MINISTRY OF FOOD

INSECT PESTS OF FOOD

The Control of Insects in Flour Mills

With a Foreword by the
DIRECTOR OF INFESTATION CONTROL

LONDON: HIS MAJESTY'S STATIONERY OFFICE
1947

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THE CONTROL OF INSECTS IN FLOUR MILLS

By J. A. FREEMAN, B.Sc., Ph.D., A.R.C.S., F.R.E.S.

and

E. E. TURTLE, M.B.E., M.Sc., Ph.D., F.R.I.C.

TABLE OF CONTENTS

FOREWORD

The National Joint Industrial Council for the Flour Milling Industry, through their Technical Education Committee, published in 1930 an excellent pamphlet by Mr. Sebert Humphries entitled " Pests in Wheat and its Products." When, in 1944, it was proposed by the National Joint Industrial Council that the work should be revised Mr. Humphries graciously surrendered any claim to undertake this task, considering that the best interests would be served if the responsibility could be accepted by those who had been identified with more recent research and practice in this field.

This courteous gesture on his part enabled me, after consultation with Mr. C. A. Loombe, C.B.E., and Dr. T. Moran, C.B.E., D.Sc., Ph.D., to include, as I had wished to do, a work on the control of infestation in flour mills in the series of Ministry publications on the subject of infestation, at the same time satisfying the desire of the National Joint Industrial Council to whom I render acknowledgment for their accommodating spirit in the matter.

Thus the charge fell upon Dr. E. E. Turtle and Dr. J. A. Freeman, who are respectively Chief Chemist and Chief Entomologist of the Infestation Control Division of this Ministry. Trained in the Imperial College of Science and Technology under Professor J. W. Munro, D.Sc., who has so greatly advanced knowledge in this field of science, they came to the Ministry of Food from the Pest Infestation Laboratory of the Department of Scientific and Industrial Research. They have been identified with the development of the Ministry's scientific and technical service on infestation in all its aspects and have full access to the valuable scientific data, largely built up to their plan, furnished by the field scientific service.

The Authors might well have been excused had they laid special emphasis on high scientific standards. They are to be commended for confining their efforts to the production of a work of economic value to the practising flour miller and to the student of flour milling practice. It is but bare justice to them that it be recognised that, in taking this course, they have deliberately refrained from discussing important scientific aspects of the general problem and have addressed themselves solely to the factors affecting the flour miller. The general student should keep in mind that the case might be presented quite differently where there are considerations other than those met with in flour milling.

I am glad to record that Mr. C. A. Loombe and Dr. T. Moran join me in commending this work as a practical and readable contribution to knowledge for which the Authors are to be thanked.

W. McAuley Gracie,
Director of Infestation Control.

Ministry of Food,
Infestation Control,
58, High Holborn, W.C.1.

September, 1946.

Section 1

GENERAL INTRODUCTION

There are only two groups of organisms which seriously challenge man's position as the dominant species in the world : one of these groups is the insects. They not only attack growing crops, seeds, stored produce, household effects, buildings and industrial equipment, but carry diseases of man, domestic and wild animals and plants. An estimate of the total losses due to the various aspects of insect attack was made for the United States of America in 1936. The figure was nearly one thousand five hundred million dollars, of which three hundred million was ascribed to losses to stored grain and grain products. There are only isolated figures available for other countries, but if an overall loss of 10 per cent. occurs in a country where the protective services are highly developed, how much more must be lost in other countries where little attention is paid to the protection of stored goods.

A few of these figures may be found of interest. In 1933 in Germany the loss due to the attacks of the grain weevil (*Calandra granaria*) amounted to 100 million R.M. The direct losses in the rice industry in the United States of America have been stated to amount to over three million dollars annually ; the equivalent of 10 per cent. of the value of the crop. This estimate takes no account of business losses, loss of goodwill, etc. In Malaya it has been found that rice stored under normal commercial conditions for more than eight months is unfit for human consumption owing to attack by insects. In 1929 the tobacco trade in this country suffered losses estimated at £100,000 owing to a severe outbreak of the tobacco moth (*Ephestia elutella*) in stored tobacco. In this country the normal expenditure on cleaning and fumigation of mills is an impressive amount without taking into account the constant losses and the interferences in production throughout the whole year. It is one of the objects of this pamphlet to assist the milling industry to reduce this heavy expenditure to the minimum and to ensure that such as has to be incurred is used to the maximum advantage.

Insects and mites are so small that many people have difficulty in understanding how they can achieve so much damage in a short time. The principal reason is the rapid rate of multiplication.

For most of the stored products insects the rate of living and breeding increases with rise of temperature and in general therefore the losses from insect attack are greater in the tropics than in temperate countries. In the tropics insects breed continuously whereas in temperate countries not only does breeding stop but many species are hard put to it to survive low winter temperatures. Some of our most important pests are, however, well adapted to temperate conditions and flourish in our climate, but are seldom of importance in the tropics. These include the brown spider beetle, *Ptinus tectus*, the flour mite, *Tyroglyphus farinae*, and the mill moth,

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Specific reference to each source of information in the text is impracticable in a pamphlet of this kind, but footnotes providing references are given where it has been thought expedient. The main sources of published information are listed in section 4.

The principal sources drawn upon in the preparation of the introductory section are as follow :— *F. Zacher :* "Die wirtschaftliche Bedeutung und wissentschaftliche Entwicklung des Vorratsschutzes" : Proceedings of the 7th International Entomological Congress, Berlin, 1938 : pp. 2903–2912, and "Die Verschleppung und Einbürgerung der Vorratsschädlingen," *ibid.* pp. 2919–2926 ; *A. I. Balzer :* Insect Pests of stored rice and their control : United States Department of Agriculture, Farmers Bulletin No. 1906 ; *H. W. Jack and R. B. Jagoe :* Rice Storage Experiments : Malayan Agricultural Journal, Volume 18, 1930, pp. 447–454. *H. H. S. Bovingdon :* Report on the infestation of cured tobacco in London by the cacao moth, *Ephestia elutella Hb.*, Empire Marketing Board Publication No. 67, H.M. Stationery Office, London, July, 1933.

Ephestia kühniella. Although we have a fair body of knowledge about the biology of many of the stored products pests it is unsound to assume that a tropical pest will not establish itself in this country. Many kinds of insects and mites are constantly being introduced and amongst the introductions may be races which are adapted to life in temperate conditions or the introductions may survive in locally favourable situations such as heated buildings.

As an example of the rapid spread of an insect originally of a very local distribution one may cite the mill moth, *Ephestia kühniella.* It was first discovered in 1877 in a mill in Saxony and was recorded in certain places during subsequent years as follows :— Lower Rhine and Belgium 1884, England 1886, Trieste 1887, Canada 1889, South Africa 1890, Venezuela 1891, California and Jamaica 1892, Sweden 1894, New York and N. Carolina 1894, Pennsylvania 1898, Wisconsin 1899, Minnesota 1910. It is now found all over the world and represents a problem to every flour miller. The spread of this insect seems to be closely correlated with the development of roller flour milling and international trade in milling products.

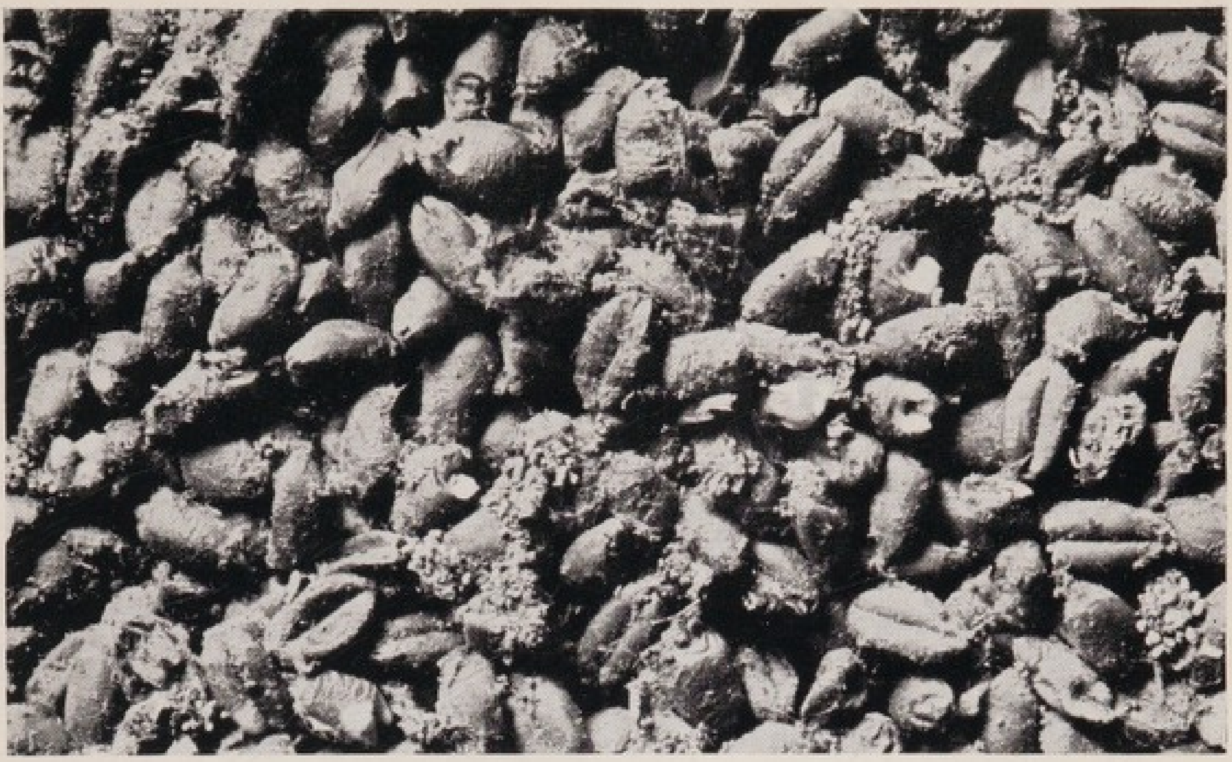
It is clear that much of the damage has already occurred by the time the wheat reaches the mills in this country, but the loss has to be borne somewhere and, over a long period, it is the consumer who suffers. It should be the aim to ensure that no further losses occur which could be avoided by careful attention to infestation control in the course of the milling operations.

The losses which are liable to occur in the milling industry as the result of insect and mite infestation may be broadly classified as damage to wheat ; interference with productive processes ; contamination and spoiling of finished products ; loss of goodwill and trade reputation.

Wheat which arrives at the mill in an infested condition may continue to deteriorate during storage and not only will actual loss in weight result from feeding by insects but the wheat may heat, become musty or mouldy and unsuitable for milling. Wheat which arrives heavily infested by mites may be tainted and require special treatment before it can be milled. It may be difficult to produce a satisfactory high extraction flour from badly " weevilled " wheat owing to the high proportion of endosperm destroyed by the insects. In the same way flour produced from wheat whose germ has been damaged or eaten by mites, flat grain beetles (*Laemophloeus sp.*) or cacao moth caterpillars (*Ephestia elutella*) is likely to contain less of the valuable germ constituents than flour made from sound wheat (Plate 1).

Within the mill there is interference with production principally owing to the webbing produced by the caterpillars of the mill moth. If this webbing is not removed regularly it is liable to cause chokes in spouts and reduce the sifting capacity of reels and of machines by covering the screening surfaces. Other insects such as the cadelle (*Tenebroides mauritanicus*) and the larder beetle (*Dermestes lardarius*) may bore into the woodwork of machines and the former, in particular, is known to bite holes in silk covers, thus reducing the efficiency of separation of stocks.

It can be readily demonstrated that flour will contain the eggs, and sometimes the adults and larvae, of insects living in the milling machinery and there is little doubt that mites can survive the whole process of milling. Although the screens used for the final stages of the production of high grade flour are adequate to exclude even the eggs of some species, this is no sure protection because quite heavy infestations of the mill moth have been observed in the packing bins and hoppers. The first stage in the protection of the finished products is, therefore, to control infestation in the machinery, but the use of non-infested bags is also of high importance. As is stated elsewhere in this pamphlet, the returned flour bags represent one of the principal sources of infestation of mills. The treatments commonly in use for the cleaning of bags are



1 Wheat webbed and germ destroyed by attacks of caterpillars.

2 Fumigation under a sheet.

inadequate for the killing of insects and mites. The practice of taking the flour dust from the sack cleaning room to the mill, even if such dust is included in the offals, results in a steady addition to the insect population in the mill. It should be the aim to deliver flour with the minimum of infestation, but it is realised that there is little the miller can do to protect flour once it has left his premises. However, if the flour or other product is likely to lie unconsumed for a considerable time, the miller should consider seriously whether it should not be packed in an insect-proof container.

This survey of the nature of the infestation problem indicates the necessity of taking action, the object of which is to reduce losses and interference with production to a minimum and to ensure that milling products leave the mill as far as possible free from infestation.

In the planning and execution of a control programme, an appreciation is necessary of the biology of the insects and mites, particularly their life histories and habits, and the conditions under which they thrive. It is, for example, of great importance in forecasting the likely development of an infestation to know that the grain weevil stops laying eggs when the temperature falls below about 60 deg. F. In the same way it is possible to forecast with some degree of accuracy when the adults of the cacao moth are likely to appear in the summer and so to be ready to apply the proper control measures well in advance. In the mill, the number of generations a year of the mill moth can be estimated from a knowledge of the average temperature conditions in the milling section. In the United States of America, control is effected by allowing the mill to cool down to outside air temperatures when the thermometer is well below zero. Steam radiators can also be used to effect control by the use of heat, but in each case the miller must know what temperatures should be reached and appreciate the fact that the effect must be achieved in all parts of the mill.

A knowledge of the habits of insects, *e.g.* the wood boring habit of the cadelle (*Tenebroides mauritanicus*), assists one in finding centres of infestation and in applying special local control measures. One of the principal places in which insects and mites maintain themselves is in undisturbed dust, sweepings, etc. Much can be done to keep infestation at a low level by regular cleaning and disposal of debris. Chemical control may be avoided if this is done properly.

The various methods of control are set out in Section 2 of this pamphlet, details of the life histories and habits of the various pests in Sections 3 and 4. Any miller who has mastered these basic principles will be in a position to devise sound programmes of control and to ascertain the degree of success obtained by control measures carried out by contractors on his behalf.

Section 2

METHODS OF PREVENTION AND CONTROL OF INFESTATION

INTRODUCTION. There are a number of measures which the miller can take to prevent infestation and to control it once it has taken root. The various methods must, however, be used at the right time and in the right way and to that end a knowledge of two main aspects of the problem is necessary. The first is the biology of the pests concerned and the second is the possibilities and limitations of the various methods of prevention and control.

The biological information is of particular importance in deciding the time and the method. For example, it is useless to endeavour to apply a contact spray against grain weevils at a time when the majority are contained as grubs within the grains, or against moths when they are in the resting caterpillar stage and may be hidden deep in cracks in the building and protected by cocoons. Control measures against certain tropical insects in unheated buildings may be unnecessary, particularly in the autumn, since winter temperatures can be relied on to kill the insects ; but it is not entirely safe to leave this to chance. Other insects, such as pea weevils, may emerge in large numbers from dried peas but be unable to breed in them, as the females can only lay eggs on peas growing in the field. The objection to presence of insects in food has to be reckoned with.

Each method of control has its own peculiar limitations and advantages and these are often directly related to the particular insects which it is required to kill, some insects being much more resistant to certain insecticides than to others. On the other hand, it is necessary that the insecticide or other method of control should not be injurious to the material or machinery to be treated and that it should be applied so that there is the minimum interference with normal routine manufacturing processes. All the methods of control described in this part of the pamphlet are based on sound entomological foundations and only those methods which have been examined by the Ministry and thoroughly proved in practice have been included. For this reason, it should not be concluded that the absence of a reference to a particular technique infers that it is regarded with disfavour : this applies especially if the method is of recent introduction.

The discussion in the ensuing sections follows broadly the course of the milling operations, viz., treatment of grain, treatment of infested bags, preventive measures, hygiene and remedial control measures in building and treatment of infested milling products.

TREATMENT OF MATERIALS ENTERING THE MILL

METHODS OF ENTRY OF INSECTS AND MITES INTO THE MILL. Most of the insects which are pests in mills spread only short distances under their own power by flying or walking. They depend for their dispersal mainly on carriage in, or on, the commodities which they infest or in containers such as bags and transport vehicles. It is a sound working principle that if the introduction of infested materials, containers and transport to a group of mill buildings can be prevented, then the mill itself can be maintained indefinitely free of infestation. In this section, therefore, the various methods of control of infestation in wheat and returned flour bags are dealt with. The methods recommended for the treatment of finished products may be applied to flour for mixing in.

TREATMENT OF GRAIN

STORAGE OF GRAIN. In normal times, the miller is not primarily concerned with the long-term storage of grain in bulk. It is, therefore, not proposed to dwell on the subject here to any length, apart from mentioning that during the past few years considerable advances have been made in the study of various aspects of bulk storage, *e.g.*, respiration, thermal conductivity of grain and attack by insects, mites and moulds.

In practice the important considerations are to ensure that the grain is kept at such a low moisture content that mites, moulds and micro-organisms cannot flourish and that, as far as possible, precautions are taken to prevent or limit attack by insects.

Attention should first be directed to the stowage space to ensure that it is dry and free from insects and mites : special cleaning, spraying or fumigation may be necessary in this connection. It may also be necessary to treat the grain itself prior to receipt for long term storage : such measures include drying and fumigation. Various insecticidal dusts, a class of which are chemically inert in character, have received attention as a possible means for controlling or preventing the insect infestation of grain in bulk, although for various practical reasons their use has never become extensive.

Since most insecticidal materials are toxic to other animals, including man, an important difficulty in this connection is to ensure that no contamination occurs, either of the whole grain or of products, such as fine offals, which are separated during the course of processing.

FUMIGATION OF GRAIN. It is not economically possible to fumigate standing bulks of grain effectively with any of the fumigants at present commercially available in this country because of the poor penetration of gas obtainable under static conditions. The difficulty is chiefly because these fumigants, principally hydrogen cyanide and ethylene oxide, are appreciably " sorbed " (*see* footnote) by the commodity ; some kind of forced circulation, *e.g.*, in silo bins, is necessary to obtain effective distribution to depths greater than a foot or so.

(Although considerable and successful experience has been obtained in their use abroad, at present no such silo circulating units are generally available in this country.)

With grain in bags the problem is much simpler ; provided that they are not too closely interwoven in the stacks, the bags can be fumigated in tight compartments such as chambers, steel barges or on sound floors of warehouses.

Bagged material may also be treated in small stacks under balloon, or similar fabric (Plate 2) : since this technique involves great care in sealing up the stacks and in maintaining the sheets in an impervious condition it is less suited for use on a routine scale.

A method of fumigating grain in silo bins by using calcium cyanide in granular form (Cyanogas G) has been employed successfully and is now available in this country (Plate 3). The grain is turned and the granular calcium cyanide is added at a known and constant rate into the grain stream at the point of delivery into the bin. The filled bin is closed up and left undisturbed for a period of not less than ten days :

" Sorbtion " is the technical term used to describe the process by which commodities, buildings, etc., take up fumigant gases and thus reduce the concentration of fumigant which actually affects the insects. Most of the sorbed gas is given off during the airing of the commodity or building, but some may be retained by chemical combination with the fumigated material.

3 Fumigation of wheat with granular calcium cyanide (*Cyanogas G*).

during this period the calcium cyanide gives off hydrogen cyanide in concentrations which are low but sufficient, with the period of exposure employed, to kill any insects freely exposed or inside the grains. With a material which liberates hydrogen cyanide it is necessary to ensure that none of the gas is given off into the working and other spaces, and care must be exercised to ensure that the powder is not spilled or added to the grain in too great a quantity. Only premises with bins of sound construction are suitable for the method and the floor at the point of delivery to the bins should be well ventilated, preferably with forced air extraction at the point of delivery of grain to each bin. Treatment is actually possible in the majority of mill silos.

The possibilities of these fumigation processes leaving toxic residues or affecting the milling and baking qualities of the wheat have received close attention and sufficient evidence is available to show that no damage occurs provided that the processes are conducted with care. The latter is also necessary to ensure that the method achieves satisfactory results.

SPRAYING OF GRAIN. As this measure only affects the outer layers of the grain bulk, it is severely restricted in application.

However, the application of sprays as a routine measure has been successfully employed to protect grain in bulk and in bags from attack by the mill moth (*Ephestia kühniella*) and by the cacao moth (*Ephestia elutella*) and to kill caterpillars at the stage when they appear on the surface of stocks and produce the typical webbing (Plate 4). Spraying is also very useful for the treatment of empty stowages before receipt of clean stocks (Plate 12).

HEAT TREATMENT OF GRAIN. In this country heat treatment has not been employed on any scale for the killing of insects in grain, chiefly because the intermittent use to which the plant would be put has generally been considered to be insufficient to justify the installation. The temperatures required to achieve disinfestation vary somewhat with species of insects and mites and also with the moisture content of the grain. As would be expected, the times required also are dependent upon the temperatures used. However, for practical purposes, two minutes at 145 deg. F., or ten minutes at 135 deg. F., may be considered as the lowest limits to obtain effective results. Attempts have been made, without great success, to adapt certain types of grain drying plants for this type of disinfestation by adjusting the rate of flow of grain and of air current. An important difficulty in this connection is that a slight overheating of the grain may cause serious deterioration in the baking quality of flour produced.

HANDLING OF INFESTED GRAIN. By careful handling in the screenroom, it is normally possible to remove the majority of free insects and also to separate the more badly damaged grains. Strong aspiration, washing and flotation processes are particularly useful for this purpose. All tailings or similar stocks should either be finely ground immediately on production (a special chute to the grinder is sometimes fitted for this purpose) or they should go straight to the heat treatment or fumigation plant to prevent spread of insects throughout the premises. For the latter purpose, it is all to advantage that the necessities of fire precautions have achieved a large measure of separation of the screenroom from other sections of the mill premises.

The " Entoleter " machine, to which further reference is made on page 27, shows considerable promise for the treatment of infested grain since not only is a high proportion of free living insects killed in passage through the machine, but there is some evidence to show that weevil grubs may be killed without damage to the wheat

4 Grain infested by caterpillars of the cacao moth at a stage when spraying is practicable.

5 A simple fumigation chamber.

grains. The machine should be fitted into the flow at an early stage in the passage of grain through the screenroom. It is necessary, however, to remove large impurities, sticks, stones, string etc., the last-mentioned, in particular, is liable to reduce the efficiency of the machine.

TREATMENT OF BAGS

There is considerable evidence to show that returned flour bags are the chief carriers of insects into the mill, particularly the mill moth (*Ephestia kühniella*), whose caterpillars and pupae are often in cocoons firmly attached to the bag fabric ; other insects commonly found on bags include the flour beetle, *Tribolium confusum*, the cadelle, *Tenebroides mauritanicus* and the brown spider beetle, *Ptinus tectus*.

Ideally no bags should be employed a second time, or they should be sterilised by fumigation or by heat prior to return to the mill premises. The practice, becoming common before the war, of using non-returnable bags, is a good example of the former procedure.

A further possibility of solving this problem is offered by recent experimental work on the impregnation of the bags themselves with insecticidal preparations : the chief difficulties in this connection are that the impregnation must remain effective under practical conditions for a considerable period whilst it must not be accompanied by a risk of contaminating the foodstuffs stored in the treated bags.

