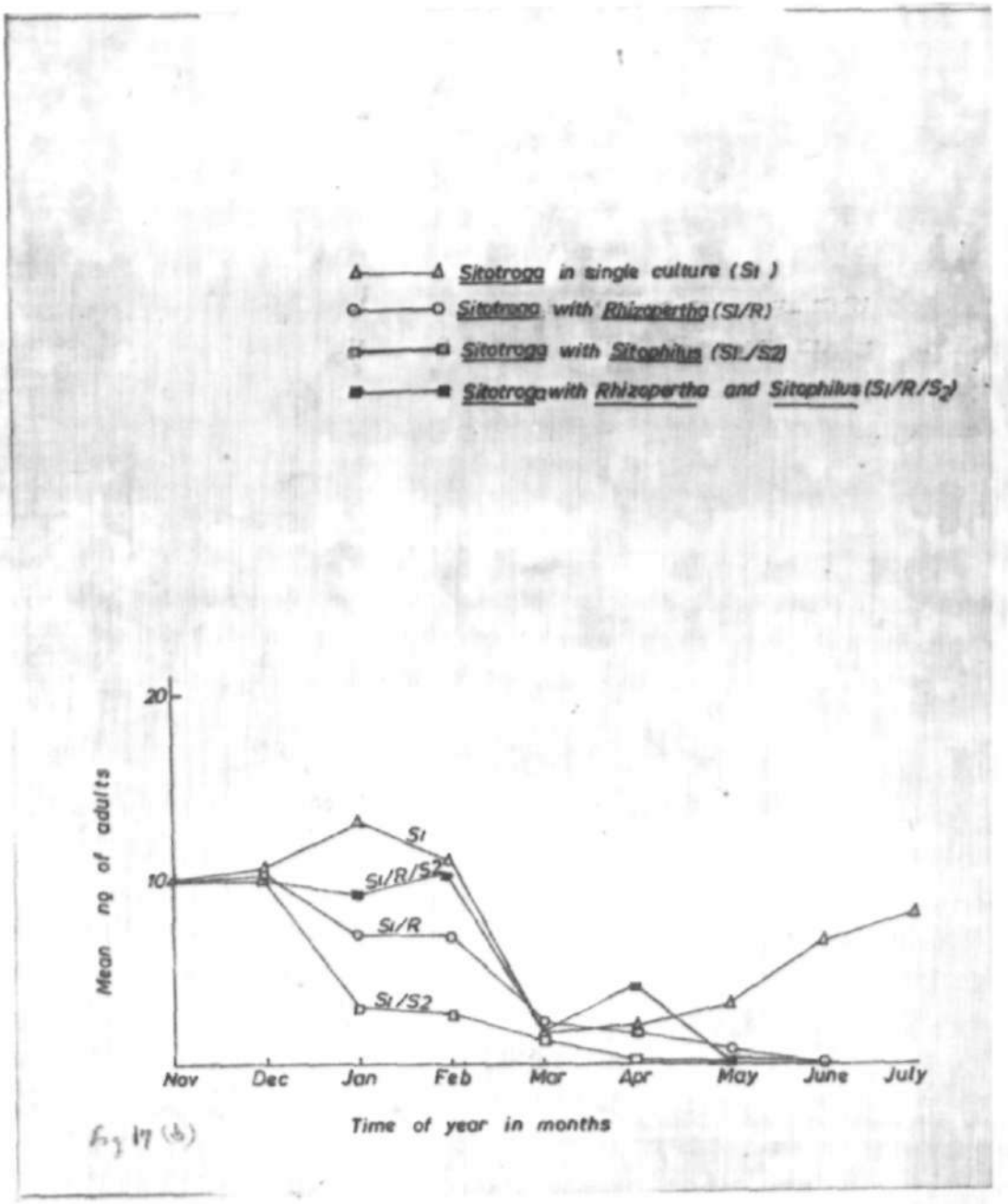

Sitotroga in single culture (S1)
Sitotroga with Rhizopertha (S1/R)
Sitotroga with Sitophilus (S1/S2)
Sitotroga with Rhizopertha and Sitophilus (S1/R/S2)
20
10
Mean no of adults
S1
S1/R/S2
S1/R
S1/S2
Nov
Dec
Jan
Feb
Mar
Apr
May
June
July
Time of year in months

Fig 19 (b)

Under the ambient laboratory conditions, because of the presence of fewer damaged grains, the population of Sitotroga was less than when it was cultured alone. This insect was eliminated when the population of Rhizopertha increased probably due to the advantage its larvae have over Sitotroga. Crombie (1944) found that Rhizopertha always eliminated Sitotroga from a medium in which both were cultured and attributed this to the struggle for space by the larvae of these insects inside grains, which often favoured Rhizopertha.

In the humidity-controlled environment, the lowest population increase in Sitotroga was recorded when it was cultured with Sitophilus. An examination of the mixed cultures of these insects shows a correspondence between the maximum population of Sitophilus and the elimination of Sitotroga (compare figs. 17a and 18a). This elimination of Sitotroga took approximately six months. Chesnut and Douglas (1971) reported that Sitotroga was eliminated by S. zeamais on corn after 6 - 8 generations because the adult weevils mechanically destroyed moth eggs as they attacked grains.

Ayertey (1979b, 1980) on the other hand found that Sitotroga elimination took 18 weeks because S. zeamais killed the immature stages of the moth in the grains that were attacked.

Under the ambient laboratory conditions, Sitotroga was not eliminated until after eight months. Though the Sitophilus population died out during the fifth month due to weather conditions, it had the greatest reducing effect on the Sitotroga population (compare figs. 17b and 18b).

When all three insects populations were cultured together in the humidity controlled environment, the population of Sitotroga was higher than when it was mixed with Sitophilus only. Sitotroga was eventually eliminated when the Sitophilus population had reached a peak and the Rhizopertha population had also increased (compare figs. 16a, 17a and 18a). The Sitotroga population here was high probably because the presence of Rhizopertha in the medium reduced the effect of Sitophilus on the population of Sitotroga. This would happen when Sitotroga is able to take a greater advantage of damage caused to grains by Rhizopertha than that caused by Sitophilus.

