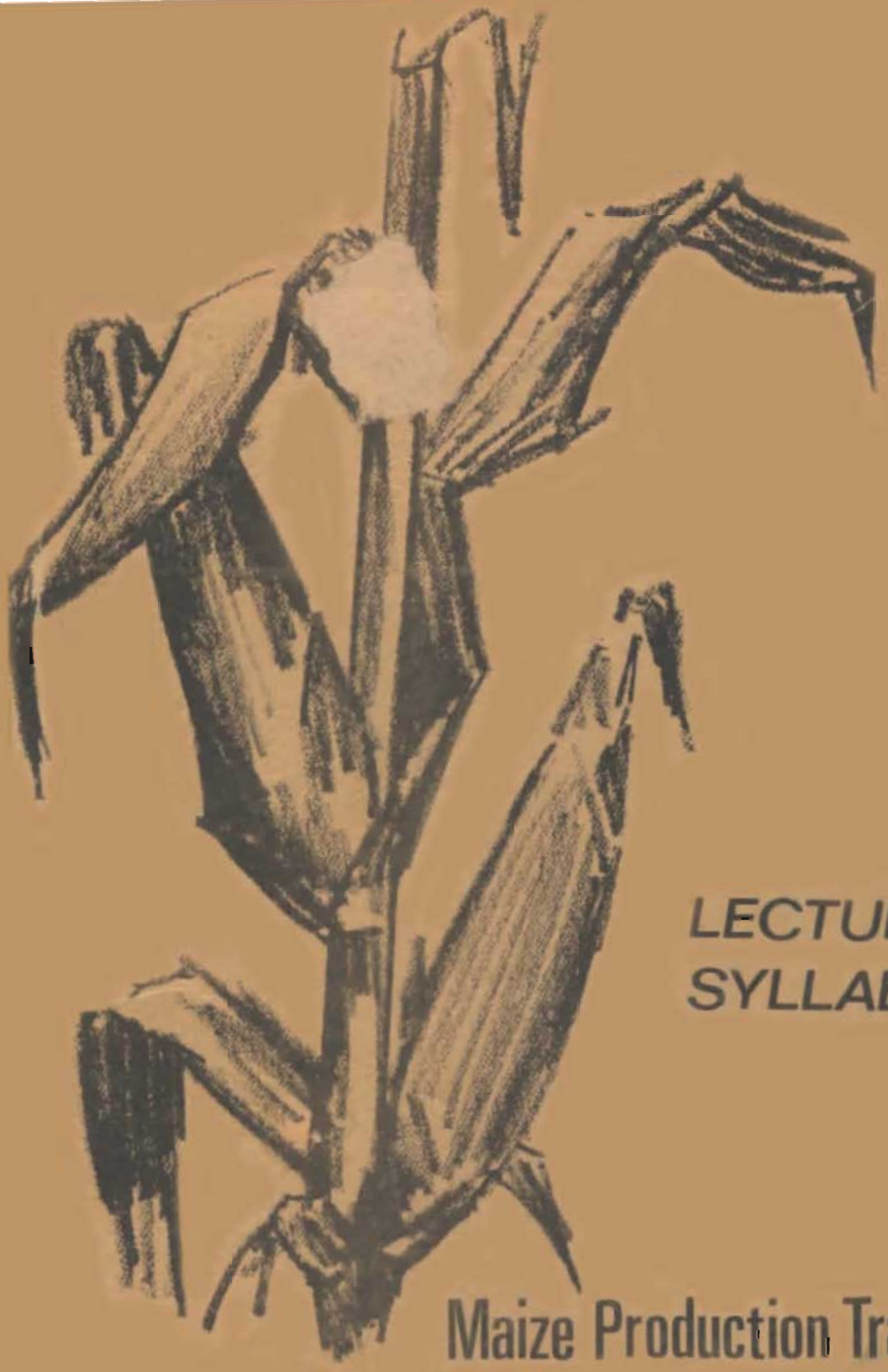

LECTURE SYLLABUS

Maize Production Training Course 1974

International Institute of Tropical Agriculture, Ibadan, Nigeria

VI. BIOCHEMISTRY OF MAIZE

ANALYSIS AND PROPERTIES OF THE MAIZE KERNEL

Properties of the Maize Kernel: A study in Nutritional Quality

Lecture given 12 July 1974 to IITA Maize Production Course

by

Dr. R.A. Luse

OUTLINE

A. Maize kernel morphology

B. Proximate composition of the kernel

Water, oil, protein, starch, etc.

C. Comparison of normal and "high lysine" maize

Protein content, amino acid composition (Table 1)

D. Biochemistry of storage protein maize

Storage proteins in normal and "high lysine" maize (Table 2)

E. The nutritional quality of "high lysine" maize

Protein utilization in children fed normal and opaque-2 maize (Table 3).

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Table 1. Amino Acids in the Defatted Endosperms of Normal and Two Mutant Stocks.

Amino acid	Normal	Opaque	Floury
		g/100g of protein	
Lysine	1.6	3.7	3.3
Trytophan	0.3	0.7	0.8
Histidine	2.9	3.2	2.2
Arginine	3.4	5.2	4.5
Aspartic acid	7.0	10.8	8.1
Glutamic acid	26.0	19.8	19.1
Threonine	3.5	3.7	3.3
Serine	5.6	4.8	4.8
Proline	8.6	8.6	8.3
Glycine	3.0	4.7	3.7
Alanine	10.1	7.2	8.0
Valine	5.4	5.3	5.2
Cystine	1.8	0.9	1.8
Methionine	2.0	1.8	3.2
Isoleucine	4.5	3.9	4.0
Leucine	18.8	11.6	13.3
Tyrosine	5.3	3.9	4.5
Phenylalanine	6.5	4.9	5.1
Protein, %	12.7	11.1	13.6

Table 2. Protein fractions found in defatted endosperms of normal and "high lysine" maize

Genotype	Fraction: Albumins	Globulins	Prolamins	Glutelins
Normal				
Wt. of fraction*	53.8	28.2	775.2	447.6
% of total protein	3.8	2.0	55.1	31.8
Opaque-2				
Wt. of fraction	152.5	64.3	288.5	629.0
% of total protein	12.1	5.1	22.9	50.1
Floury-2				
Wt. of fraction	123.3	92.6	370.7	54.3
% of total protein	9.6	7.3	29.0	40.8

* Expressed as mg/10g of ground meal.

Table 3. Protein Utilization in Children Fed Local and Opaque-2 Maize

	Local Maize	Local Maize + Lys + Try	Opaque-2 Maize
Corn intake g/day for 5 yr. old children in Guatemala	130	130	130
Protein intake from corn, g	10.4*	10.4*	13.4**
Minimum protein required, g***	15.4	15.4	15.4
Biological value,%	32	55	69
Utilizable protein, g	3.3	5.7	9.2

* Protein content, 8%
** Protein content, 10.3%
*** Biological Value of 100%

VII. PLANT PROTECTION

1. MAIZE DISEASES, THEIR CAUSES AND CONTROL

2. MAJOR INSECT PESTS OF MAIZE AND THEIR CONTROL

PLANT - PARASITIC NEMATODES ON MAIZE

by

F. E. CAVENESS

PLANT - PARASITIC NEMATODES ON MAIZE*

Introduction

In this world of living things nematodes are probably the most numerous amongst multicellular animals. In a rich soil or ocean mud flat as many as 14,000 million nematodes could be living in a single hectare.

Nematodes are sometimes known as eelworms or roundworms and live wherever there is food to support life from tree tops to ocean depths, hot deserts to polar ice, hot springs to chilled mountain streams, and, of course, agricultural soil and plant roots. Except for what they do as plant parasites, nematodes are seldom noticed because of their small size and hyaline appearance. Some of the nematodes inhabiting soil and water feed on bacteria, fungi and algae as well as other small animals, including other nematodes. Many soil-dwelling nematodes feed only on higher plant forms causing disease or functioning as an active agent in a disease complex with bacteria or fungi. Some nematode species harbor and transmit virus diseases of plants. Virtually every plant and crop has its nematode parasites and some nematodes are parasitic on many crops. Crops are affected by nematode kinds and numbers with the interplay of environmental factors as soil type, fertility, moisture and temperature.

Plant-Parasitic Nematodes Associated with Maize Plants. Considering that maize is one of mankind's major sources of protein and carbohydrate and is a major factor in the economies of some countries the study of nematode pests of the maize plant has received scanty attention. Only minor segments of the world's maize growing areas have been explored for plant-parasitic nematodes. The nematode species and their locations reported in the literature are listed in Table 1.

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* By: Dr. Fields E. Caveness
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Table 1. Plant-parasitic nematodes on maize with their reported geographical distribution.

Nematode	Location
Belonolaimus gracilis	USA
Ditylenchus dipsaci	Argentina, Africa, (north & south) Australia, Belgium, Brazil, Canada, France, USA, USSR, West Germany, Yugoslavia
Dolichodorus heterocephalus	USA
Gymnotylenchus zeae	India
Helicotylenchus cavenessi	Egypt, Nigeria
Helicotylenchus digonicus	USA
Helicotylenchus dihystera	USA
Helicotylenchus microcephalus	Nigeria
Helicotylenchus pseudorobustus	Nigeria, USA
Hemicycliophora parvana	USA
Heterodera avenae	Canada, France, India, USSR
Heterodera punctata	Mexico
Heterodera zeae	India
Hoplolaimus galeatus	USA
Hoplolaimus indicus	India
Hoplolaimus seinhorsti	Malagasy Republic
Longidorus maximus	West Germany
Meloidogyne arenaria	USA
Meloidogyne incognita	India, Nigeria, USA
Meloidogyne javanica	USA
Meloidogyne thamesi	South Africa
Paratylenchus projectus	USA
Pratylenchus brachyurus	Brazil, Nigeria, Rodesia, USA
Pratylenchus crenatus	USA
Pratylenchus delattrei	India, Malagasy Republic
Pratylenchus minyus	Canada
Pratylenchus hexincisus	USA
Pratylenchus loosi	Sri Lanka
Pratylenchus penetrans	Canada, Japan, USA
Pratylenchus scribneri	USA
Pratylenchus thornei	Europe
Pratylenchus zeae	India, Panama, Puerto Rico, USA
Radopholus similis	USA
Rotylenchus reniformis	USA (Hawaii)
Scutellonema clathricaudatum	Nigeria
Trichodorus christiei	USA
Trichodorus porosus	Puerto Rico

Nematode	Location
Tylenchorhynchus brevidens	USA
Tylenchorhynchus claytoni	Puerto Rico, USA
Tylenchorhynchus dubius	USSR
Tylenchorhynchus mixtimus	USA
Tylenchorhynchus zeae	India
Xiphinema americanum	USA

Pratylenchus spp., The Root-Lesion Nematodes

Disease. Pratylenchus spp. attack the root systems of maize causing a reduction in the numbers of fine feeder roots. The larger coarse roots show symptoms of lesions and frequently a rot from secondary invaders. Often maize grown on soils heavily infested with the root-lesion nematode will not show any symptoms to the casual observer although yields are being reduced.

Crop Losses. The root-lesion nematode can reduce maize grain yield 25% or more even when above ground symptoms are absent. The general reduction in the efficiency of the root system becomes a plant growth-limiting factor.

Biology. Root-lesion nematodes are termed migratory nematodes as all stages, adults and juveniles, enter and leave roots or move about within roots. Nematode development and reproduction occurs at no fixed site. Mature females deposit eggs within root tissue or in soil. Generally the life cycle takes from twenty to sixty-five days depending on the species. One or two eggs may be laid per day which may hatch in as little as five or more than sixteen days.

Symptoms. Symptoms are characterized by growth limitations imposed by the root-pruning effect of root-lesion nematode attack. Small feeder roots are destroyed or prevented from developing. Cortical lesions, small initially, enlarge by nematode feeding at the lesion periphery. Other organisms become involved as secondary invaders. Greatly enlarged lesions result in complete girdling destroying the function of the root.

Other Host Plants. Root-lesion nematodes have a broad host range covering field crops, vegetables, fruit and tree crops, ornamentals and many weeds. The host list for individual species of Pratylenchus would be lengthy but not all plants are equally good hosts. P. brachyurus, P. crenatus, P. delattrei, P. hexincisus, P. loosi, P. Neglectus, P. penetrans, P. scribneri, P. thornei, and P. zeae have all been reported as parasites of maize.

Distribution. Root-lesion nematodes are common in cropped soils and worldwide in distribution. P. brachyurus, P. coffeae and P. zeae reportedly only occur in the world's warm regions while the others appear in the cooler zones or in higher altitudes in the tropics.

Control. Control measures include crop rotation with poor host or non host crops. Weed control during and between maize crops would be of great benefit. Root-lesion nematodes are effectively killed by soil fumigants but the economics of their use pretty well remove them from consideration.

Belonolaimus gracilis, The Sting Nematode.

Disease. Belonolaimus gracilis causes stunting of maize especially in light sandy soils. Maize plants severely stunted in the seedling stage of growth do not recover resulting in reduced or no yield in grain. The nematode feeds ectoparasitically along succulent roots and on root tips inhibiting apical root growth. Cells in attacked root tips, including meristematic cells, become mature, enlarged and vacuolate. Root tips may become distorted and destroyed in soils with dense populations of B. gracilis. Injured roots have dark, shrunken lesions along the root axis and at the tip. Lesions in an advanced stage of development may girdle the root destroying that portion of the root below the lesion. It is characteristic in maize for proliferation of roots to occur above the injured areas.

Crop Losses. Grain loss may be total or nearly so in stunted plants which usually occur in spots in infested fields. In fields with older infestations and a history of cropping favorable to the sting nematode the spots may have increased in size and have become so numerous as to cover the entire area.

Biology. B. gracilis is primarily an external parasite of maize roots. Feeding and reproduction take place outside the root. Feeding is generally at root tips and along the sides of succulent roots. The more dense populations are found in light sandy soils which provide a more favorable habitat than heavier soils.

Symptoms. Sting nematode injury to roots usually is characterized by a lack of small feeder roots leaving the large coarse roots. The coarse roots often terminate with gall-like enlargements caused by the repeated forming of new rootlets and their tips then being killed by the sting nematode. Above ground symptoms are retarded growth seen frequently as spots throughout the field with little or no recovery of the more heavily attacked plants.

Other Host Plants. B. gracilis is a parasite of numerous economic plants of which pepper, groundnut, mellons, soybean, cotton, beans, cowpea, and strawberry are among the more important.

Distribution. B. gracilis is known to occur only in the south-central and eastern states of the United States of America.

Control Measures. The sting nematode can be effectively controlled by the use of soil fumigation although the economics of chemical control generally restricts their use in maize and other low value crops. Cultural control involving non host crops in the cropping sequence depress field populations of the sting nematode.

Ditylenchus dipsaci, The Stem Nematode.

Disease. Ditylenchus dipsaci, the stem nematode (also known as the bulb and stem nematode) is an endoparasite that invades parenchymatous tissues. Mechanical injury is generally slight. Plant damage results from the effects of nematode salivary secretion on the cells of invaded tissue. Infected plants may exhibit basal swelling, dwarfing and twisting of stalks and leaves.

Crop losses. Grain yields are reduced or no grain is produced in plants distorted and stunted by the stem nematode. Destruction of tissue in the stem base may cause toppling and broken stems in heavy winds.

Biology. D. dipsaci invades the plant at the base of the stem and the foliage. Salivary secretions containing pectinase results in the breakdown of middle lamellae between cells causing cells to separate forming enlarged intercellular spaces in which the nematodes live. The nematodes migrate within the tissues and feed on cell contents. Localized cell hypertrophy and hyperplasia result in basal swelling, twisting of stalks and leaves and dwarfing of the plant. Cell destruction in the stem base may reduce root development resulting in broken stems and lodged plants when exposed to high winds.

The stem nematode lives as an internal parasite in the stem and leaves of maize and is rarely found in roots. The nematode may proceed through several generations within the host emerging to enter the soil when unfavorable living conditions develop within the plant. Depending on temperature, host suitability and other factors development from egg to sexually mature adults take twenty- four to thirty days. One female stem nematode lays about 200 eggs during her life time. When adverse conditions are encountered larvae pass into a quiescent state. This quiescent state gives protection from high or low temperatures, by-products of decay and, particularly, drying. Stem nematode larvae have been revived after being stored in a dry state for a period of several years. Stem nematode in

survival in moist soil in the absence of a host plant is eighteen to twenty-four months.

Stem Nematode 2

Symptoms. Plants are stunted, internodes are shortened and leaves and stalks are twisted, deformed and puffy. Root development is often reduced so that winds are frequently a factor contributing to crop loss. Plant tissue may become brittle with premature drying before harvest.

Other Host Plants. About 375 different host plants have been reported for the stem nematode. The presence of biological races often restricts the transfer from one host plant to another. The "rye strain" of the stem nematode attacks maize, oats, marigold, bean, pea, tobacco, onion, flax, clovers and a number of weeds.

Distribution. D. dipsaci has been reported from North & South Africa, North & South America, Europe, Australia and Siberian USSR.

Control Measures. Stem nematode control involves sanitation, cultural practices including crop rotation and weed control, the planting of clean seed and soil free of the nematode.

Miscellaneous Plant-Parasitic Nematode Associated with Maize.

As noted in Table 1, there are numerous other species of plant-parasitic nematodes associated with and attacking maize. Some species are only of importance in local situations while little is known of other species. Investigations in Ibadan, Nigeria have shown Zea mays to be an excellent host for three species of the spiral nematode and the root-knot nematode is commonly observed in field planting of Zea mays.

Techniques in Nematology

1. Sampling soil and plants for plant-parasitic nematodes.

Soil and plant roots are sampled to determine which species of parasitic nematodes are present and to estimate their numbers. Ectoparasitic nematodes (nematodes living outside the roots and in the soil) are concentrated in the vicinity of the small feeder roots. The roots contain endoparasitic nematodes (nematodes that spend most or all of their lives feeding and reproducing within plant roots). About 200 cm^3 of soil and about 5 g of roots are adequate and convenient for examination for the presence of plant-parasitic nematodes. Soil should be taken from the root zone of the plant and a portion of the root system can be taken without damage to the whole plant. The very nature of nematodes concentrates them at points of food supply. This applies to nematodes that are free living as well as plant parasities. This fact results in an uneven or spotty distribution of nematodes in the field resulting in the need to take several samples at different locations.