HEAT TREATMENT OF BAGS. The notes given in the preceding section regarding the times and temperatures necessary to effect sterilisation of grain apply equally to sacks, it being essential to ensure that the required minimum temperatures are reached even in the coolest spots. A modified sack drying plant circulating a hot air current over the bags and using steam as a source of heat, preferably by live injection, can be employed for this purpose and, being quite simple, can be operated by the sack cleaning staff.

FUMIGATION OF BAGS (Plates 5 and 6). This is as efficient as heat treatment although a higher degree of technical supervision is necessary because, to some degree, the available fumigants are all toxic to human beings. For this reason, *before undertaking fumigations, expert advice should be obtained regarding the construction of the chamber, dosages and safety precautions, and other matters connected with the operations.*

Of the fumigants available, *hydrogen cyanide* is perhaps the most effective, but, also, the most dangerous in use. Although some risks from fire are involved in the use of *ethylene oxide* with *carbon dioxide*, the mixture is very much less toxic to man and, in the hands of any but the most skilled operators, is therefore to be preferred. Of the chlorinated hydrocarbons which are at present available, *ethylene dichloride* is the most practicable. This fumigant may readily be applied as a spray ; the liquid is only very slightly inflammable and the gas has a readily detectable odour. For these reasons, *ethylene dichloride* is suitable for use by the normal mill personnel after only an initial technical supervision. Bags readily "sorb" all of these fumigants which must, therefore, be used in fairly high dosages ; dense bundles and stacks also must be thoroughly opened up.

Methyl bromide has not yet been employed on any scale in this country. It possesses physical and chemical properties very suitable for the treatment of bags, which sorb the gas relatively slightly, rapid penetration and subsequent airing being obtainable. Very special care must be employed in using the gas, however, because it is very toxic and only possesses a slight warning odour.

In some circumstances, it is found practicable to collect the bags in sufficient batches to be treated by a fumigation servicing company before their return to the mill. However, an advantage of having a fumigation chamber on the premises is that it can be used for any infested material, bags and commodities alike. An existing brick or concrete bin or a soundly constructed shed may be suitable for adapting into a fumigation chamber. Expert advice should be obtained about such conversions, as there are a number of difficulties which are not apparent at first sight.

SITING OF BAG TREATMENT PLANT. Bags awaiting treatment should not be stored where there is any possibility of insects walking or flying from them and entering the main premises. The heat treatment or fumigation plant must also be situated at a strategic stage in the passage and handling of the bags if the results of treatment are not to be invalidated by cross infestation between the treated and untreated bags. There is little doubt that the bags should be treated as the first stage in the cleaning process. This has the advantage that not only are the bags themselves rendered sterile but also the cleanings ; the latter do not then carry infestation when transferred to the offal side of the mill. The procedure also ensures that the bag treatment and cleaning section remains, as far as possible, clear of endemic infestation.

There are various methods of cleaning bags which have been observed in mills, ranging from simple shaking to the latest types of suction cleaners. None of these methods is adequate to remove all insects and mites from the bags, although a large proportion are removed when sack cleaning apparatus is working at full efficiency. Caterpillars and pupae may be inside cocoons which are strongly spun to the fibres : other insects have considerable powers of clinging to the fabric. It is therefore

6 Sacks under fumigation in a specially constructed chamber.

necessary to have a special treatment chamber to deal with infestation : the cleaning machines are then left to carry out their proper function.

Whilst a heat treatment chamber can be fitted up inside the mill it is preferable for the fumigation chamber to be quite detached, as this reduces the dangers during the period of airing after the treatment and, therefore, allows greater freedom of operation. In any case an isolated site is to be preferred, as already stated, in order that the infested incoming bags may be segregated.

PREVENTIVE MEASURES AND HYGIENE IN MILL BUILDINGS

PREVENTION. Serious infestation in the mill, like most other troubles, is far easier to prevent than to remedy. Measures aimed at the prevention of entry of infested materials into the mill have already been described and, in this section, it is proposed to deal with those methods which are applicable within the premises. Prevention in this regard is almost completely covered by the term "good house-keeping," which includes the maintenance of strict hygiene involving the immediate removal of spillage, systematic turnover of stock, regular removal of webbing and clearing out of all hidden spaces, which form ideal breeding-places for insects.

7 Sacking used to cover a grain conveyer spout.

DESIGN. The structure of the mill itself is the first important consideration. Modern milling plants with machinery well spaced out, smooth walls and floors and well-lighted rooms possess great advantages over older premises whose floors are often worn, whose rooms are dark and frequently contain excessive quantities of machinery. In the latter type of premises, basements are often inaccessible and have a rough floor on to which dust and debris collect, forming a potent source of trouble. However, although great improvements in structure and layout of premises have been achieved, designers of machinery have not paid due attention to questions of infestation, even the most modern of machines having inaccessible places in which stock can accumulate and which form ideal seats of infestation. A particularly common fault in the maintenance and running of the machinery is the use of sacking to cover leaky places in chutes and spouts and to act as air filters or as packing sleeves. Use is often temporary in intention but becomes permanent in practice (Plates 7 and 8). The incorporation of an enclosed hopper in machinery framework is often the cause of trouble in this way. For example, from each of a number of roller mills in a modern flour mill recently about 1 cwt. of heavily matted and infested material was removed from the space between the timber hopper and the iron frame; the hoppers had to be dismantled to get at the spaces in question. These spaces would certainly not have been sterilised by a normal fumigation and there was no inspection plate or other means of reaching the space from outside the machine. On a similar principle, chutes and elevators should be designed to be as self-cleaning as possible; all end-pockets should be either eliminated or provided with ready means of access for cleaning. The latter remark also applies to elevator boots and sumps, which are often situated in most inaccessible positions.

CLEANING. As the life cycle of the mill moth, *Ephestia kühniella*, takes some seven weeks under the favourable temperature conditions normal in a mill, it is necessary to ensure that all breeding areas are cleaned with a frequency well within this period if a proper check is to be obtained. When cleaning, webbing should be removed from the insides of machinery worms and spouting; special attention should be paid to the more inaccessible spots, such as end-pockets, dead spaces and disused machinery. Spouts leading to packers and the insides of packing hoppers need special attention, as insects at this point are liable to be carried direct into the finished products. Unused spouts should be properly sealed off and not stuffed with empty sacks. Spout mauls are available for clearing webbing from spouts, although a common procedure is to draw a cloth through the spout. Ordinary sweeping is adequate for exposed areas, although this type of cleaning is more efficiently performed with the aid of industrial vacuum cleaners, which allow more work to be completed with a limited labour force and which also are able to deal with spots, such as ledges, which cannot be readily reached by sweeping (Plates 9 and 10). Accumulations of cocoons and webbing should be loosened before employing the vacuum cleaner. The webbing and sweepings obtained by cleaning operations should not be allowed to stand about and preferably should be treated by heat or fumigation before disposal. Regular routine cleaning, removal of webbing, etc., should be carried out in the screening section as elsewhere. In the warehouse, in addition to the regular cleaning, the surrounding areas of floors and walls should be cleaned on the removal of each parcel; a gangway of sufficient width to allow inspection and cleaning should always be left around each stack, which should not be allowed to rest against the walls. Finally, the warehouse and milling rooms should be kept tidy and old sacks, silks and brushes should never be left in corners or on window sills and spare pieces of machinery should not be kept in places where they can accumulate dust and become centres of infestation. (Plate 11).

8 A dirty, webbed packing spout.

REMEDIAL MEASURES

It has been found by experience, that thorough attention to the measures advocated in the preceding section has resulted in conditions which made recourse to remedial measures unnecessary. However, under present-day conditions this is seldom possible and control measures are required. Various methods of treating buildings have been employed and are outlined in the following sections. Of these, fumigation is the most effective and the most frequently employed, but it must be emphasized that it cannot be claimed that any of the methods alone can be completely successful in removing the whole of the insect population. Each method has its peculiar advantages and disadvantages and should be used appropriately.

SPRAYING. Spraying is generally employed to kill insects which are exposed on the surface of a commodity or machine, on the walls or floor of a mill room or are flying in the free space. No spraying method is effective in killing insects buried inside a commodity or below webbing or dust on the floor or in inaccessible positions inside machinery or spouts, and, for this reason the use of sprays in mill is strictly limited, being almost solely confined to isolated treatments of a small scale or in a restricted area where the spread of insects must be arrested.

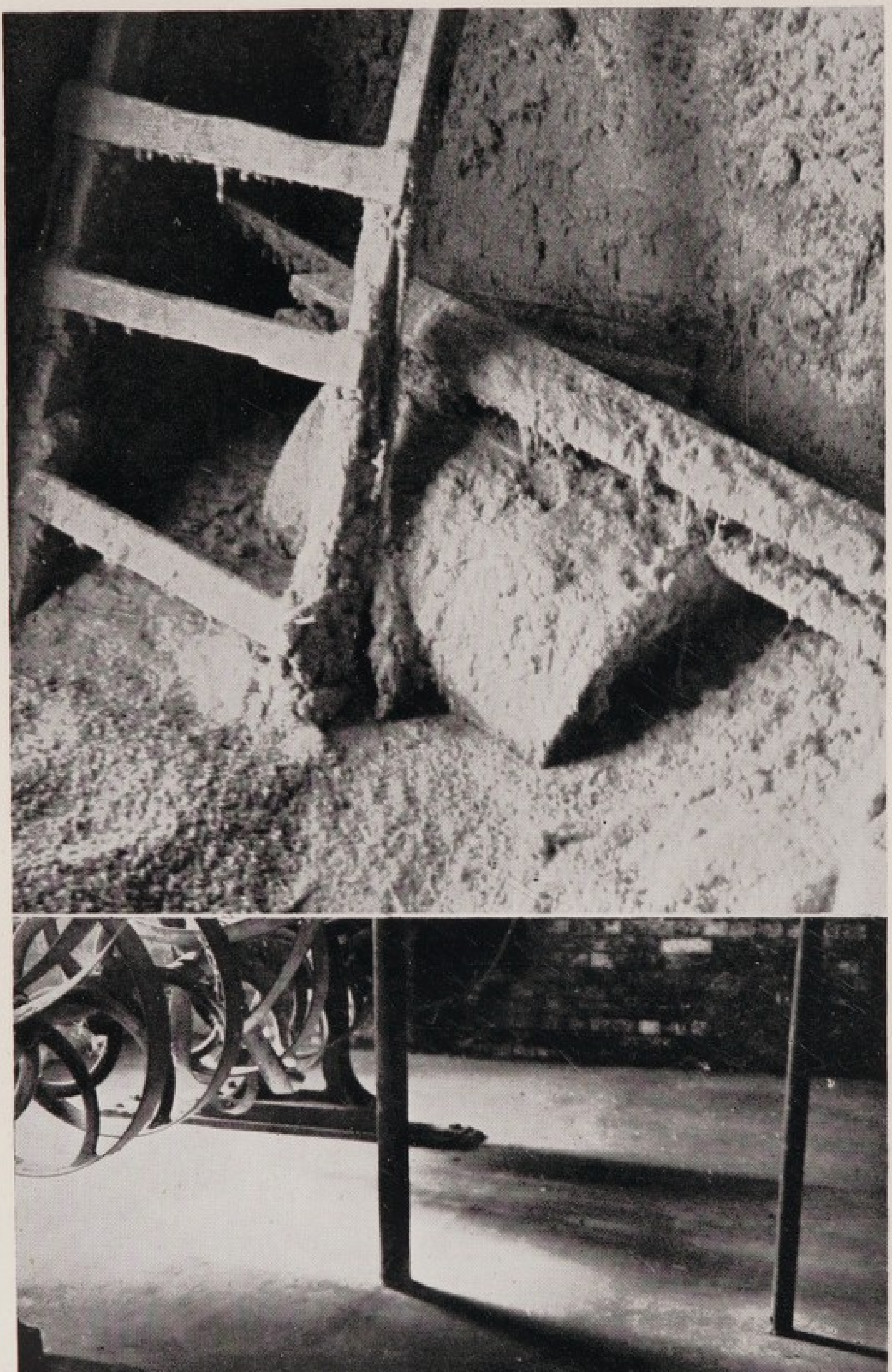
Sprays which are not toxic to human beings and do not taint foodstuffs have been developed specially for use in food warehouses. They are chiefly made up in refined heavy paraffin oil ; an oil suspension being favoured partly to avoid the wetting of goods or premises which would occur with aqueous suspensions or emulsions. An extract of pyrethrum flowers containing insecticidally active chemical substances called pyrethrins, is most commonly employed as the insecticidal material.

Sprays are most advantageously applied mechanically with spray guns worked with compressed air (Plate 12) or incorporating small electric blowers. Proprietary hand sprayers varying in efficacy are available for small scale applications, although they are mainly designed for use against flies and set up a fine mist of insecticide.

The technique of spraying should be varied according to whether it is intended to kill flying moths (mist effect), insects exposed at the time of application (direct effect), or those which may pass over the sprayed surface after the application (film effect). In the use of the first effect the spray is set up in very fine particles which float in the air, bringing down those adult moths which collect sufficient insecticide from the mist ; the method is not of much value where there is good air ventilation, which rapidly removes the mist. To have appreciable effects upon the general level of infestation, the spraying must also be carried out regularly, because adult moths are constantly appearing and, if not killed immediately, will lay eggs in places which are protected from the spray.

When employing the direct or film effects, the spray jet is directed on to the surface where the insects are walking at the time of treatment or may walk subsequently. To obtain an even spread of insecticide, the spray should be in droplets small enough to give an even spread, without being so fine as to float about as in the mist effect. The applicability of the film effect is strictly limited by the possibilities of obtaining an effective film on the available surfaces for a reasonable period ; the surface must be non-absorbent in character and in a position where it is not liable to become contaminated by dust ; the insecticide should also be chemically stable.

INSECTICIDAL DUSTS. Insecticidal dusts may be employed instead of sprays but are more suitable for use in empty rooms than when commodities are present (Plate 13).



9 Different parts of a mill basement before and after vacuum cleaning.

HEAT TREATMENT. Both heat and cold have been used in the United States of America for the treatment of mill buildings. In the first case the mills are piped with steam radiators and the treatment is carried out during the summer months when the natural air temperatures are already very high. Temperatures necessary to effect sterilisation have already been mentioned in connection with the treatment of wheat and of bags (page 8). Slightly lower temperatures are more practicable and longer periods can be employed : the latter may be necessary to ensure that the heat penetrates into all hidden or insulated localities. 125 deg. F. maintained for twelve hours is recorded as giving satisfactory results. Electric heaters have been used in this country for local treatment in food factories.

Some control is possible by the use of low temperatures, but in this country the winter temperatures are not sufficiently low for long enough to effect sterilisation within a reasonable period, even if the mill is completely opened and all heating turned off and machinery stopped.

FUMIGATION. Fumigation has long been a recognised method of controlling insects. However, it is only over the past few years, largely because of the introduction of safe and effective methods, that the process has come into common practice for the treatment of mills and similar premises.

WHEN TO FUMIGATE. From a commercial viewpoint the main considerations in deciding whether a fumigation is worth-while are (*a*) the degree to which the infestation, webbing, etc., affects the efficiency of production and (*b*) the condition in which the finished commodities leave the premises. In the latter connection important factors are the period of storage in the warehouse and the class of trade (with provender mills, for industrial purposes, with the general public or for export to warmer climates). The modern miller also is generally concerned in seeing that his premises are kept in good order and accepts the duty of reducing contamination by bacteria and other organisms associated with insect attack. In many mills it is the practice to fumigate annually ; it is not possible to make a general recommendation, however, because so much depends on the type of premises and the standard of hygiene which is maintained.

PREPARATIONS FOR FUMIGATION. To obtain satisfactory results from a fumigation, ALL SECTIONS OF THE PREMISES should come under consideration, it being remembered that moths and some beetles can fly sufficiently far in warm weather to render any part of the premises vulnerable. Strictly local fumigations, i.e., of individual pieces of machinery are not worth while unless frequently carried out, owing to the rapidity with which cross infestation takes place. The most satisfactory procedure is to fumigate all sections which are structurally suitable and are infested, and, at the same time, to clean all other sections with a view to minimising the re-infestation of the fumigated parts. Basements, outhouses, lean-to sheds and similar places should not be forgotten. It must be remarked that much money and effort has been wasted in the past by mill managements insisting on confining the treatment to the roller mill section and leaving other sections untouched to act as sources of re-infestation.

It cannot be overstressed that the process of fumigation, particularly with a gas as poisonous as hydrogen cyanide is a job for a specialist. For this reason, a servicing company experienced in this type of work should be approached. An experienced representative of the servicing company first surveys the premises and explains details of sealing and other measures to be taken prior to the day of treatment. It is in the interest of the miller to see that the work is carefully done, because if the building is leaky, due either to structural conditions or to insufficient attention in sealing, the gas is rapidly dissipated

10 An industrial vacuum cleaner in use.

11 Spilt grain and bagged sweepings in a mill basement.

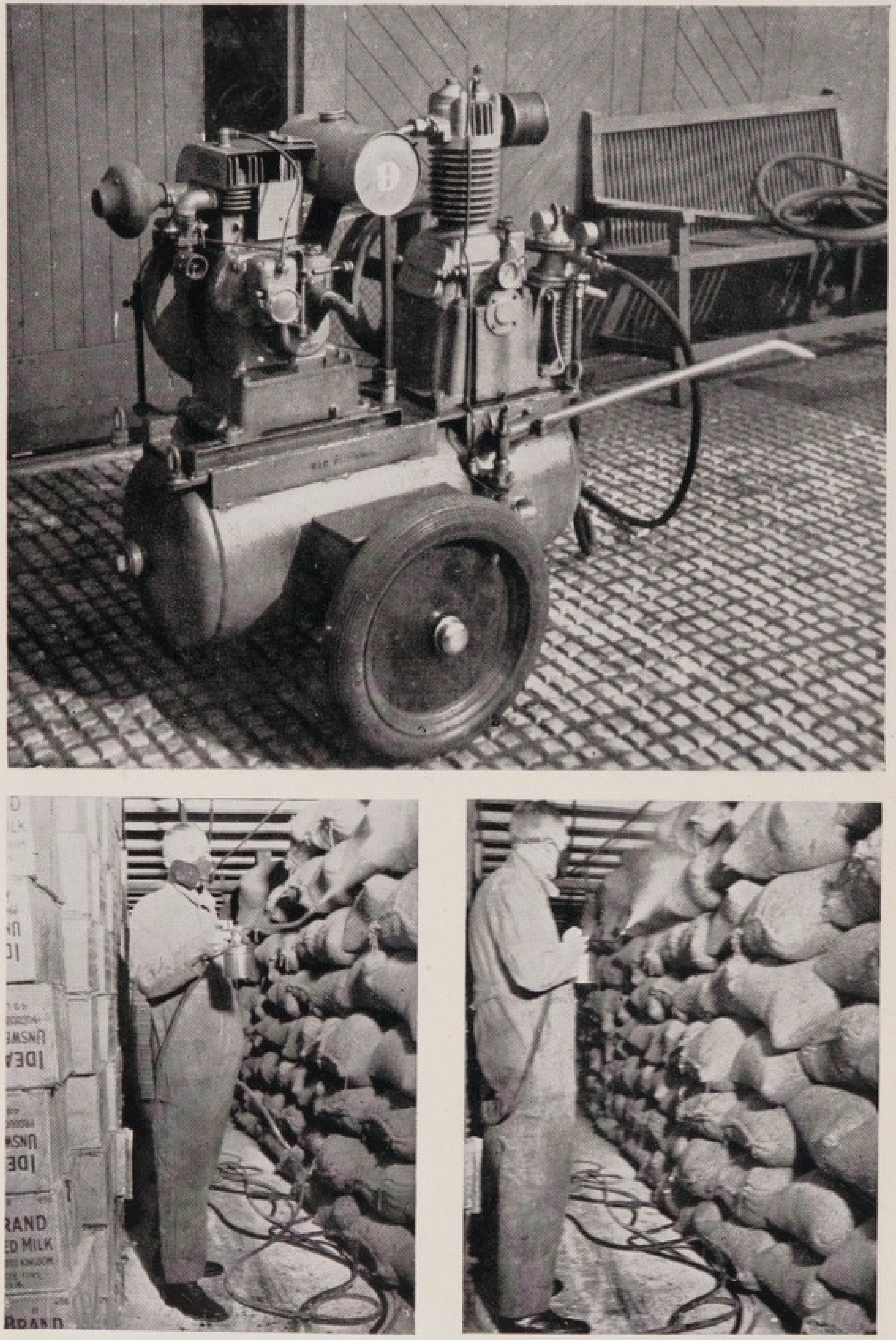
and insects in hidden spots survive. Even when the building is adequately sealed, any insects deeply in stock or below webbing in chutes or machinery, may not be subjected to sufficient gas to kill them. For these reasons, *the sealing and pre-cleaning of the building are of fundamental importance.*

As the work done by the servicing company is normally limited to the actual fumigation, whilst the sealing is the responsibility of the miller, it has been thought expedient to give detailed notes on the technique of sealing. A modern building in good condition is easily sealed, and only doors and ventilators may need attention by sealing round their edges. In old or poorly constructed buildings, a careful survey should be made to discover all gaps, faulty construction, etc., through which gas might escape. This survey often reveals displaced bricks or cement, broken windows or other parts of the fabric in need of attention. All types of ventilators, particularly the roof ventilators to cyclone dust collectors and skylights, belt and pulley holes should be sealed over, and special attention should be paid to the union between the roof and the walls, which is a place where leakage frequently occurs. Loosely fitting windows and doors can sometimes be sealed sufficiently by pasting paper around the edges, but very leaky openings such as belt holes, gangways, elevator shafts, require special attention. If materials are available the gap can be boarded over temporarily, although an efficient alternative is to employ paper impregnated with fibre and tar or bitumen. " Sisalkraft " is the material normally employed and is usually obtainable from builders' merchants (Plates 14 and 15). A light frame may be necessary to fix paper in position. This paper is fairly strong and, distinct from ordinary paper, is the almost impervious to the gases used in fumigation. It should be used in substitution for ordinary paper for any gap greater than about six inches in width. A point to note in carrying out such sealing is that no places known to be infested should be sealed off from the effect of the gas. If this is impossible such parts should be heavily sprayed with a suitable insecticide.

The mill should be run for an hour or two after shutting off the feed, to empty worms, hoppers, etc., which may contain accumulations of stock. After the stoppage the remaining stock and webbing should be removed from the inside of roller mills, purifiers, centrifugals and reels and each machine left fully opened. At the completion of the cleaning operations, all dead spaces should be opened up. The cleanings obtained during this process should be removed prior to the treatment ; in the event of their having to remain in the building, they should be spread evenly and to a depth of not more than three inches over a clear area of floor and removed immediately after the treatment. It is important that such cleanings as are removed should not be brought back into the mill after the mill fumigation, unless they have been treated by heat or fumigation. Where it is not necessary to conserve the cleanings for animal feed it is best that they should be burnt.

If the warehouse is to be included in the treatment, arrangements should be made to ensure that the stock is reduced to an absolute minimum. A treatment of an empty building is far more efficient from an insecticidal viewpoint because flour both absorbs a proportion of the gas and provides protected localities inside or between bags where insects may survive. The removal of stock also obviates queries regarding possible contamination by the fumigant.