Under the ambient laboratory conditions, Sitotroga again had a higher population growth in the mixed cultures with Rhizopertha and Sitophilus Sitophilus than when it was mixed with either of the two insect populations.

It is clear therefore that under both environmental conditions, Sitophilus had the largest reducing effect on the population of Sitotroga while Rhizopertha appeared to improve its growth through grain damage. When all three populations were mixed together, the presence of Rhizopertha reduced the effect of Sitophilus on Sitotroga. From this it can be deduced that the effect of Sitophilus on Sitotroga reported by Ayertey (1980) must be greater than the effect of Rhizopertha on Sitotroga reported by Crombie (1944).

4.333 Effect on Sitophilus of populations of Rhizopertha and Sitotroga

There were no significant differences in the populations of Sitophilus either in the single or mixed cultures under the humidity-controlled or ambient laboratory conditions (Figs. 18a and b).

Fig. 18a Mean monthly population growth of Sitophilus on 25 g. sorghum in single and mixed cultures with Rhizopertha and Sitotroga in a humidity-controlled condition.

△——△ *Sitophilus in single culture (S_2)*
○——○ *Sitophilus with Rhizopertha (S2/R)*
□——□ *Sitophilus with Sitotroga (S2/S1)*
■——■ *Sitophilus with Rhizopertha and Sitotroga (S2/R/S1)*

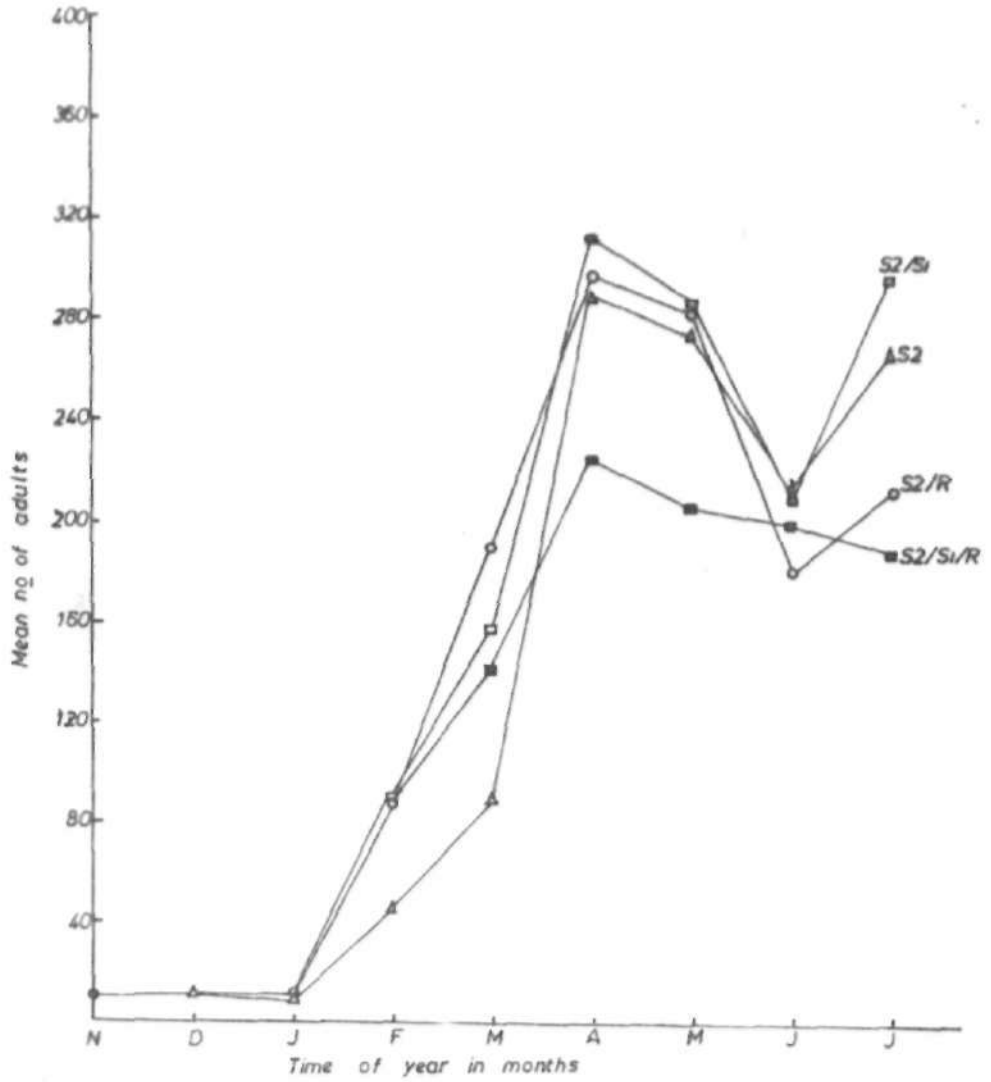
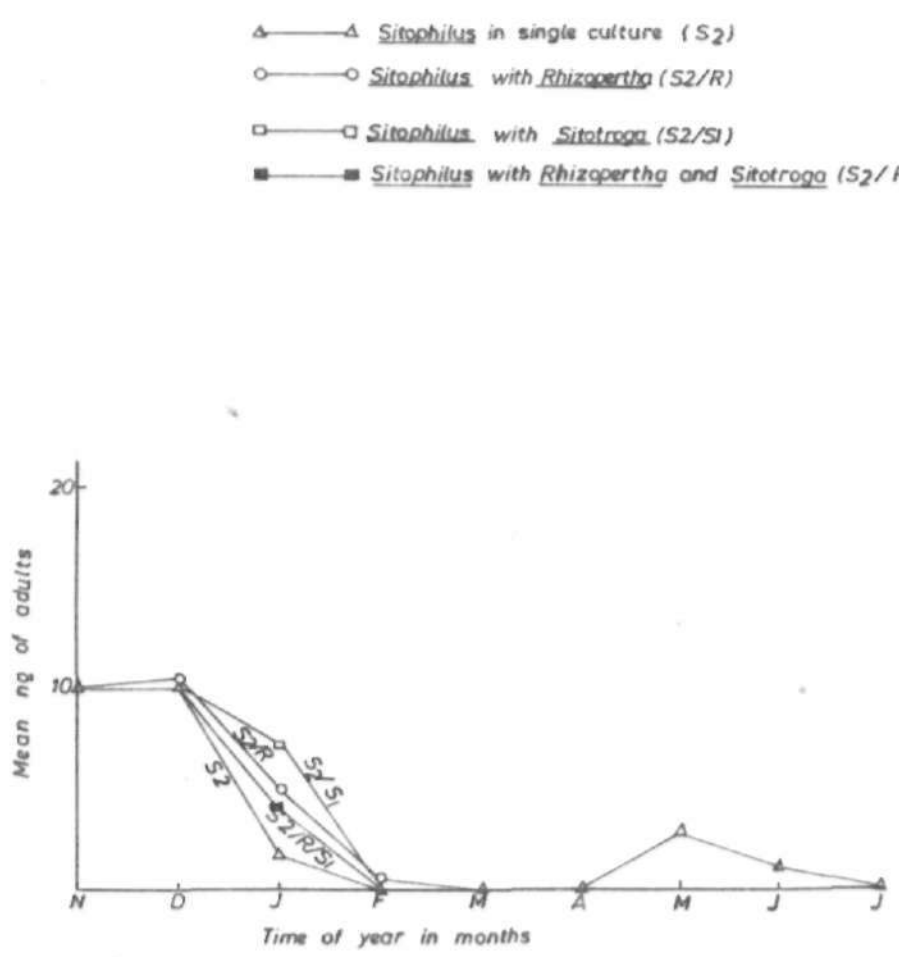