A variety of tools can be used for collecting samples. These include soil augars, soil tubes, spades, digging forks, mattocks, machettes, garden trowels and even a stick if nothing else is available. Plastic bags are useful for collecting and storing samples as they prevent drying of soil and roots. Care should be taken to keep collected samples in the shade at all times as excessive heat will kill the nematodes. Samples should be processed as soon as possible but can be stored for a few days if kept from drying and in a cool place.

2. The isolation of nematodes from soil and root samples.

The isolation of plant-parasitic and other nematodes from samples is the separation of the nematodes from soil and plant tissue so they can be seen, identified and numbers estimated. Several procedures have been developed to accomplish this separation. No one procedure is perfect as all methods have advantages and disadvantages.

Baermann funnel method. The Baermann funnel method was described by Dr. G. Baermann in 1917 and has been widely used with various modifications ever since. A modification by Whitehead and Hemming in 1965 overcame a disadvantage of poor oxygenation and is the procedure described here.

A filter of facial tissue, table napkins with "wet strength", nylon or terylene cloth, paper towels or similar material is supported by plastic mesh or a plastic sieve (metal objects may be toxic to nematodes) in a plastic tray or basin. Soil is thinly spread on the filter and water is added to the tray sufficient to wet but not flood the soil. The soil is left overnight or longer. The tray should not be disturbed to avoid turbidity. Most nematodes, by means of their activity, will migrate through the filter and, being heavier than water, will sink to the bottom of the tray. The plastic sieve must be removed carefully and quickly to obtain a clear nematode water suspension. Do not drain the plastic sieve into the tray. The water suspension from the tray containing the nematodes is poured into a plastic tumbler and left standing for about four hours. Excess water is carefully decanted leaving the nematodes in about 50 ml of water. The nematodes can now be examined under a microscope or preserved.

Nematodes can be isolated from plant roots (and other plant tissues) by using the same procedure and same equipment. If a Blendor is available the plant roots can be comminuted for 15 seconds then poured onto the filter. Good results can be obtained by cutting roots into 3 to 5 mm segments and placing on the filter.

3. Storage of nematode suspension.

Most nematodes can be stored in a refrigerator for days without deterioration or contamination. Growth of microorganisms can be retarded by adding 3 drops of 5 per cent streptomycin sulphate solution for each 5 ml of nematode suspension. The best procedure is to examine them promptly or kill, fix and preserve them.

4. Killing and fixing nematodes.

Concentrate the nematodes in a few ml of water by allowing them to settle in a glass vial or similar vessel and decanting the excess water. Plunge the vial into a beaker of water heated to 65°C for about 2 minutes. After the nematodes are dead add an equal volume of fixative. Most nematodes can be stored satisfactorily in fixative for an indefinite period.

Nematodes can be fixed and preserved in formalin or TAF solution.

Formalin fixative:	formalin (40 percent formaldehyde)	8 ml
	Calcium carbonate ($CaCO_3$)	pinch
	distilled water	92 ml
TAF fixative:	formalin (40 percent formaldehyde)	14 ml
	triethanolamine	4 ml
	distilled water	82 ml

5. Additional information.

Southey, J.F. 1970. Laboratory methods for work with plant and soil nematodes. Ministry of Agriculture, Fisheries and Food. Technical Bulletin no. 2. Her Majesty's Stationery Office, London. About US$3.00.

Taylor, A.L. 1971. Introduction to research on plant nematology. Food and Agriculture Organization of the United Nations, Rome. About US$3.50.

O.A.U./S.T.R.C. Cereals Research Conference,
I.I.T.A. July 1974

Ten Years Of Major Cereals Research

by

K.R. Stockinger,

Soil Scientist, JP 26 Samaru, Nigeria.

The major Cereals Project, JP 26, started functioning 10 years ago with the arrival of Drs. Webster and Futrell. The project was to apply the coordinated research team approach to the agronomic, disease, and pest problems of cereal production in West Africa. The team has expanded to include one plant breeder, two pathologists, one entomologist, a soil scientist, and a seed production specialist. Our project is phasing out in 1975 and hopefully the continuity of much of our work will be carried on by substations in West Africa of the International Crops Research Institute for the Semi-arid Tropics.

In the next few minutes I will attempt to summarize the activities of the project and indicate pressing problems which still remain. I will do this on a crop basis rather than by disciplines.

MAIZE

Little if any maize is grown in the northern Guinea Savannah. When Dr. Webster arrived, he was told that this was because it was too dry. However, the rainfall at Samaru is similar to the annual rainfall in the heart of the American corn belt but it is all concentrated into the growing season. Trial plantings at Samaru showed that excellent crops could be grown if nitrogen and phosphorus fertilizers were applied but only 100 to 500 kg/ha without fertilizer. The maize that is grown in this region is usually eaten green and is grown close to the compound where extra fertility from the refuse is available.

Without extra nitrogen and phosphorus, maize yields are less than that of sorghum or millet which seem to be able to produce better yields at low fertility levels.

However, maize has a much higher yield ceiling and yields as high as 10,000 kg/ha have been reached at Samaru compared to 5,000 kg/ha for sorghum with ample supplies of nitrogen and phosphorus. For this reason maize breeding and agronomy have received considerable emphasis from the project. If nitrogen and phosphorus fertilizers become easily available to farmers, there is a broad band across West Africa where maize

will be a highly productive cereal crop.

So far there are no serious insect or disease problems on maize in this area except Striga. Striga severely attacks the present varieties of maize and unless a control or resistant variety is found will limit maize growing to areas with little or no striga. It is urgent that resistant varieties be developed as soon as possible. At present there appears to be little or no resistance present in the germ plasm available in Nigeria and it will be necessary to screen the would collection to identify sources of resistance, if they exist, and introduce them into our present breeding material. Plant quarantine restricts the entrance of maize seed into Nigeria from several important maize growing areas of the world. Procedures must be developed to permit the importation of this seed so that the germ plasm becomes available for striga testing and other needs as they arise.

At Samaru the insect and disease problems of maize are not very great. There is some leaf blight and also some Storey streak. The streak can become serious on late planted maize but is not important for maize planted at the usual time. In the south other diseases become more important such as rust and root rot and breeding programs are underway to select for resistance to these diseases.

When maize is used as a food for humans and as a feed for non-ruminants, the quality and quantity of protein supplied becomes very important. Ordinary maize contains about 8 - 10% protein which is low in lysine and tryptophan. However, maize lines have been found which contain adequate levels of lysine and tryptophan. These have been incorporated into breeding programs and have resulted in the release of some varieties such as Western White. Unfortunately these varieties have problems because the seeds dry slowly in the field, the kernels shrivel and are light, and the yield is less than the standard varieties. A breeding program has been started to improve the quality and quantity of maize protein. This is being done by selection within the existing lines of breeding populations by analyzing for high protein content with the Acid Orange 12 dye binding method. Since the dye is bound to the basic amino acids of which lysine is one, using this test will select lines which are high in protein, high in basic amino acids or both. The advantages are that a large number of lines can be screened very rapidly and it will be interesting to see if this technique for testing for recurrent selection of the various populations will produce higher and better quality protein maize.

In 1968 a conference was held at Ibadan in which participants interested in maize breeding in West Africa discussed

the maize composite breeding technique and decided to set up a regional maize composite program. Three composites were set up with material from various maize production centers throughout the world using the combined experience of the participants to select the maize varieties for each of the composites. These were combined to synthesis the formation of the composites at Moor Plantation and NCA was also combined at Mokwa and Samaru. This material now forms the basis of much of the breeding and selection work going on at Samaru, Mokwa, and Moor Plantation by our group.

The composite breeding program now underway in Nigeria is the result of the work done by Dr. Eberhart and Mr. Harrison in East Africa on the techniques involved and the interest of Dr. Eberhart, Dr. Webster and Dr. Craig in getting the program started in Nigeria.

MAIZE IMPROVEMENT : A MULTIDISCIPLINARY APPROACH

Ernest W. Sprague

Introduction

In thinking about integrated crop research and production one must think about the planning, the activities and functions from the time a cross is made in the breeding nursery to production at the farm level. When we think in these terms, it readily becomes evident that all disciplines must be involved.

The term "team approach" has been used to describe this kind of work, but it has become jargon among agricultural research and production workers. Like most such terms it is used in a such a general and excessive way that its precise meaning is lost.

All research groups, be they universities, institutes or Departments of Agriculture, say that they work as a team - they cooperate. Such comments are consistently made without any real thought as to what the comment actually means.

The real situation is that cooperation or the team approach ranges from absolutely no cooperation or antagonism among the different disciplines to truly integrated efforts within the various research organizations around the world. This situation is not unique to agriculture, nor is it correlated with levels of development of nations.

Since the jargon " team approach" has lost its meaning or impact, I shall discuss the subject under the term "integrated research and production."

Organization

How then does one organize a team of researchers in such a manner that will assure the effective performance of all of the functions in the process of developing the variety with insect and disease resistance, and an economic production package ? It seems obvious that the greatest degree of efficiency in terms of time required, monetary costs and staff should be of paramount concern to all responsible for agricultural research and production.

Yet, in far too many situations, we see the entomologist screening and selecting for insect resistance, the pathologist screening and selecting for disease resistance-- and both of these functions are independent of each other and independent of the breeding program. This usually results in a material

resistant to a disease or diseases, but of little value otherwise; the same statement holds true for the entomologist's progress in field tolerance to insects.

The breeder, in turn, develops the variety that is as resistant as natural field infestation and infection will permit, if he takes diseases and insects into consideration in his selection program. As a general statement, the breeder is inclined to do the best he can to take insect and disease ratings--- but, in fact, he does not use them as he bases his selection, recombination, crossing program, etc. on the yield values alone. One can argue, of course, that disease and insects take their toll; thus levels of resistance or tolerance are reflected in yield. Seasons with low incidence of diseases and insects, and escapes will tend to disrupt any uniform influence these characters will have on yield.

People using the above system pride themselves on having developed sources of resistance. In reality, however, to combine this into a superior variety in the breeding program requires another lengthy period of time.

In hybrid programs, the pathologist and entomologist have taken standard lines, put resistance into them, and then substituted these for the original line in the hybrid. This is of course a contribution, but it is not adding genetic potential for yield, per se.

The production agronomist is sitting on the side lines, so to speak, in that he is handed a variety or hybrid that is a fixed entity for which he is to work out the most economical production package. Unfortunately, he looks at his responsibility as one of determining rate of seeding, time of seeding, fertility response, etc.

Plant protection people then watch the occurence of diseases and insects, and try fungicides and insecticides to determine economical packages of plant protection.

Are there not organizational strategies to integrate all of these activities and functions to save time, land requirements, costs, etc. and do a more efficient job ? As an example, why should the entomologists and pathologists have many separate nurseries ? Why should they screen only for insects or for diseases with duplicate nurseries ? Simply because a given disease is important and creates a necessity to screen a large number of materials for resistance does not preclude the possibility of also looking for resistance and tolerance to many other characters, as well as a search for genes for other characters such as grain type, plant type and yield. If programs were truly integrated, every nursery would serve several purposes and would also bring out the interaction of the different diseases and insects.

In the routine breeding nurseries, couldn't the pathologist, entomologist and agronomist work in cooperation with the breeder so that the impact of all of the functions would be part of the selection process ?

It seems quite feasible to select for a wide range of characters simultaneously if the program is integrated and the specialists are working harmoniously together on breeding and pest nurseries.

There are, of course, other functions that are more specifically identified by discipline. Rearing insects for artificial infestation and producing inoculum for artificial inoculation, fall in the area of specifics. Working out methods of inoculation and infestation also are specific. Basically, however, these are simply tools that are used in any well organized research and production program.

Production Level

Where does the production agronomist fit into this integration ? There are a great number of opportunities to impose management practices into the breeding program and at a level that will provide additional criteria for selection.

Thus far, we have only been concerned with integrated research on the experiment station. How does all of this fit together at the farm level ? It seems obvious that in developing a successful production package, all disciplines should be involved. Plant protection at this level is a production function and should be built into the on-farm research program.

In my opinion, varieties and hybrids should be tested in large plots under farm conditions before being released. This system provides three advantages : (1) The larger scale plantings under farm conditions permits one to measure the measure the performance of the variety in conditions under which it is likely to be grown. (2) It brings the farmer and research staff into contact and involves the farmer in research. (3) It forces the researcher off the experiment station and brings him face to face with the realities of production problems at the farm level.

At the farm level, we are not concerned, for example, with testing new insecticides but we should be very much concerned with the rate and number of applications of an insecticide that will give the greatest economic return with the recommended variety, fertility level, etc. Therefore, to really put together the best production package, it seems to me that breeders, entomologists, pathologists are all involved. This is true even though, in general, I would agree that the production agronomist should be held responsible that the work is conducted.

I have touched very briefly on the systems that are more commonly used and suggested the need to integrate all of the functions, and therefore personnel, in

agricultural research and production. Intentionally, however, I have not gone into the many field techniques and systems of management that are required to implement an integrated program. This, I am sure, will be covered by a number of papers that are to follow.

Restrictions to Integration

Perhaps at this point we should ask why, if this integration leads to more efficiency, all programs are not automatically operated in that manner.

Science is a process of evolution, of acquiring knowledge and putting pieces together as they fit. In the early days of scientific endeavor biologists were taught to observe and try to understand what they saw. Later more precise experimentation was employed. Over the years the various disciplines, such as breeding, entomology, pathology and agronomy, became fields of full time study- each in their own right. Now, in 1974, these broad fields have evolved or bi- furcated and specialized to delve more deeply into scientific investigation. This process provides the tools that the applied agricultural scientist need.

Unfortunately, however, administrative systems have not evolved in a parallel fashion with science. Thus, we are still organized administratively on a departmental basis of breeding, pathology; entomology, agronomy, etc. The more fundamental aspects of the disciplines have been spun off into departments of basic biology, etc. This further bifurcation is quite common; however, only in a very few cases have there been an amalgamation of disciplines at the applied level.

This process has left the work of the applied agricultural scientist separated into departments or divisions. They are reporting to different administrative heads and competing by department or division for scarce resources, which in many situations are provided on the basis of the number of projects that can be submitted

They also are endowed with too much professional jealousy and desire to main- tain their disciplinary identification so that they will be counted in the fraternity of their discipline. That is, they must publish-- and the number of articles (pages) seems to be more important to their superior than the actual contribution that they may have made to increasing food production. Further, disciplinary scientific journals (that are over-crowded with articles) have evolved to a point that they will not accept the type of meaningful article that could be written around the applied and integrated work that I am promoting. In other words, our scientific journals have followed the evolution of the fundamental scientists and left the applied oriented cadre without a journal or avenue for publication of their legitimate applied technological material.

In answer to some of the above problems, I argue for the re-organizing of agricultural research on a commodity basis for the major food crops. The immediate counter-argument is that "we cannot afford to have an entomologist spend full time on maize." I ask "Can we afford not to ?" There are several points that will perhaps support my argument. (1) Industrial crop research has traditionally been commodity oriented and has been far more successful than our food crop research and production programs. (2) In many situations, a commodity team organization would not require more people per discipline than already exist within the present departments of divisions, (3) With our population growth rapidly out growing our capability to produce food, we must look for more efficient means of obtaining a great acceleration in the rate of increase in food production very, very quickly if we are to prevent large scale famines.

Simply reorganizing the approach from a disciplinary to a commodity team administrative structure is not likely to result in instant success. Regardless of system or organization, the success or failure still is the product of the people involved. Thus, there is a genuine need for researchers to fully understand the importance of integration and recognize that the coordinated effort of all will lead to greater individual accomplishments for each than would be likely alone.

In an integrated program, cooperation and spirit is essential for success, and by the same token they are the product of dynamic and successful programs.

Besides an integration of effort to increase efficiency, there is a genuine need on the part of most countries to more clearly define their objectives, with a sharper focus on the research and production activities that will assure the greatest pay off in terms of increased production in the shortest possible time.

In other words, we have discussed integrated research efforts without defining the magnitude of work that should be done or the number of people necessary to constitute the team. This obviously will vary from one country to another depending upon the importance and acreage of the crop. The actual team that can be fielded will also depend upon the number of qualified people that the country has to call upon.

With the blend of international, regional and national efforts going into crop improvement, countries with very few well qualified people still have the opportunity to make great strides in accelerated production.

This does not suggest as a long range objective that countries, where the crop is important, should not have a full team for applied research and production. It does argue that in the short range, countries should plan very carefully to apply selectively production systems worked out in other countries with similar physical, cultural and social conditions.

Education and Training

If this approach is correct, and I believe it is, then why should we not look for ways of training and educating students and young scientists in such a systems? The answer is relatively simple-- there are very few opportunities for young or mature scientists to train in such a system, because few are in operation.

To the best of my knowledge, there are few or no educational institutions that are not organized on a fairly strict disciplinary basis. The level of cooperation or integration in educational institutions is dependent upon degree of interest that staff from different departments or divisions have in a common problem, and upon personal relationships. In other words, there is no structure or system that necessarily encourages integration. I am fully aware of the fact that the staff of any educational institution will declare that they cooperate. I ask to what extent they truly integrate and truly support one another across disciplines as I have described here.

Even when projects are written to get special funding, the allocation of the funds, the independent role of each researcher, etc., is spelled out.

Each department offers its own set of courses, yet there are many students who need subject matter that applies across departments. As an example, the severe food shortages and protein malnutrition suggest that agricultural scientists should have a better understanding of the interrelationships and genetic manipulation of cereal protein, cereal protein chemistry, nutrition and its health and social implications. Where can the student find such a course ? He can get a full course in genetics, a full course in protein chemistry, in public health, etc. The student often is without the background or the need for a full course in all these subjects, and he is not likely to be able to synthesize all this material into the meaningful understanding that he needs because they are not taught in that way. Instead, they are taught for the geneticist or the chemist, etc.