FUMIGATION OPERATIONS : HYDROGEN CYANIDE. There are three principal methods of applying hydrogen cyanide. A common procedure is to instal temporary piping terminated by fine nozzles at various positions on the floors to be treated. On completion of the sealing, the hydrogen cyanide is pumped from steel cylinders outside the building, the quantities of fumigant necessary for each section of the building being added separately. The nozzles must have fine



12 Insecticide spraying : petrol driven air compressor ; spraying in progress.

constrictions and the hydrogen cyanide passed through them under pressure to ensure adequate atomization and, therefore, immediate vaporization of the liquid. *Liquid hydrogen cyanide must not be allowed to come into contact with any absorbent material, particularly any foodstuff* and to reduce this risk to a minimum careful attention by the fumigator is necessary in fitting leak proof piping and connections. The chance that such contamination may occur is the chief objection to this method, which, however, possesses the advantage that none of the operating personnel is required to enter the premises during the initial period of high concentration.

An alternative method employs absorbed hydrogen cyanide. Cans containing absorbent material such as discs of wood fibre, or kieselguhr, or gypsum in granules, or cubes, containing known quantities of hydrogen cyanide are hermetically sealed before despatch from the factory. The required number of cans are opened, sealed with rubber caps and placed in position. The contents of the cans are distributed throughout the building by the operator who commences furthest from the point of exit, which is sealed after his withdrawal. No cyanide is present in free liquid form and the possibilities of contamination of commodities or of undue absorbtion by any part of the structure are much lower. Under normal circumstances the absorbent carrier retains only a very slight amount of cyanide, or none at all, and may be safely disposed of without special precautions. The principal drawback to this method is that great care must be exercised by the operators to protect themselves from the hazard necessarily involved by their presence inside the fumigated building during the placing process.

Some millers may have encountered the pot method of liberating hydrogen cyanide. Sodium cyanide is tipped into a strong solution of sulphuric acid distributed in earthenware pots around the premises. The method has almost gone out of use as it possesses considerable disadvantages. It is messy ; droplets of the liquid are liable to be splashed out of the pot : the residue must be carefully disposed of ; the quantity and purity of the gas evolved is very variable ; and a much greater volume of apparatus and materials are necessary to obtain the result secured by the use of the two preceding methods.

A period of airing is necessary after the building has been opened up following a fumigation, before persons can safely enter and work in the premises. It is not possible to define the period necessary with different types of premises owing to dependence upon a number of factors, some of which are unpredictable, *e.g.*, tightness of structure, presence of absorbent materials, weather etc. However, in mills the airing period is rarely greater than twelve and sometimes may be as little as two to three hours.

The conduct of hydrogen cyanide fumigations is regulated by the Hydrogen Cyanide (Fumigation of Buildings) Regulations, S.R. & O. No. 1578 of 1938, which apply to Great Britain. The Regulations bind the servicing operators to take stipulated precautionary measures, when employing the fumigant. They contain safeguards to ensure that only competent operators carry out the work. They also include requirements for evacuating premises within specified distances, the fixing of warning labels, the posting of watchers and a declaration of freedom from gas based on a test at the end of the airing period. Before foodstuffs can be left in a building being fumigated it is also necessary to obtain the sanction of the local Medical Officer of Health. Although these Regulations may, at times, be irksome, it must be remembered that they are for the protection of mill personnel and the general public in addition to the operators themselves.

DOSAGE SPECIFICATIONS: HYDROGEN CYANIDE.

Recent studies have shown that, in practice, a considerable proportion of the re-infestation of flour mills can be attributed to the insects which survive fumigations, this being particularly marked when the mill is of loose construction or contains much old woodwork and resistant species of insects. In this connection, chemical measurements of the gas concentrations present in mills undergoing fumigation have shown that doses often used in practice leave no reserve for penetration of lethal concentrations into cracks, between boards, or into any residues of stock left in machinery or caked on to shutes, even although the apparent results, (as judged by superficial examination, *e.g.* by the numbers of adult moths killed by the treatment) may have been satisfactory. This position justifies the expenditure of very special efforts to ensure that maximum results are obtained at the time of fumigation.

A number of factors, in addition to the above-mentioned degree of preparation, should decide the dosage specifications to be employed. Within the normal limits, insects are more susceptible at higher temperature and, if possible, treatments should therefore be carried out during the warmer months of the year. This should not be considered as absolute however because lower temperatures can be compensated for by using higher doses of gas. Insects also vary considerably from species to species in their resistance to fumigation. For example, the grain weevil *Calandra granaria* is much more resistant to hydrogen cyanide than the mill moth, *Ephestia kühniella*. The variation in the habits of different species can also influence the results obtained by fumigation. For example, meal worms (*Tenebrio molitor*) often survive because they burrow deeply into floor cracks, whereas other species may remain on the surface and be exposed by the prefumigation cleaning.

13 Grain weevils killed by benzene hexachloride ("*Gammexane*") dust.

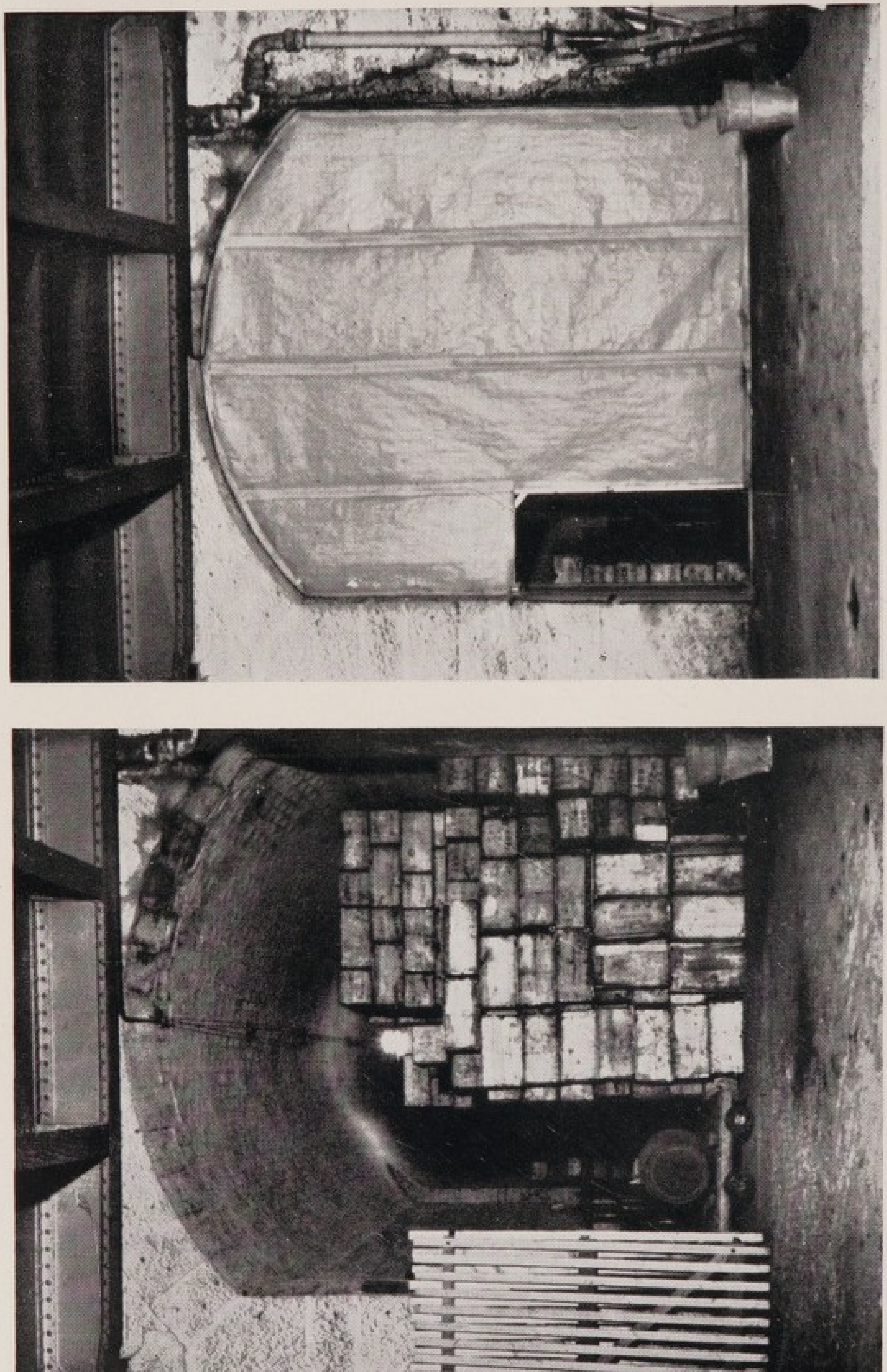
Other, and more obvious factors influencing the amount of gas to be used are the tightness of the building itself, the standard of cleaning which has been achieved and the presence of absorbent material including plant and commodities. In the latter connection, it is worthy of mention that chemical measurement actually performed during practical treatments have on occasion failed to detect the presence even of traces of the fumigating gas in the midst of piles of bags.

In view of the various factors involved, the dosage necessary to achieve satisfactory results must often be left to the servicing company who have a wider experience to guide them than the miller. However, it should be borne in mind that the employment of an higher dosage, in the long run, may more than justify the extra immediate expenditure involved. The range of dosages, given in the following chart, is given as a guide to the miller in dealing with his servicing undertakers. The figures apply to the treatment of empty premises normally prepared : they do not apply to exceptional circumstances, such as when quantities of stocks or of sacks and bags are included. Under average conditions a dosage of 12 oz. per 1,000 cubic feet has been found to give a reasonable standard of control and should not normally be reduced.

Chief deciding factors			Dosage specification
A *Leakage* Structural condition Standard of sealing, etc.	B *Harbourage* Cleanliness Age and Condition of plant	C *Infestation* Intensity Species present	To be controlled by worst of factors A B C.
Tight	New and clean	Light mill moth	8 oz. per 1,000 cu. ft. 16 oz. per 1,000 cu. ft. 24 oz. per 1,000 cu. ft. or more } *or intermediately*
Doubtful for fumigation	Old and dirty	Species various : beetles especially numerous	

The building is usually left sealed for a period of 24 hours. This period is necessary because the kill obtained depends both on the concentration and the time for which the insects are exposed, *i.e.* a higher concentration kills rapidly whilst a low one takes longer. In practice, the concentration present at the end of 24 hours has usually been reduced, by leakage and sorbtion, to such a low figure that little advantage is gained by increasing the exposure period above 24 hours.

RESIDUAL HYDROGEN CYANIDE IN COMMODITIES. Objections have been raised from time to time to the fumigation of flour and similar stocks left in mill premises owing to the possibility of poisonous contamination and damage to baking qualities. Experiments have shown that the exposure of flour to gaseous hydrogen cyanide encountered during the treatment of mills neither leaves harmful residues in the flour, nor materially affects its baking qualities. If chemical analyses are carried out on the flour, the residual hydrogen cyanide is found to decrease rapidly, chiefly by airing off. However, it is possible to detect effects on baking properties by conducting the tests immediately after the com-



14 An archway (*a*) before and (*b*) after sealing for fumigation.

pletion of the fumigation process. In practice, therefore, to cover eventualities, it is advisable to withhold flour from consumption for a week after the date of fumigation.

It must be stressed that these conclusions are based on exposure to *hydrogen cyanide* in gaseous form : in the event of *liquid hydrogen cyanide* being employed for the treatment, *it is vital that no liquid comes into contact with the commodities concerned.* In cases giving any cause for doubt, chemical analyses of the treated commodity should be carried out prior to its release for consumption.

FUMIGATION OPERATIONS: OTHER GASES. The preceding notes have been confined to treatments with *hydrogen cyanide* because this gas is far more commonly employed than any other. Almost the only other material at present used commercially for the fumigation of mills or similar premises in this country is *ethylene oxide.* This gas is normally applied from cylinders through piping and jets, in a manner similar to that employed for *hydrogen cyanide.* The liquid possesses the disadvantage of being highly inflammable and the vapour is explosive over a range of concentrations in air not greatly above those employed in fumigation practice. The gas is used with an excess of *carbon dioxide* the latter being not less than sufficient to displace 10% of the total air present : this diminishes the explosive dangers and, probably also, increases the insecticidal efficacy of the treatment. *Ethylene oxide* possesses the advantages of having a marked odour and of being considerably less toxic to man than *hydrogen cyanide.* There are at present no regulations covering the safety aspects similar to those for *hydrogen cyanide*, although proper care, particularly against fire, but also against leakage into inhabited areas, must be exercised by the servicing company. The large quantities of carbon dioxide required limit the application of the method to premises of from small to moderate size.

The notes already given regarding the sealing and cleaning of premises prior to fumigation apply equally to treatments with *ethylene oxide* as with *hydrogen cyanide*. Treatment with *ethylene oxide* is appreciably more expensive than with *hydrogen cyanide*, although certain circumstances, *e.g.* quantities of foodstuffs present, justify the former treatment.

Methyl bromide has been little used in this country up to the present. The gas is applied from cylinders. Its toxicity to insects is only slightly less than that of *hydrogen cyanide.* The chief advantage lies in its low sorption by most commodities and its high rate of penetration. The latter property, however, appears to demand a very high condition of structure and sealing to maintain sufficiently high concentrations in a building. Unfortunately the gas is highly toxic to man and possesses only a very slight warning odour. It remains to be seen whether the gas will displace any of the fumigants at present employed for the treatment of buildings : its exceptional penetrative powers indicate its main application to be for the treatment of commodities.

The fumes of *burning sulphur* are sometimes used for fumigation purposes. After thorough cleaning and sealing of the building, the sulphur is normally placed in metal containers or direct on to the stone floor in the basement (Plate 16). A source of ready ignition is added to the sulphur (in proprietary sulphur blocks a wick may be fitted and a chlorate, or similar, solid mixture forms the surface layer : with plain sulphur, methylated spirit is sometimes used). The sulphur, applied at a rate of from 4 to 12 lbs. per 1,000 cu. ft., gives off gases which, being warm, rise into the space being treated : as the available oxygen is used up the vigour of the fire decreases, although the sulphur may continue to burn throughout the whole of a

24-hour period of exposure. Under careful supervision the method is capable of giving reasonable control and possesses the advantage of being relatively inexpensive. However, specially thorough cleaning is necessary because the gases do not penetrate well, foodstuffs are susceptible to contamination and bright metalwork must be protected from the corrosive properties of the gases. The latter factors, together with the fire risks, have almost eliminated the method from general use.

MISCELLANEOUS CONTROL MEASURES. Because this pamphlet only describes well tried methods, it should not be inferred that the position regarding methods of control is a static one. As specific examples, the possibilities offered by the newer synthetic and chemically stable insecticides, such as D.D.T. and benzene hexachloride (Gammexane), have still to be fully assessed under practical conditions. This assessment involves both the possibilities of contaminating foodstuffs and the degree of control achieved when the insecticides are employed in various ways, which include their incorporation in paints and washes and the impregnation of equipment. As a note of caution, however, it is extremely unlikely that the use of any of these methods would warrant a relaxation in the general hygiene requirements previously emphasised.

15 How to seal a stairway.

TREATMENT OF INFESTED MILLING PRODUCTS

The ultimate object of all the measures so far described is the production of pest-free products. The degree of tolerance of infestation by the public health authorities varies considerably from country to country, and in the United States of America the mere presence of pieces of dead insects or their droppings is sufficient to cause the condemnation of flour. In this country, although the regulations are less stringent, an undue proportion of complaints and seizures of infested milling products on grounds of infestation would lead to loss of prestige.

Infestation in milling products is likely to build up in the mill in odd stock balances and may be found in goods returned, for various reasons, by bakers and other customers. There is also the question of the condition of flour brought to the mill for the purpose of blending and of mixing in with the normal production. It is very important that all such materials brought to a mill should be carefully examined on arrival and segregated from the normal stock if there are any signs of infestation.

The principal methods which can be applied to the milled products are mechanical measures such as grinding, screening or the use of centrifugal force : the use of heat and cold : and fumigation.

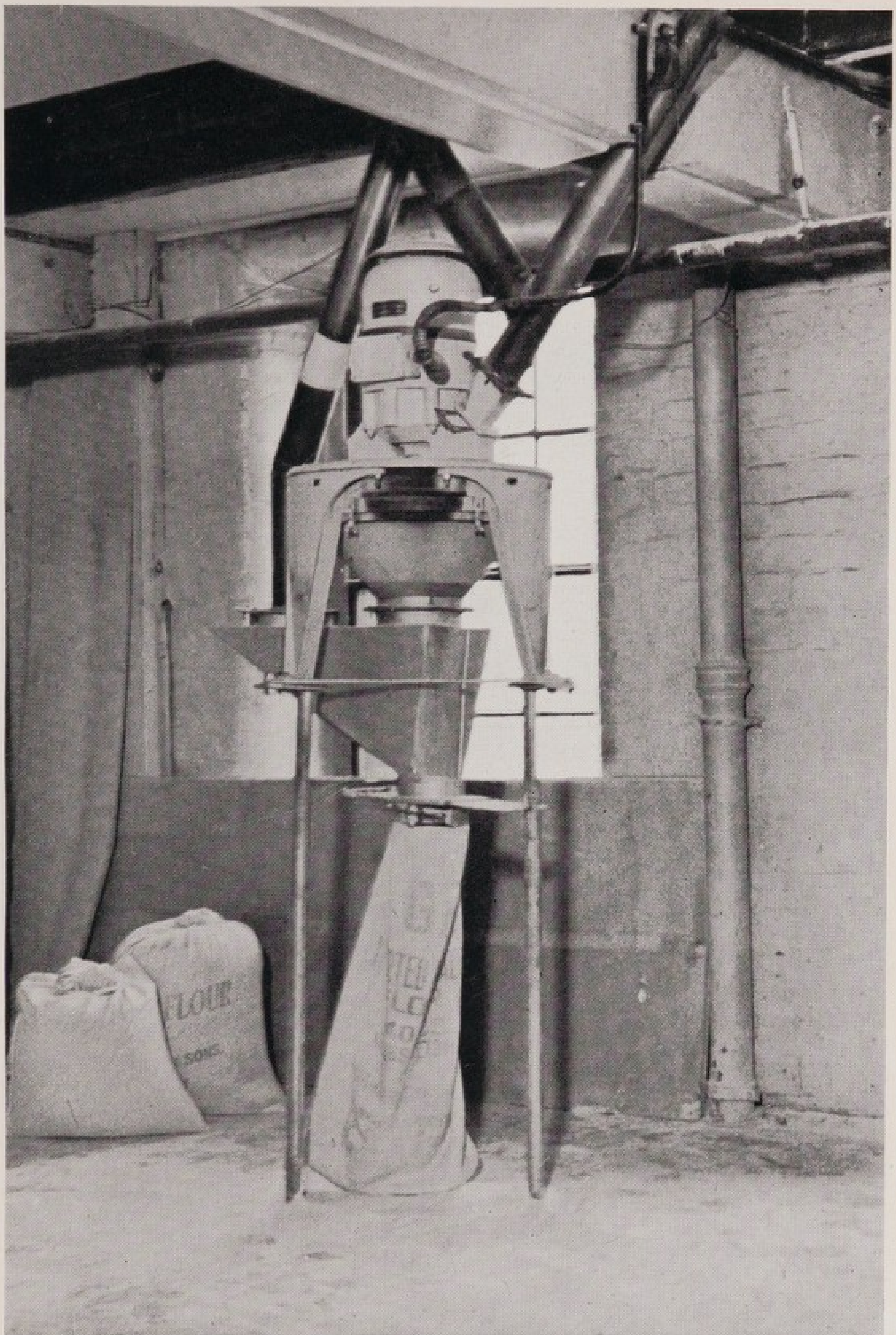
MECHANICAL MEASURES: SCREENING & GRINDING. If the infestation is not unreasonably heavy, screening may be sufficient for normal purposes. Special care must be taken to remove and destroy the screenings as soon as they are obtained. A screen size 38 grit gauze (aperture size 0.5 mm.) will remove all the adults and most of the larvae of the common species of insects, but a silk of the order of 10 XX (aperture 0.13 mm.) is necessary to remove the eggs. The eggs of mites, being of the order of size of flour particles, will pass through the finest silks and therefore screening is of little value for dealing with infestations of mites in flour. Even the finest covers normally fitted in the mill flow will only result in a proportion of the adults of common mites being removed.

If material has been treated only by screening to remove adults or mites, it is necessary to ensure rapid consumption of the stock as otherwise trouble will break out again on continued storage.

M.M.: CENTRIFUGAL FORCE (Plate 17). Reference has already been made, page 8, to the use of the " Entoleter " machine for the treatment of infested whole grain, but the machine is even more successful for the treatment of milled products. The makers recommend its installation at various points in the milling process and claim that this reduces the general level of infestation in the machinery. For the present purpose it is recommended that the machine should be fitted so that flour and offals pass through it immediately before packing. It is of further advantage to have a separate machine suitably placed for the treatment of returned infested flour and flour for mixing in, before such flour reaches any part of the normal mill flow and becomes blended with normal production. Small scale experiments, which have been carried out with the machine in this country, have shown that it is effective in killing a high proportion of all stages of the mill moth, *Ephestia kühniella* ; the flour beetle, *Tribolium confusum* ; the brown spider beetle, *Ptinus tectus*, and the flour mite, *Tyroglyphus farinae*, in infested flour and flour mixtures. For example, the mite infestation of flour was reduced, by passage through the machine, from about 60,000 mites per 200 c.c. of flour to only one mite per 200 c.c. The method of operation of the machine is as follows :—flour spouted to the machine is thrown by centrifugal force between two flat steel discs or plates that revolve on a central shaft at 2,900 r.p.m. (For whole wheat the speed should be 1,450 r.p.m.). Small round hardened steel posts are closely spaced in two concentric rings between the two discs. The impact of the flour against the revolving discs and posts and against the housing of the machine is so great that all stages of insects and mites, including the egg, that may be in the flour, are killed. The treated flour passes out through a spout at the base of the machine.