Fig. 18b Mean monthly population growth of Sitophilus on 25 g. sorghum in single and mixed cultures with Rhizopertha and Sitotroga under ambient laboratory conditions.


Sitophilus in single culture (S2)
Sitophilus with Rhizopertha (S2/R)
Sitophilus with Sitotroga (S2/S1)
Sitophilus with Rhizopertha and Sitotroga (S2/R/S1)
Mean no of adults
20
10
S2
S2/R
S2/S1
S2/R/S1
N
D
J
F
M
A
M
J
J
Time of year in months

However there was a decrease in the population of this insect when cultured with both Rhizopertha and Sitotroga under the humidity controlled conditions.

In the humidity controlled environment, the Sitophilus population in mixed culture with Rhizopertha had a higher peak than when it was cultured alone, though the single culture declined less than it did in the mixed culture. An examination of the Rhizopertha population when cultured with Sitophilus shows that rapid population growth of Sitophilus corresponded with the initial slow rate of growth of the Rhizopertha population and the decline in the Sitophilus population corresponded with rapid increases in Rhizopertha. This suggests that Sitophilus, with a more rapid rate of development initially suppressed the population of Rhizopertha, but Rhizopertha eventually suppressed the population of Sitophilus to a greater extent resulting in a more rapid decline in Sitophilus than when it was cultured alone (Phardke and Bhatia 1976).

The peak in the Sitophilus population and the greatest increase occured when it was cultured with

Sitotroga in the humidity-controlled environment. The rapid increase in this Sitophilus population corresponded with a decline and slow growth in the moth population.

A major decrease in the population of Sitophilus occured when this pest was cultured with Rhizopertha and Sitotroga (Fig. 18a) under the humidity controlled environment. An examination of the Sitotroga popula- in this mixed cultured shows that the Sitotroga population was relatively high during the first five months while the Sitophilus population also increased but at a slower rate. This lower rate was probably due to a secretion by Sitotroga into the culture medium. (Ayertey, 1979a). An examination of the Rhizopertha population also shows that the population of Sitophilus declined as the population of Rhizopertha was increasing, which suggests that Sitophilus was suppressed by the rise in the population of Rhizopertha. It could be concluded that the lower population of Sitophilus in mixed oultures with Rhizopertha and Sitotroga compared with when it was oultured alone or mixed with either of the two pests probably resulted from the initial effect of Sitotroga

and at a later stage of effect of Rhizopertha.

Under the ambient laboratory conditions, the population of Sitophilus in both the single and mixed cultures became very low and in some cases, died out after four months. This was probably due to the effect of the weather conditions, especially the effect of moisture (see 4.2).

Thus, Rhizopertha was depressed by Sitotroga and Sitophilus when in mixed culture with either or both of these insects but it was able to compensate for the initial depression at a later stage when it was mixed with Sitotroga. Sitotroga populations were eliminated by Rhizopertha and Sitophilus in mixed cultures with either or both of them. The elimination was more rapid when Sitophilus was present in the mixed culture. The Sitophilus populations were suppressed by Rhizopertha when both developed in the same medium. Sitotroga depressed the Sitophilus population initially but it was able to recover later.

5. GENERAL DISCUSSION AND CONCLUSIONS

5.1 GRAIN INFESTATION AND DAMAGE BY RHIZOPERTHA, SITOTROGA AND SITOPHILUS SPECIES AT THREE CLIMATIC ZONES IN NORTHERN NIGERIA.

The collection of samples of stored food over periods of time has been used in many studies on the changes in the populations of storage insects over different seasons. The damage to grains during storage has also been assessed through such samplings (Giles, 1964b; Halliday, 1966). Through such sample collections, some workers have suggested that infestation by stored products insects is induced by high moisture levels. This suggests that insect populations are at their minimum during the dry and usually cold seasons and at their maximum during the moist and usually warm seasons. Stored products insects that have been so reported upon include Rhizopertha dominica, Sitotroga cerealella and Sitophilus species. These have different optimal temperature and relative humidity ranges under which they develop (Reddy, 1950; Birch, 1945; Pingale and Girish, 1967).

