Hull, R. (1959). *Plant Path.* **8**, 145.
Hull, R. (1960). *Brit. Sug. Beet Rev.* **28**, 113.
Hyslop, J. A. (1938). Losses Occasioned by Insects, Mites and Ticks in the United States. U.S.D.A. Bureau of Entomology and Plant Quarantine. Publ. E444.
Jones, F. G. W., Dunning, R. A. & Humphries, K. P. (1955). *Ann. appl. Biol.* **43**, 63.
Massee, A. M. (1956). *Proc. int. Congr. Ent.* x. *Montreal*, **3**, 163.
Mudie, F. (1955). Report of the Commission on the Desert Locust Control Organisation. Nairobi: East African High Commission.
Ordish, G. (1952). *Untaken Harvest.* London: Constable.
Ripper, W. E. (1956). *Annu. Rev. Ent.* **1**, 403.
Strickland, A. H. (1957). *Plant Path.* **6**, 1.
Symes, C. B. (1954). *Colston Pap.* **6**, 11.
Teisseire, M. (1960). La Lutte Antiacridienne dans les Départments Français d'Algérie et du Sahara au Cours de la Campagne 1958–9. Unpublished Report from Chef du Service de la Protection des Végétaux de l'Algérie.
Uvarov, B. P. (1951). *Colon. Res. Publ.* no. 10.
Way, M. J. (1959). *N.A.A.S. Quart. Rev.* no. 46, p. 60.
Way, M. J., Bardner, R., Van Baer, R. & Aitkenhead, P. (1958). *Ann. appl. Biol.* **46**, 399.

Losses resulting from the infestation of stored products by insects

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My purpose in presenting this paper is not to provide a comprehensive survey of the extent and types of damage sustained by stored foodstuffs as a result of insect attack, nor to deal with the methods available for combating these losses. Both of these aspects have been covered by Parkin (1956).

In the short space available I would like to draw attention to the scale on which foodstuffs may be damaged by insects, the irrevocable nature of these losses, the problems attendant upon their assessment and, as far as possible, to indicate the progress that has been made towards their reduction. The problem of feeding the increasing world population is almost invariably considered in terms of increasing food production; very rarely is recognition given to the need for conserving our harvested crops for human as opposed to insect consumption. The few estimates that have been prepared on a global or continental scale indicate the short-sightedness of this attitude. FAO: Expert Committee (1946) published an estimate of 5% loss annually through insect infestation of all harvested cereals, peas, beans and oilseeds, equivalent to one-half of those products entering into world trade. This was officially considered to be a conservative estimate.

Insects, being cold-blooded organisms, will be more active and will cause most damage in tropical and subtropical countries, and where favourable climatic conditions are linked, as they often are, with a poorly organized pest-control system the consequences can be very serious indeed. Thus an on-the-spot study made by a Working Party of the United Nations (United Nations: Department of Economic Affairs, 1950) showed that the average losses sustained by six Latin American countries amounted to as much as 35% of cereals and pulses during storage each year. Even in temperate and more highly organized countries the insect damage to harvested crops is often very great; of the grain harvested in the Great Plains region of the United States, 10% is said to have been lost during one season's storage; and maize grown in the southern United States may lose up to 9% of its weight per month of storage (Cotton, 1950), which agrees with a figure of 50% loss of maize stored during one summer on farms in Alabama (Eden, 1953).

These general estimates of losses are fully supported by the results of scientifically controlled storage experiments. For example, in the Belgian Congo after 1 year's storage, the loss of weight resulting from insect attack was, for sorghum 50%, for beans 20 and for groundnuts 15 (Scientific Council for Africa South of the Sahara, 1957). During a similar period an experimental stack of par-boiled paddy, in Sierra Leone, lost 25% by weight (Scientific Council for Africa South of the Sahara, 1957). These figures do not take into account the weight of insects and of insect frass. These can be highly significant, as is shown in an experiment in which parboiled paddy was stored under infested conditions in Sierra Leone for 1 year. The apparent loss during this period was 25·5%, but after sieving the figure rose to 41% (Scientific Council for Africa South of the Sahara, 1957). Similarly, 3000 bags of maize, infested by *Trogoderma granarium* and stored for 2 years in Nyasaland, showed an apparent loss of 7% which, after sieving, rose to 14% (Scientific Council for Africa South of the Sahara, 1957). The list could be extended, but the examples quoted should be sufficient to emphasize the magnitude of the problem.

The damage inflicted by insects to growing agricultural plants is essentially different from that done to the harvested crop, inasmuch as early damage to a field crop may be compensated for by an increased yield from the surviving plants. No such compensation can occur when the harvested crop is the object of insect attack. Moreover, in agriculture the damage has to be estimated in terms of what might have been produced, whereas with stored products the losses are real and can be assessed as a proportion of something that has actually existed.