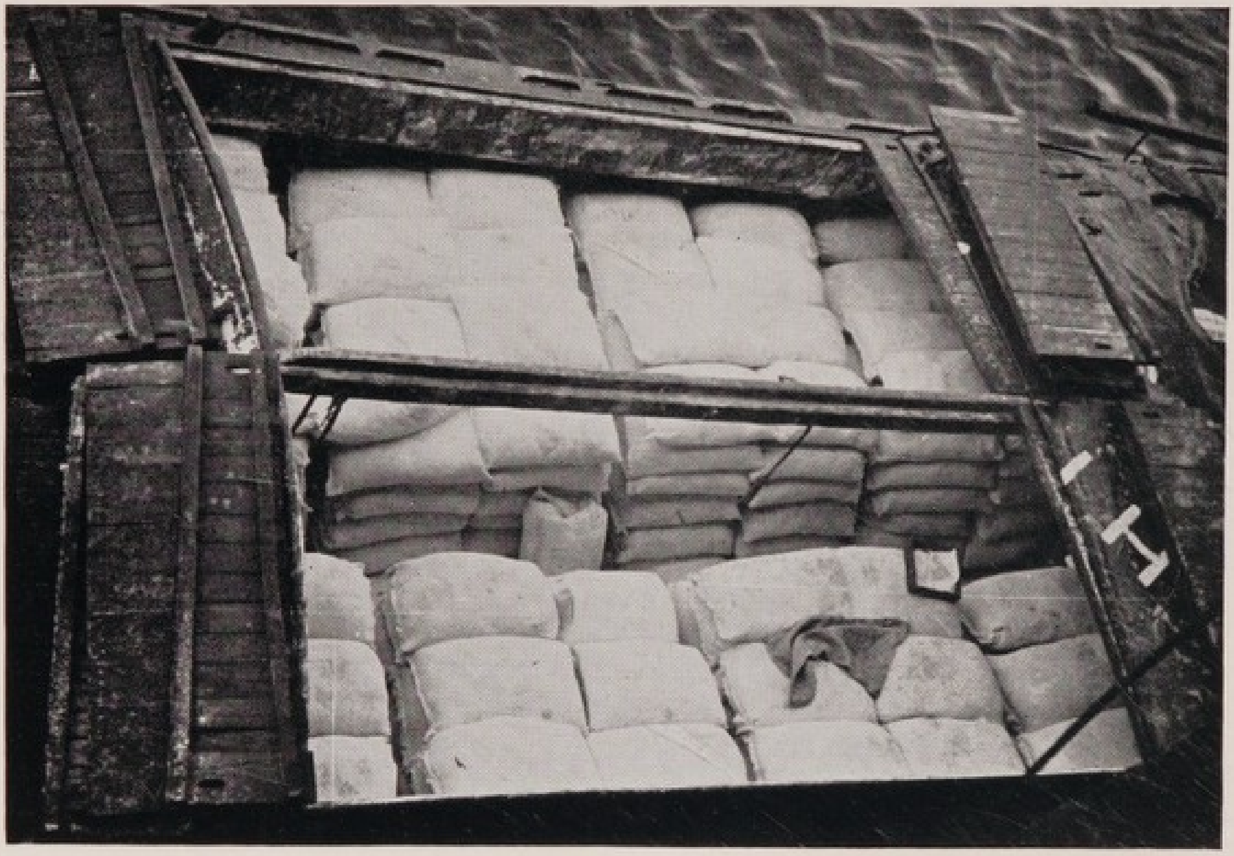
HEAT TREATMENT. The use of heat for the treatment of bags was discussed on page 10 and the same principles apply to the treatment of commodities. It has the advantage that all stages of insects and mites can be destroyed. It may be used with products such as spaghetti and semolina, which cannot be disinfested by screening. It should be reiterated that the lethal temperatures noted on page 8 must be reached everywhere in the material, otherwise some insects will survive.

16 Fumigation by burning sulphur.



17 A centrifugal force infestation destroyer (The Entoleter).

FUMIGATION (Plate 18). Fumigation is an equally effective method of ensuring that all stages of the insects are destroyed. Whatever gas is employed the method must be carried out under careful supervision to ensure that adequate penetration of gas is obtained without leaving toxic residues or otherwise damaging the commodity. For this reason the miller should obtain expert advice regarding suitable fumigants and their dosages for different circumstances before treatment is undertaken. This is particularly desirable if frequent small lots are involved. A small chamber for fumigation is necessary and should be situated apart from the main premises; such a chamber could also be suitable for the treatment of bags.



18 Flour stowed in a barge for fumigation.

Section 3

LIFE HISTORIES AND HABITS OF INSECTS AND MITES

INTRODUCTION

There is a lingering fallacy, much less widespread than formerly, that the presence of insects and mites in food is inevitable, due to the belief that they are an inherent part of the food or are "germinated" in it. If this were so we should be fighting a battle which had been already lost and no amount of application of control measures would be of any use. Fortunately insects and mites breed like other animals and the entomologist has yet to find an insect or mite which has been specially created and has not developed from eggs laid by the mother.

There are more kinds of insects in the world than of all other kinds of animals, but fortunately only a few of them are pests of stored products. Insects and mites have certain features in common since both belong to the big group called ARTHROPODA, or jointed limbed animals, to which belong also spiders, crabs, lobsters, shrimps, woodlice and barnacles.

INSECTS. All adult insects have certain features in common, which enable them to be recognised easily. These features are :—

(1) The body consists of three regions called the "head," "thorax" and "abdomen" respectively.

(2) The head bears a pair of "antennæ" or feelers, a pair of large compound eyes and the mouthparts.

(3) The thorax bears three pairs of jointed legs. It usually also carries two pairs of wings but these may be reduced to a single pair or sometimes be absent altogether.

(4) The abdomen consists of a number of segments or joints and in the adult insect carries no legs.

The insect cuticle or skin is hard and horny, and has much the same function as the internal skeleton of the vertebrate, the muscles being connected to the infoldings of the cuticle. Insects breathe air, but this is conducted directly to the tissues by a series of branching tubes, known as "tracheæ" which lead in from breathing holes, or "spiracles," on the sides of the body. Insects have very little control over their temperature, such as have warm blooded animals. They are thus directly affected by changes in the temperature of the air surrounding them and, in common with other living things of similar organisation, live more quickly the higher the temperature. There are, however, limits to this phenomenon, and above about 90 deg. F. they die after a longer or shorter period, so that at 140 deg. F. they are dead in a few minutes. At the lower end of the scale, most insects are immobilised at temperatures at or below 40 deg. F. Many of them, however, are capable of withstanding great cold for long periods.

All insects lay eggs, which, particularly in the higher groups of insects, do not hatch into individuals like their parents, but into small worm-like beings, known as "larvæ," "grubs" or "caterpillars." The eggs from which these hatch are usually very small, being seldom more than 0.5 millimetres in length. The "larvæ" have no wings and the abdomen is usually proportionately much longer than in the adult. Usually the thorax can only be distinguished from the abdomen by the fact that it carries the jointed legs. Many larvæ of stored products insects are, however, so adapted to a life spent surrounded by a mass of foodstuff that they have lost all their legs and have only retained the mouthparts with which they masticate their food. It is the "larvæ" which consume most of the food and do the greatest damage, and as they eat they grow larger. Since the skin or cuticle is hard they cannot increase their size steadily but do this in a series of stages. At the end of a stage they shed the cuticle and expand in size during the short time which it takes the new cuticle to harden. Eventually after moulting a number of times, the larva becomes fully grown and, after feeding for a short time longer it finally sheds its skin, but the resulting stage is unlike the larva, yet not like the adult. It is known as the pupa, which generally does not move or has only very limited powers of movement. During this stage the larva is transformed into the adult insect. During the latter part of the stage the adult organs can be seen through the pupal skin, which will be cast when the adult emerges. The pupa may lie free in the foodstuff but much more frequently the larva forms a cocoon in which the pupal stage is spent. Eventually the adults emerge and mate, and the life cycle starts again with the laying of eggs by the females. The adult insects do not moult and remain the same size throughout their lives.

The life cycle of an insect thus consists of four parts : egg, larva, pupa, adult. Insects develop from eggs laid by the females and are not spontaneously generated in grain or in flour, however much the apparent evidence may sometimes suggest that this is the case.

The period taken by the life cycle varies considerably from kind to kind, being as short as three weeks or as long as four years. Some have a habit of not completing their life cycle at one operation but the fully grown caterpillars go into a resting stage, or "diapause," instead of moulting and forming a pupa. As this stage often takes place when the caterpillar has gone deep into the fabric of a building, this habit represents a severe and difficult problem when the question of control arises. This is the stage in which most of the moth caterpillars spend the winter in this country in unheated premises, whereas most beetles overwinter as dormant adults. If the building be heated so that the minimum temperature is about 50 deg. F. the insects will breed continuously.

There are three principal kinds of insects which the miller is likely to meet. These are :—

Beetles (or *Coleoptera*). The front pair of wings is hardened to form a protection for the membraneous hind wings. These fore wings which are known as "elytra" meet in a straight line down the back. The larvæ vary in type from active mealworms to sluggish fleshy grubs. Larvæ and adults have mouthparts for biting, and both thus feed on and damage foodstuffs.

Moths (or *Lepidoptera*). The body of the moth is clothed with scales and the mouthparts are adapted for sucking up juices. The larvæ are typical "caterpillars," with fleshy "prolegs" on the abdomen. The mouthparts of the larvæ are adapted for biting. Only the larvæ damage foodstuffs.

Wasps (or *Hymenoptera*). These have membraneous wings, of which the hind pair are smaller and hooked to the front wings. The first segment of the abdomen is fused with the thorax. The mouthparts of the adults are adapted for licking and biting. The larvæ, especially of those likely to be met with in the mill, are highly modified for a parasitic life inside the moth caterpillars.

MITES. All mites may be distinguished from insects by the fact that they are generally much smaller, being about the size of a pin head, and the body is distinctly separated into two parts, the head plus thorax, or "cephalothorax" and the abdomen.

The body is generally somewhat compressed from above. There are no antennæ but the mouth parts are generally similar to those of insects. There are four pairs of legs but no wings. The body is covered with a number of hairs or " setæ," which vary considerably in number and length from species to species. Some mites breathe in a similar way to insects, but others breathe directly through the skin. They are affected by temperature in much the same way. On the other hand, mites, being very much thinner skinned than insects, are much more affected by changes in the relative humidity of the air, generally preferring damp conditions.

NOMENCLATURE. There are a number of reasons why it is necessary to identify the insects present before measures are taken to control them.

(1) Insects vary considerably in their habits and in their resistance to control methods, which must be varied according to the particular species to be controlled. Thus spraying may be used against beetles which may be running about on the surface of the walls of a building, but be quite ineffective against moth caterpillars hidden deep in the cracks. Or a miller may have his mill fumigated by a much higher concentration of fumigant or for a much longer time than is necessary to kill the particular insects present, thus increasing the cost.

(2) Closely related insects may have differences in their life histories which make it necessary to take active and energetic measures against the one, but not against the other. The cacao moth and the fig moth are almost indistinguishable except to the expert, but the former can live through our winter and is a serious pest whereas the latter normally dies out. The bean weevil, which is very similar to the pea weevil, can go on breeding in the dried beans, but the latter can only infest beans in the field and once the adult beetles have all emerged from the harvested beans no further damage ensues.

(3) Correct identification is important where there is the necessity of tracking back the origin of the infestation and finding out whether the insects got on to, say, the flour at the mill or at some subsequent stage. Such identification may often be a deciding factor in commercial practice.

(4) The name of the insect or mite acts as an index to all the information which is available regarding biology and control.

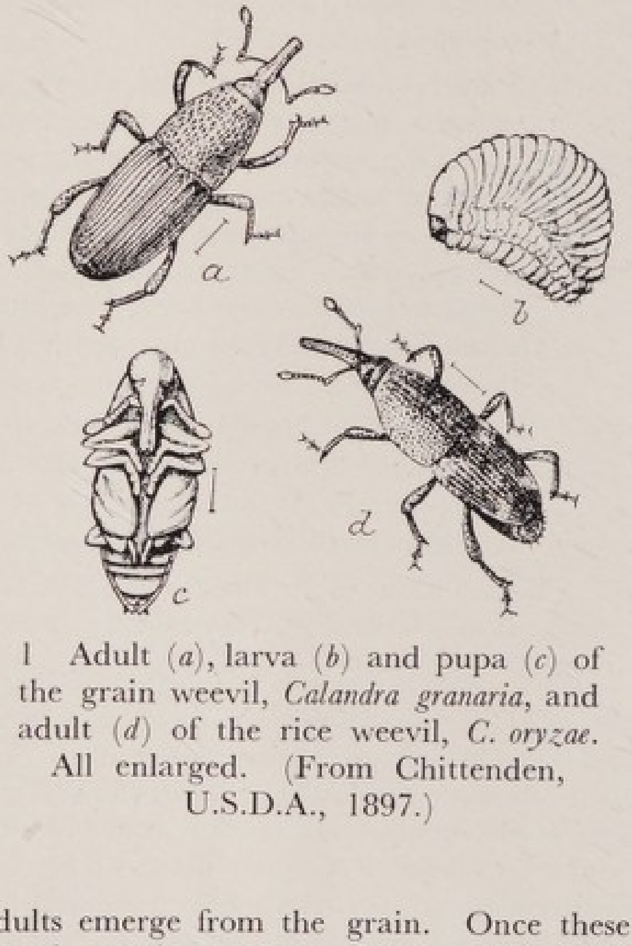
Insects and mites have common names and scientific names. Only a few of the large number of species found in grain and its products have common names, and these vary from country to country. They are often misleading. For example, the moth *Ephestia elutella*, is known in the tobacco trade as the stored tobacco moth, and in the cocoa trade as the cacao moth. Another source of confusion may be where two insects of quite different appearance and habits have closely related common names, *e.g.* the rust-red flour beetle, *Tribolium castaneum* and the rust-red grain beetle, *Laemophloeus ferrugineus*. As the common name very often refers the insect to a particular commodity this may lead to unjustified assumptions on the origin of a pest. Thus the red rust flour beetle is relatively uncommon on flour but is very common on oilseeds. It is best where possible to use the scientific name since this clearly identifies the insect to everyone concerned. This name consists of two Latin words. The first describes the genus or closely allied group of similar insects (*e.g. Calandra*). The second is applied to individuals which cannot be distinguished from one another by obvious characteristics and which breed together (*e.g. granaria*). A list is given on page 63 of all the insects and mites referred to in this pamphlet with their scientific and common names.

LIFE HISTORIES OF COMMON PESTS. Only the most common and important species are dealt with in detail, although many others occur and may be mentioned in other sections of this pamphlet. Any insect or mite found in the mill which cannot be identified from these descriptions is unlikely to be of importance. Reference is made in Section 5 to various useful books in which descriptions of these insects may be found.

COLEOPTERA (BEETLES)

CURCULIONIDAE (TRUE WEEVILS)

CALANDRA GRANARIA (the grain weevil) (Fig. 1 and Plate 19). The grain weevil, *Calandra granaria L.*, is a polished dark brown or black insect, about 2.5 to 4.7 mm. long. The hind wings are not developed and therefore this insect cannot fly. The adult female bores a small hole in the grain with her mandibles and then turns about and lays an egg in the hole which is then sealed with a gelatinous fluid. The adult beetles live 7–8 months, and during this period the female lays some 100 eggs. The larva, which is a small white legless grub, hatches from the egg and tunnels in the endosperm of the grain. After moulting several times it finally turns into a pupa within the grain. The adult eats its way out and the life cycle is complete. The whole life cycle lasts from 28 to 40 days depending on the temperature, but since a heavy infestation of grain weevils frequently causes heating of the grain an accelerating effect is found whereby the insects themselves produce favourable conditions. (The heating of grain is discussed in greater detail on page 71.) The damage to the grain, whilst mainly due to the feeding of grubs is also done by adults. The typical signs of weevil damage, the holes in the grain, are a sign that at least one generation has bred in the wheat, since the holes are made when the adults emerge from the grain. Once these holes have been made adults will enter the grains and continue the damage, but they do not normally attack sound grains in this way. In temperate countries and in the absence of heating in the grain itself, the adults over-winter often massing together in cracks and crevices in buildings, particularly in damp places. In the spring the over-wintered females become active and lay eggs in grain whose temperature exceeds 55 deg. F. The grain weevil not only attacks wheat, oats, barley, maize, rye, rice and other seeds but can also breed in flour.



1 Adult (*a*), larva (*b*) and pupa (*c*) of the grain weevil, *Calandra granaria*, and adult (*d*) of the rice weevil, *C. oryzae*. All enlarged. (From Chittenden, U.S.D.A., 1897.)

CALANDRA ORYZAE (the rice weevil) (Fig. 1). *Calandra oryzae* (the rice weevil) occurs commonly in wheat, and has a similar life history to the grain weevil. In appearance it is similar but it may be distinguished by the four red or yellow spots on the wing covers and by the presence of hind wings, under the elytra. In warm conditions, either warm sunny weather out of doors or in warehouse rooms where a pile of heating grain has raised the air temperature to about 70 deg. or more, *Calandra oryzae* will fly readily and it has been observed in London to have flown some 500 yards across a dock and on to the roof of a grain warehouse from a ship discharging maize. Spread by flight is, however,

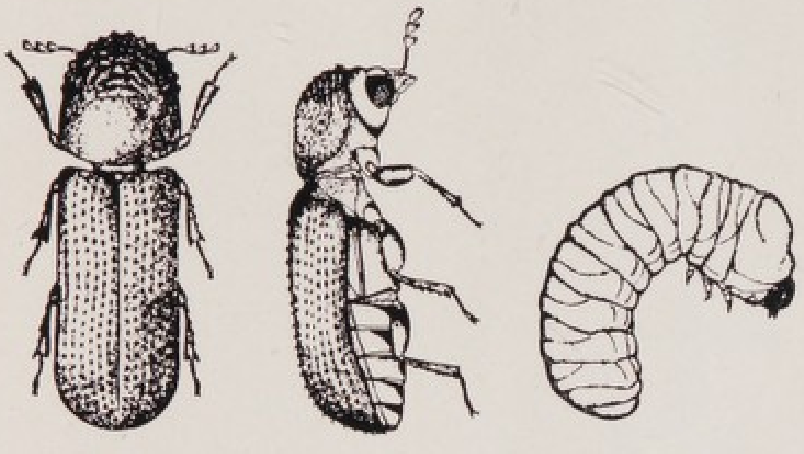
19 Grain weevils, *Calandra granaria*, and damaged wheat.
(From D.S.I.R. & Dr. Lubatti, "Pests of Grain," 1939.)

not of any great importance in this country. It is better adapted to tropical conditions than the grain weevil. The rice weevil has been observed abroad to fly out from stores to fields of ripening grain and infest it shortly before harvest. The adults live about five months and are unable to over-winter in this country except in mild winters, and then usually only in the southern part of the country. Under optimum conditions, about 80 deg. F., the life cycle is passed in about 26 days. It has been estimated that some 10% of the maize crop is annually destroyed in the U.S.A. by the depredations of this species.

The rice weevil attacks a similar range of grains to the grain weevil.

BOSTRYCHIDAE

RHIZOPERTHA DOMINICA (the lesser grain borer : the hooded grain borer) (Fig. 2). *Rhizopertha dominica* belongs to a family of beetles most of whose members are wood borers ; a few species however breed in grain and flour.



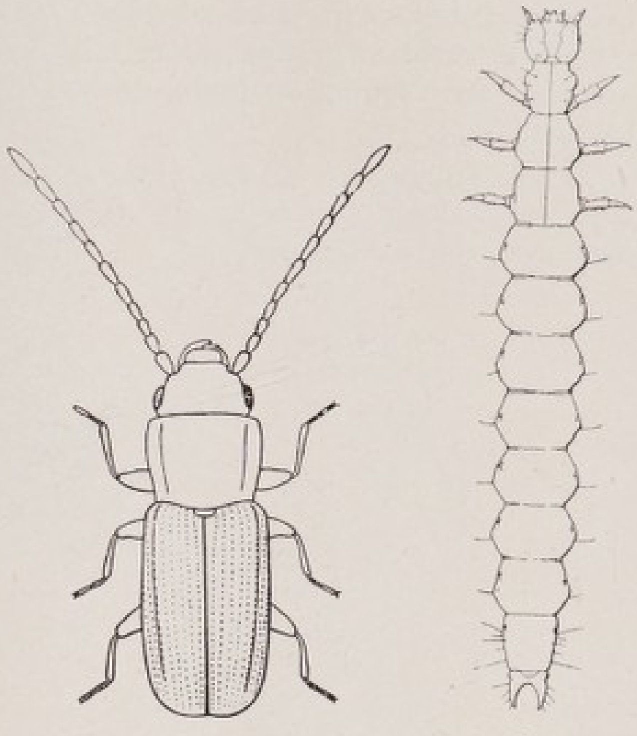
a b c

2 Adult and immature stages of the lesser grain borer, *Rhizopertha dominica* ; *a*, adult, dorsal view ; *b*, adult, side view ; *c*, mature larva (all enlarged 12 times). (From Vayssiere & Lepesme.)

The adults of the lesser grain borer are about 2.5 to 3 mm. long and of slender cylindrical form. The head is turned down under the thorax and is armed with stout jaws capable of cutting directly into wood. The surface of the body, particularly at the front end of the thorax, is roughened. The adults lay eggs singly or in clusters in the grain, either loose or attached to grains. The number of eggs varies from 300 to 400 and as many as 600 eggs have been recorded from a single female. The eggs hatch in about 5–26 days and the young larva, which is white, hairy and has three pairs of legs, chews its way into a grain which it hollows out, moulting a number of times in the process. Eventually it turns into a white pupa, changes into the adult beetle, and then bores its way out of the grain. The whole life cycle varies from 24 to 133 days, depending on the temperature and moisture content of the grain, but this species is seldom very destructive at temperatures below 70 deg. F. It can, however, attack grain which is much drier than that in which the *Calandra* species thrive. All stages are normally killed in the course of an English winter, unless the grain is heating or is stored under such conditions that its temperature remains high. The damage done by *Rhizopertha* is much greater than that of the true weevils as the adult beetles destroy all the endosperm leaving only the husk. It attacks all kinds of seeds, including wheat, maize, barley and rice.

CUCUJIDAE

LAEMOPHLOEUS SPP. (flat grain beetles) (Fig. 3). These beetles are found not only attacking sound wheat but also in the milling machinery and in grain products. The two species which occur most commonly are the flat grain beetle *Laemophloeus minutus* and the rust red grain beetle, *Laemophloeus ferrugineus*. The former ranges in length from 1.3 to 1.5 mm., and the latter from 1.5 to 2 mm. The beetles are thus very small, and they are much flattened. In colour they range from light to dark red and have relatively long antennæ. They have a typical walk, turning the head and thorax from side to side as they progress. The adult females lay small white eggs loosely in the foodstuff and the young larva crawls about actively. This larva, which is yellowish white in colour with two black spines at the hind end of the abdomen, finds a minute hole in the seed coat covering the germ and bores inside. The mature larvæ form small gelatinous cocoons in which they pupate. The larvæ may remain within the germ or may move actively in the spaces between the grains. Under the most favourable conditions the length of the life cycle is about 35 days, but it may extend to 75 days.



a *b*

3 *Laemophlœus minutus*, the flat grain beetle. *a*, Adult, enlarged 20 times (from Patton) ; *b*, larva, enlarged 30 times (from Hinton).

Since *Laemophloeus* can cause heating in grain, favourable conditions are assured if a sufficient number of individuals are present. Once heating begins it proceeds rapidly and may reach a temperature of 120 deg. F.