In the samples collected and reported in this thesis, it was found that the incidence of three insect genera were dominant throughout the nine-month sampling period. These insects are Rhizopertha, Sitotroga and

Sitophilus which constituted between 60 and 80% of the total insects found on sorghum and maize at the three climatic locations in Nigeria included in this survey. This finding confirms earlier work carried out by Giles (1964b) Halliday (1966) and Caswell (in press).

The populations of the three stored products insect genera and the damage they caused to grains were found to be generally low during the dry season (December-March) due to the low moisture and temperature during the period. This finding conforms with observations by other authors elsewhere. Khare and Agrawal (1962) in India reported that the numbers of Rhizopertha and Sitophilus found on wheat and maize from January to June were low. Damage, they said, was also minimal at this period. The two insects were however found in abundance from July to October with the maximum in August, a period which coincided with high relative humidity. Damage also reached a peak in August. They concluded that the low population and damage was due to the low moisture and temperature of the dry season, while the abundance

of pests and high damage between July and October was also attributed to the high moisture and temperatures of this period. Giles (1964b) in his sampling in Samaru, Nigeria concluded that the low moisture content of grain during the dry season explained the few insects and the low level of damage recorded from December to June. He also associated the increase in insect population and damage from July to October with the maximum moisture content and high ambient temperature. Halliday (1966) observed that the low level of damage to sorghum and maize from December to April in Kano was due to the low grain moisture, which made conditions unfavourable for insect attack.

The three insect pest populations found on the two grain types in the present survey were found to develop first in the Southern Guinea Savannah before they did in the Northern Guinea Savannah and Sudan Savannah zones. This confirms Caswell's finding that insect pest populations develop first in the south of Nigeria. However, the report by Caswell that population development was earlier in the Northern Guinea Savannah than in the Sudan Savannah was not confirmed by the the present study. It was

however observed that grains from the Sudan Savannah had a relatively higher moisture content than those from the Northern Guinea and this explains the change in infestation and population levels at the two locations. Thus, Caswell's observation that pest populations tend to follow the moisture movement was confirmed by this survey.

In this survey, Sitophilus was found to be the dominant insect pest on both maize and sorghum in the Southern Guinea Savannah but the incidence was higher on maize than on sorghum. Giles (1964b) reported that S. oryzae (L) was one of the primary pests of sorghum and S. zeamais (Motsch) appeared only to occur in the southern-most part of northern Nigeria. He further reported that S. zeamais was not found at or north of about 10°N, only S. oryzae was found beyond 10°N. This suggests that most of the Sitophilus found in the Southern Guinea were S. zeamais especially on maize grains. The population of Sitophilus decreased northwards, especially on maize, and this is in conformity with the findings of Caswell. The population of Rhizopertha in this survey also decreased northwards, especially on

sorghum, and this is contrary to the findings of Caswell who reported that populations of Rhizopertha and Sitotroga were not different from one another at the three climatic zones.

The maximum damage to sorghum found in this survey was 13%. This level was less than was recorded by Giles (1964b) in his samplings at Samaru where 15% damage was reported but was more than that found by Caswell, in which he reported 7.5% maximum damage or that reported by Halliday (1966) in Kano which was only 4%. The maximum damage to maize found in this survey (21%) was higher than the level reported by Halliday (1966) in Kano (5%). However this maximum damage was recorded at Mokwa where moisture was high enough to encourage insect activity, especially Sitophilus on maize. Cornes and Rilley (1961) recorded damage levels ranging from 2 to 60% in seven months (August-February) on maize in Ilora, Oyo State and they attributed the damage to the principal pest found in the area - S. zeamais. This suggests that the nearness of Mokwa to Ilora explains the high damage level recorded for Mokwa and confirms further that the lower damage levels recorded at the more northern zones of Nigeria is due to the corresponding reduction in grain moisture.

5.2 THE ROLE OF MOISTURE IN THE BUILD-UP OF POPULATIONS OF RHIZOPERTHA, SITOTROGA AND SITOPHILUS ON STORED GRAIN IN NORTHERN NIGERIA.

The effect of humidity on the development of storage pests can be said to operate indirectly through the moisture content of grain. There is a fairly well defined relation between water content of grain and the relative humidity of the air surrounding the grain. Consequently, the amount of moisture in grain changes according to the relative humidity of air. Insect activity is generally rapid at relative humidities in excess of 75%; the corresponding moisture contents of most grains are in the region 14-15% and above (Pingale and Girish, 1967). For the majority of of storage pests, moisture contents below 10% are not adequate for normal activity and development. There always seems to be a defined range of relative humidity and moisture content that creates optimum conditions for the development of all insect populations. Moisture is also closely related to temperature as the amount of water retained in the air depends on the prevailing temperature conditions.

Rhizopertha dominica is reported to be able to breed in grain of 8% moisture content (Thomson, 1966, Pingale and Girish, 1967) and Birch (1945) also reported that the moisture content of the driest grain in which Rhizopertha was able to develop varied with temperature, falling as the temperature increased from 18.2°C to 34°C, but this increased at temperatures above 34°C. According to Howe (1965) the minimum temperature for the development of Rhizopertha is 23°C while the minimum relative humidity for its development has been recorded as 30% (Prevett, 1971). Khare and Agrawal (1970) found that the optimum relative humidity for the development of Rhizopertha ranged between 60 and 75%. In the experiment reported here, the population of Rhizopertha was higher in the humidity-controlled environment than it was under ambient conditions. The ambient temperature from December to February/ March averaged 22°C, below the minimum required for the development of Rhizopertha and this was responsible for the low populations recorded under the ambient laboratory conditions. As temperatures increased, the effect of moisture on the population growth

of Rhizopertha became apparent as its population under the humidity-controlled environment increased rapidly while that under ambient conditions declined. This pest did not die out during the dry cold weather under ambient conditions because it could tolerate low relative humidities (Khare and Agrawal, 1970; Prevett, 1970).