This is not to imply that courses in depth are not needed, however, it is to plead for much more consideration of what the student needs and what could be provided by an in-depth approach broadened across disciplines.

In general, postgraduate students are encouraged to follow the same rather narrow area of specialization throughout their entire student program. Often the professors are responsible for this. They encourage students to overspecialize and to follow a single general subject area. As a consequence, the student is inclined to continue to research that particular small area after he finishes his studies. This is particularly disastrous, for example, when students from tropical and developing countries do their advanced studies in Europe and North America on topics that may be totally irrelevant to problems of agricultural production in their home country.

What would be wrong in encouraging students to switch from one discipline to another as they move from one level to another in their educational programs ? Of course, one can argue that he will not be well educated, that he will not be able to compete with students with a high degree of specialization. Is this really true ? Is it possible that he will, in fact, be better educated-- but perhaps not as well trained ? Will he not have a much better appreciation for the interrelationships of causes and effects in biology, and thus be much better equipped to operate successfully in an integrated program.

Perhaps another approach would be a group of students working as a team across disciplines attempting to solve a complex problem involving several aspects of the various disciplines. This would cause them to have to plan and investigate the problem as a group with each contributing his input and at the same time sharing his time and ideas with the others in the group.

It seems to me that students obtaining their education in this way would have a much better understanding of the value of integration and the interdependence between different disciplines than would the student who follows the traditional path of post graduate education.

In no way am I suggesting that agricultural students today should receive less, or a poorer quality of education. I am, however, arguing that perhaps it is time to take stock of the world food an population situation and explore ways of more successfully combating what is sure to be tragedy if rapid increases in production do not occur.

When we look at average production of maize per unit area and at the increase in yield over years one cannot help but be impressed with the failure rather than the success. In other words we have nothing to support the argument that our present system, as understood by most people, will solve our problems. The easy jobs have been done.

To solve the tough production problems that remain, and we do not have much time to do it, requires an imaginative intensification of efforts to develop scientists whose education and training motivate them to work together in evolving a comprehensive production system to increase maize yields. While food production was increasing at a rate faster than population and production problems were simple, the world could afford the luxury of isolated individual efforts/duplications. Today when we have to be concerned with population growth outstripping food production, especially in the poorer countries less capable of competing in the world food grain market, we must improve our efficiency in conducting applied agricultural research as a first step towards improving our efficiency in production.

I have only involved breeding, entomology, pathology and agronomy as disciplines in my discussion. I have done this for simplicity recognizing that many other fields such as chemistry, social science, etc., are important and should be built into the system.

Further I have approached the subject on the basis that applied agricultural scientists are practitioners using the tools that are developed by the more fundamental sciences. I further believe that the applied scientist is one of the most important entities in the complex society of mankind and that he should proudly and boldly pursue the cause of accelerated food production - man's greatest problem today paralleled only by his uncontrolled population growth.

O.A.U./S.T.R.C. Cereals Research Conference,
I.I.T.A. July, 1974

Genetic Resistance To Pests in Maize

by

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Mexico.

CONTENTS. CIMMYT'S INTEGRATED APPROACH IN IMPROVING GENETIC RESISTANCE TO PESTS IN MAIZE

1. INTRODUCTION

CIMMYT's plant protection concept involves a complete integration of plant pathology and entomology. We feel that this linkage is necessary to cope more efficiently with the kinship that exists among pathogens and insect pests.

Particularly in the maize plant, there are several outstanding examples that support this need. We are concerned with maize streak in Africa which is disseminated by leafhoppers; corn stunt which is also spread by leafhoppers in Mexico, Central America and South America; and the cosmopolitan sugarcane mosaic which is propagated by aphids.

There are less well defined, but still close associations in other maize-pathogen-insect relationships. Maize ear and stalk rots can become more prevalent when earworm and stalk borer larvae are abundant.

In considering the above kinds of host plant and pest interrelation our plant protection approach working jointly with breeding and agronomy staff, attempts to produce appropriate pest management practices to reduce pest damage.

Quarantine regulations have in some instances retarded the dispersal of economically important pests, but they are, as implemented now, serious obstacles to a systematic movement and evaluation of new germplasm and new sources of resistance that should be available for all programs.

If superior genetic diversity is to be recognized, it will be through the exposure of the maize germplasm in contrasting environments in close association with national programs and regional net-works. Adequate support and an efficient systematic testing can produce a continuous flow of genetically broad-based, superior progenies, with balanced genetic resistance. Such a process allows simultaneous monitoring of genetic shifts in the pest complexes. Therefore, it is important that governments review their policies concerning maize seed movements and not simply wait passively behind a negative fence of regulations for protection. There should be a positive attitude change, accompanied by all necessary precautions in seed desinfection and treatment with suitable pesticides before shipment to the testing site.

Again, only an aggressive worldwide germplasm testing program can yield superior, widely adapted materials with adequate levels of field resistance to pests. When coupled with efficient production practices and freely accepted by farmers, these materials could demonstrate their remarkable potential.

2. MAJOR MAIZE PEST PROBLEMS

A useful and informative review of the geographical distribution and relative importance of major diseases of maize in temperate and tropical environments, was recently presented by Renfro and Ullstrup (8). CIMMYT's maize program also produced some information on both diseases and insects in 1971, which was based on a written survey and personal experience of the maize staff (6).

Both studies reveal that the most widespread and economically important diseases in the world are (Table 1) the northern and southern leaf blights, common and southern rusts, the downy mildew complex, maize streak, sugar cane mosaic, maize dwarf mosaic, corn stunt, stalk and ear rots. Other problems such as seedling blights, kernel rots, and nematodes, are usually of minor importance.

Among the foliar diseases, the downy mildews can be regarded as one of the most important maize disease complexes in the world. In addition to its major importance in Southeast Asia, the endemic presence of sorghum downy mildew (Sclerospora sorghi) on sorghum and maize in several countries of East and West Africa and its dispersal in several countries in the American Continent (Argentina, Honduras, Mexico and the United States) poses a serious threat to maize production (4). The sorghum downy mildew seems to have spread and is becoming more prevalent in those areas where narrow genetic diversity of widely cultivated maize varieties is a common denominator. Also, the spread of the downy mildew seems to be associated with the considerable expansion of the area devoted to sorghum, at least in the northeastern part of Mexico, Southern United States of America and in some of the maize growing areas of Argentina.

In addition to the downy mildew complex, other major diseases which require attention are the maize streak virus disseminated by the leafhopper vector Cicadulina spp. in East and West Africa; the corn stunt, disseminated by Dalbulus spp. leafhoppers in Mexico and Central America; and the cosmopolitan sugar cane mosaic virus complex spread by several aphid species, mainly Rhopalosiphum maidis.

With regard to insects, stem borers represented by different genera in tropical America, Africa and Asia, the Spodoptera budworms, the Heliothis earworms and the stored grain insects can be regarded as the most important. In addition to their direct damage, the borers and earworms favor the invasion of ear and stalk rotting organisms.

We recognize that there are other pest problems which may be more important than those mentioned above in some localized areas. For the most part, they will have to be tackled by the national or regional programs. Whenever possible, CIMMYT may assist in such problems.

Pathogens causing disease and insect pests are more prevalent and more severe at altitudes below 1,200 to 1,500 m. elevation in the tropical belt. Under these conditions temperature and moisture and the prevalence of insect vectors influence the severity of the pest complexes in time and space and seem to be the major agents regulating their geographical distribution.

3. MAJOR FUNCTIONS AND OBJECTIVES

The interrelated core functions (Fig. 1) of the maize plant protection group are to contribute:

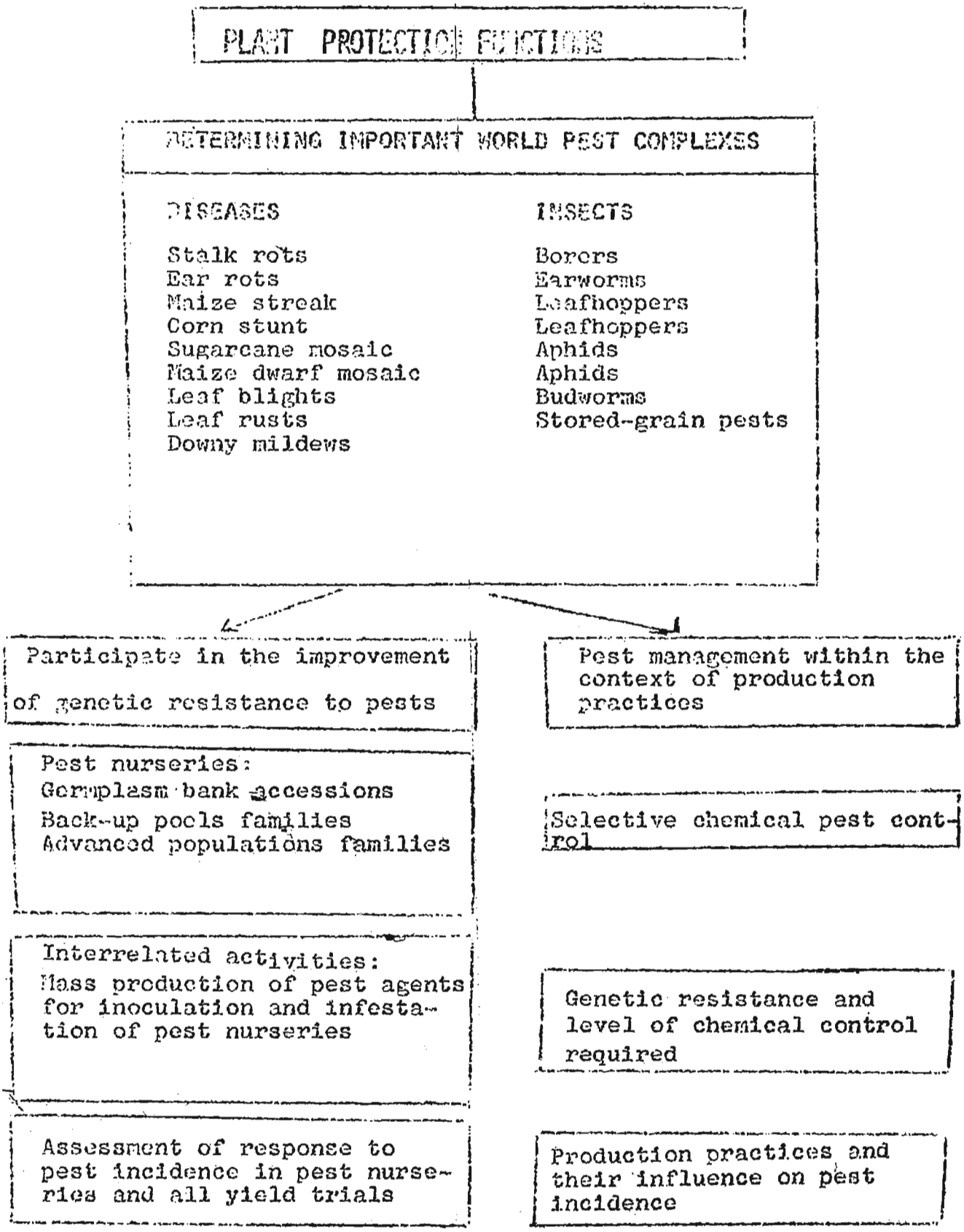
First, to the improvement of genetic resistance to major pests as will be described later. To accomplish this objective effectively there is a need to adopt and develop efficient techniques for the mass production of maize pathogens and insect materials. To adopt and develop artificial inoculation and infestation techniques and produce accurate methods for assessing the response of the germplasm under improvement to the pest complexes.

Second, generate pest management approaches by combining ecologically selective chemical pest control, genetic resistance and an understanding of the interaction among agronomic practices and pest incidence.

4. STRATEGY FOR ALTERING RESISTANCE TO MAIZE PESTS

The search for genetic resistance was initiated with the aim of developing specific sources. For this purpose the reaction of several hundred bank accessions was evaluated independently. That is, each eas examined for a single specific character. We soon found that some materials resistant to one of the pests might be rather susceptible to other pest problems. Because of this, our program has now shifted to encompass as many of the pest problems as possible.

F I G U R E 1.


PLANT PROTECTION FUNCTIONS
DETERMINING IMPORTANT WORLD PEST COMPLEXES
DISEASES
Stalk rots
Ear rots
Maize streak
Corn stunt
Sugarcane mosaic
Maize dwarf mosaic
Leaf blights
Leaf rusts
Downy mildews
INSECTS
Borers
Earworms
Leafhoppers
Leafhoppers
Aphids
Aphids
Budworms
Stored-grain pests
Participate in the improvement of genetic resistance to pests
Pest management within the context of production practices
Pest nurseries:
Germplasm bank accessions
Back-up pools families
Advanced populations families
Selective chemical pest control
Interrelated activities:
Mass production of pest agents for inoculation and infestation of pest nurseries
Genetic resistance and level of chemical control required
Assessment of response to pest incidence in pest nurseries and all yield trials
Production practices and their influence on pest incidence

Our overall effort has evolved toward a more dynamic and systematic approach to maize population improvement. A continuous flow of information and materials is sought, from raw materials to superior progenies, experimental varieties and elite experimental varieties, with each step to be closely coordinated with national programs and regional networks.

Thus, the program has contributed to the development of broad based composites such as the Caribbean and the so called World Composite, which can generate germplasm complexes to provide resistant sources among other attributes.

Four populations have been generated by the above activities. Two of these populations, Cogollero and IDRN, have entered the international progeny testing phase of the improvement program. In addition, they have also become components of several lowland tropical back-up pools.

The Cogollero population was derived from the Caribbean Composite. Some of the Caribbean land varieties have consistently shown less damage by ear rots, budworm, stem borer, and corn stunt when compared to germplasm sources from other areas.

The IDRN population was developed by recombining 36 maize collections previously identified as having been less damaged by the three borer species occurring in Mexico. Some collection, like those from Antigua, in addition have shown to be somewhat tolerant to budworm. Other materials, like Zapalote Chico are resistant to earworm. In addition, those materials carrying resistance to ear and stalk rots, leaf blights and corn stunt were incorporated. The 36 entries represented equal proportions of early, intermediate and late maturing types of tropical, sub-tropical and temperate origin.

Another dimension was added to the IDRN population when in 1972, over a thousand F_1 varietal crosses were evaluated by Dr. V. Gracen from Cornell University at their Aurora Experimental Station. Out of these F_1's, 190 crosses showed resistance comparable to that of highly resistant European corn borer inbred lines from the United States corn belt. During the off-season 1972, 1973, the materials were evaluated and selected for corn stunt, budworm, ear and stalk rots at Tlaltizapan, in Mexico. In the summer of 1973, at Cornell the resistant selections were crossed to European corn borer-resistant sources. Presently, 287 highly resistant crosses are being evaluated at Tlatizapan under sugar cane borer artificial infestation. This pool has shown remarkably wide adaptation, since it has been grown successfully at both 42° and 18° North Latitude, and will be the material in which attempts will be made to incorporate resistance to African

and Asian borer species, along with other traits.

CIMMYT shares the approach that the pest nursery is one of the most powerful tools to alter the susceptibility of the maize plant to pest complexes. These nurseries involve exactly the same germplasm bank accessions, or families being progeny tested for yield and other agronomic traits. The best performing entries are selected after evaluating their response whenever possible, under adequate levels of artificially supplemental pathogens or insects.

Although land varieties are individually susceptible to pests, particularly when transferred to a new environments, the genetic diversity represented by the hundreds of narrowly adapted varieties has prevented large-scale pest losses, particularly in the centres of distribution in tropical America.

Using the large genetic diversity available in the germplasm banks, CIMMYT intends to systematically evaluate reaction to pests in different parts of the world. Reference was made earlier to such an activity whereby more than a thousand entries were evaluated and some materials selected, based on their tolerance to corn stunt, borers, ear rots, and budworms.

Germplasm Bank Pest Nurseries

The response of each lowland tropical and subtropical, highland, and temperate accession from the bank will be evaluated for resistance to the attack of pests under natural incidence on their respective environments.

Briefly, this procedure consists of growing a five-meter row per accession, with 33 plants, half of which are protected by hill systemic insecticide soil treatment at planting time and whorl granular applications later on, if desirable. The unprotected half is used to estimate the response to insect pests and the protected half to evaluate disease raction.

Selected bank accessions which are to enter the back-up pools are determined by the information produced by the pest nursery, coupled with pest incidence data recorded in the yield trials, and information received from trials established by cooperating programs in key sites in different parts of the world.

Back-Up Pools Pest Nurseries

The back-up pools are developed by recombining desirable materials for several cycles. A core of the pool is identified and then worked with as a family structure.

New families are assimilated into the core from 'donors' after their performance has been raised to the desired standard. New donors are added constantly as new sources of variability to correct deficiences. The back-up pools pest nurseries are established along with progeny testing trials, with both using families from the core of a given pool.

Two nurseries are now planned: one for insect pests and the other one for diseases. The disease nursery and half of the insect nursery are protected with insecticides as indicated for the back up nursery. In each nursery, each progeny is represented by about 33 plants in a five-meter row. These nurseries are established in one or two locations. Back-up pool development and/or improvement occurs mainly in Mexico. The progeny tests established in several sites add information concerning pest reaction. Thus, every cycle of recombination superior families selected on the basis of their pest resistance, yield, plant-height and wide adaptability may be fed to the appropriate advanced populations, and also remain as components of the donating pool.

Advanced Populations Pest Nurseries

The pest nurseries--one for insects and one for diseases for the advanced population--are established at only one location in Mexico. Essentially, the same general procedure is followed as indicated for the back-up pools pest nurseries. At this stage in the improvement process, we enter the international progeny testing phase of the program, applying maximum selection pressure for pest resistance in these steps for further refinement. The data from the international progeny testing trials will be essential in revealing where our weaknesses lie and what action is needed for correction.

Our approach has a built-in mechanism-with multi-location testing of bank materials through all stages to the elite experimental varieties- for selecting for horizontal or generalized resistance. These tests should contribute to wide adaptation and yield stability, and allow for monitoring shifts in pest pathogenicity.