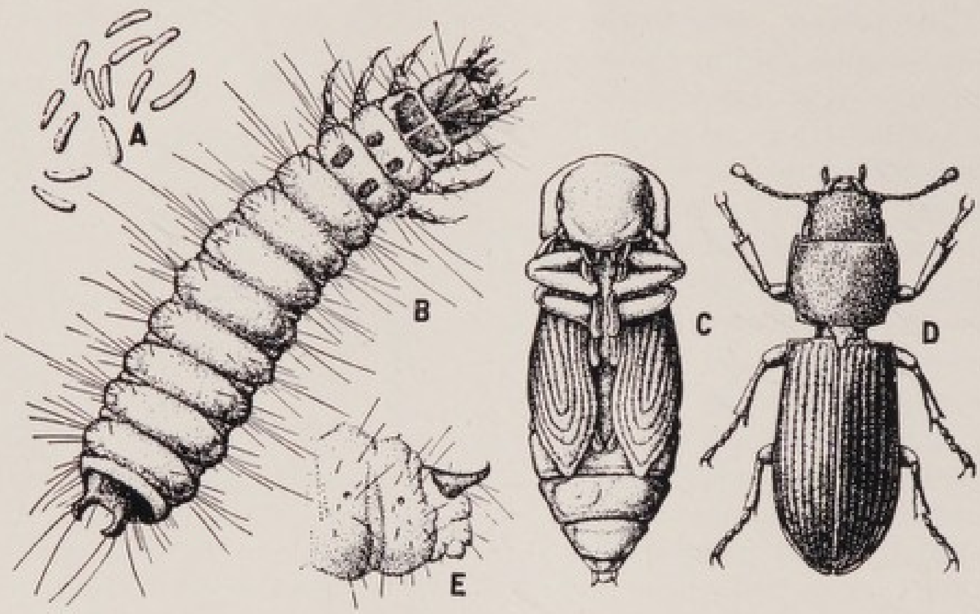
The adult beetles can survive the normal winter, and outbreaks in wheat appear to start at points where there is slight excess moisture, such as from a hole in the roof or a crack in the floor. Damage to wheat is normally confined to the destruction of germ, but the excessive heating caused by this species often leads to secondary attack by moulds and wheat may cake and be rendered very musty. In the mill *Lcemophloeus minutus* is found most frequently where there is caked and mouldy stock adhering to spouts, especially at points of high temperature. *Laemophloeus* has been found breeding not only in grain and grain products but in a wide range of foodstuffs including oilseeds.

OSTOMIDAE

TENEBROIDES MAURITANICUS (the cadelle) (Fig. 4). The cadelle is one of the larger beetles found in the mill. The adult is a black, elongated, oblong, flattened beetle about 10 mm. long. The adult female lays about 1,200 eggs in clumps of 10 to 40 in the foodstuff or in crevices in the buildings. At a temperature of 70 deg. F. the eggs hatch in 10 days, and the larval life may last from 39 to 1,250 days depending not so much on the temperature as on the nature of the food. The larvæ are white, with black head and prothorax, and have two black horns at the hind end of the abdomen. When fully developed they are 19 mm. long. At this stage the larvae tend to leave the food and bore into woodwork where they pupate. As the holes by which they enter the woodwork are very small, it is possible to overlook large numbers of hibernating larvae or pupae when examining empty wheat or flour bins or cleaning down machinery. All stages can survive the winter in unheated warehouses.

The principal importance of this pest to the miller arises from its habits of biting holes in the silk covers of machines thus reducing their efficiency. The habit, already referred to, of the mature larvae boring into wood makes them difficult to eradicate by cleaning methods and also allows other insects to hide away in these tunnels.

Tenebroides not only attacks grain and grain products and a wide range of other commodities but also feeds on other insects, but on balance its destructiveness outweighs this advantage.



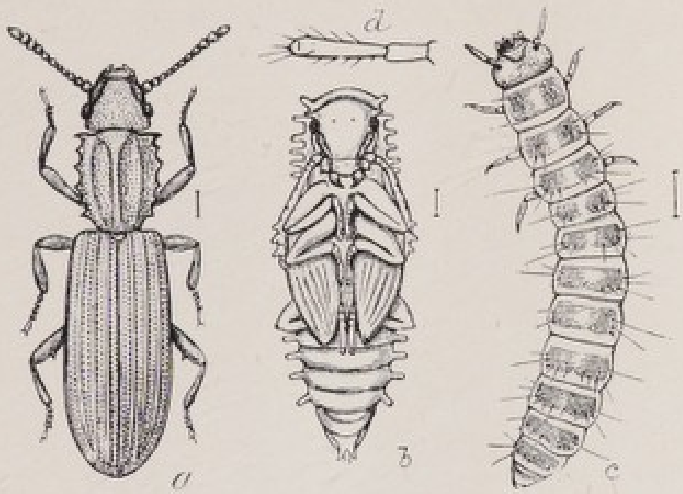
4 The cadelle, *Tenebroides mauritanicus*, about four times natural size : *a*, eggs ; *b*, mature larva, dorsal view ; *c*, pupa, ventral view ; *d*, adult ; *e*, last three abdominal segments of larva in side view. (Metcalf and Flint, 1939.)

SILVANIDAE

ORYZAEPHILUS SURINAMENSIS (the saw-toothed grain beetle) (Fig. 5 and Plate 20). The saw-toothed grain beetle is usually found in the mill in association with other insects in the machinery. It is a small brown beetle about 2.5 to 3.5 mm. long. The body is flattened and the species derives its name from the series of teeth along the sides of the thorax. It is very active.

The adult females, which may live as long as three years, although the average duration is 6–10 months, commence to lay eggs 5–7 days after emergence from the pupa and continue to lay singly or in batches over a period of 2–5 months. The total number of eggs laid may be nearly 300. These eggs hatch in 3–17 days and the larva, which is whitish in colour, has a dark head and bands on the abdomen The larval stage lasts from 2–7 weeks and the pupal stage about 10 days. The length of the life cycle varies according to temperature from 22 to 315 days. Adults can over-winter successfully in unheated warehouses.

20 Saw toothed grain beetles, *Oryzaephilus surinamensis*, and wheat. (From D.S.I.R. & Dr. Lubatti : Pests of Grain, 1939.)



5 Adult and immature stages of the saw toothed grain beetle, *Oryzaephilus surinamensis* : *a*, beetle ; *b*, pupa ; *c*, larva—all enlarged ; *d*, antenna of larva, more enlarged. (From Chittenden, U.S.D.A., 1902.)

This beetle has been the subject of nutritional studies, and it has been found that carbohydrates are essential and that its Vitamin B requirements are very low. It will develop successfully on foodstuffs whose moisture content is as high as 20%.

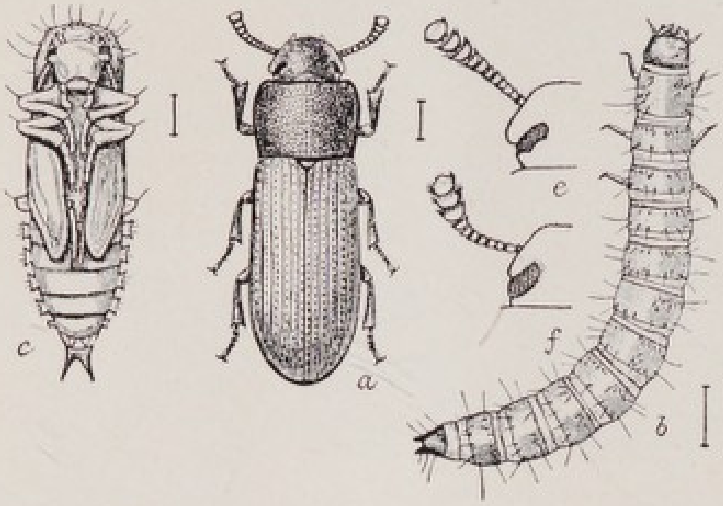
It is seldom that this beetle represents a problem in the milling section, although it may be troublesome in the wheat silos and in finished products. It cannot attack sound grain, but is frequently found associated with weevils and lesser grain borers gaining access to the grains through their exit holes. It is, however, known to be able to breed in oats which have not been attacked by other insects. Its principal importance, however, is as a pest of finished products, and as the adults are very active a neglected focus of infestation may rapidly lead to the distribution of beetles all over a store in a very short time. It has been recorded breeding in a wide range of foodstuffs.

The observations on the nutritional requirements of *Oryzaephilus surinamensis*, *Tribolium confusum*, *Dermestes lardarius*, *Ptinus tectus*, *Ephestia elutella* and *Ephestia kühniella* are based on the work of Fraenkel G. and Blewett M. "The utilisation of metabolic water in insects": Bulletin of Entomological Research, Vol. 35, Part 2, July, 1944 ; and "The natural foods and the food requirements of several species of stored products insects": Transactions of the Royal Entomological Society of London, Vol. 93, Part 2, December, 1943.

TENEBRIONIDAE

A large number of the beetles attacking stored products belong to this family but only four of the most important are described here.

TRIBOLIUM SPP. (flour beetles) (Fig. 6 and Plate 21). These beetles are seldom found attacking sound wheat, although they can do so under experimental conditions. They are usually found in wheat in association with primary borers ; they are also found in the milling machinery and in all kinds of grain products. There are two common species, the rust red flour beetle (*Tribolium castaneum*) and the confused flour beetle (*Tribolium confusum*), the latter being the most common in the milling machinery, although both are equally common in wheat. Both species have been found breeding in a large number of different kind of foodstuffs.



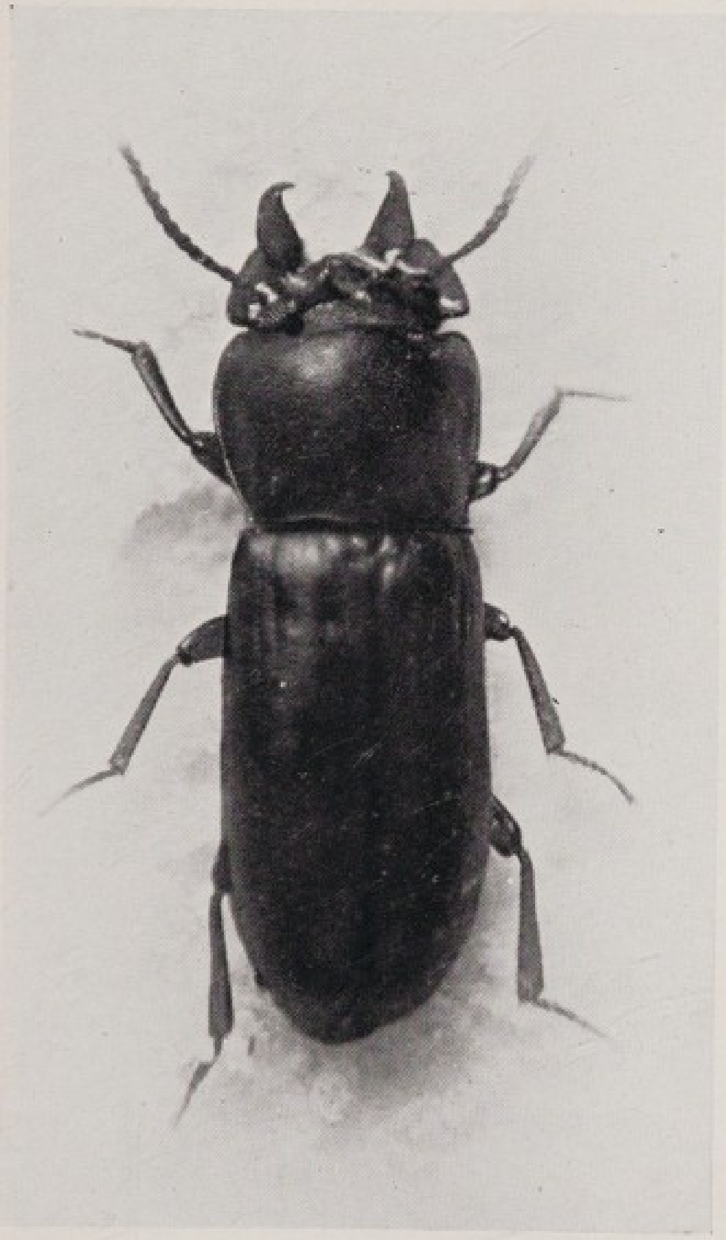
6 Adult and immature stages of the confused flour beetle, *Tribolium confusum* ; *a*, beetle ; *b*, larva ; *c*, pupa ; all enlarged : *e*, head of beetle, showing antenna ; *f*, same of *T. castaneum* ; all greatly enlarged. (From Chittenden, U.S.D.A., 1897.)

21 Adults and larvae of the confused flour beetle, *Tribolium confusum*. (From D.S.I.R. and Dr. Lubatti : Pests of Grain, 1939.)

The confused flour beetle ranges from 3.5 to 4.2 mm. long. Adult females live for about 12 months and lay from one to two eggs every day to a total of about 500. The eggs are sticky and adhere to the meal or flour in which they are laid. The larvae hatch in about seven days and are yellow in colour. They crawl actively through the food and are fully grown in 22 days at 80 deg. F. when they pupate. The pupae lie loose in the foodstuff. They change, during the ten days in this stage, from white, through yellow to dark brown. The adult immediately after emergence from the pupa is a light brown colour, but this rapidly deepens to the typical dark reddish brown. In a normal warm mill there may be five generations a year, but in unheated premises in this country both *Tribolium confusum* and *Tribolium castaneum* appear to be unable to survive the winter. The confused flour beetle does not lay eggs at a temperature of less than 60 deg. F., and all stages die after exposure to a temperature of 45 deg. F. for 25 days. *Tribolium castaneum* is less resistant to cold than *Tribolium confusum*.

It has been shown by experiment that the rate of growth of *Tribolium confusum* is best on 100% extraction flour and least on highly refined patents. In spite of the fact that it is such an important pest on cereals it can grow well on a diet which contains no carbohydrates although the life cycle then takes a much longer time. The main limiting factor is its need for vitamins of the B group, and this explains why it not does breed readily on short patent flours. When in whole grain *Tribolium* tends to attack the germ, the very young larvae finding their way into the embryo through minute holes in the bran.

Flour which is infested by *Tribolium sp.* acquires a sour pungent smell from the secretions of the beetles. It has also been found that heavily infested flour does not produce a dough which rises as readily as that from sound flour. As the dead beetles are bright red in colour they contrast well with the colour of bread and are readily spotted by the consumer.



22 Adult male broad horned flour beetle, *Gnathocerus cornutus*. (Enlarged 20 times.)

23 (*a*) Adults and larvae of the meal worm, *Tenebrio molitor*, amongst oats.

23 (*b*) Adult and immature stages of the meal worm, *Tenebrio molitor*, *a*, larva ; *b*, pupa ; *c*, adult (twice natural size). U.S.D.A.

In the mill *Tribolium*, when present, is generally distributed in the milling machinery, particularly in masses of mill moth webbing and in crevices and cracks in the woodwork.

GNATHOCERUS CORNUTUS (the broad horned flour beetle) (Plate 22). The broad horned flour beetle is very similar in size and habits to *Tribolium*, and is found in the mill in similar situations. The adult male beetles can be distinguished from *Tribolium* by the pair of large horns on the jaws ; both males and females are slightly larger, more stoutly built, and are more shiny than *Tribolium*. This insect is very similar in life history to *Tribolium*, and like it is unable to over-winter in unheated stores, its lower limit of temperature being about 50 deg. F.

Gnathocerus is found in association with other beetles in infested wheat and breeds readily in the milling machinery. In common with *Tribolium* it has been found boring into flooring of mills and framework of machinery. *Gnathocerus* is seldom found infesting commodities other than cereals.

TENEBRIO MOLITOR (hardback beetle : "clock" : mealworms) (Plates 23 (*a*) and 23 (*b*)). Mealworms and hardback beetles (*Tenebrio molitor*) are not usually found in the milling machinery except in parts where there are liable to be accumulations of stock left undisturbed for long periods, such as in the boots of elevators or disused spouts. The adult beetles are dark brown or black about 13–17 mm. long, and are thus the largest beetles which occur in the mill. The female lays about 160 eggs in numbers varying from 1–16 at a time. From the eggs emerge the small yellow larvae or mealworms, which feed not only on cereal products but also act as scavengers, attacking dead insects and other animals. They prefer dark damp places and may be trapped in large numbers under damp sacks on the floor. The length of the larval life depends on the temperature and the nature of the food but usually is about twelve months. The fully grown larvae, 28 mm. long by 4 mm. broad, pupate either loose in the food or, more commonly, in the folds at the top of a sack, or under a sack, and after about 14 days the adult emerges. Adults live for about 3 months.

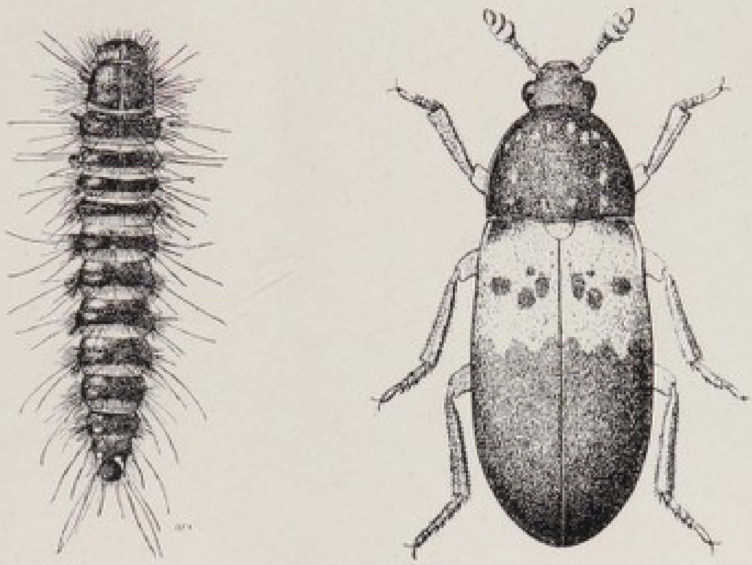
The adults emerge in April or May ; the larvae carry out most of their feeding during the summer and hibernate in that stage pupating in March or April of the following year. Although the amount of damage actually done by this species to food is not large the presence of these conspicuous unpleasant insects, even in small numbers, may lead to the refusal of the parcel by the consumer. Not only may one discover adults and larvae but also an accumulation of the skins cast by the larvae in the course of development. Since the larvae frequently develop in the folds at the top of a sack, it is found that they fall on to the top of the flour when the sack is untied, thus becoming immediately obvious to the user.

DERMESTIDAE

DERMESTES LARDARIUS (the bacon or larder beetle) (Fig. 7 and Plate 24). An insect which, though frequently found in the milling machinery, does not feed directly on the stock to any extent, is the larder beetle (*Dermestes lardarius*). The beetle is dark brown, 7–9 mm. long, with a fawn, six-spotted band on the elytra. The adult female lays up to 175 eggs, which hatch in about 12 days. The larvae which are dark brown in colour and very hairy, with a pair of sharp spines at the end of the abdomen, crawl about in the foodstuff and feed on dead insects and other animals. After moulting five times and increasing in size to about 10 mm. in length the larvae tend to leave the foodstuff and burrow into surrounding wood, where they pupate. The pupal stage lasts about 10 days, and the adult may live for

12 months. The complete life cycle may be completed in 50 to 60 days, but under normal conditions in unheated warehouses there is one generation a year.

Although this species does little damage except by boring into floors and the framework of machinery its presence, like that of the mealworm, is an indication of poor hygiene and means that there is a large population of important unpleasant pests which needs to be controlled. It must have food of animal origin on which to feed in order to complete its life cycle and its general occurrence is limited thereby.

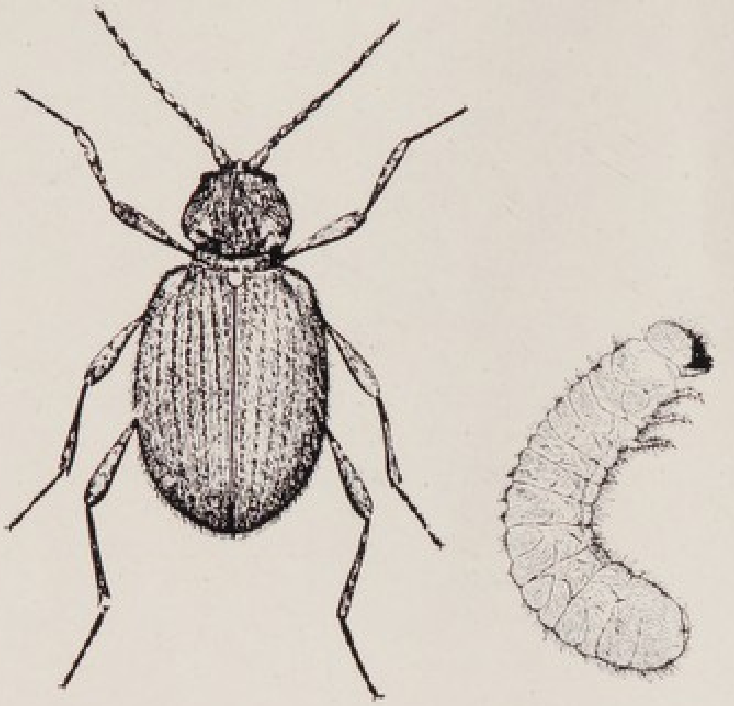


7 Larva and adult stages of the larder beetle, *Dermestes lardarius* (both enlarged about 6 times). (From Hinton.)

24 Pupae of the larder beetle, *Dermestes lardarius*, in wood.

PTINIDAE (SPIDER BEETLES)

PTINUS TECTUS (the brown spider beetle) (Fig. 8 and Plate 25). The brown spider beetle is about 3–3½ mm. long, dark brown in colour and globular in shape. Its original home was probably Tasmania, and the first record of its occurrence in England was in the year 1892, in London. It was not recorded from the Continent until 1916. It is now the most widespread and common stored products pest in this country. *Ptinus tectus* is an important pest in temperate conditions but not in the tropics, and has been very seldom recorded in tropical produce arriving in this country.



a *b*

8 Adult and larva of the brown spider beetle, *Ptinus tectus*. (From Hinton). *a*, adult ; *b*, larva (both enlarged about 10 times).

The adult beetle lays up to 120 eggs in the foodstuff and continues to lay eggs readily so long as it has access to water. The eggs hatch in about 5–7 days to produce small white grubs which lie curled up in the food. They tunnel through it and, when more or less fully grown, find their way to the surface and either spin their cocoons to the under surface of the bag or burrow into the floor of the warehouse. The fully-grown larvae may bite holes in the surface of sacks of flour and lie just within the sacks voiding their droppings in little piles on the surface of the bags. These droppings are flatened, like wood shavings, and can be easily distinguished from flour by the use of a magnifying glass. The presence of such "eruptions" forms a useful indication of infestation by this species. Within the cocoon the larva pupates and gives rise to the adult in due course. The life cycle may take as short a period as 30 days but may be very extended, development and activity of all stages proceeding at low temperatures. There is at least one generation a year under normal unheated warehouse conditions, but there may be more than one generation in special circumstances.

When infestations are severe the whole of the inside of the sacks may be covered with cocoons and the bag fabric be so weakened as to tear easily. *Ptinus tectus* is seldom found in the flour mill except in the flour warehouse and the sack rooms, but is a serious pest of flour in normal warehouse storage. It has been found in spouts and machinery of mills whose standard of hygiene was very low.