There were no significant differences in the populations of Sitotroga under the humidity-controlled and ambient conditions for six months of this experiment. After this period Sitotroga under the ambient conditions died out while the population under humidity-controlled conditions continued during the period of observation. According to Grewal and Atwal (1969) and Prevett (1970) the development of Sitotroga was more favoured at temperatures between 25 - 30°C and relative humidities of 70 - 80%. The higher maximum reached by Sitotroga under the humidity-controlled condition could be attributed to the higher moisture level. Howe (1965) also reported that the maximum temperature and relative humidity for the

development of Sitotroga were 16°C and 30% respectively. Thus the low temperature (22°C) and relative humidity (35%) of December and January were higher than the minimum for the insect, hence the population could increase, reaching a peak during January in this experiment. The stress of moisture was only effective on this insect after the temperature had increased in March. Sitophilus kept under ambient conditions died out five months after the experiment was started. The relative humidity from December— February was less than 40%. On the other hand the population under the humidity-controlled conditions continued until the end of observation and the relative humidity was above 65% during the observation period. Significant differences in population under both conditions was observed from the third month (December) to the end of observation. According to Reddy (1950) the optimum relative humidity range for oviposition and development of Sitophilus was 75 - 90% and the optimum moisture content was between 13 - 17%. In grains of moisture content of 8 - 10%, Sitophilus did not develop (Birch, 1945; Reddy, 1950; Pingale and Girish, 1967). Pingale and Girish (1967)

also reported that the rate of development and reproduction of S. oryzae increased as the moisture content of rice was increased from 12.2 to 17.6%. According to Howe (1965) S. oryzae will not develop at humidities of less than 60%. Thus Sitophilus died out in February in the experiment described here because the relative humidity of this month was less than 40%. The moisture content of grains at this period was also less than 8%. This insect continued to breed in the humidity-controlled condition because the high relative humidity and grain moisture suited its development.

From the above, it can be concluded that although some stored product insects can withstand a low relative humidity, especially Sitotroga and Rhizopertha, their populations are usually low during the periods of low relative humidity. In the present experiment Sitotroga could also tolerate low temperatures ($16^{o}C$). Consequently its population during December - April was able to increase, as was found at Kano during January/February (see 4.1). As soon as the moisture level improved, the population of these

insects increased and this confirmed the earlier survey by Giles (1964b), Halliday (1966) and Caswell (in press) that the low populations and damage recorded during the months of December to April was due to the low moisture content of the grains in their samples, while the high infestation recorded during June to October was due to the high grain moisture during this period.

5.3 EFFECT OF ONE INSECT POPULATION ON ANOTHER IN THE DEVELOPMENT OF POPULATIONS OF RHIZOPERTHA, SITOTROGA AND SITOPHILUS

Birch (1957) defined competition as that occuring when a number of animals (of same or different species) utilise common resources, the supply of which is short; or if the resources are not in short supply, competition occurs when the animals seeking that resource nevertheless harm one or other in the process. Inspite of the criticisms of Birch by Milne (1961), this definition seemed more appropriate to the results obtained from experiments reported in this thesis. The insect species dealt with are known to feed and develop on sorghum grain, hence they make use of the same resource. In seeking this

resource the insect species will interact and harm one another in the struggle that ensues, even when the grains are not in short supply. In a mixed culture of Sitotroga and Rhizopertha or Sitophilus or both, Sitotroga was found to be eliminated. Rhizopertha had its population depressed initially by Sitotroga but was able to compensate for the initial depression by increasing very rapidly when Sitotroga had been eliminated from the medium. Rhizopertha was also depressed initially by Sitophilus but it later increased, though not as much as when it was cultured alone. Sitophilus appeared to be unaffected by Sitotroga in the same medium but when it was in a mixed culture with Rhizopertha, its population was depressed. Crombie (1944) found that larvae of Sitotroga and Rhizopertha attack each other directly after encounters at random within wheat grains with the weak or later arrived larvae killed or forced to migrate. Such migration may lead to survival in an unsaturated environment but when the environment is limited a point is reached when migration from grain to another will only lead to death in another place. He concluded that Rhizopertha larvae are

more successful in such encounters which eventually leads to the elimination of Sitotroga from such media. Crombie (1947) also observed that competition for space, which limits population, occurs among insects which compete for definite oviposition sites e.g. S. oryzae, R. dominica, S. cerealella etc. He concluded that superiority of one species over another depends on:

a) rate of reproduction and survival

b) interference through direct attack, conditioning of medium or rapid use of resources.

Sitophilus has been shown to outnumber Rhizopertha in the same medium (see 4.3) and this was probably due to its higher rate of reproduction, while its survival rate could be about the same. Sitophilus and Rhizopertha may have interfered with Sitotroga through direct attack by adult Sitophilus on immature stages of Sitotroga during feeding, and the attack by the more active Rhizopertha larvae on Sitotroga larvae. This resulted in the elimination of Sitotroga from the mixed cultures described here.

Phardke and Bhatia (1976) observed a mutual suppression of population growth in a mixed culture of S. oryzae and R. dominica. They found that S. oryzae

outnumbered R. dominica during their population growth and this was attributed to greater activity and faster rate of development in S. oryzae, as compared with that of R. dominica. It was found that the population of the insect species was higher when cultured alone than when cultured together.

The elimination of Sitotroga from the mixed culture by the other insect species in this experiment took about six months. Chesnut and Douglas (1971) found that the elimination of Sitotroga by S. zeamais in corn field in Mississippi was after 6 - 8 generations and this was because the eggs of the latter were destroyed by mechanical damage caused by the weevils. Ayertey (1979b; 1980) on the other hand reported that Sitotroga was eliminated within 18 weeks in a mixed culture with S. zeamais because of the mortality of immature moths inside grains caused by the feeding of S. zeamais.