Although research evidence is scanty, some findings suggest that resistance is controlled by several factors and is additive in nature particularly in the case of downy mildew and European corn borer (4,11,12). Therefore, breeding approaches that exploit the additive genetic variance such as full sibs or half sibs should allow pyramiding of genes for resistance. However, there is a need for additional efforts to understand inheritance of resistance to pests. Such studies might be developed as research problems for M.Sc. or Ph.D. candidates.

Experimental Varieties and Elite Experimental Varieties

The international progeny testing trials (yield trials) if well conducted should permit the identification of several outstanding families within each advanced population at each testing site. Obviously, selection should be based on traits such as yield, standability, pest reaction and maturity. Then, for each population, the remnant seed of the selected families can be planted so that the families can intercross to produce an experimental variety for the site at which the families were selected. Of course, an experimental variety could also be produced by recombining families selected across sites.

After the experimental varieties, generated from the different advanced populations, have been tested in as many sites as seed supply would permit we should be able to determine which are the elite performers, that is the elite experimental varieties. These are the improved materials together with the agronomy-production package that has been generated simultaneously with which the farmer is to be approached by research and extension staff.

We feel that in the outline described above, from the germplasm bank accessions to the elite experimental varieties, there is an opportunity to enhance pest resistance. In addition to the pest nurseries, we would like to regard every yield trial as a replicated pest nursery in which careful and meaningful notes should be taken to assist in a continuous and dynamic overall maize improvement.

Development of Resistance to Pests of Widespread Importance

Four major pest problems require intensive and systematic work to complement the efforts of national programs, regional networks, and sister institutions. They are: maize streak virus, corn stunt and its associated insect vectors, the downy mildew complex, and the borer complex.

The first objective will be to develop populations for countries that have planting seasons differing widely from those in Mexico; a second objective is to build resistance to those pests that are limiting production. In addition (because we now cannot determine with any degree of certainty when these pest problems will invade new areas), we shall attempt to use these pools as donors to our back-up pools and appropriate advanced populations.

During the summer of 1974, four pools with grain textures and colors fitted to needs of large specific areas will be crossed to resistant sources available in the program.

When new sources are identified, they will be fed into the system. We hope to work out arrangements through which about 500 to 1,000 F_1 families generated from each pool will be simultaneously tested in Southeast Asia, Central America and Africa, in at least two key sites within every region. At these sites, crosses among F_1 plants from resistant families if any, will be generated and their seed returned to CIMMYT. These families will be then back crossed to their respective pools and may contribute to the pollen source. These steps will be repeated as long as is necessary. Another alternative or following step to the above in case no resistance is found at the F_1 level will be to advance the F_1 crosses to F_2's and send them to the testing sites. This segregating generation would be handled as suggested above. A third possibility, perhaps less desirable, would be to test the F_2 generation in the problem areas. Resistant families could be determined and remnant seed back-crossed to the respective pool.

5. DEVELOPMENT OF TECHNIQUES

Techniques for mass production of inoculum for ear rots and stalk rots and inoculation techniques have evolved to the point that every progeny can be inoculated with several major pathogens. Spore dilution tests are permitting us to identify the spore concentration most suitable to assist in discriminating between susceptible and resistant maize families.

For example, previous evaluations showed that injection of heavy spore suspensions or toothpick inoculation with Diplodia ear rots were too severe. Spraying silks with a spore suspension was not reliable either. The techniques which has proved the most efficient so far is the injection of a diluted spore suspension about ten days after silking. In addition, this latter technique has given enough sensitivity to the test to be useful in discriminating among diverse germplasm sources.

Field inoculation techniques have been improved by reducing considerably the amount of time required to inoculate large numbers of progenies. Techniques have also been streamlined for inoculating with rusts, blights, and corn stunt utilizing the insect vectors.

Study has been made of the relative efficiency of injury rating techniques for both diseases and insects. For the most part, foliar diseases and stalk or ear rot reactions are being visually estimated in a rating scale of 1 = no incidence to 5 = very high incidence. The same visual rating scale of 1 to 5 has proved to be equally useful in

determining damage by the budworm when compared to actual leaf area removed. For foliar borer damage the rating scale used is from 1 to 9, and stem boring damage is estimated by determining the number of damaged internodes instead of using the more time-consuming technique of stalk splitting, since both are highly correlated.

The production of borer earworm and budworm eggs for artificial infestation is increasing rapidly. Adequate quantities will be available in coming cycles to determine the reaction of maize families, from the back-up pools and advanced populations. The diet can be used successfully to grow five different species: Diatraea saccharalis, Zeadiatraea lineolata, Z. grandiosella, Spodoptera frugiperda, and Heliothis zea. Techniques for artificial infestation are similar to those developed for the European corn borer in the corn belt of the USA.

Maintenance of high genetic variability in the insect colonies and pathogen cultures is done by regularly introducing new material from the wild populations.

As experience dictates, we shall also be improving our procedures for infesting, inoculating and assessing the reaction of the materials under improvement. For example the approach for selection against stalk rot resistance should be reviewed critically. All too often, severely rotten stalks, bear well-developed ears. Are these very efficient genotypes? Just what factors are involved?

Possible study questions are: Is the insidious nature of stalk rot organisms in any way preventing a higher grain-to-stover relationship? Stalk borers also tend to complicate the issues, not only in reducing the 'plumbing system', but as well as agents that favor pathogen invasion.

As resistant materials are developed, joint efforts with other institutions will allow a more comprehensive analysis of resistance factors. For example such a study is being conducted in collaboration with Dr. Gracen (Cornell University). It has been established that the DIMBOA content (the chemical substance responsible for resistance) in first generation European corn borer resistant lines is about ten times greater than that found in susceptible lines. On the other hand, his determinations show that the DIMBOA content in the IDRN resistant families is low. This has suggested that there are other mechanisms that are involved in providing resistance to borers. Furthermore, DIMBOA seems to play a significant role in resistance to Helminthosporium turcicum and also has been associated with resistance to the stalk rot caused by Diplodia zea (3).

Again, the low levels of DIMBOA in IDRN, suggest other sources of resistance to these pathogens.

Ideally, there should be service-oriented pest mass production facilities in key sites in different parts of world to cope with present and future problems that do not occur in Mexico. Thus, the inoculum and insect materials produced would be used to expose the progenies undergoing improvement from national and international programs. The overall aim is to raise the level of generalized resistance to pests complexes.

Finally, in addition to the pest nurseries, a high plant density nursery managed by the agronomists includes the same sets of families from each pool and population. This occurs in both the back-up unit and advanced unit, providing an opportunity to monitor pest reaction when the crop is grown at very high plant densities.

6. INTERACTION AMONG AGRONOMIC PRACTICES AND PEST INCIDENCE

It should be recognized that increased production will demand among other inputs, higher fertility levels and higher plant densities of short plants. There is very little information concerning the interaction of such practices and pest incidence in the tropical belt. The general trend suggests that intensive management favors higher levels of pathogens and insects in temperate environments (1,2,5,7,9, 10,13).

Preliminary research initiated at CIMMYT on normal and opaque populations indicates that budworm populations and stalk rots were not influenced by nitrogen levels. Ear rots in opaque 2 varieties would seem to increase slightly at high nitrogen levels. Also in these trials, it was found that ear rot incidence increased as plant density was increased. Earworm damage increased only slightly.

Although, the actual percentage of damaged plants due to budworm, earworm, and stalk rots is lower under higher plant densities; the total number of damaged plants per hectare increases with increased plant population. However, some varieties reacted differently to this general tendency.

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TABLE 1

MOST IMPORTANT MAIZE PATHOGENS AND INSECT PESTS AFFECTING WORLD MAIZE PRODUCTION. 1974.

	COMMON NAME	CAUSAL AGENT	ASSO.* INSECT	ENVIRONMENT	DISTRIBUTION
	FOLIAR DISEASES				
1.	Southern Leaf Blight	Helminthosporium maydis		Tropical	World Wide
2.	Northern Leaf Blight	H. turcicum		Temperate	"
3.	Southern Maize Rust	Puccinia polysora		Tropical	"
4.	Common Maize Rust	P. sorghi		Temperate	"
5.	Downy Mildews	Sclerospora spp. Sclero*		Tropical	"
6.	Maize Mosaic	Virus	Rhopalosiphum maidis(os)*	"	"
7.	Corn Stunt	Mycoplasma-like	Dalbulus spp.	"	America
8.	Maize Streak	Virus	Cicadulina spp.	"	Africa
	STALK ROTS				
9.	Diplodia Stalk Rot	Diplodia maydis	Stem Borers(?)	Trop.-Temp.	World Wide
10.	Gibberella Stalk Rot	Gibberella zeae	"	" "	"
11.	Fusarium Stalk Rot	Fusarium moniliforme	"	" "	"
12.	Charcoal Rot	Macrophomina phaseoli	"	" "	"
13.	Phythium Stalk Rot	Phythium aphanidermatum	"	" "	"
14.	Cephalosporium Stalk Rot	Cephalosporium acremonium	"	" "	"
15.	Late Wilt	C. maydis	"	" "	Afr. S. Asia
16.	Bacterial Stalk Rot	Erwinia chrysanthemi	"	" "	World Wide
17.	Bacterial Stalk Rot	Pseudomonas lapsa	"	" "	"
	EAR ROTS				
18.	Gibberella Ear Rot	Gibberella zeae	Earworms(?)	" "	World Wide
19.	Diplodia Ear Rot	Diplodia maydis. D. mac.*	"	" "	"
20.	Fusarium Ear Rot	Fusarium moniliforme	"	" "	"

* Sclerophthora spp.(Sclero)

* Macrospora (Mac.)

* ASSOCIATED (Asso)

* Others(os)

T A B L E 11

MOST IMPORTANT MAIZE PATHOGENS AND INSECT PESTS AFFECTING WORLD MAIZE PRODUCTION. 1974.

	COMMON NAME	CAUSAL AGENT	ASS. IN.	ENVIRONMENT	DISTRIBUTION
	BORERS				
21.	European Corn Borer	Ostrinia nubilalis		Temperate	World Wide
22.	Sugar Cane Borer	Diatraea Saccharalis		Tropical	America
23.	Neotropical Corn Borer	Eoodiatraea lineolata		Tropical	America
24.	Asian Maize Stalk Borer	Chilo partellus		"	Afr.-India-Pakis*
25.	Maize Stem Borer	Busseola fusca		"	Africa
26.	African Pink Borer	Sesamia spp		"	Africa
27.	Pink Borer	S. inferens		"	S.Asia-S.Europe
28.	Millet Stem Borer	Hemibothia (=)*		"	Africa
29.	African Sugar Cane Borer	Eldana saccharina		"	Africa
30.	Corn Borer	Ostrinia furnacalis		"	S.E.Asia
	ARMY WORMS				
31.	Maize Budworm	Spodoptera frugiperda		"	America
32.	Army Worm	S. exempta		"	Africa-S.Asia
33.	Army Worm	S. exigua		"	Africa
34.	Army Worm	S. littoralis		"	Africa
	EARWORMS				
35.	Corn Earworm	Heliothis zea		Trop.-Temperate	America
36.	Bollworm	H. armigera		" "	Africa
37.	Budworms	Spodoptera spp.		"	Africa-America
38.	Borers	Several genera		" "	Afr.-Ame-S.Asia
39.	Root Worms	Diabrotica spp.		" "	America
40.	Stored-Grain Insect Pests	Sitophilus Spp., Sito*.cere(os)		" "	World Wide

*(=)(Coniesta)ignefusalis

*Sito (Sitotroga cerealella (others)

* Pakistan

O.A.U./S.T.R.C. Cereals Research Conference,
I.I.T.A. July, 1974

Varietal Resistance To Insect Pests Of Maize

by

P. E. Soto

Entomologist - IITA.

With the rising need for food supplies interest in maize production has been given top priority in many West African countries many of which are now in the process of developing programs in maize production, increasing their cultivated areas and introducing high yielding materials as a means of increasing yields. These changes in maize technology may create conditions favourable for diseases and insect pests which at present are of minimal importance. With increased productivity we can expect diseases and insects to play an important role as limiting factors in maize production.

Throughout the African continent various insect pests attack the maize plant. Appert (1970) presented a complete review of insects harmful to maize in Africa and Madagascar and summarized the various methods for their control presently being employed.

The following list reviews those insect pests more frequently mentioned in the literature:

STEM BORERS:	Chilo partellus
	Busseola fusca
	Sesamia calamistis
	Sesamia botanephaga
	Eldana saccharina
ARMYWORMS:	Spodoptera exigua
	S. exempta
	S. littoralis
EARWORMS:	Heliothis armigera
APHIDS:	Rhopalosiphum maidis
LEAF HOPPERS:	Cicadulina mbila (vector of streak virus)

Some insect pests such as stem borers are always present. Others like the armyworms do not appear every year but when they occur they are capable of destroying crops over vast areas. Among the leaf hoppers C. mbila and other Cicadulina sp. are capable of inflicting major losses in yield as they serve as vectors of streak virus. In trials conducted at the IITA losses in unsprayed plots infected with streak virus were 97% (Soto unpublished data).

No detailed information is available concerning the economic importance of each of these insect species. It is essential to assess damage and yield losses so this can serve as the basis for selecting those insect pests which are limiting maize production in an ecological zone or a localized area. Plant protection methods such as insecticides, resistant varieties etc. can then be condidered for those pests of primary importance.

Among the various plant protection methods used against insect pests, varietal resistance is the ideal way and in many cases the only practical and economical way of controlling some insects. It is the only method that requires no special effort or expense by the farmer and it is compatible with all other methods of control.

Methods for Measuring Plant Resistance

Most plant resistance programs in maize concerning insect pests emphasize resistance to stem borers. This discussion confines itself to the various methods being used to evaluate resistance to stem borers. Some of the measurements often used to evaluate plant resistance to stem borers are

1. Leaf-feeding injury
2. Cavity counts in the stalk and ear shank
3. Development of larvae on split stems
4. Insect counts
5. Dead hearts
6. Tunneled length in the stalk
7. Number of internodes with holes
8. Plant injury ratings vs. borers per plant.

In many instances some of the above measurements have been used without prior knowledge of the biology of the insect on the host plant. Only when we know the insect-plant relationship can we decide upon the method for evaluating plant resistance to a particular insect pest. The study of the biological relationship between the European corn borer and the corn plant was instrumental in establishing methods for measuring resistance to 1st Brood and 2nd brood larvae and the subsequent identification of resistant donors to this insect (Guthrie, 1972).

Another important factor essential to the success in plant resistance has been the development of artificial mass rearing methods for stem borers. According to Guthrie (1972) progress in plant resistance to the European corn borer would have been nil without artificial infestation techniques. Other methods should be developed to augment borer populations as not all locations have the space or financial backing to develop artificial mass rearing techniques. In order to make rapid progress plant materials need to be submitted to high borer population so as to permit the selection of resistant material.

International Cooperation.

There is a critical need for wider and more permanent resistance to insect pests and diseases. International cooperative nurseries will be extremely useful in the identification of resistant materials. These nurseries will allow testing against a wider spectrum of insect pests and diseases which often operate in combination. They will also aid in testing at various locations under conditions which favour their attack. Material for screening should include pest-resistant donors and breeding material from National and International maize improvement programs.

Breeders pathologists and entomologists should work in cooperation so as to :

1. Have clearer and unified objectives.

2. To improve methods for evaluating plant resistance which will be relevant to resistance under field conditions.

3. To evaluate material in the earlier stages of selection so disease-insect results can become part of the selection process rather than only an evaluation of final material.

4. Make joint decisions about crossing of materials and the purposes for such crossings.

5. Improve precision and standardization of screening methods and to develop an understanding in terminology so communication on such topics as resistance-susceptibility will have a meaning and not just be the basis for misunderstanding among the different disciplines.

6. To improve the knowledge of each group about the other group's objectives, requirements and capabilities. The breeder should understand the difficulties associated with managing borer populations and of the need for research on borer biology. The entomologist and pathologist should acquire better knowledge about plant breeding methods and materials in the areas outside of disease and insect needs.

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I.I.T.A. July 1974.

Breeding for Resistance to Maize Diseases

by

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Introduction.

The use of resistant varieties is a simple, effective, and economical means of controlling maize (Zea mays) diseases. Resistance helps stabilize yields, since disease epidemics are important causes of wide fluctuations in yields, and helps extend maize adaptation. For example, direct introduction of temperate types into the tropics has been unsuccessful, largely due to disease susceptibility. To use temperate germplasm in the tropics the gene dosage must be kept below 50 percent. McNew (2) stated that there are 112 separate, distinct diseases of maize. Not all of these are important nor do they occur in a single geographic area. The most important ones in tropical and subtropical areas are several stalk rots, maize streak in sub-Sahara Africa, corn stunt in Latin America, the downy mildew diseases in Asia, and late wilt in UAR-Egypt and India.

Much has already been accomplished in breeding maize to resist diseases and it represents one of the greater contributions of maize breeders. The accomplishments have been greatest in the temperate areas and for the foliar diseases in the more highly developed national programs in tropical countries. Much more resistance needs to be incorporated in tropical maize types to control the important diseases mentioned in the preceding paragraph and certain other moderately important ones. Moreover, new and more virulent disease forms continue to arise or be introduced into an area.

The basic requirements for breeding a disease resistant variety are a source of resistance, ability to differentiate between resistant and susceptible plants, and the selection of parents for the next generation in order to combine resistance with other desirable attributes of maize. Continual adjustments are then required to meet the changing crop requirements, as well as changes in pathogenicity of the causal organisms. Resistance breeding is, therefore, a continuous process which is most effective when coordinated with the overall improvement of maize.

The pathologists responsibility is large and important, It should emphasize the continuous study of the pathogens concerned, their variability, hosts and reaction to environment; the nature of resistance, its heredity, and its reaction to environment; and the improvement of testing and screening procedures whereby resistance can be effectively intergrated with general maize improvement.

Breeding for resistance in maize is augmented by: (1) adequate resistance being present without having to resort to transfer from related species or to mutation breeding; (2) the extensive knowledge of the genetics of maize; (3) its cross-pollination habit - heterogenity and heterozygosity allows retention of wide genetic diversity; (4) ease in controlling pollination and the production of a large number of seeds from a single pollination; and (5) the crop being easy to grow, widely adapted, and quite variable as a species. The main disadvantage is that plants are large, require a lot of space, and are difficult to grow well in pots and under low light conditions beyond the seedling stage.