Estimates of damage such as those that have been referred to above are usually based on measurements of weight reduction and may be described as a direct loss. In passing, it may be noted that a reduction of weight resulting from insect attack may be partially or even completely masked by an uptake of water from the atmosphere during storage in a humid environment.

There are, however, less obvious ways in which foodstuffs may be damaged by insects, and such damage is often much more difficult to assess. Some cereal pests, for example mites and certain moth larvae, have a predilection for the germ, and it is not uncommon to find a high proportion of infested grains with the germ completely eaten away, while the endosperm has remained untouched. The percentage weight loss in such circumstances would be very small by comparison with the loss of nutritive value, and the effect on the germinative capacity of seed grain or malting barley is disastrous.

Infestation may have other serious effects on the quality of the foodstuff or on its processed end-products. P. Prevett (unpublished report) has summarized the literature on the effect of infestation on the thiamine content of rice. The few references bearing directly on this topic clearly show that loss of thiamine is greater during storage if the rice is infested. Thus Pingale, Kadkol, Narayano Rao, Swaminathan & Subrahmanyan (1957) report average losses of thiamine, from infested rice stored for 8 months, 10–15% greater than that sustained by uninfested samples stored for the same period.

One of the most serious effects of the infestation of groundnuts by beetles such as *Tribolium casteneum* and *Trogoderma granarium* is the marked increase in free fatty acid (f.f.a.) in the oil from infested nuts. This may be partly due to enzyme action, but more probably results from the reduction of the whole nuts to smaller particles with a correspondingly greater area exposed to oxidation. Thus in an experiment in which infested and uninfested groundnuts were stored for 13 months in Nigeria, the initial f.f.a. content of both lots was about 1%; after 13 months the f.f.a. content of the uninfested lot was: whole nuts, 6%; halves and brokens, 10%. The infested parcel gave significantly higher results: whole nuts, 18%; halves and brokens, 28·5% f.f.a. (Hayward, 1953–4).

Most important, however, of all the forms of indirect damage to foodstuffs that can result from infestation is the phenomenon of heating, and all the troubles that it can cause. Although it may be experienced in a wide variety of different types of commodity, it is perhaps most commonly noted in grain, and it may be useful to consider in some detail how it is that insects can cause grain to become heated.

It is well known that when grain is stored in bulk at a high moisture content, at or above 17%, it will, by its own enhanced respiration, produce more heat than can be dissipated to the outside. Hot moist air rises through the grain by convection until it is cooled in the upper layers, thereby increasing in relative humidity and imparting moisture to the surrounding grain near the surface. Temperatures up to 60° are frequently reached, and the translocation of moisture will cause germination and even rotting of the upper layers of the grain. This phenomenon, which we may refer to as 'damp grain heating' is fully recognized and feared by the grain trade. What was not realized until comparatively recently is the fact that dry grain, i.e. with a moisture content of, say, 11–15%, which traditionally is regarded as suitable for safe bulk storage, can also suffer damage by heating if it is infested.

No bulk of grain is ever completely homogeneous, and insects will tend to congregate in damper or in warmer patches or in both. The heat generated by their activity, though relatively small, remains localized and stimulates the insects to greater activity. This self-accelerating process proceeds until the temperature in the 'hot spot' reaches the thermal death point for the insects, about 42°, killing all immobile stages and driving the remainder of the insects to the periphery of the heated zone. In this way the hot spot expands throughout the bulk of the grain and links up with others that may have been developing. Convection currents are formed within the grain bulk, with consequent translocation of moisture to the upper cooler layers. In fact, in the absence of systematic temperature measurements, the appearance of patches of germinating grain on the surface of a bulk may be the first indication of the existence of trouble below. It is typical of dry grain heating by insects that the temperatures do not rise significantly above 42°. This temperature is not sufficient to cause damage to the grain, the real losses resulting from water translocation to the upper layers and, more particularly, from the weight of grain consumed by the insects. It is noteworthy that the grain that has been subjected to 'insect heating' has the infestation confined to the outer cooler layers of the bulk, the inner portions being effectively 'heat sterilized'.

So far we have been considering the heating of bulk grain but the same phenomenon can also occur in tightly built stacks of bagged grain. Some years ago in East Africa weevil infestation of very large stacks of bagged maize was causing heavy losses. In an attempt to keep the grain as cool as possible the stacks were deliberately built with air spaces between the bags, to allow maximum ventilation. As a result, the interior of the infested stacks never reached lethal temperatures, but was, instead, maintained very near to the optimum developmental temperature, this being only about 10° below the thermal death point. It was accordingly recommended (Oxley, 1950) that the stacks should be built as tightly as possible with the object of inducing heat sterilization and of driving the insects to the periphery where they could be dealt with by insecticides. In view of the high ambient temperatures prevailing in E. Africa it was expected that lethal temperatures would be reached so rapidly that comparatively little grain would be destroyed by the weevils in the process. These expectations were fully realized, and the previous losses, that had been very heavy indeed, were cut by about 50%.