These three insect genera are abundant in stored sorghum and maize in northern Nigeria as shown in 4.1 above. Giles (1964b) reported different peak periods for the insects with Sitotroga increasing

rapidly in July, Rhizopertha in August and Sitophilus in September/October. It could be deduced that the population of Sitotroga declined in August because of the interference of the growing population of Rhizopertha and, Rhizopertha also declined when the Sitophilus population became high in September/October. It is however evident that Sitotroga was not eliminated in nature in the Nigerian situation because of the interference of weather (low moisture and temperature) which reduces the Sitophilus population from December to April and the low temperature which limits the development of Rhizopertha, none of which has as much effect on Sitotroga. This may be the reason for the earlier population peak reported for Sitotroga. Rhizopertha which could tolerate low moisture was limited in development by temperature and could not reach a high population from December to April to eliminate Sitotroga. Thus the three insect genera continue to develop together on grains in Nigeria, but with peaks at different periods of time.

SUMMARY

A study of the development of populations of three major pests - Rhizopertha, Sitotroga and Sitophilus - on stored sorghum and maize seeds in three climatic zones of Nigeria was carried out over a nine-month period.

The methods used in the study included a survey of the relative incidence of the three pest genera and damage caused to sorghum and maize at Mokwa, Zaria and Kano (representing the Southern Guinea Savannah, the Northern Guinea Savannah and the Sudan Savannah respectively), observations on the growth of the populations of the three pest genera under laboratory conditions when each population was cultured alone or with another.

Results of the survey showed that Rhizopertha, Sitotroga and Sitophilus together constituted between 60 and 80% of all insects found on the two grain types obtained from markets at the locations. Populations of these insects were much higher at Mokwa than at Zaria or Kano. The insect pest populations developed first at Mokwa followed by those at Zaria and Kano. The earlier arrival of the rains and

higher moisture at Mokwa was found to be responsible for this. Sitophilus was the dominant pest, especially on maize on which its population was higher than that of Sitotroga or Rhizopertha. Damage to grains closely followed infestation of these grains. Damage to sorghum was low during December to April and damage to maize samples from Mokwa was higher than that from Zaria or Kano. Relatively high weight losses were recorded at the three locations on the two graintypes.

To determine the role of moisture in the population growth of Rhizopertha, Sitotroga and Sitophilus, single population cultures of these insects were observed in the laboratory under humidity-controlled and ambient laboratory conditions. In all cases, insect populations under the humidity-controlled conditions were higher than those under ambient laboratory conditions. The Rhizopertha population under the ambient laboratory conditions was very low until the eighth month when the relative humidity increased at the beginning of the rains. The Sitotroga and Sitophilus populations died out under the ambient laboratory conditions while those in the humidity-controlled conditions continued breeding to the end of observation.

Single and mixed population cultures of these three genera were also observed for nine months under humidity controlled and ambient laboratory conditions to study the effects of one population on the other. Rhizopertha was initially depressed by temperature and Sitotroga but was able to compensate after temperatures increased and Sitotroga was eliminated from the mixed cultures. In mixed cultures of Sitophilus and Rhizopertha, a mutual suppression of the populations of the two insects was observed. Sitotroga was eliminated in mixed cultures with either Rhizopertha or Sitophilus or both, and the elimination was faster whenever Sitophilus was present in the medium. Sitophilus was depressed when it was cultured with Rhizopertha and Sitotroga.

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Appendix 1a: MEAN NOS. OF ADULT INSECTS COLLECTED MONTHLY FROM ONE KG. SORGHUM SAMPLES OBTAINED FROM MARKETS AT MOKWA, ZARIA AND KANO.

MONTHS	MOKWA				ZARIA				KANO			
	R	S_1	S_2	OT	R	S_1	S_2	OT	R	S_1	S_2	OT
OCTOBER	42	2.7	318.3	139.3	38.7	5.7	23.7	37	52.3	7.0	66.7	28.3
NOVEMBER	22.7	1.0	185.3	81.7	20.3	24	41.3	27.7	11.7	0	24.0	32.3
DECEMBER	8.7	20.3	141.0	30.0	0.7	17	1.7	0	2.0	19	6.0	2.7
JANUARY	0.	22.7	29.7	6.7	0	4.3	0.3	0.3	26.3	5.7	8.7	2.7
FEBRUARY	14	22.3	149.7	6.7	0.	20.3	2.3	1 3	36.3	8.0	8.7	5.0
MARCH	68	9.3	1.3	8.3	1.3	6.3	0.7	2.0	2.0	11.3	3.7	5.7
APRIL	26.3	1.0	12.3	11.3	1.7	6.0	0	3.3	2.0	3.0	4.0	8.7
MAY	123	1.3	3.3	14.3	2	7.7	6	11.0	9.3	24.7	4.0	12.0
JUNE	177.3	0	72.7	50.0	5.3	9.3	2.7	5.7	34.3	33.3	8.0	31.0

R = Rhizopertha dominica
S_1 = Sitotroga cerealella
S_2 = Sitophilus spp.
OT = Other insects

Appendix 1b: MEAN NOS. OF ADULT INSECTS COLLECTED MONTHLY FROM ONE KG. MAIZE SAMPLES OBTAINED FROM MARKETS AT MOKWA, ZARIA AND KANO.

MONTHS	MOKWA				ZARIA				KANO			
	R	S_1	S_2	OT	R	S_1	S_2	OT	R	S_1	S_2	OT
OCTOBER	1.0	72.3	106.3	19.3	4.7	2	9.3	3.3	1.0	0.0	14.3	1.7
NOVEMBER	0	108.	66.0	11.7	0.7	1.3	4.3	2.7	0	0	4.7	1.0
DECEMBER	0.7	16	141.7	22.3	0	2	3.0	0.7	12.3	0	21	25.0
JANUARY	0.3	3.7	31.7	11.0	0.3	1.7	2.3	0.3	0	3.3	5	1.7
FEBRUARY	0.3	4	32.3	5.3	0	1.0	5.7	16.3	0.7	3.7	5	3.7
MARCH	1.3	7.7	108.3	18.3	2	0.7	0.3	8.3	1.7	0	7.7	9.3
APRIL	0	0	98.7	51.3	0	0	0.7	11.0	0.7	0.3	13.7	12.0
MAY	1.3	0	37.7	11.7	0.7	2.0	13.3	17.7	0	2.7	2.3	4.0
JUNE	0.7	0	195.7	50.3	2	2.7	24.3	13.0	1.0	0.3	20.7	14.0

R = Rhizopertha dominica
S_1 = Sitotroga cerealella
S_2 = Sitophilus sp.