Patterns of Resistance.

Resistance to diseases is not an absolute quality. It ranges from partial resistance to immunity and is expressed in many ways in plants. Variations have been shown to be brought about by (1) differences in the pathogenicity of the causal organisms, (2) differences in the host genes governing resistance, and (3) the environment which effects the final expression and amount of development. Resistance results from an incompatible relationship between the metabolisms of the host and the pathogen, both genetically controlled or by host structural means.

Procedures for Screening.

In breeding programs the pathogen should be managed to assure that the full range virulence is present from the areas being served. The nursery should be located where the disease severity can be expected to be high and uniformily distributed. Artificial epidemics should generally be established as natural epidemics are unreliable. Standard procedures of isolation, increase, inoculation, and rating systems of most of the pathogens of maize have been published. When an insect vector is involved and the disease cannot be transmitted manually, as is the case with maize streak and corn stunt, it may be necessary to rear the vector in an insectary, allow it to feed on diseased plants, then either release them on the susceptible spreader plants or over the entire nursery.

Controlled environment chambers are necessary in breeding for resistance to some diseases if rapid progress is to be made. In addition to providing ideal conditions for development of a disease

and rearing a vector, controlled chambers permit a program to (1) proceed throughout the year, (2) serve an area distant from the facility, (3) conduct many precise studies on the pathogen, disease development, and inheritance of resistance, and (4) prevent spread from nurseries to other experimental plots and commercial fields. A pertinent example for Africa is work by Rosenkranz (3) with corn stunt, a disease similar in vector transfer to maize streak. He obtained 8, 15 and 3.5 times as much stunt infection in maize in screen houses as in the field in three successive years in 10 cultivars (averaged) and about three times as much infection by individual plant inoculation and releasing infested insects on plants in a screen house as compared to exposure to natural infection. Controlled chambers were used in Connecticut (4) to obtain precise information on the pathogen and on disease development, and to simulate epidemics which lead to a prediction system for southern leaf blight.

Genetic Control of Resistance.

The genetics of resistance is known for many maize disease. This aids the selection of parents, breeding procedure, and population size for managing segregating populations. In broad terms resistance in corn in controlled by (a) one to a few genes, (variously referred to as monogenic-if only one locus, vertical, specific, qualitative, and differential resistance) (b) several genes, (variously referred to as polygenic, horizontal, nonspecific, quantitative, generalized, uniform, and field resistance) or (c) the cytoplasm. Two types of resistance to a single disease are often present. Resistance to southern leaf blight (Helminthosporium maydis) and yellow leaf blotch (Phyllosticta maydis) is both polygenic and cytoplasmic. Both monogenic and polygenic inheritance patterns are known for resistance to northern leaf blight (H. turcicum), Helminthosporium leaf blight (H. carbonum: to race I, monogenic; to race II, polygenic), common rust Puccinia sorghi), southern rust (P. polysora), and the Sclerospora incited downy mildews. Maize mosaic (sugarcane mosaic virus), maize dwarf mosaic (virus), and mosaic-stripe (virus) resistance is reported to be monogenic. Three loci control resistance to the systemic phase of bacterial wilt (Erwinia stewartii). One to three loci appear to control resistance to both Pythium (P. aphanidermatum) and bacterial (E. chrysanthemi) stalk rots (5). Resistance to the other stalk rots, the seedling blights, Curvularia leaf spot (C. lunata),brown spot (Physoderma maydis), common smut (Ustilago maydis), and brown stripe downy mildew (Sclerophthora rayssiae var zeae) are reported to be polygenic in nature. In most cases resistance is dominant to susceptibility but are reported to be either additive or dominant in effect in polygenic systems. The inheritance of resistance to the ear and root rots is not well defined.

In general a resistant character controlled by one to a very few gene pairs is stable in its expression over a wide range of environments. Thus, segregating progeny can usually be easily recognized as fitting distinct classes and specific resistance is relatively easy to insert

into varieties or lines. However, specific resistance places the greatest pressure on the pathogen to survive. The high frequency with which new races of many pathogen have arisen have led some people to believe resistance is only temporary as it requires only one change in the pathogen to overcome monogenic resistance.

However, there are many cases of resistance remaining stable and there are several such cases in maize. While generalized resistance is not so well understood, as it apparently occurs in different forms, it is effective, long in duration, and can be used with good likehood of success. As much generalized resistance as possible should be placed into varieties - the limits being the genetic source, the amount of protection needed, and the time and resources needed for accomplishing other breeding objectives. Generalized resistance is often difficult to recognize as the effects of a single gene is usually slight. But, it can and has been used effectively in maize breeding. It serves as a buffer to sudden shifts in pathogen virulence. For example resistance to northern and southern (to-race 0) leaf blights, Gibberella and Diplodia stalk rots, and common smut has remained stable since they were established many years ago. An ideal situation would be to have both systems operative in the same plant. One limitation to this is the ability to recognize polygenic effects if specific resistance is already present.

To repeat, the expression of generalized resistance is influenced much more by fluctuations in the environment than specific resistance. With the present system of using many sources of germplasm and maintaining wide diversity in breeding maize varieties for tropical and sub-tropical regions, the task of screening large numbers of plants to particular diseases under good management becomes great, as polygenic resistance is used almost exclusively in these areas. If the test is not severe enough, escapes occur; if the test is too severe, valuable germplasm may be discarded. An appropriate quantum of disease at the proper time with an appropriate breeding system will permit the accumulation of polygenes.

Breeding Systems for Population Improvement.

Many breeding systems and modifications of them are used in maize. Selection of the one to use is based on the objectives of the program, the maize population concerned, the disease involved and its heritability, the funds, manpower, land, and water available, the number and kinds of seasons per year, and personal bias. Breeding for disease (or insect) resistance does not differ from breeding for the improvement of maize for other characters except for the important difference that it involves the genetic variability and plasticity of both the host and the causal organism. Basically the breeding schemes in vogue can be classified as: (1) mass selection, with various modifications of it; (2) family selection schemes, most notably the half-sib, full-sib, and S_1 line methods; (3) back-cross especially for simply inherited characters; and, (4) schemes for developing hybrid varieties.

These schemes most always involve recurrent selection.

If a disease is sufficiently expressed by pollination time to be clearly discerned so that susceptible pollen sources can be eliminated, the mass selection and half-sib progeny test methods are efficient systems for resistance breeding. Thus, these would be satisfactory methodologies in breeding for resistance to the downy mildew diseases, leaf blights, rusts, virus diseases, corn stunt and Pythium and bacterial stalk rots. In India we were also able to discriminate among plants infected with late wilt (Cephalosporium maydis) when inoculations were made 18 to 21 days before the date of pollination.

However, a family structured, replicated progeny test, where one has control over the staminate parent has several advantages. The genetic relationship of parent-progeny of S_1, full-sib, and half-sib families (and mass selection) is 1.0, 0.5, and 0.25. The evaluation in mass selection is based on a single individual. Evaluation in family structures is based on a mean of a number of individuals which lessens the environmental influence. The influence of environment can be even better evaluated by replicating over locations or time. The S_1 progeny test method has the advantages of complete parental control; i.e., there is no interference or masking by the tester or sib parent. This is an advantage since most resistance is dominant or additive in inheritance. By inbreeding, a much higher frequency of deleterious recessive alleles for susceptibility are expressed phenotypically and can be removed from the population. Further, (1) a wider separation in family means is obtained with the S_1 than with other methods, (2) it is a rapid way to increase the frequency of resistance genes, and (3) it is an effective way in utilizing additive genetic variance. The main fault with the system is the effect of inbreeding itself, as a lowered vigor has a profound influence on the development of some diseases.

Another method for making rapid improvement is full-sib selection. It affords parental control and provides a progeny test of highly structured families. While it obscures a greater frequency of undesirable recessives in a heterozygous conditions than the S_1 line progeny method, it compensates by having no inbreeding depression, a one to two season per cycle scheme can be used, and twice as many seeds can be obtained for evaluation by reciprocal pollination.

The incorporation of disease resistance in hybrids has not been seriously considered here, simply because a viable seed industry is lacking in most countries located in tropical and sub-tropical areas. For nations that have a portion of their maize area planted to hybrids, such as Kenya, India, and Pakistan, the reciprocal recurrent selection method as outlined in fugure 1 can be used to satisfy an ultimate commercial use. The selection of two superior populations, which combine well with each other and undergo simultaneous improvement, provides this flexibility of use.

Examples of Intergrated Breeding in the Thailand Program*.

Two of the best performing varieties in the Inter-Asian Corn Programs low land tropical trial in recent years has been Thai Composite #1 and Cupurico x Flint Compuesto (Table 1). Thai Comp. was formed in 1969 from 36 adapted, but diverse germplasm sources. It was subsequently improved by the S_1 progeny test method and Cupurico x Flint Comp. by the full-sib method. The improvement made for yield in 4 cycles was about 22 percent in each population (Figure 6). Marked progress was made for several other characters including resistance to the prevalent foliar diseases and lodging, and for lower plant and ear height (Figure 6). Smaller gains were also made in extending the grain filling stage, shortening the silking date and selection for resistance to Coletotrichum stalk rot. The F_1 cross of the two outyielded the mid-parent mean and the high parent by 14 and 15 percent.

In 1971 downy mildew became spread over most of the major corn growing area. Each of these two populations were crossed with the improved varieties Philippine DMR (downy mildew resistant) 1 and 5 and the respective breeding systems continued. Three backcrosses were made, each time to the most recent cycle of the respective recurrent selection scheme (Figure 2), and selection for downy mildew resistance made in the segregating generations. Progeny were established during the early rainy season under mildew conditions. They were evaluated during the rainy season under mildew conditions. They were evaluated during the late rainy season by planting two replications each at three locations - one location under an artifically established mildew epidemic and the other locations for the evaluation of yield and other characteristics, including resistance to other diseases. Selected progeny were recombined the same season and population advanced during the winter (cool, dry, and no mildew) season. The distribution of downy mildew infection among 296 S_1 progeny of Thai Comp. 1 DMR is presented in Figure 3. Figure 4 depicts the scheme used to improve protein quality in Thai Comp. 1 DMR. Very similar results were obtained with Cupurico x Flint Comp. as with Thai Comp. 1. No significant change of either population, as compared to the original susceptible one, was measured for yield, plant or ear height, lodging or reaction to other prevalent diseases.

Figure 5 shows the progress made in transferring downy mildew resistance to Thai Comp. 1. The percent infection was reduced from 85 to 30 in two cycles of selection and, again, corresponding gains were made with Cupurico x Flint Compuesto BC^3 DMR.

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* The paper and figures by Dr. Sujin Jinahyon (1) was used extensively in preparation of this section.

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TABLE 1 - Mean grain yield, plant and ear heights and number of days to silking for entries in LACP Yield Trial #2, grown in 11 Asian countries.

Variety	Origin	Grain Yield kg/ha	Height (cm)		Number of Days to Silking
			Plant	Ear	
Thai Composite "1 (S) C2	Thailand	5020	216	111	58.3
Cupurico x Flint Compuesto (F)C4	Thailand	4768	217	107	59.6
Cuba 40 x Cuba Gr.1 (F) C4	Thailand	4758	214	113	59.6
Puerto Rico Gr. 1 (E) C3	Thailand	4511	215	112	57.9
Guatemala (M) C5	Thailand	4430	242	136	61.2
Tuxpeno Planta Baja	CIMMYT	4328	211	107	60.5
Mezcala Amar Planta Baja	CIMMYT	4502	212	115	58.7
ETO Blanco Planta Baja	CIMMYT	3576	200	94	60.4
V520C x Cubanos	CIMMYT	4705	232	127	61.0
Composite H_1	India	3615	215	112	61.6
Composite H_3	India	3544	198	88	55.7
Composite H_{74}	India	-	205	97	59.5
J M L 305	India	4678	232	122	59.6
E. H. 4116	India	4466	200	103	57.6
UPCA VAR 1	Philippines	4049	228	125	59.4
ETO Amar x Cuba Gr.1	Philippines	3895	222	122	59.8
Bogor Composite 2	Philippines	4513	225	120	58.3
Overall mean		4341	217	112	59.3
No. of tests		19	16	14	18

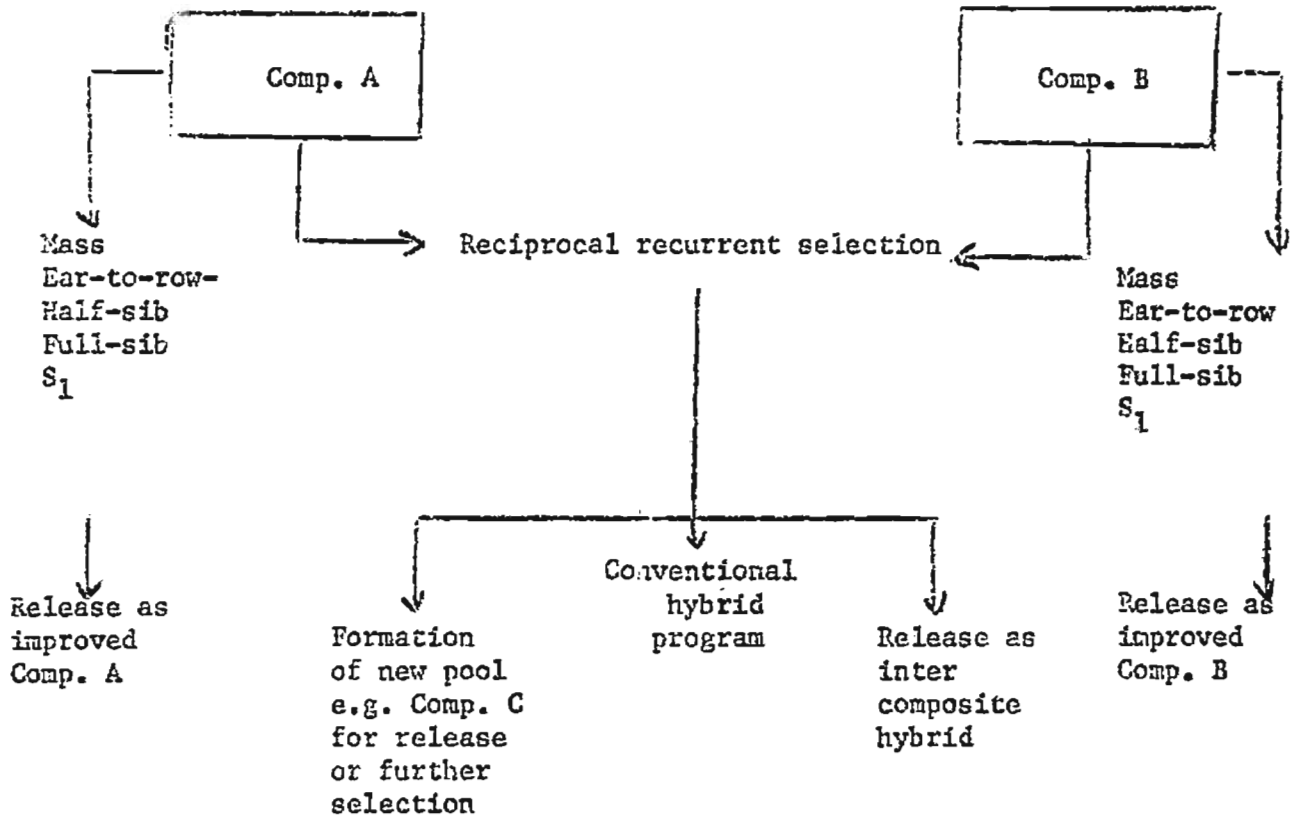

FIGURE 1 - A scheme used to utilize maize germplasm.

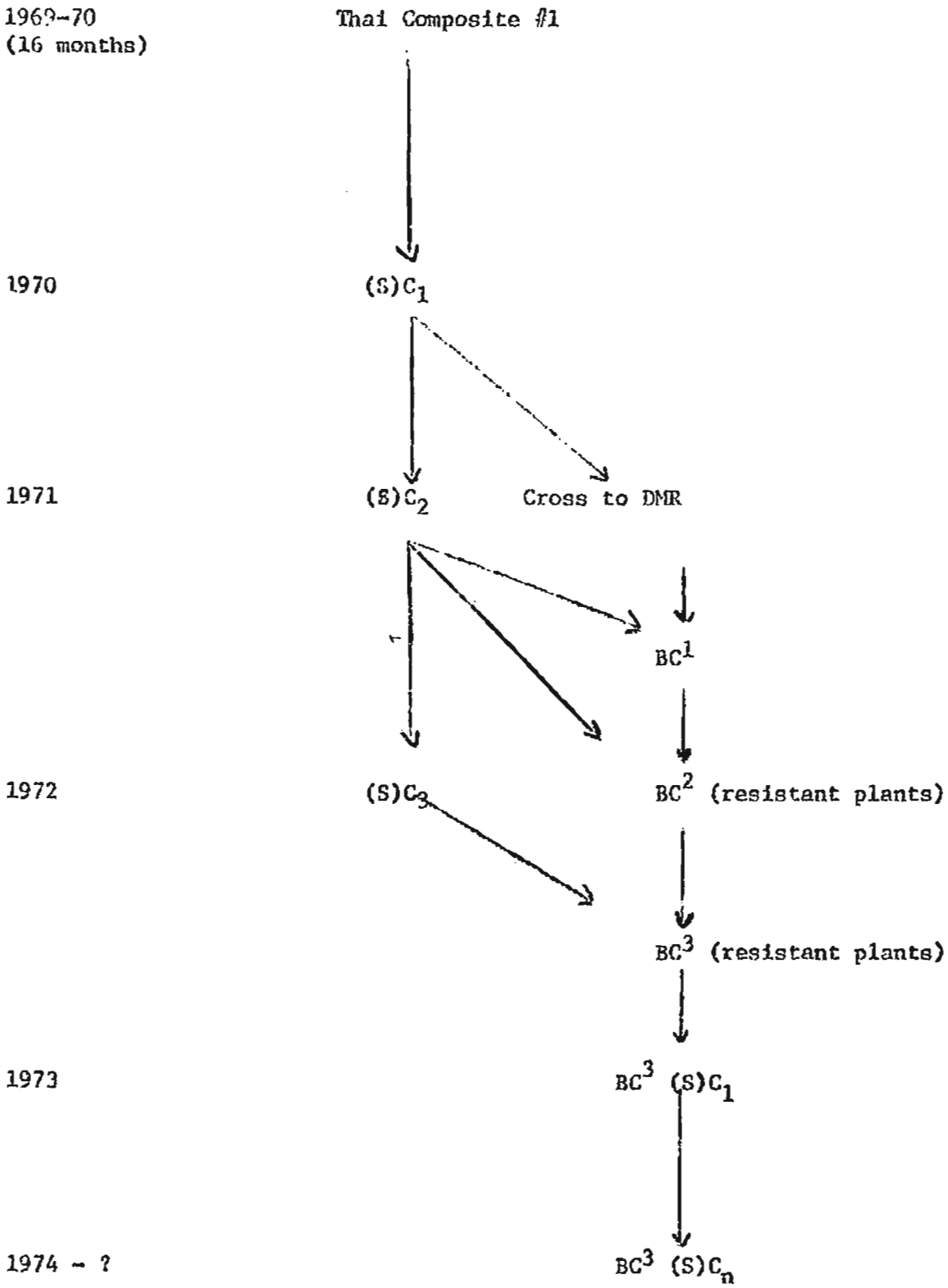

FIGURE 2 - Recurrent Selection (S_1 Progeny) for Grain Yield, Disease Resistance and Other Important Traits.