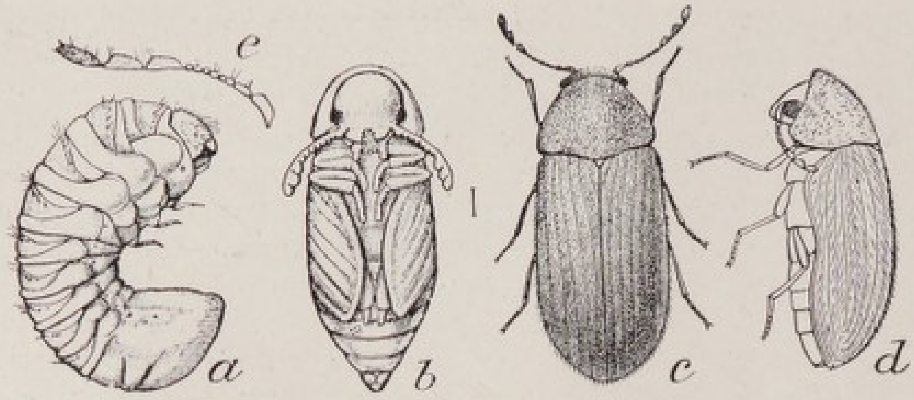
Ptinus tectus will feed on a wide variety of basic foodstuffs and thrives particularly on materials which have a high content of group B vitamins. It can breed on a diet of dead insects and this may help to explain how small populations of spider beetles keep going for long periods in empty warehouses.

25 Flour infested by the brown spider beetle, *Ptinus tectus*, showing surface "spotting" and tracks in flour dust on the floor produced by the grubs.

ANOBIIDAE

The *Anobiidae* are a family of wood boring beetles of which at least two species are adapted to feeding in foodstuffs.

STEGOBIUM PANICEUM (the biscuit weevil, bread beetle or drug-store beetle) (Fig. 9 and Plate 26). A pest which is frequently found in small bag flour returned from retail shops and by consumers, and which appears to be a serious pest in flour only when this is stored under warm conditions, is the biscuit weevil or drug-store beetle, *Stegobium paniceum L.* The adult beetle is about 1.75 to 3.75 mm. long and is cylindrical in shape and of a uniform light brown colour. The body is covered with fine silky hairs. The antennae are long and have the last three segments enlarged into a club. The adult beetle lays eggs singly in the flour up to several hundred in number. The period required for the eggs to hatch depends on the temperature, being as long as 37 days at about 60 deg. F., and only 8 days at 80 deg. F. The first stage larva is active and, since it is only about 0.5 mm. long, is able to find its way into packages without any indication of the way by which it entered. The larva feeds in the food, and during growth is very similar to the larvae of the spider beetles ; it is a white, globular grub with a dark brown head and lies on its side tunnelling through the food. When fully developed, about 5-mm. long, it forms a cocoon either in the food or near the surface. This cocoon is produced by a sticky secretion and the food material sticks to it on the outside. In this cocoon the larva changes to a pupa and eventually to an adult beetle. The adult beetle bites a hole in the cocoon and emerges. The larvae may not necessarily remain in the original packet in which they either penetrated or in which the original eggs were laid. In the course of

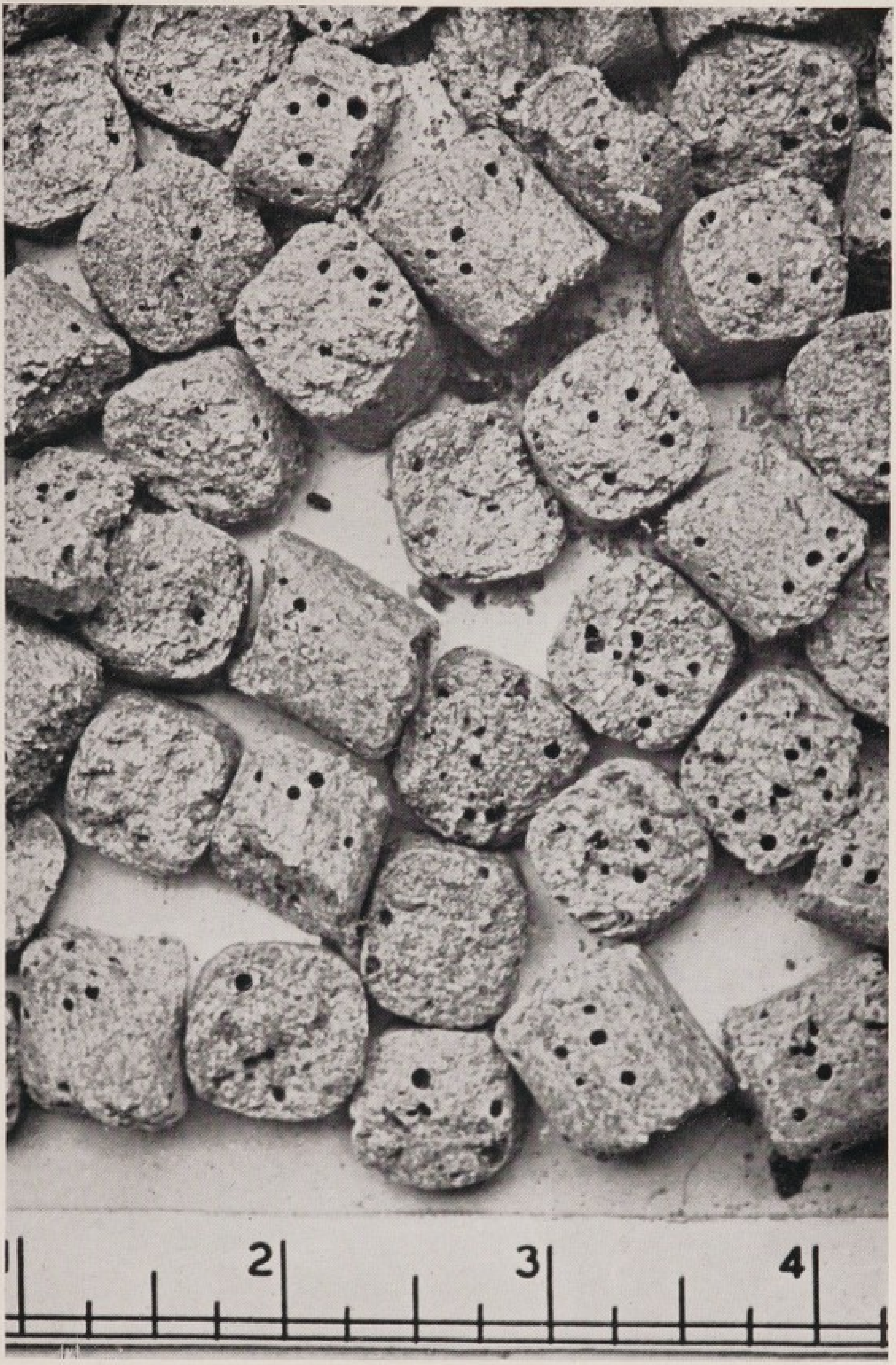


9 Adult and immature stages of the bread beetle, *Stegobium paniceum*. *a*, Larva ; *b*, pupa ; *c*, beetle, dorsal view ; *d*, lateral view—all much enlarged ; *e*, antenna—more enlarged. (From Chittenden U.S.D.A., 1902.)

their wanderings they may bite through the paper or cloth containers and so penetrate other foodstuffs. The larvae are omnivorous and an infestation which commences in flour may spread to practically all the other foodstuffs kept in the food store. At 60 deg. F. the whole life cycle takes about 200 days, whilst at 80 it is about 70 days. Under normal conditions in this country there is one generation a year, but under warm larder conditions the number of generations will vary with the average temperature. In this country it is mainly a domestic pest occurring in small stocks of food kept in retail stores, in the housewife's larder, or the food stores of hospitals and similar institutions. The first sign of attack is often the sudden emergence of a large number of beetles, which spread over all the other foodstuffs, and which leads to the destruction of a much larger quantity of food, from the mere presence of insects, than has actually been damaged by direct attack.

Experiments on the nutrition of this beetle show that it can complete its life cycle on foods containing very small quantities of carbohydrates. The principal point of interest is the fact that it has yeasts within its body from which it obtains vitamins of the B group and is thus independent of external sources.

Although this species is seldom found in the mill, it is very likely to be introduced in flour and flour mixtures returned by customers. It has been recorded from a very wide range of commodities.



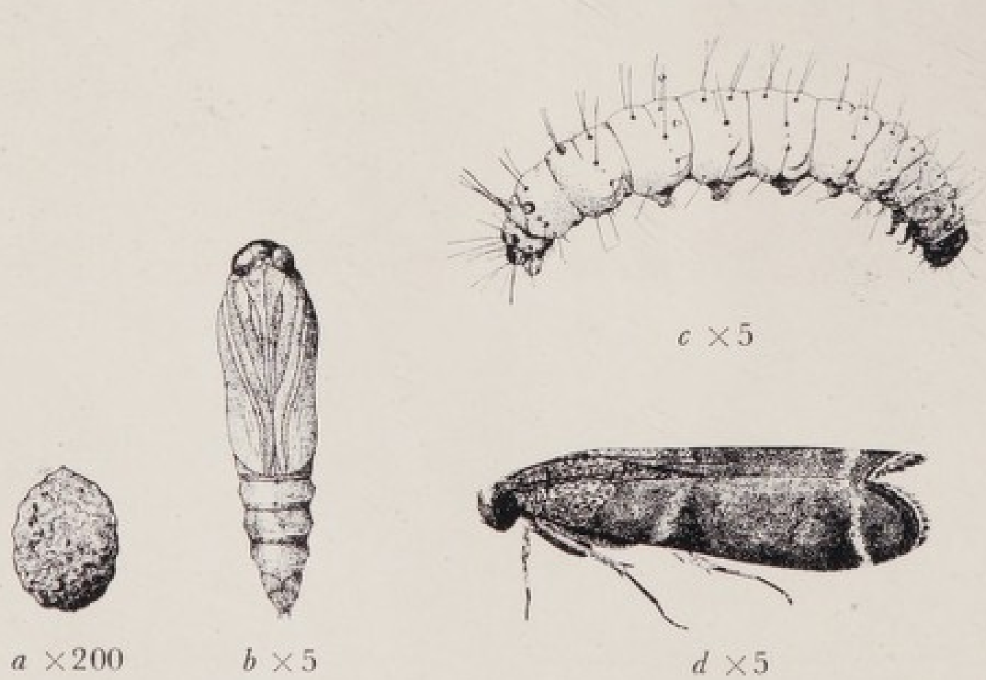
26 Cattle cubes tunnelled by the bread beetle, *Stegobium paniceum*.

LEPIDOPTERA (MOTHS)

PHYCITIDAE

EPHESTIA ELUTELLA (the cacao moth) (Fig. 10 and Plates 27, 28 and 29). One of the most important pests of grain stored in this country, though seldom met with in grain on importation, is the cacao moth, *Ephestia elutella*. The adult moth, which is about 7–9 mm. long, grey in colour, with a pair of fairly straight lighter bands across the fore wings, appears in the warehouses during June and July. After mating, the females lay their eggs loose on the surface of the grain. The young larvae penetrate the germ and remain within it for the first two stages, eventually leaving it and crawling about in the intergranular spaces eating the germs. It has been estimated that each larva consumes the germs of 47 grains in the course of its development. The fully grown larvae are greyish-white in colour, with black or brown spots from which arise hairs or " setae." When fully grown, which is about 60–70 days after the eggs are laid, the caterpillars cease feeding and crawl up to the surface of the bulk or stack and wander about without feeding for a period of about 56 hours. Since, throughout their life history the caterpillars spin a silken thread from their mouthparts, their wandering on the surface produces eventually the typical sheet webbing, whose thickness depends on the number of caterpillars present. The wandering caterpillars finally leave the grain and crawl up the walls of the store and into cracks and crevices where they spin cocoons and go into a resting stage. A small proportion may turn into pupæ and emerge as adults during October, but the vast majority remain as resting caterpillars until May of the following year, when they pupate.

Grain which is attacked by *Ephestia* has a sour smell and is contaminated by the webbing and droppings of the caterpillars. Movement of the grain during the period when the caterpillars are feeding may destroy large numbers by mechanical means, but some at least survive, particularly those young stages within the embryos and in this way this pest has been carried from one store to another. The moths

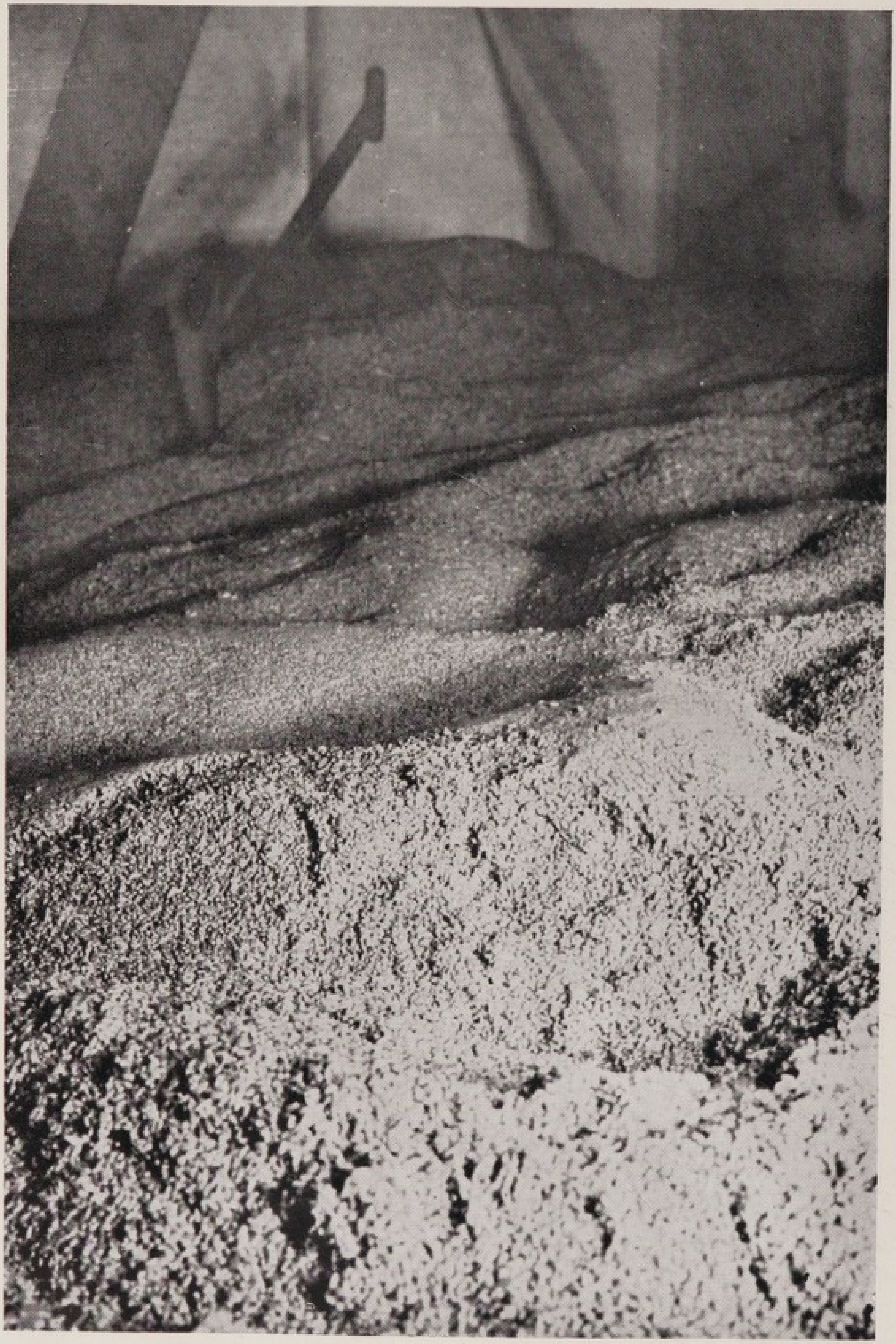


10 Adult and immature stages of the cacao moth, *Ephestia elutella*. *a*, Egg ; *b*, pupa ; *c*, larva ; *d*, adult. (From Bovingdon.)

are also active fliers and are known to have flown for at least a quarter of a mile from known centres of infestation. The species has greatly extended its range during the past few years, and, being well adapted to temperate conditions and, in addition, being constantly introduced on commodities other than wheat, it is likely to prove a most serious pest even under peace time storage conditions. It will breed in flour and wheat offals, but not unless there are adequate quantities of B group vitamins present. It has been found breeding in a large number of foodstuffs, other than grain, including cacao beans, groundnuts, linseed and other oilseeds and tobacco.

So far it has not established itself as a pest in the flour mill but the real possibility is there.

27 Surface webbing of caterpillars of the cacao moth, *Ephestia elutella*.

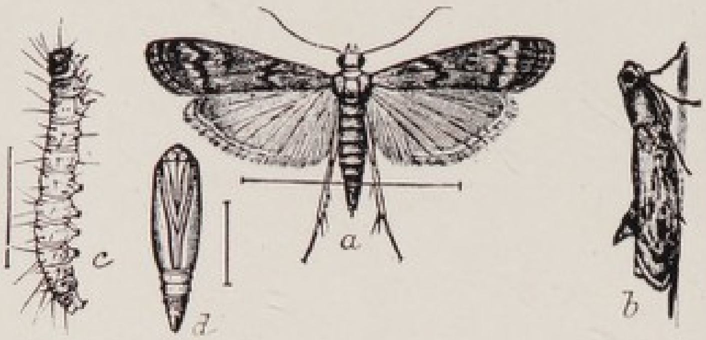


Wheat webbed by caterpillars of the cacao moth, *Ephestia elutella*.

29 Oilseeds badly webbed by larvae of the cacao moth, *Ephestia elutella*.

EPHESTIA KÜHNIELLA (Mill Moth : Mediterranean flour moth). (Fig. 11 and Plates 30 and 31.) There is no doubt that this species is the principal pest in the flour mill.

The adult moths, about 13 mm. long, are of a pale grey colour, with two pairs of dark wavy markings on the fore wings. The adults sit quiet on the walls of the mills or in the machinery and, after mating, the females lay between 50 and 350 eggs. The eggs hatch in 7–14 days and the young caterpillars crawl about in the foodstuff trailing a silken thread which is produced from an opening near the mouth. After 8–10 weeks the larva is fully grown and it then leaves the food and spins a fairly stout cocoon usually in crevices in machinery, on sacking, at the tops of walls and similar places. The larvae are pinkish white in colour, with distinct dark spots from which spring the body hairs. In the cocoon the larva pupates and the adult emerges in some 17–20 days. In warm mills there are about 5 generations a year, but development will also take place, at a slower rate, in unheated warehouses, since the larvae can survive our winters.



11 Adult and immature stages of the mill moth, *Ephestia kühniella* ; *a*, moth ; *b*, moth from side, resting ; *c*, larva ; *d*, pupa—enlarged. (From Chittenden, U.S.D.A., 1897.)

It has been shown that the mill moth larva can feed as well on flour of low extraction as on wholemeal, although it breeds much faster on the latter. It is capable of developing in flour of a moisture content of less than 1 per cent., the insects getting their water from the food in the digestive process. The mill moth will not only breed in grain products but also on the whole grain provided the moisture content is sufficiently high.

The main objection of the miller to the presence of *Ephestia kühniella* in the mill is the webbing produced by the larvae. As the caterpillars crawl about inside the spouts, on flour and offal elevators, inside centrifugals and plansifters, they web the stock together into masses which are eventually dislodged and cause blockages unless the machinery is regularly cleaned. The feed to roller mills is frequently reduced at the feed plate by large numbers of small pieces of webbing which prevent the even flow of stock. The eggs of the mill moth are normally held back by the final dressing, but the inclusion of coarser branny fractions in the flour allows eggs and small larvae to pass through. There is always the infestation of the packing bins and the sacks to provide a source of insects. In addition to interference with the running of the mill, *Ephestia kühniella* is liable to show itself in flour and wheat offals which have been stored too long and cause webbing of the material and even " souring " when the infestation is very heavy. *Ephestia kühniella* is seldom recorded breeding in commodities other than cereals and cereal products.

30 Caterpillars of the mill moth, *Ephestia kühniella*, and webbed stock from mill machinery.

31 A sack of meal badly webbed by caterpillars of the mill moth, *Ephestia kühniella.*

HYMENOPTERA (PARASITIC WASPS)

The two particular insects described here are not pests but are beneficial insects in so far as they attack the caterpillars of the mill moth. On the other hand they seldom occur in large numbers unless the host population is already high and, being efficient parasites, allow the host caterpillar to complete its full development before killing it. Their presence is, therefore, an indication that hygienic and chemical measures of control are long overdue.

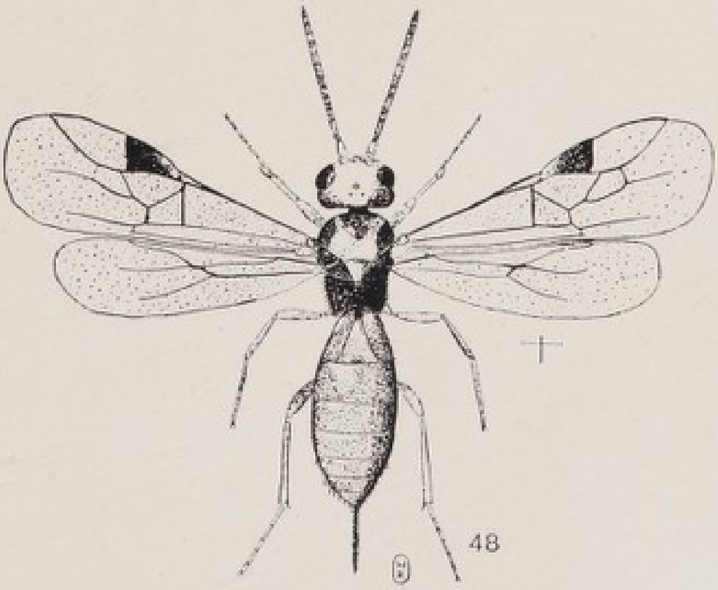
ICHNEUMONIDAE (ICHNEUMON FLIES)

NEMERITIS (IDECHTHIS) CANESCENS (the Ichneumon fly). (Fig. 12). *Nemeritis* is a slender wasp with a reddish brown abdomen, with head and thorax black and the legs reddish brown to yellow. The adult female, which is about 10 mm. in length, has a long ovipositor, or egg laying apparatus. It lays its eggs inside the body of the caterpillar and the whole development of the wasp grub takes place inside. The host caterpillar continues to feed until it is ready to pupate, by which time the parasite is itself fully grown and then kills the host, pupates, and in due course the adult emerges. The life cycle of the parasite takes about 3–4 weeks.

12 Adult ichneumon fly, *Nemeritis* (*Idecthis*) *canescens*.
(Original illustration—Bryn-Jones.)

BRACONIDAE

MICROBRACON HEBETOR (the Braconid wasp). (Fig. 13, Plate 32.) *Microbracon* is much smaller than *Nemeritis* being 2–3 mm. long ; the head and thorax are black in colour and the abdomen either black or yellowish. The adult female paralyses the flour moth caterpillar by stinging it several times. It then lays several eggs on the caterpillar. The eggs hatch into small grubs which feed on the juices of the paralysed caterpillar, finally pupating in thickly woven cocoons. The whole life cycle from egg to adult wasp may be as short a period as 2 weeks.



13 Adult braconid fly, *Microbracon hebetor*.
(From Richards and Herford, 1930.)

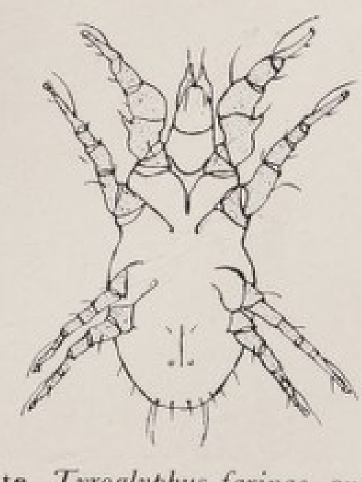
32 Caterpillars of the mill moth, *Ephestia kühniella*, paralysed by the braconid fly, *Microbracon hebetor*, cocoons of which can be seen near the caterpillars.