Appendix 2a: Percent Damage and Weight loss in sorghum samples obtained from markets at Mokwa, Zaria and Kano.

MONTHS	MOKWA		ZARIA		KANO	
	% Damage	% Wt. loss	% Damage	% Wt. loss	% Damage	% Wt. loss
OCTOBER	10.7	26.0	7.7	18.8	9.2	17.4
NOVEMBER	12.2	34.4	1.4	22.7	6.6	33.7
DECEMBER	5.4	14.4	0.6	30.7	2.4	10.7
JANUARY	1.5	9.7	1.2	33.4	13.4	35.8
FEBRUARY	1.6	4.1	0.7	31.3	8.3	25.8
MARCH	2.7	10.4	0.8	35.9	2.5	24.3
APRIL	2.3	14.2	1.2	23.0	2.1	7.8
MAY	4.0	23.0	3.0	19.6	6.5	14.4
JUNE	9.2	15.9	1.9	24.2	5.0	12.6
Av. for 9 months	5.5	16.9	2.1	26.6	6.2	20.3

Appendix 2b: Percent damage and weight loss in maize samples obtained from markets at Mokwa, Zaria and Kano.

MONTHS	MOKWA		ZARIA		KANO	
	% Damage	% Wt. loss	% Damage	% Wt. loss	% Damage	% Wt. loss
OCTOBER	13.9	23.7	0.3	25.4	2.0	7.4
NOVEMBER	13.7	34.2	0.9	2.2	2.1	29.3
DECEMBER	20.9	24.7	2.3	11.5	10.0	19.4
JANUARY	12.0	12.6	2.2	14.5	5.9	27.0
FEBRUARY	8.1	15.9	12.7	21.5	6.8	21.4
MARCH	9.1	18.6	7.3	13.0	11.4	20.2
APRIL	12.5	18.4	1.8	33.6	6.5	19.5
MAY	9.1	20.1	13.3	9.4	6.0	23.7
JUNE	7.9	30.9	6.1	10.5	8.4	37.6
Av. for 9 months	11.9	22.1	5.2	15.7	6.6	22.8

Appendix 3: Moisture content of monthly grain samples obtained from Mokwa, Zaria and Kano markets.

MONTHS	MOKWA		ZARIA		KANO	
	Sorghum	Maize	Sorghum	Maize	Sorghum	MMaize
OCTOBER	11.1	13.1	9.6	12.2	10.6	13.5
NOVEMBER	10.1	11.9	9.2	9.4	9.0	8.1
DECEMBER	10.4	10.0	7.5	8.2	8.6	7.8
JANUARY	9.0	9.5	7.0	6.9	7.6	7.6
FEBRUARY	7.4	8.4	6.1	6.7	6.3	6.3
MARCH	7.6	8.2	5.9	6.3	6.4	6.7
APRIL	8.6	8.4	7.3	7.0	7.9	7.8
MAY	10.5	10.6	8.3	8.9	10.8	10.1
JUNE	11.7	11.7	10.7	10.1	10.4	9.8

Appendix 4: Mean Monthly Population growth of Rhizopertha, Sitotroga and Sitophilus initially seeded with 20 adults under Humidity-controlled and Ambient conditions.

MONTHS	RHIZOPERTHA		SITOTROGA		SITOPHILUS	
	Controlled condition	Ambient condition	Controlled condition	Ambient condition	Controlled condition	Ambient condition
OCTOBER	20	20	20	20	20	20
NOVEMBER	20	20	62	61.7	57.3	63.7
DECEMBER	25	22.3	13.3	19.3	221.7	130
JANUARY	26.7	22.0	96	84.3	229.7	135.7
FEBRUARY	18.0	14.7	40.7	16.7	203.7	1.3
MARCH	12.7	9.3	19.3	0.7	206.3	0.7
APRIL	32.3	4.3	27.3	2.3	158.3	0
MAY	51.3	4.3	21	0	109	0
JUNE	95	13.3	32.3	0	147.7	0

Appendix 5a: Mean Monthly Relative Humidities and Temperatures in the Humidity Cabinets and the Ambient - Laboratory Conditions.

MONTHS	CABINET A		CABINET B		AMBIENT CONDITION	
	R.H. %	TEMP. ^{o}C	R.H. %	TEMP. ^{o}C	R.H. %	TEMP. ^{o}C
NOVEMBER	76.3	26.2	58	25.4	48.6	26.0
DECEMBER	80.6	22.1	66	21.8	35.8	22.5
JANUARY	82.2	23.4	69	22.7	29.4	23.3
FEBRUARY	83.9	24.8	70.1	24.5	26.4	25.5
MARCH	84.7	28.3	71.5	28.0	35.2	29.0
APRIL	84.5	29.6	71.4	29.6	44.3	29.8
MAY	88	27.6	74.7	27.7	76.1	28.1
JUNE	90.3	27.2	77.6	27.6	83.1	27.3
JULY	91.4	25.7	80.0	25.8	85.1	25.8

Appendix 5b: Moisture content of sorghum grain kept in the humidity-controlled cabinet and ambient laboratory conditions (Grain moisture was determined at 3 - 4 monthly intervals).

	NOVEMBER	FEBRUARY	JUNE
CABINET A	12.2%	12.1%	13.2%
CABINET B	10.5%	11.5%	12.9%
AMBIENT	9.2%	5.9%	11.1%

Appendix 6a STATISTICAL ANALYSIS OF NO. OF INSECTS FOUND IN MARKET SAMPLES FOR NINE MONTHS FROM MOKWA, ZARIA AND KANO.