In the last decade considerable progress has been made in the entomology of stored products. As a result of intensive work, in the laboratory and in the field, there exists a solid foundation of knowledge of the bionomics of at least the most important insect pests and considerable experience of control methods.

There is also a slowly growing awareness of the magnitude of the losses such as have been referred to above. This is well illustrated by a comparison of the numbers of qualified entomologists and chemists employed in the colonial and 'emergent' territories on stored-products problems in 1950 and today, namely four in 1950 and thirty-one today. In addition there are now spraying and fumigation teams employing some 300 men. There is, however, no room for complacency. Many problems remain to be solved; new insecticides await evaluation for use on or near to stored foodstuffs and under widely differing climatic conditions; recent advances in the plastics industry suggest many possible uses for plastics as portable storage buildings, fumigation sheets and insect-proof packages; and all too little is known of the possibilities of preventing cross-infestation from one commodity to another, for example, in the holds of ships. Nevertheless the prime need today is for the application of existing knowledge, which if more widely applied would effect savings out of all proportion to the cost of the control measures.

REFERENCES

Cotton, R. T. (1950). *Pest Control*, **18**, no. 10, p. 8.

Eden, W. G. (1953). *Leafl. Ala. agric. Exp. Sta.* no. 40.

FAO: Expert Committee (1946). *Destruction of Food in Storage by Insects, Mites, Rodents and Mold Fungi.* Nu/Wa WP3. Washington, D.C.: Food and Agriculture Organization of the United Nations. (Mimeo).

Hayward, L. A. W. (1953–4). *Annu. Rep. W. Afr. Stored Prod. Res. Unit.*

Oxley, T. A. (1950). *Colon. Res. Publ.* no. 5.

Parkin, E. A. (1956). *Annu. Rev. Ent.* **1**, 223.

Pingale, S. V., Kadkol, S. B., Narayana Rao, M., Swaminathan, M. & Subrahmanyan, V. (1957). *J. Sci. Fd Agric.* **8**, 512.

Scientific Council for Africa South of the Sahara (1957). *Stored Food Products*. C.C.T.A. Publ. no. 31. London: C.C.T.A.

United Nations: Department of Economic Affairs (1950). *Agricultural Requisites in Latin America. Report of the Joint ECLA/FAO Working Party, Lake Success, New York*. U.N. Publ. Sales no. 1950 II.G.I. New York: United Nations.

Disease losses in potatoes

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The diseases of potatoes in Britain (for which see Beaumont, 1959; McKay, 1955; Moore, 1959; Whitehead, McIntosh & Findlay, 1953), are of three main kinds: fungus and bacterial diseases caused by parasitic organisms; virus diseases which, as Bawden (1959) puts it, are aberrations in the nucleoprotein metabolism of the growing plants; and nutritional diseases caused by deficiencies of major and minor elements needed for plant growth. In the consideration of losses it is convenient to take these three types of disease in reverse order.

Deficiency diseases

Potato crops suffer here and there, and fairly frequently on limestone soils, from deficiency of potash. This disorder, which is all too easily mistaken for potato blight, is manifested by a marginal scorching of the leaves, often followed by collapse of the stems and premature death of the plants (Large, Blenkinsop & Le Riche, 1946). The consequence is a reduction in yield, and sometimes a predisposition of the tubers, in association with bruising and other factors, to darken on cooking. Less common, among the deficiency disorders, is manganese deficiency, causing premature yellowing of the foliage and reduction of yield, particularly on fen soils. Deficiencies of other trace elements also occur. No estimate is possible of the losses caused by these troubles, but they exist, and the attention they receive from the soil chemists contributes to the gradual rise in the level of our potato yields over a long-term period.

Virus diseases

The two principal virus diseases of potatoes, leaf roll and rugose mosaic (virus Y), are spread by aphids. In the course of their feeding these insects take sap from the diseased plants and inject it into healthly ones. The sap contains products of the disordered nuclei in the plant cells, and these products derange more nuclei in the plants injected, causing not only a partial breakdown in the normal genetic functioning of the plant, but also the production of more virus by a kind of chain reaction, which spreads from the point of injection into other parts of the plant. Externally the diseases are manifested by various mottlings, crimpings and rolling of the leaves, followed by a general reduction in the whole vigour of growth. The viruses go down into the tubers and if these are planted for seed an enfeebled crop is produced in the following year. As the viruses spread to more and more plants in a potato stock it is said to 'run out' or degenerate. The virus diseases affect the growing plants and