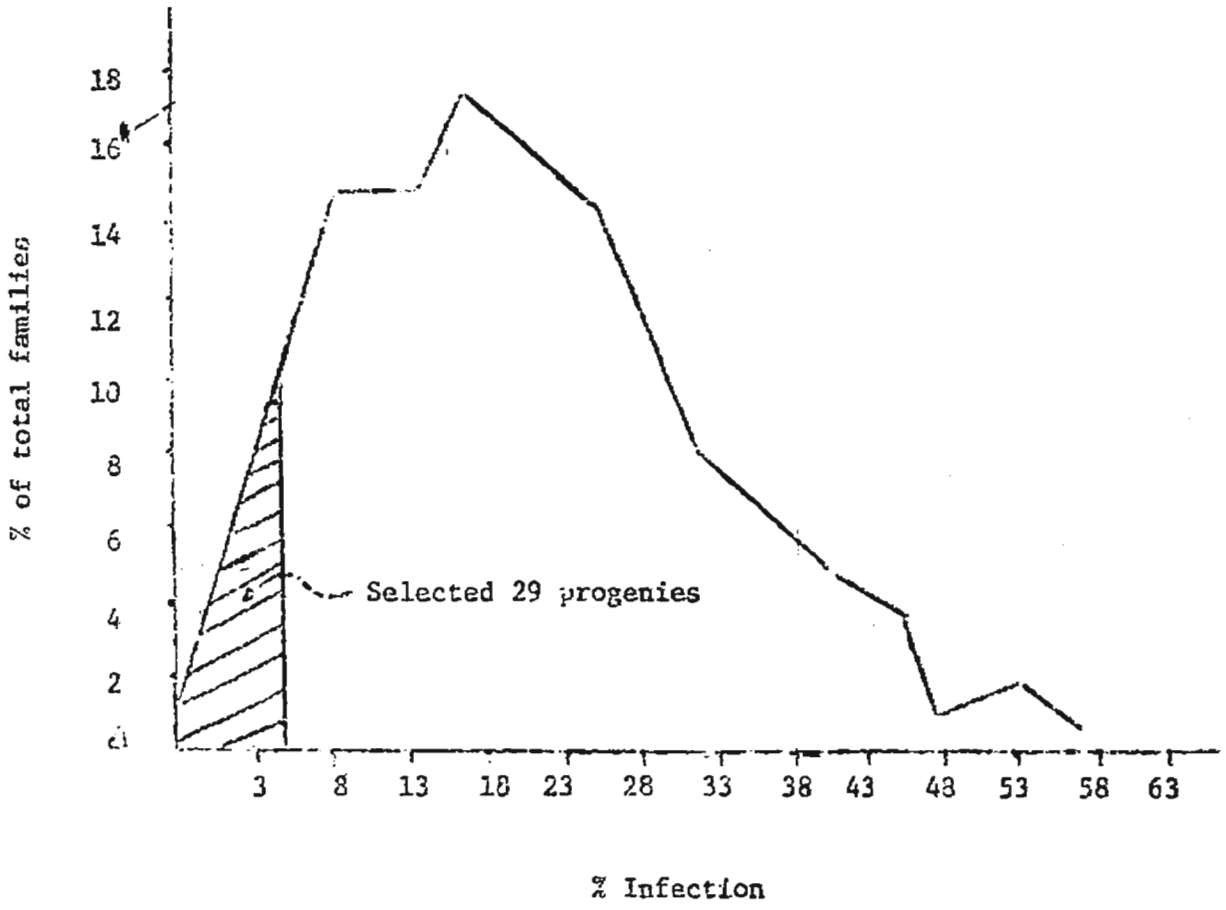

FIGURE 3 - Distribution of Phil. DR 1,5 x Thai Composite #1 BC^3 S_1 lines (296 lines) for downy mildew reaction under natural epiphytotic at Farm Suwan (Block B-9), 1973L.

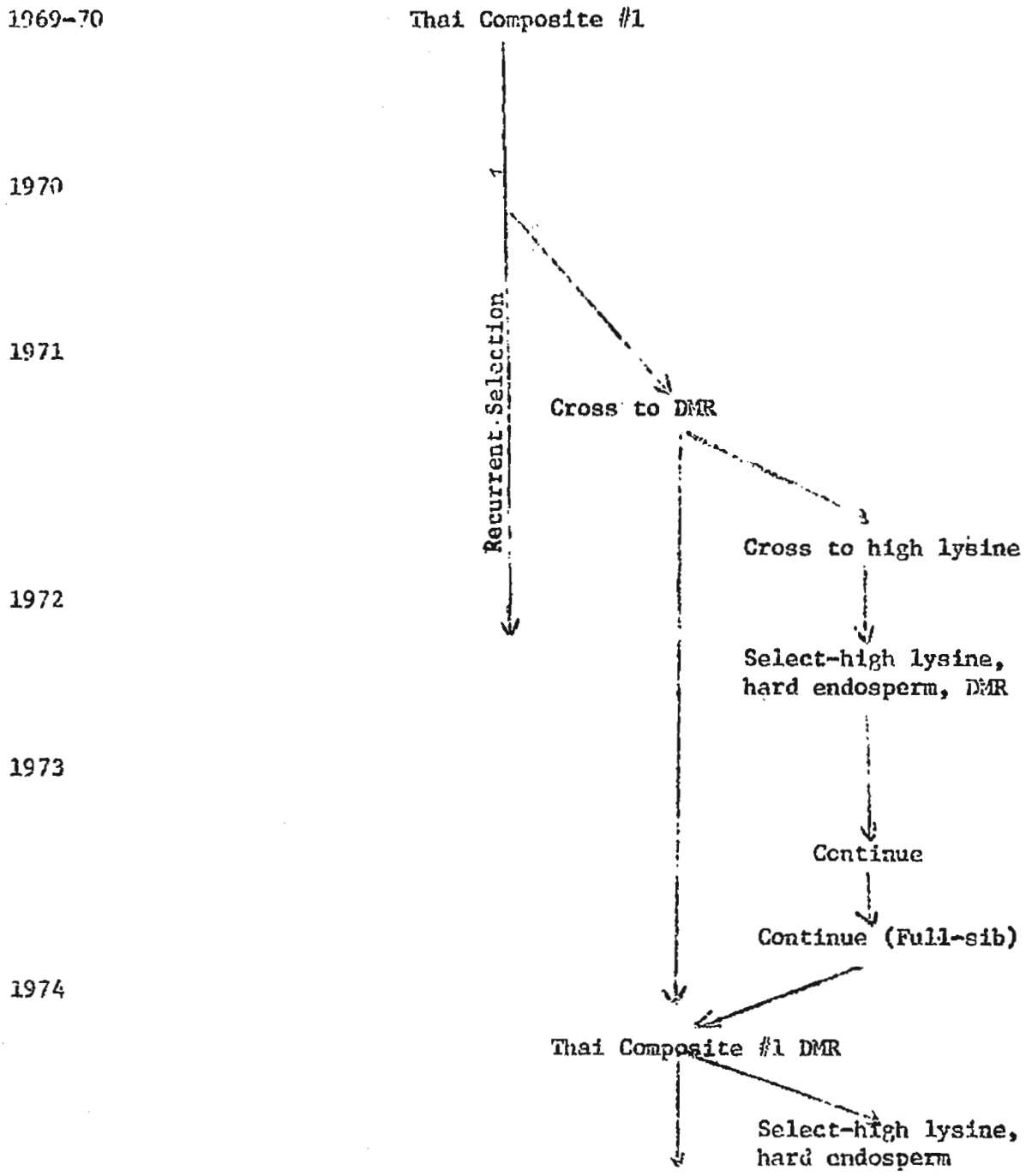

FIGURE 4 - Development of High Lysine Maize with High Yield and other Important Traits.

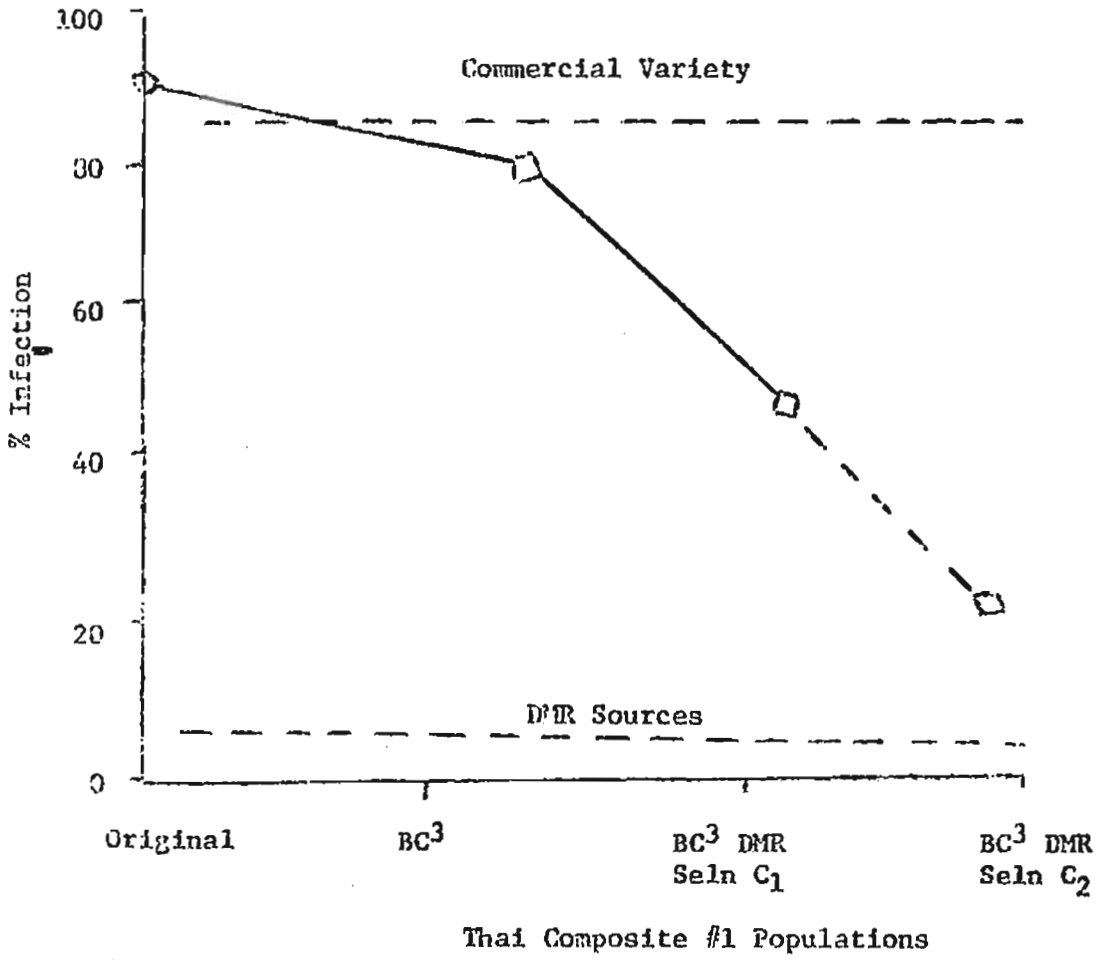

FIGURE 5 - Progress in the Transfer of Downy Mildew Resistance to Thai Composite #1.

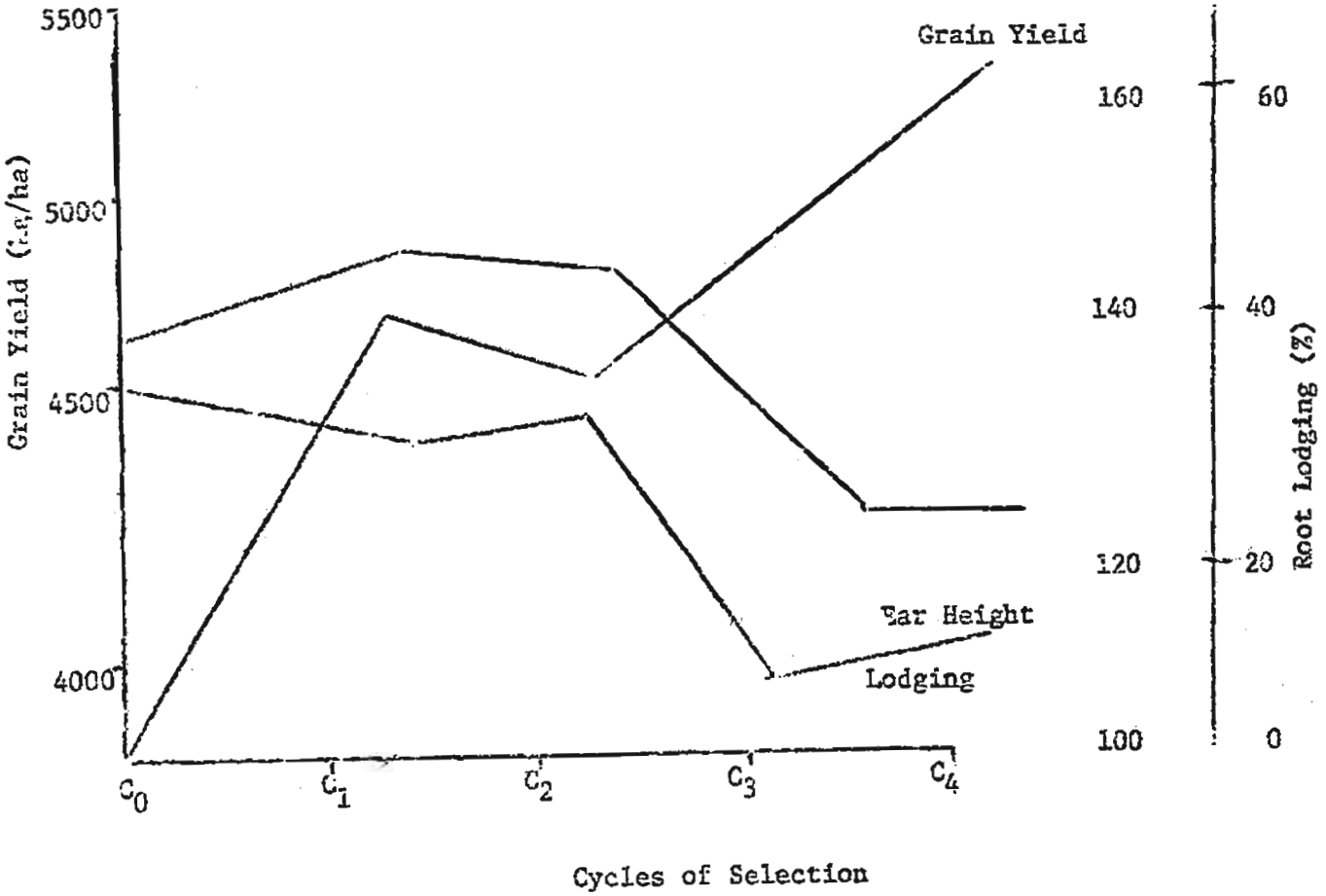

FIGURE 6 - Cupurico x Flint Compuesto

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RESISTANCE OF MAIZE, SORGHUM AND MILLET TO DISEASES IN WEST AFRICA

by

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NOGENT-SUR-MARNE, FRANCE

The main method to control cereal diseases in maize, millet and sorghum in West Africa is the cultivation of high yield and resistant strains. Thanks to the work of breeders and phytopathologists in introducing, conserving and attempting to find the best ways of using different resistance techniques, encouraging results have been obtained over that past couple of decades. Of course, not every problem has been solved and close collaboration between plant pathologists and breeders is vital for a combined effort towards creation of inproved strains.

Are we to think exclusively in terms of varietal resistance and complete elimination of chemical treatment? I do not believe so. For instance, in the case of covered smut (Sphacelotheca sorghi) and loose kernel smut (S.cruenta) in sorghum, it is known that treating seed with thiram at a rate of 200 g. active ingredient to 100 kg. of seed almost entirely eliminates infection. Bearing in mind the reasonable cost of the treatment, it would seem impractical to think in terms of systematic incorporation of genes resistant to these two parasites. These genes do exist, but in view of the many kinds of parasites and the possible appearance of new species, it would seem preferable to give priority to seed disinfection. Efforts must be concentrated upon a commercial organisation capable of supplying growers with fungicides at the right times and in the right places. The incidence of Sphacelotheca reiliana in maize at the present time poses a different problem. It is established that under natural conditions the infection appears up to the 4th-5th leaf stage in the growth of the plant, which is over quite a long period. To protect the maize relatively costly systemic fungicides must be used as a seed coating. Positive results were obtained by this means by W.J. JOOSTE (1969), but J.Y. PRAQUIN has carried out an experiment in Cameroun (1973) which has not confirmed those findings. The incorporation of varietal resistance against this fungus in maize cultivated at a high altitude therefore still continues in Cameroun.