SORGHUM ANOVA TABLE

Source	D.F.	Sum of Square	Mean Sum of Square	F
Site	2	107786.71	53893.355	24.02
Period	8	96860.21	12107.526	5.396
Species	3	40441.642	13480.547	6.008
Site x Period	16	50954.957	3184.685	1.419
Site x Species	6	81351.414	13558.569	6.043
Period x Species	24	124566.802	5190.283	2.313
Residual	264	592325.807	2243.658	
Total	323	1094287.543	3387.887	

Appendix 6b

MAIZE ANOVA TABLE

Source	D.F.	Sum of Square	Mean Sum of Square	F
Site	2	62158.617	31079.309	29.341
Period	8	15371.562	1921.445	1.814
Species	3	55147.935	18382.645	17.355
Site x Period	16	21499.383	1343.711	1.269
Site x Species	6	71984.00	11997.333	11.326
Period x Species	24	35870.759	1494.615	1.411
Site x Period x Species	48	50524.889	1052.602	0.994
Residual	216	228796.000	1059.241	
Total	323	541353.145		

Appendix 7 Mean monthly population growth of single and mixed cultures of Rhizopertha, Sitotroga, and Sitophilus under Humidity-controlled or ambient conditions, each species being started with 10 adults.

A

MONTHS	RHIZOPERTHA				SITOTROGA				SITOPHILUS			
	HUMIDITY-CONTROLLED CONDITION		AMBIENT CONDITION		HUMIDITY-CONTROLLED CONDITION		AMBIENT CONDITION		HUMIDITY-CONTROLLED CONDITION		AMBIENT CONDITION	
	MONO-CULTURE	MIXED	MONO-CULTURE	MIXED	MONO-CULTURE	MIXED	MONO-CULTURE	MIXED	MONO-CULTURE	MIXED	MONO-CULTURE	MIXED
November	10	10	10	10	10	10	10	10				
December	10	10	10	10	10.7	10.3	10.7	10.7				
January	9.7	9.3	8.7	9	11.3	47	13	7				
February	12	13.3	6.7	6	10.3	30	11	7				
March	10	31.7	5	5	12	55	1.7	2.3				
April	36.3	39	3.3	3	1.7	2	2	1.7				
May	88.3	134	4	4.7	0	1	3.3	0.7				
June	140.3	219.7	21.3	9	0	1.3	6.7	0				
July	166.3	385.3	43.3	13.7	0	0	8	0				
Totals	482.9	852.7	112.3	70.4	56	156.6	66.4	39.4				
November	10	10	10	10					10	10	10	10
December	10	11	10	10					11	11.3	10	10.3
January	9.7	9	8.7	9.3					8.7	10.7	1.7	5
February	12	24.3	6.7	8.7					45.7	85.7	0	0.3
March	10	29.7	5	3.3					89	191.3	0	0
April	36.3	56.7	3.3	2.3					289.7	297.3	0	0
May	88.3	111.3	4	1					275	283.3	2.7	0
June	140.3	156.3	21.3	2					214.7	180.7	1	0
July	166.3	194.3	43.3	6.3					266.7	212.7	0	0
Totals		602.5		52.9					1210.5	1283	25.4	25.6

MONTHS	RHIZOPERTHA				SITOTROGA				SITOPHILUS			
	HUMIDITY-CONTROLLED CONDITION		AMBIENT CONDITION		HUMIDITY-CONTROLLED CONDITION		AMBIENT CONDITION		HUMIDITY-CONTROLLED CONDITION		AMBIENT CONDITION	
	MONO-CULTURE	MIXED	MONO-CULTURE	MIXED	MONO-CULTURE	MIXED	MONO-CULTURE	MIXED	MONO-CULTURE	MIXED	MONO-CULTURE	MIXED
November					10	10.	10	10	10	10	10	10
December					10.7	10.3	10.7	10.3	11	10	10	10
January					11.3	9	13	3	8.7	9	1.7	7.3
February					10.3	3.3	11	2.7	45.7	90.7	0	0
March					12	6.7	1.7	1.3	89	159	0	0
April					1.7	0.7	2	0.3	289.7	313	0	0
May					0	0	3.3	0.3	275.	287.7	2.7	0
June					0	0	6.7	0	214.7	210.7	1	0
July					0	0	8	0	266.7	296.7	0	6
Totals						40	27.9	27.9		1386.8		27.3

B

MONTS	HUMIDITY-CONTROLLED CONDITION						AMBIENT LABORATORY CONDITION					
	Rhizopertha		Sitotroga		Sitophilus		Rhizopertha		Sitotroga		Sitophilus	
	Mono-culture	Mixed culture	Mono-culture	Mixed culture	Mono-culture	Mixed culture	Mono-culture	Mixed culture	Mono-culture	Mixed culture	Mono culture	Mixed culture
November	10	10	10	10	10	10	10	10	10	10	10	10
December	10	10	10.7	10	11	10	10	10	10.7	10	10	10
January	9.7	8.3	11.3	20	8.7	9	8.7	9	13	9.3	1.7	4
February	12	20	10.3	25.7	45.7	89	6.7	7.7	11	10.3	0	0
March	10	24.7	12	27	89	141.7	5	4.7	1.7	1.7	0	0
April	36.3	30	1.7	1	289.7	224.7	3.3	3.7	2	4.3	0	0
May	88.3	64.7	0	1	275	207.7	4	7.3	3.3	0	2.7	0
June	140.3	116	0	0	214.7	202.3	21.3	15	6.7	0	1	0
July	166.3	167.3	0	0	266.7	188.7	43.3	31	8	0	0	0
Totals	482.9	454.0	56.0	113.7	1210.5	1083.1	112.3	98.4	66.4	45.6	24.7	24

N.B.

6A: Single and Mixed populations of two genera.

6B: Single and Mixed populations of three genera.