ACARINA (MITES)

TYROGLYPHIDAE (GRAIN MITES)

TYROGLYPHUS FARINAE (the flour mite). (Fig. 14, Plates 33, 34.) There is little doubt that, except in warm dry stores, the principal pest of stored wheat, flour and wheat offals, is " mite," particularly the flour mite, *Tyroglyphus farinae*. The adult female mite, which is about 0.4 to 0.6 mm. long, lays, after mating between 20 and 30 eggs scattered about in the foodstuff. Each egg is about 0.12 mm. long by 0.08 mm. across. After four days the six legged larva (0.15 mm. long) escapes from the egg shell and after feeding for a few days it becomes inert and moults to produce an eight legged nymph. This stage lasts from 6–8 days and may be followed either by an active or relatively inert stage. The active stage is followed by a further nymph which in due course moults to produce the adult. The relatively inert stage is one which is adapted for dispersal or for resistance to adverse conditions and is known as a " hypopus." It is oval in shape with a hard convex surface and ventral suckers. The "hypopi" may be distributed by the wind, by clinging to the hairs of mammals or to the clothing of human beings or to the surface of insects. Up to 700 hypopi have been removed from a single adult hardback beetle (*Tenebrio molitor*). The hypopus (0.3 mm. long $\times$ 0.16 mm. broad) is followed by an active nymphal stage which then changes to the adult. Hypopi are generally very resistant to extremes of heat and cold and to many fumigants and sprays.

The whole life cycle may take from 17 to 28 days but is considerably influenced by temperature and particularly by humidity. Mites breed much more rapidly in damp conditions and cannot thrive on material which has a moisture content of less than about 12 per cent. It should be observed, however, that this moisture content is not the general average of the material but the moisture content at the point where the mites are living. Thus a sack of flour may have a much higher moisture content near the surface than in the centre and be infested round the periphery by mites, even though the bulk of the sack is of too low a moisture content for breeding. In the same way the surface layers of bulk wheat may be infested although the centre portion may have a moisture content as low as 10 per cent. There is little or no infestation at moisture contents of 13 per cent. or below but the extent of breeding rises rapidly with increase of moisture content above this figure. The optimum range of temperature lies between 64 and 77 deg. F., but mites are very resistant to cold and cease to feed at only a few degrees above freezing point, below which they hibernate. They have been recorded as surviving temperatures as low as —40 deg. F.



14 A flour mite, *Tyroglyphus farinae*, enlarged 90 times. (From Zakhvatkin, 1936.)

33 Bagged wheat infested by the flour mite, *Tyroglyphus farinae*. Note dust on floor and on surface of bags.

34 Flour heavily infested by the flour mite, *Tyroglyphus farinae*.

Mites damage wheat in two ways. They tunnel into the germ and feed within it and they impart a typical "minty" smell from a fatty surface secretion. The damage done by mites may be distinguished from that of caterpillars (*Ephestia elutella*) since the mites leave the surface bran untouched, whereas the caterpillars eat off the germ, bran and all, leaving a white scar (Plate 1). The tainting of the wheat may be so pronounced that it may persist through to the finished flour, and instances are on record where such infested wheat has had to be worked in at as low a proportion as 2½ per cent. in the grist. Such tainting may occur when the mite population in the grain exceeds 500 individual mites per 100 cubic centimetres of wheat.

The presence of the flour mite in commodities may be detected by the "minty" smell or by screening over a 30 mesh wire sieve. In flour which is infested a sample may be smoothed with a spatula and in a short time the mites may be seen moving and throwing up little piles of flour. With bagged commodities the mites tend to come out of the bags and fall to the floor. Their movement also tends to carry quite large quantities of flour out of the bags (Plates 33 and 34).

In flour, mites probably feed selectively destroying the more valuable food constituents but the principal objection is again the taint, which is liable to persist through into bread, scones and cakes. The taint is apparently more likely to persist in unfermented materials. Mity flour used for flour mixtures such as pudding powders, custard powders, etc., also results in the production of an unpalatable cooked article and it has been stated that mites breed more readily in articles containing sugar. When flour, which has been severely attacked by mites, is used for bread-making the bread has a sour taste, poor colour, and may not rise adequately.

Wheat offals, particularly bran stored during the summer, may suffer severely from the attacks of mites, which may cause a reduction in weight of up to 10 per cent and, in conjunction with the attacks of moulds, cause the offals to become heated, sour and lumpy. In this condition they are said to be unpalatable to livestock.

AN ALPHABETICAL LIST OF COMMON INSECTS AND MITES

Scientific name.	*Common name.*	*Where found.*
Alphitophagus bifasciatus Say.	Two banded fungus beetle	Damp and musty grain and grain products.
Anobium punctatum De G.	Furniture beetle	Boring in structural timbers.
Caenocorse subdepressus Woll.	Depressed flour beetle	Secondary pest in whole grain.
Caenocorse ratzeburgi Wissm.	Small eyed flour beetle	ditto
Calandra granaria L.	The grain weevil	Whole grain and flour.
Calandra oryzæ L.	The rice weevil	ditto
Dermestes lardarius L.	The larder beetle	Scavenger on insect remains in flour mills.
Endrosis sarcitrella L.	The white shouldered house moth	Damp whole grain and grain products.
Ephestia cautella Wlk.	The fig moth	Wheat, flour.
Ephestia elutella Hb.	The cacao moth, tobacco moth.	Whole grain, flour.
Ephestia kühniella Zell	The mill moth : Mediterranean flour moth.	Whole grain and grain products; milling machinery.
Gnathocerus cornutus F.	Broad horned flour beetle	Milling machinery, flour.
Hofmannophila pseudospretella St.	Brown house moth : false clothes moth.	Flour and cereal dust.
Laemophloeus ferrugineus Steph.	Rust-red grain beetle	Whole grain, grain products.
Laemophloeus minutus Oliv.	Flat grain beetle	ditto and milling machinery.
Latheticus oryzæ Waterh.	Long headed flour beetle.	Secondary pest in whole grain.
Microbracon hebetor Say.	Braconid wasp.	A wasp parasite of moth caterpillars.
Nemeritis canescens Grav.	Ichneumon fly.	A wasp parasite of moth caterpillars.
Niptus hololeucus Fald.	Golden spider beetle	Flour.
Oryzaephilus surinamensis L.	Saw toothed grain beetle	Grain and grain products.
Oryzaephilus mercator Fauv.	Merchant grain beetle	ditto

Plodia interpunctella Hbn.	Indian Meal Moth	Grain and grain products.
Ptinus tectus Boild.	Brown spider beetle	Grain and grain products.
Ptinus fur L.	White marked spider beetle	ditto
Pyralis farinalis L.	The meal moth	Damp whole grain : grain products.
Rhizopertha dominica F.	Lesser grain borer : Australian wheat weevil : Hooded grain borer.	Whole grain ; flour.
Sitotroga cerealella Oliv.	Angoumois grain moth	Whole grain.
Scenopinus fenestralis L.	The window fly	Larva a predator in dust in floors.
Stegobium paniceum L.	The biscuit weevil : drug store beetle.	Flour and flour mixtures.
Tenebrio molitor L.	The yellow mealworm ; hardback beetle ; "clock"	Flour, wheat offals and sweepings : milling machinery.
Tenebroides mauritanicus L.	The cadelle.	Whole wheat and wheat products ; milling machinery.
Tineola biselliella Humm.	The webbing clothes moth	Flour.
Tinaea granella L.	The grain moth ; the wolf moth ; the European grain moth ; the corn moth.	Whole grain and grain products.
Tribolium castaneum Hbst.	The rust-red flour beetle ; bran bug ; ship's ant	Whole grain ; grain products.
Tribolium confusum J. du V.	Confused flour beetle	ditto and milling machinery.
Tyroglyphus farinae L.	Flour mite ; common forage mite; grain mite.	Whole grain ; grain products.

Section 4: Infestation in the Mill

THE INFESTATION OF WHEAT AND MILLING PRODUCTS

The types of material entering the flour mill fall into two main classes. There are the true raw materials : wheat, barley, oats and sometimes rye ; and imported flour for mixing in. There are also finished products returned for reconditioning, empty sacks for cleaning and refilling and possibly secondhand machinery from other mills.

HOME GROWN WHEAT

Home grown wheat usually arrives at the mill free of insect infestation, but if it has been held in store it is liable to be attacked by mites, particularly the flour mite (*Tyroglyphus farinae*).

IMPORTED WHEAT

The principal sources of supply at the time of writing are Canada and the Plate.

CANADIAN WHEAT. Manitoba wheat usually arrives in this country either entirely free from infestation or very slightly infested. It is most exceptional to find a parcel infested by any of the major pests, *e.g.*, *Calandra sp.* and when these are found their presence may usually be explained by the previous history of the ship, the insects having been left behind from a previously infested cargo. The principal insect pests found in Canadian wheat are the rust-red grain beetle *Laemophloeus ferrugineus* and the flat grain beetle *Laemophloeus minutus*. Normally these beetles only occur in very small numbers, but their presence is an indication that the wheat may heat owing to the breeding of the beetles, and the wheat should normally be consumed as soon as possible. The other more or less regular inhabitants, although in very small numbers, are mites, particularly the flour mite *Tyroglyphus farinae*. Other mites may occur from time to time. It is probable that all Canadian wheat arrives with a small number of mites, possibly in resistant hypopal stages, but they are not always detected owing to the very small numbers in which they occur. The extent of infestation in Canadian wheat on arrival is never sufficient to have caused any appreciable damage, and one can rely on such wheat arriving in first class condition. Wheat shipped from Vancouver may show slightly more infestation than that from Eastern ports. The principal places in the holds of the vessels where the small amount of infestation can be detected are usually along the temporary wooden bulkheads which, being frequently of green timber, are damp. The grain in contact with the bulkheads gets damp and the breeding of mites is encouraged. The grain may also get mouldy and small mould feeding beetles may also be found.

In view of the trouble which has been experienced from attacks of the cacao moth, *Ephestia elutella*, on Manitoba wheat stored in this country, it is of great interest to note that this species is hardly ever found on the wheat at the time of import. Practically all the infestation arises by attack from our indigenous population or by cross infestation from other imported commodities.

U.S.A. WHEAT. U.S.A. wheat usually arrives with little or no infestation. Shipments during 1945 showed regularly the presence, in small numbers, of the weevils *Calandra granaria* and *C. oryzae*, the hooded grain borer, *Rhizopertha dominica* and flat grain beetles, *Laemophloeus sp.*

PLATE WHEAT. Plate wheat, on the other hand, seldom arrives in a sound and cool condition. In the ship, the grain temperature is seldom less than 80 deg. F., and may be as high as 110 deg. F. The surface layers of the wheat are often completely hollowed out and covered with a seething black mass of insects. Further down in the bulk the wheat may be caked hard and, under certain circumstances, be damaged by moulds, particularly if it has got damp. The wheat is also liable to be very dusty, the dust being mainly due to the activities of the insects. The primary pests normally occurring in Plate wheat are *Calandra oryzae* and *Calandra granaria* (weevils), *Rhizopertha dominica* (lesser grain borer) and, occasionally *Sitotroga cerealella* (the Angoumois grain moth) ; secondary pests regularly found include *Tribolium castaneum*, *Tribolium confusum* (flour beetles), *Laemophloeus spp.* (flat grain beetles), *Latheticus oryzae* (long headed flour beetle), *Oryzaephilus surinamensis* (saw toothed grain beetle) and *O. mercator* (merchant grain beetle), *Tenebroides mauritanicus* (the cadelle), *Ephestia cautella* (the fig moth), *Caenocorse ratzeburgi* and *C. subdepressus* (grain beetles), *Gnathocerus cornutus* (the broad-horned flour beetle) and various wasp parasites and small bugs, predators on the major pests. Mites, including *Tyroglyphus farinae*, occasionally occur, particularly if the wheat has been damaged by water.

DETECTION OF HIDDEN INFESTATION IN GRAIN. In dealing with both lightly infested Canadian wheat and heavily infested Plate wheat, it has been found necessary to employ a technique for ascertaining the extent of larval infestation within the grains. This may be necessary in regard to two extreme cases. If Manitoba wheat is found to be infested by a small number of adult grain weevils but a careful search of the grain reveals no exit holes some rapid means of determining the extent of larval infestation, if any, will give a guide to whether it is safe to store the grain or whether it should be milled at an early date. With Plate wheat, on the other hand, whilst there is usually plenty of evidence of adult infestation and cut grains, it has been found that there may be such an accumulation of carbon dioxide in the holds during the voyage and such high temperatures may have been reached, that the larvae within the grains may have been largely killed.

The technique[1] which is used depends on measuring the concentration of carbon dioxide present in a known volume of grain incubated under standard conditions for 24 hours. Since the output of carbon dioxide by sound dry grain under such conditions is almost negligible (0.2–0.3 per cent.) any figure above that indicates the presence of insects and by experience it is possible to relate the figure to the actual population of larvae present.

IMPORTED FLOUR

Turning now to the second group of materials, *i.e.*, imported white flour for mixing in.

CANADIAN FLOUR generally arrives in this country quite free of infestation and the few instances of insects being found in the flour on arrival have been traced to infestation in the ship or to exceptional conditions of storage in the exporting country. Canadian flour direct ex ship cannot be regarded as at all dangerous to a mill. If it has been lying in store, as the great proportion has, then it is liable to be infested, on arrival at the mill, with any or all of the following : *Ptinus tectus*, *Ptinus fur*, *Niptus hololeucus*, *Ephestia elutella*, *Hofmannophila pseudospretella*, *Endrosis sarcitrella*, and

[1] This method is fully described in R. W. Howe and T. A. Oxley : The use of Carbon Dioxide production as a measure of infestation of grain by insects. Bulletin of Entomological Research, Vol. 35, Part 1, April, 1944.

by the flour mite, *Tyroglyphus farinae*, the presence of the latter being the main factor determining the storage life of the flour. If stored under warm conditions the flour is liable to be infested by *Ephestia kühniella* and by *Tribolium*.

PLATE FLOUR, on the other hand, is seldom lightly infested on arrival but more commonly carries a heavy infestation, even when it is imported as a sole cargo. Over 40 different kinds of insects were reported from Plate flour during 1944. The following species occurred regularly in fairly large numbers :—*Tribolium castaneum*, *Tribolium confusum*, *Latheticus oryzae*, *Laemophloeus spp.*, *Tenebroides mauritanicus*, *Rhizopertha dominica* and *Calandra oryzae*. The following occurred less frequently :—*Oryzaephilus surinamensis*, *O. mercator*, *Gnathocerus cornutus*, *Calandra granaria*, *Ephestia cautella*, *Ephestia elutella* and *Ephestia kühniella*, and *Psocids*. There are two points of interest in this list. First it will be observed that there are a number of pests which are known to be established in milling machinery and secondly the list includes certain species which are commonly thought to be able to breed only in whole grain, *i.e.*, *Calandra* and *Rhizopertha*. All stages of these beetles have been found in the flour. An examination of the flour indicates that there is a small proportion of fairly large endosperm particles and there is little doubt that much of the infestation in this flour has arisen from the exporting mills.

AUSTRALIAN FLOUR may be regarded as intermediate in general level of infestation between Canadian and Plate. The following species have been recorded from time to time :—*Tribolium castaneum*, *Tribolium confusum*, *Ephestia kühniella*, *Rhizopertha dominica*, *Calandra oryzae*, *Laemophloeus sp.*, *Tenebroides mauritanicus* and *Oryzaephilus surinamensis*. Both Plate and Australian flour which have been held in store are liable to be infested by the same insects as those which attack Canadian.

HOME MILLED FLOUR

The infestation of home milled flour which has been held in store depends to a considerable extent on the possibilities of cross infestation from other commodities in the store in which the flour has been held as well as on the moisture content and original infestation of the flour. Thus flour which has been stored on the top floor of a small bakery, under temperature conditions of say 60 deg. F. and upwards is liable to be returned heavily infested by *Ephestia kühniella* and by *Tribolium*, with *Oryzaephilus surinamensis*, sometimes, in addition (Plate 35). Such flour may be so badly tainted and webbed as to be unsuitable for screening and might have to be classified for animal feed. Flour which has been stored under normal warehouse conditions might be attacked by *Ptinids* or, more commonly, by mites, particularly *Tyroglyphus farinae* (Plate 34). In the case of the latter the extent of infestation and the amount of taint will have to guide the miller in deciding whether reconditioning is worth while.

EMPTY SACKS

Empty sacks returned for cleaning are frequently infested, the most common insects being the mill moth (*Ephestia kühniella*), flour beetles (*Triboleum spp.*) and the cadelle (*Tenebroides mauritanicus*). Mites, especially *Tyroglyphus farinae* (the flour mite) may be present. Others which may occur from time to time include the flat grain beetle (*Laemophloeus spp.*), saw toothed grain beetles (*Oryzaephilus surinamensis*) and spider beetles, especially *Ptinus tectus*. In the dust removed from the bags will be found many or all of these insects and the practice of taking this flour dust across to the mill and feeding it regularly into the offal side is one which cannot be recommended.

Moth caterpillars and pupae and the immature stages of spider beetles may be strongly attached to the bags by webbing. Other insects may be found in the seams For these reasons it has been observed that the usual methods of cleaning, even with a strong suction, are insufficient to remove all the insects and the mites, and it is recommended in this pamphlet that all sacks returned to a mill should receive routine automatic fumigation or heat treatment.

INFESTATION OF MILL BUILDINGS AND MACHINERY

The several pests occur in different proportions in various parts of the mill. In this section the various infestations are described.

SILO AND SCREEN ROOMS

The insects found in the wheat in the bins will usually be mainly those introduced with the kind of wheat being used ; there are, however, normally some insects which can maintain themselves in dust and grain spillage and find their way on to new stocks when they are brought in. Such insect populations are known as "endemic" as contrasted with the "specific" populations on particular commodities. The insects most commonly recorded as making up the " endemic " populations of silos and screen rooms are the yellow meal worm (*Tenebrio molitor*), the grain weevil (*Calandra granaria*), the larder beetle (*Dermestes lardarius*), the fungus beetle (*Alphitophagus bifasciatus*), the false clothes moth (*Hofmannophila pseudospretella*), the white shouldered house moth (*Endrosis sarcitrella*), the meal moth (*Pyralis farinalis*), the clothes and grain moths of the genus *Tinaea*, and predatory bugs. Many mites may also be found.

Under normal conditions of rapid turnover of mill stocks there is little chance for either the introduced or the endemic populations to build up rapidly in the wheat stored in the mill silos. If, however the wheat is likely to be left undisturbed for more than about 4 weeks, some trouble may be expected, particularly during the summer. Under such circumstances the miller should, in addition to keeping a watch for attacks by beetles, also bear in mind the danger of attack by *Ephestia elutella* (the cacao moth) or by *Plodia interpunctella* (the Indian meal moth).

In the course of the *cleaning of the wheat*, most of the free living insects and mites and the light, holed berries, are removed in the zig-zag separator or other type of machine carrying out a similar function. Small insects, mites and insect eggs, may be carried away in the exhaust at various stages and be discharged to the atmosphere or fall down with the cyclone dust. When heavily weevilled wheat has been undergoing cleaning and the light screenings have been falling from the separator to be bagged up on the floor below, it has been found that they tend to leave the sack and get all over the room. This is due to a reaction on the part of most insects whereby if they are disturbed they immediately become very active and tend to leave their original foodstuff. Such a layout of the screening section under which all screenings pass automatically to a grinder and grading reel is strongly advised since a large proportion of the insects are killed in the grinder and have no opportunity of escape.

A particular place in the screening section where endemic infestation may build up is in that part where the " whizzer " is housed. The high humidity provides favourable conditions for such insects as *Endrosis sarcitrella* and for mites.

In the wheat conditioning bins there is a liability for *Ephestia kühniella* (the mill moth) to breed, particularly in damp wheat and dust impacted between the slats making up the bins. A particularly bad centre of infestation in some mills has been

35 Flour stored in a warm bakery, heavily webbed by caterpillars of the mill moth, *Ephestia kühniella.*

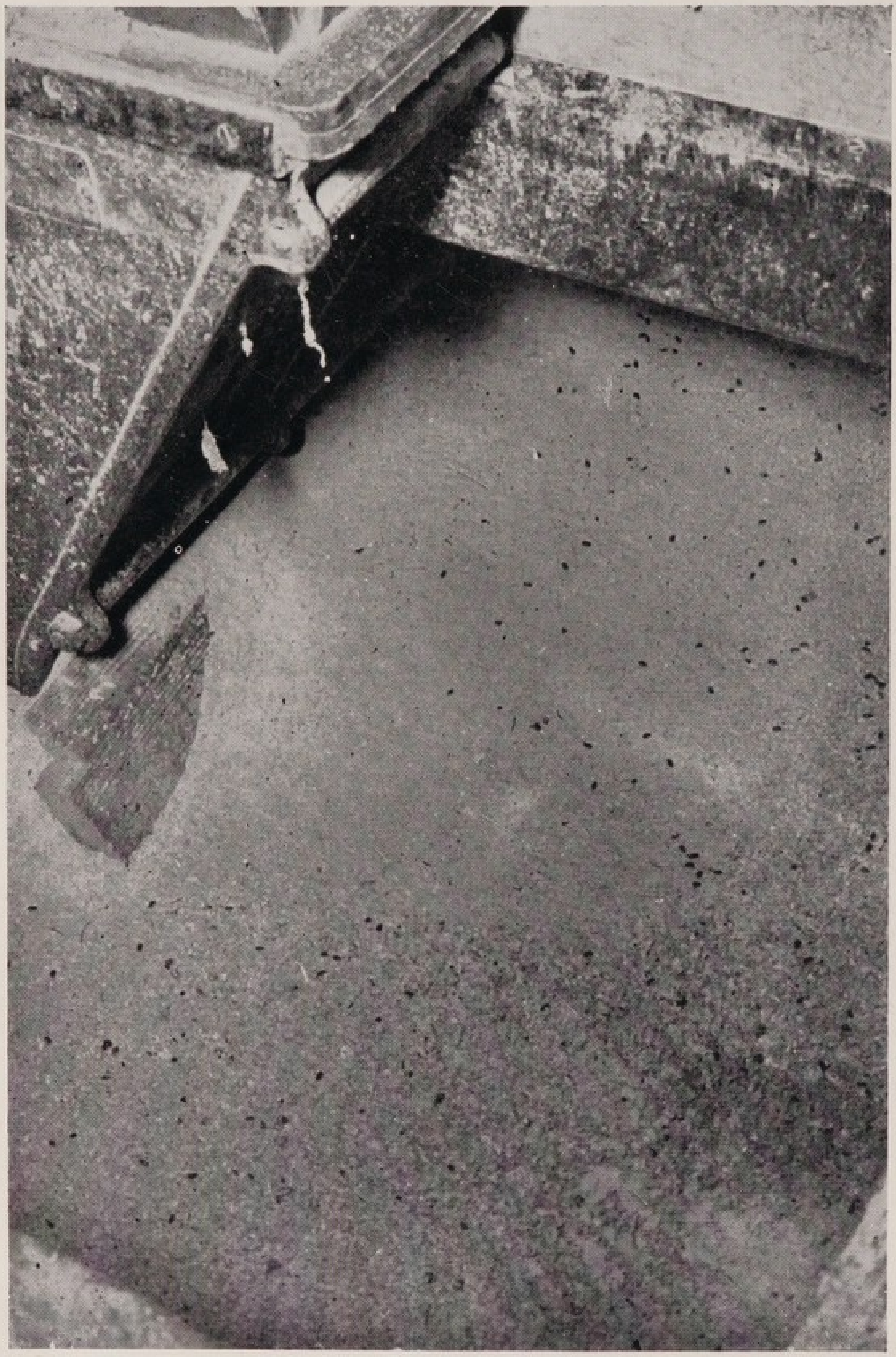
the small space between the bins and the ouside walls of the building, this space being too narrow to allow of proper cleaning.