Before taking a look at the principal diseases of the three cereals mentioned, it is important to emphasize the following two points:-

1) The necessity of taking into consideration resistance to drought. Any so-called improved strain must be capable of as high a yield as the local varieties whatever the rainfall for a particular year. Varietal behaviour tests must be conducted in the driest zones of the cultivation area of any given variety;

2) The necessity for determining the extent of losses caused by underground parasites (fungus, nematodes and insects) which attack successively one after the other, the fungi taking hold after attacks by insects and nematodes, as demonstrated by W.R. LANDIS (1971). As in the case of all cereals, the incidence of aerial attacks on the development of underground attacks has to be considered, as has been pointed out by S.M. FAJEMISIN and others (1974). In addition, since some diseases (downy mildew and ergot in sorghum) are still limited to restricted areas, there is good reason for exercising caution in seed exchange, for keeping under close observation plants grown from introduced seed and destroying them in the event of abnormal symptons appearing.

MAIZE

A) NON-PARASITIC DISEASES

In the case of numerous strains of maize cultivated with a high degree of fertilisation, reduction of the height remains an important point to be considered; one sees at the present time heavy lodging which does not appear to be of parasitic origin. To our knowledge little research has been done on this subject. In Cameroun in 1973 the variety Ecuador 573 was particularly badly hit. The incorporation of dwarfing genes must, therefore, be continued.

Although not of such importance as for irrigated rice, the physical and chemical properties of the soil can influence the choice of strains. At the IITA (M.N. HARRISON - 1972) it has been shown that too high a soil temperature at the commencement of growth can impede development of the plant, and that there are grounds for breeding strains with this factor in mind. Deficiencies in standard trace elements (chiefly copper and boron) have been reported; these should be corrected rather than research be carried out into varietal resistances. If the pH drops below 4.5 growth anomalies can be seen in the form of leaf blight.

In every region one sees plants whose leaves do not unfold; in the majority of instances there are only minute patches affected. It appears that this disease is a physiological disorder and that it cannot be connected with an outbreak of Fusarium moniliform.

On leaves tiny translucent spots can frequently be seen. Among the many hypotheses put forward up till now is that held by M. PANJAN (1966) which maintains that the cause is some genetic anomaly, and this seems to

us the most plausible. This speckling does not seem to have any effect on the yield.

B) PARASITIC DISEASES

Tropical rust (Puccinia polysora) is still very widespread, but except in very humid conditions, it is confined basically to the lower leaves. In Dahomey and the Ivory Coast the breeding carried out by J. LE CONTE (1964) making use of recurrent selection has resulted in productive and resistant strains.

The chief leaf parasites are at present 2 types of Helminsthosperium, H.turcicum and H.maydis. Varietal resistance must be used in controlling these.

Against H. turcicum one can have recourse to:-

- polygenic resistance
- Use of the gene H t which is manifested in chlorotic spotting, delayed necrosis and reduced sporulation (H.M. HILU and A.L. HOOKER, 1963). According to R. CASSINI (in a private communication) this resistance has been unsuccessful in Hawaii.

Against H. maydis one can use:-

- polygenic resistance
- monogenic resistance which is characterised by small chlorotic lesions (J.CRAIG and others, 1968).

We should observe that virus type particles have been noticed in cases of H.maydis and that the presence of these particles is linked to the pathogeny of the fungus (R.F. BOZARTH and others 1972):-

Among the Smuts, Sphacelotheca reiliana, which occurs in the high ground to the East of Dschang (Cameroun), spreads slowly (in the order of ten kms. per year), and in dry years can cause losses of about 30% on local maize. In a wet year losses are much reduced.

The high-yield strain Comiteco chiapas 235 has shown a high degree of resistance to this Smut (4% as opposed to 56% for the local varieties, according to local witnesses). When crossed with Mexican 5, the rate of attack is 16% (35% for Mexican 5). We may assume that this Smut which thrives in cooler regions will remain localised in mountainous districts. (J.Y. PRAQUIN 1973).

The symptoms of a viral disease known as streak, but whose transmission by Cicadulina mbila has not been definitely established in West Africa, (C.L.M. Van EIJNATTEN 1965), were very prevalent in Dahomey in 1972. Maize strains from Reunion, known by the name "Revolution",

have shown excellent resistance (J. LE CONTE 1974). It is known that "Revolution" is resistant to stripe (RAT and ETIENNE 1973). Several hypotheses are possible: presence of stripe in Dahomey, resistance of "Revolution" to stripe and streak?

Several other fungi (Cercospora sorghi, Physoderma maydis, Cephalosporium sp., Macrophomina phaseolina, Diplodia macrospora, Pythium sp., Fusarium moniliform, Fusarium spp. etc. etc..) as well as a bacteria Erwinia sp. have been observed, but only as isolated instances, with no economic importance.

In 1973 maize in BAMBEY (Senegal) produced stunted growth with extensive patches of mosaic. It has not been possible to find the cause of this irregularity.

SORGHUM

A) NON-PARASITIC DISEASES

A disorder manifested in failure of leaves to unfold and linked with a lack of water at the commencement of growth was observed on some vertisols in the Niger during the years 1965-70. The local variety JAN JARE offered a far higher degree of resistance to 137-62: M. DELASSUS 1970).

B) PARASITIC DISEASES

For various reasons it is advantageous to be able to harvest sufficiently early, in principle at a time when the rains have only just finished. To be able to do this, however, a way must be found of controlling the development of grain moulds which form a group belonging to the geni Fusarium, Helminthosporium, Colletotrichum, Gleocerospora, Choanephora, Penicillium, Aspergillus, etc.. Tests have shown differences in varietal behaviour, for example, C.E. 90 is fairly resistant. According to J.C. GIRARD (in a private communication) the reddish coloured varieties are less susceptible and the glumes give effective protection to the grains. Very often, the red colour is not looked on with favour, but I think that there are grounds for making a compromise between culinary qualities and the imperatives of reliable and abundant production.

In Senegal, Ramulispora sorghi is prevalent on some lines, in Cameroun Cercospora sorghi is frequent, while Sphacelotheca reiliana is the Smut most commonly found in Nigeria. Mildew (Sclerospora sorghi) and ergot (Sphaeelia sorghi) are virtually limited to a few places in Nigeria (S.B.KING, 1972). Macrophomina phaseolina has lately been discovered in Senegal. Several more fungi have been reported for sorghum in West Africa, but these do not appear to cause significant damage. Also, little work has been done on varietal resistance.

Among the hazards as yet of unknown origin are certain instances of sterility and irregular emergence of leaves from the sheath.

PEARL MILLET

A) PARASITIC DISEASES

Three diseases, mildew (Sclerospora graminicola) Smut (Tolyposporium penicillariae) and ergot (Claviceps microcephala), must of necessity be considered in the task of selecting pearl millet.

On traditional millets mildew only causes slight damage in Senegal. Both early (Souna) and late (Sanio) varieties have good resistance. This resistance does not exist in millets of the Mauritanian oases where S.graminicola has not been recorded. In the Upper Volta and the Niger more significant damage has been observed. Three Upper Volta varieties selected for their resistance have proved resistant in Senegal and Nigeria.

In order to obtain dwarf millets, the breeders have had to work with highly susceptible parents. The research of J.C. GIRARD (1973) has shown that there are very distinct differences in varietal behaviour, the percentage of infection depending, all other things being equal, on the level of inoculum (infection by zoopores). It is possible to infect by zoospores.

In Senegal A.BILQUEZ (private communication, by crossing a susceptible Tift line with a resistant one (maiwa), has obtained a resistant F_1 which at F_2 has given 3/4 resistants and 1/4 susceptible.

Other crosses carried out at SAMARU by BHARDWAJ (S.KING 1970) between Tift 23 and local strains of maiwa have given 46 to 72% diseased plants at F_1 whereas the self-fertilised maiwa strains had a rate of attack of between 15 and 47%.

It seems, therefore, that there are differences in resistance in pearl millet to S.graminicola which might be attributed to either vertical resistance or to horizontal resistance.

In the former case the totally resistant line 7301 at Bambey shows some degree of attack in other districts of Senegal and at Samaru (S.B. KING 1974). It therefore looks as though there exist physiological species of S. graminicola. This research is being continued, notably in regional studies being conducted by several research bodies in West Africa.

Where Smut, a disease transmitted through the air, is concerned, behavioural differences have been noted between various lines in

Senegal. Work on selfed spikes in 1967 and 1968 revealed ten or so resistant families (less than 1% of seeds affected by smut, whereas the susceptible ones showed more than 50% affected). The most resistant families came from the PS 32 breed, (Anonymous, 1968).

Ergot can cause large-scale losses. Local varieties are fairly resistant. By contrast, on some imported hybrid varieties serious attacks have been noted.

Among the other parasite fungi Pyricularia grisea is frequently found on Tift millets and their hybrids. Sterility from unknown causes is fairly common.

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OAU/STRC Cereals Conference, I. I. T. A. July 1974

Is Maize Streak Virus Present in Nigeria?

Dr. G.E. Cook OAU/STRC Maize Pathologist, Ibadan.

The disease called maize streak virus (MSV) has been present in Africa for more than 70 years and until recently had not been found on any other continent. Fuller (Fuller, 1901) first reported the disease in 1901 and Storey (Storey, 1925) described the disease in 1925. Since that time diseases with symptoms similar to MSV have been found in many parts of Africa (Etienne and Rat, 1973) and in India (Seth et. al., 1972). Many of these reportings probably are MSV; however, this has not been conclusively demonstrated in Nigeria and many other West African countries.

Storey (Storey, 1925, 1928) described the symptoms of MSV as being broken almost continuous, narrow, chlorotic streaks centered on secondary and tertiary leaf veins and distributed uniformly over the leaf surface. Partial to almost complete fusion may occur between the parallel chlorotic streaks leaving irregular green lines or islands centered between the veinlets. Stalk internodes, leaves, and ears may be reduced in size. MSV is not mechanically transmitted and is not seed borne, but is transmitted by five leaf hoppers of the genus Cicadulina of which C . mbila (Naude) and C. bipunctella zea China are the most important (Storey, 1928; Storey and Howland 1967a). This disease has also been identified by using antisera in East Africa and an electron microscope has been used to identify virus like particles in infected tissue (Sylvester et.al., 1973). Visual symptoms of MSV make it difficult to distinguish MSV from other virus diseases in particular Maize mosaic virus or stripe transmitted by Peregrinus maydis (Ashmead) (Etienne, 1973). The vectors are used to distinquish MSV from MMV.

In Nigeria, a disease called MSV has been present for many years. The importance of this disease was described in 1966 ([illegible], 1956) and the intensity of the disease has increased over the years especially during the dry season on irrigated maize. Many Nigerian farmers indicated that this disease was more prevalent in their fields in 1973 than in previous years. During the dry season of 1973 this disease nearly destroyed some experimental plots. It is possible that this disease may become more intense during the earlier growing seasons.

Identification of this disease to date has been on the basis of visual symptoms. There is some evidence that the disease is not mechanically transmitted and that it is not seed borne; however, more studies are needed to confirm this, (Fajemisin, personal communication).

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It might also be added that Perigrinus maydis is also present in Nigeria. To date no antisera has been used to identify the disease, and maize resistant to MSV in East Africa (Gorter, 1959; Storey and Howland, 1967a, 1967b) has not been screened in Nigeria.

This disease must be identified and the vector identified and maintained to aid the development of resistant maize cultivars. The only means of screening breeding material in Nigeria is to plant it during the dry season; however, if the natural infection is light then escapes may be mistaken for resistance.

Studies are currently underway to capture and identify the vector, develop efficient inoculation techniques, and to screen maize cultivars from Nigeria and throughout the world for resistance or tolerance. Various specimens of the disease collected throughout Nigeria will be checked against antiserum supplied by Dr. Bock and Dr. Guthrie of E.A.A.F.R.O. in Kenya, to identify the disease and aid in the separation and identification of strains as described by McClean (1947). Alternate hosts of the virus will also be identified. In the future, a set of differential varieties may be obtained to identify strains of the virus in other West African countries. It may be possible to utilize advanced laboratory techniques to catalogue and identify the virus when equipment is available.

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VARIETAL RESISTANCE TO INSECTS IN AFRICA

Illustrated by

CASES OF MILLET, SORGHUM AND MAIZE

J. BRENIERE

May 1974

VARIETAL RESISTANCE TO INSECTS IN AFRICA CASES OF MILLET, SORGHUM AND MAIZE

Insect control does not depend only on solutions permitting their direct destruction (insecticides) or in direct destruction (entomophagous - disease).

The solution we can theoretically consider as "ideal", extensively used in phytopathology, and which consists of obtaining a perfectly resistant or tolerant plant material through breeding can also be sought after in insect control, because there is no fundamental difference.

With regard to insects, varietal resistance is rarely complete. Nevertheless, the dynamics of their rapid multiplication which constitutes the major destructive agent, can be highly modified according to the nutritive quality of the absorbed plant, and the conditions offering access to this food.

Although varietal resistance to insects is at present rarely studied in Africa, it has been known since the discovery of vine resistance to phylloera.

In most cases, if the breeder does not take into consideration resistance to insect pests, the obtainment of better productivity is accompanied by a higher plant sensitivity. This can be explained by the fact that productivity improvement can also favor the development of an insect pest which now receives more nourishing or abundant food.

We may even apprehend the unexpected development of an enemy which till now has been considered less harmful.

Therefore it is necessary to know for each problem, the mechanisms governing the plant-insect ratio, not only for the improvement of control conditions, but also for prevention of the creation of sensitive varieties.

PAINTER, in his works "Insect Resistance in Crop Plants" (1951) analysed the resistance mechanisms that we must know to be able to carry out crosses.

We can distinguish three forms of plant resistance :
Preference or Attractivity - which is a faculty for a plant, to be more or less attractive (or repulsive) to the insect at egg laying time or feeding time for the larva.
Resistance or Tolerance - is the plant capacity to bear and to rise above attacks without influencing the insect pest development.
Finally, Antibiosis is the plant capacity which influences insect pest life directly.

These three modes of relations are not of equal importance when considered in breeding.

The most easily distinguished mode is attractivity. It appears every time we compare damages to varieties subjected to comparative trials. Without doubt, it is the least valid criterion because the female in order to lay eggs can be selective when the opportunity arises but without it, she will be able to adapt herself and lay her eggs on a variety which she would have left if the choice were possible.

Therefore, to be sure that this attractivity or repellence is reserved for breeding, we must proceed to control tests to know the insect reaction to lack of possible choice. The more reliable will be the actual resistance or tolerance factors.

They will mainly be reflected in the effects of the insect action on the plant. The latter may be resistant owing to its anatomic structure. For example, a ligneous plant has a better resistance to breakage due to borer passages. The rapid growth of the plant may enable it to have an advantage over the speed of the insect pest; precocity, in certain cases, enables the plant to get over the critical sensitive stage before the evading time of its enemies. For the grasses, a high tillering makes up for the losses due to early damages on young plants.

But it is especially the Antibiosis which is the most important and most reliable resistance criterion.
influence effectively insect pest populations and certainly reduce the size.

We can distinguish two antibiosis types : Antibiosis by mechanical effects making difficult or impossible egg laying, penetration, and nutrition for the insect pest : pilosity, long bracts, lignified tissues, special plant reactions, sap secretion, a,s,o.

The most subtle will be the Antibiosis by toxic effect of the sap, unable to make the insect survive, because of the presence of toxic agent or food insufficiency.

These effects are, of course, rarely absolute, but mere inadequate feeding can sufficiently reduce the development and multiplication for the agricultural consequences to become manifest.
All these cases apply to African grasses.

SORGHUM AND MILLET

The main enemies are borers (pyralidae and noctuidae) and the diptera (muscidae : Atherigona sp. shoot fly on millet and sorghum, and Contarinia sorghicola on sorghum inflorescences).

In addition, the sorghum with compact panicles are often attacked from the inside of the panicle by several lepidoptera species : Pyroderces, Salebria, Eublema, Stitotroga, etc.

NONVEILLER (p969) studied this problem in the Cameroun. He showed the close relation between panicle compactness and extent of damage. The hybridization of "Djigau" varieties with compact panicles must take this fact into consideration.

The problem of the sorghum Atherigona is more important. It is in India that the problem has been most extensively studied. This species : Atherigona varia soccata started to pose a serious problem when we introduced improved varieties originating from the U. S. A. The latter immediately revealed sensitivity developed such an increasing fly population that the local resistant or tolerant varieties had, in turn, to suffer losses.

As from 1944, PONNAIYA found fifteen tolerant types showing 10% to 15% of healthy stalks against a maximum of 5% sensitive one. (PONNAIYA 1951) The failure in pesticide treatment, and their costly and dangerous use confirmed the need for this research.

The execution of the " All India accelerated sorghum improvement project" permitted a systematic analysis of the entire sorghum world pool in improving the techniques for the seeding period in order to increase the infestation rate on the trials. A list of thirty-five resistant varieties was obtained, and these constituted a genetically diversified source of resistance. However, these selections were obtained by comparing damages in the field with varieties tested in comparative trials.

In 1971, Soto and Lakshminarayana developed a standard breeding of fly and made a rigorous screening by placing in cages along with the insect, the varieties known to be resistant either for comparison, or in isolation.

This procedure showed among the resistant varieties some important differences resulting from the distinction between preference and antibiosis. So, among twenty-nine resistant varieties studied, only three presented a real antibiosis demonstrated by the absence or weakness of oviposition even in isolated cages. It is the latter of course, rather than the former which are to be known as carrying genes sought after.

In Uganda, DOGGETT distinguished a primary resistance which might be due to a barrier caused by silica in the leaves of certain variety, and a recovery resistance resulting from the plant reaction in an abundant production of replacement tillers.