In silos and screen sections where the boots of elevators are below floor level and fit into wells (Plate 36), it has been found that these wells become filled with spilt wheat, dust and rubbish. This material rapidly becomes infested and such places represent serious centres from which insects spread to other parts. There are no particular insects which are liable to be found there rather than elsewhere, with the exception that, being often damp, such places are favourable to mites, fungus beetles, and moths such as *Pyralis farinalis*, *Endrosis sarcitrella* and *Tinaeids*.

In the silo wheat should be carefully watched and temperature readings taken at intervals. Except when the external temperature is high, 70 deg. F. should be taken as a deadline for action. Since steady rise in temperature is normally taken as indicating something wrong with the wheat, it may be convenient at this point to describe the results of research into the heating of wheat caused by insects, as this will help to indicate why many common methods of dealing with heating wheat merely help to worsen conditions rather than improve them.

The causes of the spontaneous heating of wheat have been investigated by Oxley[1] who has shown that it can be of two kinds according to whether the wheat

[1] Oxley T. A. The spontaneous heating of stored cereals. Royal College of Science Journal, Vol. 15, 1945, pp. 71–80. Oxley, T. A. The Scientific Principals of Grain Storage : " Milling." Liverpool, 1946.



36 Infested wheat sweepings in an elevator boot pit.

affected has a moisture content of 17–18 per cent. or higher (*damp grain heating*) or one of 15 per cent. or less (*dry grain heating*).

He has shown by experiment that the natural respiration of wheat increases rapidly with increase of moisture content from 15 to 20 per cent. and that from about 17 per cent. and upwards this respiration may produce sufficient heat to cause spontaneous heating. Damp grain is also liable to be attacked by insects, which may start heating as in " dry " grain, but more particularly by moulds and bacteria. The heating of maize is apparently sometimes due to the presence of moulds rather than of insects. A characteristic of heating caused by moulds is that they can tolerate much higher temperatures than insects and wheat damaged by moulds will show charred berries and temperatures up to 140 deg. F. It is attack by moulds and bacteria which is a very common cause of heating in home grown wheat.

On the other hand the respiration of wheat of a moisture content of less than 15 per cent. is so low that the heat produced is insufficient to induce " spontaneous heating." With dry grain such heating is almost always due to the presence of insects, and, to a lesser extent, of mites.

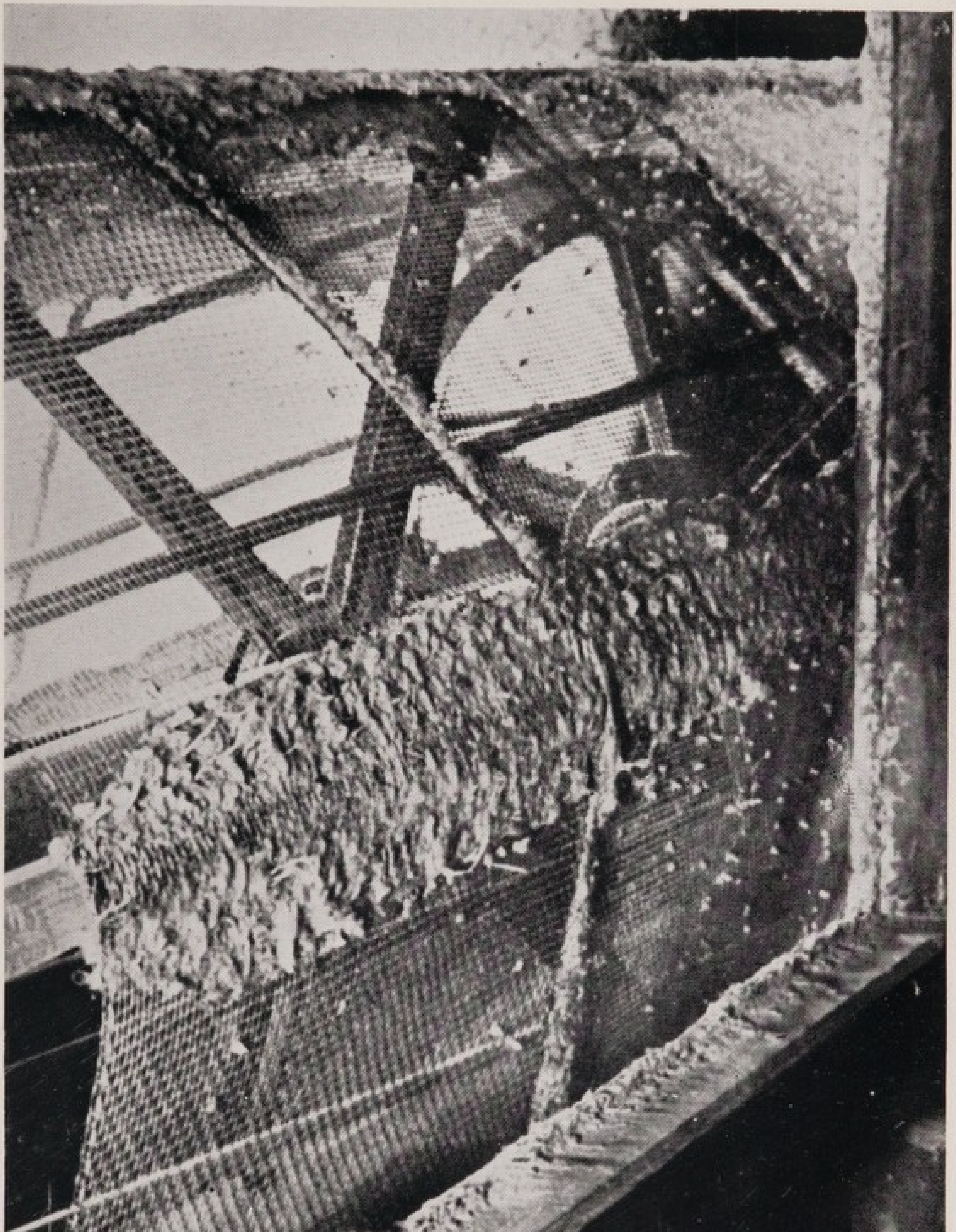
[1] Insects, particularly larvæ, are, however, respiring much more rapidly than the grain in which they are living, and produce heat much faster than the grain. So long as the insects are only present in small numbers distributed through the bulk or at the surface of the grain the heat they produce leaks away. But if there is any appreciable concentration of insects at any point in the bulk, they produce heat faster than it can escape, since wheat is a poor conductor, and the temperature rises slightly at that point. This causes the insects to respire and live more quickly thus producing more heat. This heat leaks away from the point of production, producing an ever increasing sphere of high temperature, grading down in all directions to the air temperature at the surface and sides of the bulk. Eventually the temperature at the middle passes above 80 F., which is about the optimum for the life of most of the grain insects. As the temperature continues to rise those insects which are free living (*e.g.*, the adults of *Calandra* and *Rhizopertha*, the larvae and adults of *Laemophloeus* and *Tribolium*) move outwards in the zone of most favoured temperature. Those insects which cannot move away (larvae of endosperm borers such as *Calandra*, *Rhizopertha* and *Sitotroga*) continue to develop for a time (producing more heat) but eventually die. The final temperature does not normally exceed about 105 deg. F. for a *Calandra* infestation, but may reach 120 F. for a *Laemophloeus* infestation. The temperature at the centre does not fall because it is surrounded by an ever increasing sphere of wheat at maximum temperature. Eventually the whole bulk reaches a high temperature below the surface at which stage the surface is usually found to be covered with a seething mass of adult insects. A secondary result of the heating is caking and mould formation (Plate 37). This results from the following causes. The air round the grain at the centre of the hot spot is heated by the grain and, being warmer is able to take up more moisture from the grain than cool air : *i.e.*, at the centre of the hot spot the grain tends to dry out. The warm air rises and when it meets the cool layer of grain on the surface or passes along a cool wall or up a cool stanchion, it is cooled and some of the water is condensed out. As this process continues the moisture content at the point of condensation rises considerably (actual drops of water can easily be seen) providing conditions suitable for germination and the rapid development of mould. This results in caking. Under extreme conditions the moulds may penetrate down into the bulk, certain moulds being

[1] This account is based on the following published work : Oxley T. A. and Howe R. W. Factors influencing the course of an insect infestation in bulk wheat. Annals of Applied Biology, Vol. 31, 1944, p. 76.

37 Wheat caked to the walls of a store following heating due to attack by grain weevil, *Calandra granaria*.

capable of attacking dry grain. The excessive moisture content is thus the *result*, not the cause of the insect infestation and the water content increases locally as the result of convection currents set up by the heating and does not originate from the vital activity of the insects themselves.

MILLING SECTIONS. The most important pest inside the milling machinery is the mill moth (*Ephestia kühniella*). The larvæ spin a silken thread as they crawl about and so web together the stock. This usually starts at a place where there is a slight interruption to the flow, *e.g.*, at a change of direction. If not regularly removed, the webbing may proceed so far that the spout may be blocked, so causing a " choke " and stoppage of production whilst it is cleared. The webbing also gets carried down the spouts with the stock and may cause slight blockages in the feed to the roller mills, thus reducing their efficiency. Webbing may be produced on silk and wire covers reducing their effective screening area (Plate 38). The larvæ may also develop on the cotton belts of the flour and offal elevators. The cotton belts, after a long period of running, may sometimes be found covered with webbing and cocoons. Another place is the space between the hoppers and the sides of the frames of roller mills. The heaviest infestation and greatest amount of webbing seems to occur where there is a good mixed stock of not too fine a consistency, *i.e.*, the unpurified and ungraded stocks to the plansifters and mixed graded stocks from them. The continuous breeding of the mill moth in



38 A wire screen partly blocked by the cocoons of the mill moth, *Ephestia kühniella*.

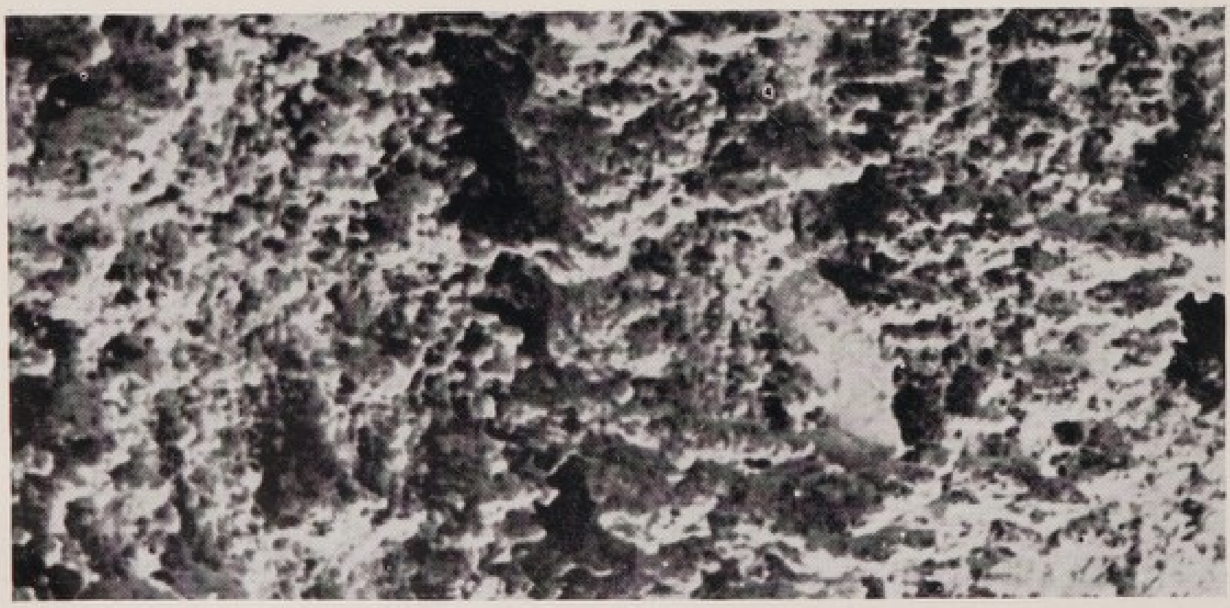
the flour mills is assisted by the high temperatures produced in the machinery during the milling process, especially in or near the roller mills. It is generally true to say that the temperature in the milling section is not less than about 60 deg. F. throughout the year.

It is in the masses of webbed stock that many of the other insects found in the mill find the most suitable breeding places. Here may be found all stages of the flour beetles (*Tribolium castaneum* and *Tribolium confusum*), the broad horned flour beetle (*Gnathocerus cornutus*), the flat grain beetles (*Laemophloeus spp.*), the cadelle (*Tenebroides mauritanicus*), the saw toothed grain beetle (*Oryzaephilus surinamensis*), and the larder beetle (*Dermestes lardarius*). It is not to be assumed that this is the only place in the machinery where these insects may be found. They are found throughout, particularly where flour dust tends to settle and remains undisturbed. Interference with the milling process is caused not only by the webbing of the mill moth, but also by the habit of the cadelle in biting holes in silk covers, thus reducing their efficiency. This species, as well as the flour beetles (*Tribolium* and *Gnathocerus*) and the larder beetle (*Dermestes*) may damage the woodwork of machinery by tunnelling.

Other insects likely to be found in the fabric of the building of the milling section, rather than in the machinery, unless such machinery or spouts are disused, are the yellow mealworm (*Tenebrio molitor*), particularly under sacks, and in dark corners ; the window fly (*Scenopinus fenestralis*), the adults on windows and the wire-like larva between floor boards ; and the two wasp parasites of the mill moth (*Nemeritis* and *Microbracon*) on or near the windows. The furniture beetle (*Anobium punctatum*) may be found burrowing in floors and the woodwork of machinery.

In stive rooms and on dust extractors the false clothes moth (*Hofmannophila pseudospretella*) may frequently be found, the cocoons being spun on the extractor sleeves (Plate 39).

THE WAREHOUSE. If the warehouse is of modern construction and has little harbourage for insects, the amount of endemic infestation should be very slight. The packing and movement of flour and offals results, however in the production of



39 Surface of the roof of a stiphon room showing webbed dust.

much dust. Unless there is scrupulous attention to hygiene, such dust will collect and provide breeding places for insects and mites even in modern buildings. In older buildings there are already many harbourages in which dust can collect and where insects may breed.

In the mill warehouse there are always likely to be found the same kinds of insects as in the mill, particularly the mill moth, *Ephestia kühniella* ; the flour beetles, *Tribolium spp.* ; the cadelle, *Tenebroides mauritanicus* ; the mealworm, *Tenebrio molitor* ; and the brown spider beetle, *Ptinus tectus*. Particular sites of breeding are in dust spilt round packing weighers, in and under piles of bags and where spiral sack chutes are attached to the floors.

As the degree of infestation in the mill warehouse is normally low, it is sometimes omitted from the fumigation treatment applied to the milling section. This practice cannot be recommended as there is always the danger that the mill may be reinfested from the warehouse by a small number of insects. As has already been stressed, one of the dangerous characteristics of mill pests is their rapid rate of multiplication so that a few insects from the warehouse may soon give rise to a large number in the mill where breeding conditions are more favourable.

HOW INSECTS REACH THE MILL

The entomological section of this pamphlet may well be concluded by a discussion on the subject of how insects get to a mill. It is not long after a new mill is opened up or a fumigated mill restarted before the inevitable signs of webbing appear and a few moths are seen flying about ; the following notes are an endeavour to indicate how this comes about.

Only a few of the insects with which we are concerned can breed in the open in this country. Most of them are limited in their breeding places and are normally carried from place to place in commodities or their containers and on transport. A few of the moths will fly from one building to another and some of the beetles fly actively in hot weather but their main means of spread is as passengers.

The principal ways in which insects reach an uninfested mill are :

(1) in empty flour bags ;
(2) in wheat ;
(3) in flour for mixing in or reconditioning.

IN EMPTY FLOUR BAGS. Many bakers draw supplies of flour from more than one miller and, even if one miller sends out uninfested flour, his sacks may get infested from other flour and from the endemic population in the bakery. The kinds of insects which turn up regularly in empty sacks are those which cause the most trouble in the mill. In effect, however, the miller is only really getting back his own pests in a more advanced stage and unless he is making a real effort to send out pest-free flour he has no justifiable complaint. The problem can be tackled in more than one way. All the sacks could be fumigated or treated by heat, in ways described elsewhere in this pamphlet, as a routine measure before they are cleaned. If this were done the main objection to the transfer of flour dust from the sack cleaner to the mill would be removed. Flour may be sent out in non-returnable sacks ; some millers who adopted this practice reported a considerable reduction in the extent of infestation in their mills. Millers who supply flour almost exclusively to large scale bakeries and to biscuit manufacturers, who extract every ounce of flour from the bags before they are returned, report that they rarely find insects in these sacks.

IN WHEAT. The kinds of insects found in the wheat have been described elsewhere in this pamphlet and it will be seen what a serious source of mill insects the wheat represents. The miller generally has little control over the general nature of the infestation in the wheat, but in view of the menace which mite or insect infested wheat represents, millers might well bear in mind the desirability of some kind of routine treatment of wheat either prior to shipment or on arrival in this country.

IN IMPORTED WHITE FLOUR AND FLOUR FOR RECONDITIONING. The insects and mites which are liable to be introduced into flour mills on imported white flour have been described on page 66. It would appear to be a common practice to pass the imported flour only over a screen of about 14 mesh before it is blended with the finished flour. This is liable, in particular, to lead to heavy mass infection of finished flour with mites, especially the flour mite, *Tyroglyphus farinae*. Although the young stage of mites cannot be removed by screening the advisability of passing all suspected of infestation flour through a 10 XX mesh before mixing in should be considered, as this will remove all stages of insects and all except the eggs and young larvæ and nymphs of mites.

IN OTHER SOURCES. Other sources, of secondary importance, include the following. Where mills are placed close together, and near warehouses, provender and oilseed mills, there is a danger that moths (especially *Ephestia kühniella*, the mill moth) and certain beetles may *fly or crawl* from one building to another, or from building to building within the one unit mill. Where a flour mill also carries out provender milling and compounding there is a grave danger of insects reaching the flour mill from the provender, either by flight or by the actual passage of material and bags. It is known that insect and mites and their eggs can be carried on or in the clothing of operatives. Finally, there is the possibility of introduction on secondhand machinery brought from another mill.

LIST OF PLATES

LIST OF TEXT FIGURES

INDEX

(References to plates in heavy type ; to text figures in italics.)

Sources of Information

For further information on the subject of the infestation of stored products reference may be made to the published literature, a list of the more important papers being given later in this section. Advice and assistance on various infestation problems which arise from time to time in the course of his business may be obtained by the miller from the following four principal sources.

Cereals Research Station.

For general advice on milling problems enquiries should be directed in the first place to the Research Association of British Flour Millers, Cereals Research Station, Old London Road, St. Albans, Herts. The staff of the Station work in close co-operation with other organisations more directly concerned with infestation problems and are often in a position to direct the miller's initial enquiry to the proper place for an answer.

Natural History Museum.

Insects may be sent for identification to the Keeper of Entomology, British Museum (Natural History), Cromwell Road, South Kensington, London, S.W.7. They should be securely packed so that they cannot get damaged in the post.

Infestation Division, Ministry of Food.

Advice and assistance in dealing with problems of control which arise in the course of normal milling operations and in connection with periodic treatments of mill premises can be obtained by application to the Director of Infestation Control, Ministry of Food, Infestation Division, 58, High Holborn, London, W.C.1, or to the nearest Infestation Inspector of the Division.

Pest Infestation Laboratory.

Long term research work on various aspects of infestation problems is the responsibility of the Pest Infestation Laboratory of the Department of Scientific and Industrial Research ; this laboratory is situated in London Road, Slough, Bucks., and enquiries should be addressed to the Director.

LITERATURE

Some of the books referred to in the following list may be purchased readily through any bookseller or borrowed through local public libraries from the National Central Library. Some millers may have access to University or Technical College libraries in which they may be found. The following specialist libraries may, however, be found, in practice, to be the best sources. The Science Library, Science Museum, South Kensington, London, S.W.7, and the Library of the Imperial Institute of Entomology, 41, Queen's Gate, South Kensington, London, S.W.7.

General Entomology.

Outlines of Entomology. A. D. Imms, D.Sc., F.R.S., Methuen, 12s. 6d.

Economic Entomology.

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Report on a Survey of the Infestation of Grain by Insects. Department of Scientific and Industrial Research. J. W. Munro, D.Sc. H.M. Stationery Office, London, 1940. 1s. 3d.

Insects, Ticks, Mites and Venomous Animals of Medical and Veterinary Importance. Part 2. W. S. Patton. 1931. Liverpool School of Tropical Medicine.

Destructive and Useful Insects. C. L. Metcalf and W. P. Flint. 2nd Ed. 1939. McGraw Hill Book Company, Ltd., London.

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Insect Pests in Stored Products. Hayhurst and Britten. Chapman and Hall, London. 1940.

Die Vorrats-, Speicher-, und Materialsschädlinge und ihre Bekämpfung. F. Zacher. 1927. Paul Parey, Berlin.

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Common Pests of Grain and other Stored Produce. Department of Scientific and Industrial Research. H.M. Stationery Office, London, 1939. (Out of print.)

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Common insect pests of stored food products. (A guide to their identification). H. E. Hinton and A. S. Corbet. British Museum (Natural History), Economic Series No. 15.

A monograph of the beetles infesting stored products. H. E. Hinton. British Museum (Natural History). 1945.

Insect pests of food. (1) The larvæ of the Lepidoptera associated with stored products. H. E. Hinton. (2) Keys for the identification of the Lepidoptera infesting stored food products. A. S, Corbet and W. H. T. Tams. H.M. Stationery Office. (Out of print.)

Tyroglyphid mites in stored products. 1. A survey of published information. M. E. Solomon. Department of Scientific and Industrial Research. 1943. 9d. Supplement 1944. 2d.

Insects found associated with cacao, spices and dried fruits in London warehouses. O. W. Richards and G. V. B. Herford. Annals of Applied Biology, Cambridge, Volume 17. No. 2. May, 1930.

Insect Pests of Food. (3) The larvæ of the Ptinidæ associated with stored products. S. M. Manton. (4) The Histeridæ associated with stored products. H. E. Hinton. H.M. Stationery Office. 2s. 6d.

The Ptinidæ of Economic Importance. H. E. Hinton. Bulletin of Entomological Research, Vol. 31, Part 4, January 1941.

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