The local varieties Namatera and serena which have a good reaction to attacks were used in a breeding program.

In Nigeria and Upper Volta, ANDREW and DOBOS noticed that the damage occurs essentially when short cycle varieties are planted late.

Finally, we must note that USMANN (1971) developed resistant mutants by irradiation from M 35-1 and G M 2-3-1 varieties.

The sorghum midge, Contarinia sorghicola, is a major pest of sorghum in Africa. a

The search for resistant varieties was envisaged as far back as 1961 by HARRIS in Nigeria, LECLERG in 1962 in Senegal, BOWDEN in 1965 in Ghana.

From 1968 to 1970, COUTIN studied in Senegal the population biology and dynamics. The infestation increase depends on the flowering succession in the same zone during a long period.

It is the mixed cultivation of early and late maturing crops and crops with different cycles which cause serious infestations in late season. Therefore, the breeder must be on the look out for grouped flowering and avoid late secondary coming into ear.

There are varietal differences in sensitivity but until now the problem has been inadequately described due to variation in midge dynamics.

BOWDEN (1965) in Ghana, observed that the Nunaba group varieties belonging to the sorghum membranaceum species are resistant because of their long enveloping glumes; unfortunately crosses have a tendency to reduce the glume length and partly cause the loss of the repulsive effect.

Thus, the Contarinia problem is not at the present time settled by varietal selection. It seems that it is mainly the difficulties in resistance analysis which have discouraged scientists and breeders.

Resistance to sorghum and millet insects has been equally studied in the world. Such insects include lepidopterous borers - Pyrausta in Russia (IVANYUKOVICH 1970), CHILO partellus in East Africa (EAAFRO report in 1968) and Schizaphis graminus aphis in U. S. A. (WOOD 1971).

Finally, we must note the classification of sorghum varieties in relation to their insect resistance during storage.

MAIZE

Obviously, maize was studied more than sorghum and millet. It is essentially with regard to the lepidopterous borers that selections were carried out.

It is not possible in this paper to give full details of the numerous works covering the main borer or insect pest of the foliage : Heliothis zea, Diabrotica spp., Sesamiacretica and nonagrioides, Chilo suppressalis, Ostrinia mubilalis, Prodenia litura, etc... as well as Chloropide Oscinella frit and Rhopalosiphum meidis. In Africa, maize is mainly attacked by Busseola fusca, Eldana saccharina and different species of Sesamia.

Unfortunately, there are only a few detailed studied on resistances to these African insects.

Without going into details, let us exemplify with the cases of Sesamia nonagrioides and Ostrinia nubilalis.

Varietal resistance to S. nonagrioides could only be developed with the creation of artificial infestations in order to ensure the necessary homogeneity for the experiments. In addition, it is important to evaluate the different damage levels according to the insect localisations on the plant (attack of the ear stalk, stem breakage, reduction of ear growth, direct grain destruction).

By means of controlled artificial infestation, we can reliably analyse in detail the development of the settled population, its growth and mortality, the adult fertility obtained, and plant reactions according to a given plant stage. It was in this way that ANGLADE (1955-1968) was able to classify strains from different origins into sensitive tolerant, and resistant, and studied the transmission to F1 of the observed resistance. Strain A 257 for example, shows a true resistance which is found again at hybrid level after crossing with a non-resistant control plant.

This type of research has been equally applied before to the study of resistance to Ostrinia nubilalis (european corn borer) especially in the U. S. A. and in Russia. It requires the knowledge of biology of the insect, its relationships with the host plant, the use of artificial infestation techniques, standard breedings, the choice of simple and rapid criteria for measuring the resistance and of defining the norms for the latter.

This group of techniques has been applied to Chilo zonellus in East Africa by STARKS and DOGGETT.

We would also find similar examples in the case of sugar cane and rice as regards the selection of varieties resistant to insects and methods used.

The following essential points mentioned in the paper are recapitulated for our reflection :

1. The selection for insect resistance is one way which may bring to Africa practical and positive results within a short time.

2. The dangers irregularities, or anomalies that we may have noticed in replying on the only varietal comparison come essentially from lack of experimental precision and inadequate knowledge of the insect, its biology and effects on the plant.

3. A rational study of varietal resistance must be carried out on every aspect of plant-insect relationship in each case.

It may lead to the knowledge of many relationships between varietal, morphological or physiological characteristics of the plants and their biotic or antibiotic effects on the insect.

Consequently, it is only by an interdisciplinary approach uniting breeders, entomologists, physiologists, and biochemists, that we can progress effectively.

O.A.U./S.T.R.C. Cereals Research Conference,
I.I.T.A. July, 1974.

Disease Resistance In Maize.

by
J.M. Fajemisin.

Maize Pathologist-Breeder.

INTRODUCTION:

About thirty diseases have so far been recorded on maize in Nigeria but serious investigations on maize diseases began only in 1953 following the onset of the rust (Puccinia polysora Underw.) epidemic. This disease struck first at Sierra Leone in 1949, spread to Ghana in 1950 and got to Nigeria in 1951. The disease dealt a mighty blow on our local maize varieties, causing considerable yield losses and in some instances total crop failure. This explosive outbreak gave birth in 1952 to the West African Maize Rust Research Unit at Moor Plantation, Ibadan. The Unit worked on combating this disease through investigations on chemical control and importation of maize stocks from Central America and the Carribean for selection for resistance or tolerance.

With the introduction of rust-resistant or rust-tolerant maize varieties, the Southern maize leaf blight, caused by Helminthosporium maydis Nisik and Miyake, which was first recorded for Nigeria in 1933, proved to be a disease to be reckoned with in the country. These afore-mentioned introduced varieties were very susceptible to blight. The two diseases, namely rust and blight, still stand as the most important maize diseases in Nigeria. Maize rust is capable of reducing yield by up to 44 percent and blight by 37 percent. Our research efforts have therefore been concentrated on these two diseases. Our general principle of operations on working on any disease has been first to establish the economic importance of the disease through the conventional use of fungicides and thereafter initiate a programme on disease resistance.

Maize Rust: A large number of local and exotic maize varieties were screened for resistance to P. polysora. Through a process of artificial inoculation and pollination, a hypersensitive form of resistance was extracted from an East African maize selection. This high grade resistance is conditioned by a single dominant gene. But in the heterozygous form, some of the hypersensitive spots later develop tiny pustles about sixteen days after inoculation. There is usually no pustle development on the homozygous resistant plant.

The resistance has to date proved reliable against the two physiologic races of P. polysora present in Nigeria. In addition to the continuing monitoring of its stability we are also investigating the histological and physiological basis of this form of resistance.

Southern maize leaf blight: Following a comprehensive screening of maize cultivars for reaction to H.maydis, a qualitative form of resistance was located in a Kenyan selection. The lesions on this resistant maize type are chlorotic and smaller in size compared to the tan and bigger lesions incited on the susceptible variety. Sporulation is greatly inhibited, thereby cutting down on the rate and amount of conidia production. This resistance is governed by two recessive genes linked in the coupling phase at a recombination frequency of 16.83 percent. The resistance operates in the seedling and at later stages of development. It is functional in Nigeria, United States of America and wherever it has been tested. This chlorotic lesion resistance is currently being incorporated into many United States elite inbred lines.

BREEDING FOR HORIZONTAL RESISTANCE

Vertical resistance may be more difficult to come by but once located it is usually easier to deploy than horizontal resistance. On the other hand, horizontal resistance being a relative form of resistance is almost always available in a particular agroclimate but its deployment is much more involving. Furthermore, vertical resistance is complete but not permanent in that it is absolutely effective against some biotypes or races of a pathogen but completely ineffective against other races of that same pathogen. Horizontal resistance, though not providing a complete protection against any particular race cuts across all the races of the pathogen in its effect. It is therefore more longer-lasting and thereby provides a better means of ensuring yield stability than vertical resistance.

We are currently utilizing Recurrent Selection methods to concentrate the genes for horizontal resistance to rust and blight in one of our main breeding composites - NCB (Nigerian Composite B). S-1 method is being practised for rust and blight separately. In addition, Modified Mass Selection is being used for blight for purposes of comparing the two methods of recurrent selection. Disease resistance and grain yield are the primary selection criteria.

Screening of germ plasm -- local and exotic --for horizontal resistance is a continuing aspect of our programme.

OTHER DISEASES

Two other diseases are gradually becoming important in maize production in Nigeria. They are (1) Maize Streak Virus disease and (2) Curvularia leaf spot caused by a fungus Curvularia pallescens Boed.

We are currently screening our germ plasm for both qualitative and quantitative resistance to Curvularia leaf spot. We have found a few promising selections and will next season begin a programme of developing disease resistant populations. With regards to streak, efforts are on to design efficient transmission technique so that we can screen many maize cultivars and ultimately develop truly resistant maize types.

DEVELOPING MAIZE TYPES WITH MULTIPLE DISEASE RESISTANCE

It is not common in nature to find a plant with resistance to more than one disease. At the same time, an ideal variety for release to the farmer is one that combines resistance to most, if not all, of the important diseases affecting his crop.

We have combined qualitative resistance to both rust and blight in one maize selection. This combined resistance has also been incorporated into our genetically wide-based composites NCA and NCB to give the disease resistant versions NCARb and NCBRb. This double resistance has greatly enhanced the yield potential of these breeding stocks. In one of our programmes, we shall in addition to combining horizontal resistance to both rust and blight be concentrating the genes for stalk rot resistance -- all within one maize population.

X. HARVESTING, DRYING, STORAGE AND MARKETING

1. HARVESTING AND SHELLING
2. DRYING AND STORAGE
3. ECONOMICS OF STORAGE AND MARKETING

MAIZE PRODUCTION BROCHURE

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3.	Temperature, Moisture Content, Relative humidity.	3 hrs.
4.	Insect identification and control	3 hrs.
5.	Insecticides and Fumigants	3 hrs.
6.	Moulds and their control	2 hrs.
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9.	Artificial drying	2 hrs.
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11.	Envelope fumigation etc.	2 hrs.
12.	Plastic bag techniques	2 hrs.
13.	Mud crib construction & insect control	8 hrs.
14.	Metal drums and insect control	2 hrs.
15.	Warehouse management.	1 hr.

HARVESTING, SHELLING, DRYING, STORAGE AND MARKETING

A. Harvesting & Shelling

A.1. Optimum harvest time

If the crop is to be stored for use as grain the optimum ripeness is indicated by the dryness of the leaves, the husk and the silk and the time since planting, which usually is between 90 and 105 days. The moisture content of the grains will be around 27% at this stage, but could be as high as 35%.

Once the crop is ripe, the cobs could be allowed to remain on the stalks in the field. If there is a well defined dry season following ripening of the crop, there is an advantage in leaving it for sometime in the field for the following reasons:

(a) the grains will dry out further thus eliminating drying problems,

(b) the harvest can be spread out to suit the farmer's situation,

(c) shelling is easier, the drier the grains are.

There is however some dangers other than wet weather that need to be faced. If the cob is damaged by bird attack, not only is there a loss of grain but the opening of husk facilitates the entry of insects and further loss can thus occur. Similarly, if the variety of maize has a loose sheath formation, insect attack can take place in the field, even if no bird damage had previously occurred.

If wet weather follows, the ripening of the crop is also likely to be attacked by fungi and bacteria.

In most of the humid tropics these various attacks may even occur before ripening of the crop, so that the earliest possible harvesting after ripening is generally

desirable. This means that most of the maize would be between 25-35% moisture content, well above the 12 to 13% moisture content which is the safe moisture content for storage.

A.2. Harvesting systems

The most common harvesting system is that entailing hand labour. A man should be able to pick between 230kg. (500 lbs.) and 320kg. (700 lbs.) of ears per day.

At the other extreme, with mechanized harvesting by corn snapper (picks and dehusks the ear), corn picker-sheller (picks, dehusks and shells) and the combine harvester it is possible to harvest as much as 25 hectares per day.

However, the justifiable average for mechanized harvesting, to reduce the capital cost per acre to reasonable levels, will be in the order of 250 to 500 hectares of maize, or preferably more, per annum.

Mechanical harvesting also is only really suitable when the land is reasonably flat, and the crop is of even height and ripens evenly. In addition, artificial drying of the crop afterwards will most certainly be necessary and in the humid tropics, the very high moisture content of the grains at harvest time would adversely affect the efficiency of shelling of the mechanical harvester.

On the whole therefore, one would need to very carefully consider these factors before deciding on the introduction of mechanical harvesting and it would be rare for the conditions to favour it, especially in the humid tropics. Much could however be done to increase the efficiency of harvesting by hand:

(a) The setting of daily tasks for labourers for picking of maize (8-10 bags of maize in the cob per day would be reasonable).

B.2.1. Sampling techniques

B.2.2. Temperature, Moisture content, Relative humidity.

The relative humidity is the ratio of the quantity of moisture in the air at a certain temperature divided by the quantity of moisture which the air will contain when it is saturated at that same temperature.

At 100% humidity, the air will thus be saturated, at that temperature. If that air is heated, the relative humidity will drop below 100%.

A crop which is exposed to high relative humidity air will tend to absorb moisture from the air, whilst if the relative humidity is low, the crop will tend to give up moisture to the air, according to the relationship shown below for maize in the humid tropics.

If we want our maize to be below 12-13% moisture content (the 'safe' m.c.) it should obviously be stored in an atmosphere below 70% relative humidity, as measured in a meteorological screen at the site. The question that can well be asked is why crops dry at all in the humid tropics where the relative humidity is for much of the day, after harvesting above 70%?

The answer to this question is twofold.

(a) If the crop is exposed to the sun during the day, the temperature will rise quite high and the relative humidity will drop sharply. The further it drops below 70% the more the crop will give up moisture, and so get drier.

(b) When the atmosphere cools during the night, the relative humidity will rise to well above 70%. Although the crop will tend then to absorb moisture, there is evidence to show that it will do so at a slower rate than what it gave up at during the day.

Practical Exercise:

1. Temperature measurement - Thermometers, ^{o}F & ^{o}C, recording thermographs. Comparison of shade and sun temperature.

2. Moisture content measurement - The oven methods, field instruments - Marconi meter, Cera Tester, probe type meters.

3. Relative humidity - Whirling hygrometers, use of Psychrometric chart, comparison of relative humidity in the shade and in the sun. Recording thermohygrograph.

B.2.3 Insect identification and Control

B.2.4. Insecticides and Fumigants

B.2.5. Mould and their control

B.2.6. Storage loss assessment

B.3. Drying Techniques

B.3.1. Sun drying

Farmers use this method a great deal. It makes use of the fact that the high temperature generated by the sun on the crop, reduces the relative humidity and enables drying of the crop to take place. The simplest way of sun-drying is where farmers lay the cobs or shelled maize on a flat piece of ground in the sun. This has several weaknesses, firstly the movement of air through the crop is restricted and the dispersion of moisture air is reduced. Secondly, when collecting the crop, there is a tendency also for dust and stones to be collected and so to contaminate the crop. Also when a sudden rain-storm appears, the farmer might not be able to collect the crop quick enough to avoid wetting by the rain. A much improved method is to dry the crop on mats on a simple platform. This allows for ventilation, avoids contamination by dust and stones, and enables the farmer to quickly gather the crop together in the event of rain.

The use of plastic sheets on which the crop is spread, has been successfully used in certain cases. The plastic sheet allows for rapid spreading and collection of the crop and could also be used as a container in which to fumigate the crop. Where plastic sheets are easily and cheaply available to farmers, this method is most useful.

B.3.2. Artificial means of Drying

This is a technique whereby the air in contact with the crop is deliberately heated by a fire or heat source other than the sun, hence the reference to "artificial" means.

Basically, artificial drying is only relevant where large-scale production of a crop is carried out, and especially where combine harvests are used.

They are costly, both to install and to run. The principles on which they operate are:

> A source of artificial heating of the air, a method by which the air is blown through the crop (often by means of a fan) and finally a method of concentrating the crop to enable the air to pass through it.

The amount by which the air has to be heated is dictated by the relative humidity of the air. If the air is well below 80% relative humidity it might even be possible to dry the crop without artificial heating by merely forcing the low humidity air in large volumes through the crop. Heating of the air can be done through the use of oil burners or electricity. The "Bush Drier" developed for Cocoa drying in Cameroon and Samoa uses firewood for heating the air and depends on convection currents to allow the air to flow through the crop.

Several methods exist by which the crop and the air is brought into contact. Basically, they are of three types - insack drying, batch drying or continuous drying.

(The different types of mechanism and driers will be illustrated in the practical).

B.4. Combined drying and Storage Techniques

B.4.1. Traditional systems of drying/storage

The storage of husked and undehusked maize in a well ventilated environment has been undertaken by farmers in many instances. By so doing, drying takes place whilst the crop is being stored. The simplest system consists of hanging undehusked maize in bunches on branches of trees or on poles stuck in the ground. This method is more popular in drier areas than in humid wet areas.

Another common traditional method consists of storing husked or undehusked maize in an inverted latticework type of cone crib. These are easy to make although it does not give the crop much protection against rodents. To protect the crop from rain, a thatched roof is often included.

A further method is for the maize to be placed on a raised platform covered in thatch. It is common for a fire to be periodically lit below the platform to assist in drying and there is a belief that the smoke from the fire possesses certain fumigating qualities in the control of insects.

Traditional storage cribs of more complicated design usually are round in shape and utilize locally available materials almost exclusively, such as bamboo, palm leaves and thatch.

B.4.2. Recent trends in crib design

The factors involved in crib design are being more closely studied at the present time, but it is possible to make some recommendations in this respect, at this stage.

(a) The crib may be round or rectangular, depending on local custom and convenience. A diameter or width of about one meter is both convenient in building and seems to allow effective drying in even relatively difficult conditions.

(b) A convenient height for a crib is about 2.5 meters, allowing for one meter clearance between the ground and the base of the crib, and about 1.5 meters storage height. The one meter clearance ensures that rodents cannot jump onto the side of the crib and if furthermore, the legs are made of bamboo, rodents will not be able to climb up to the crop.

(c) Rectangular cribs have the advantage that a farmer can always extend the length, and thus his storage space as future needs may dictate. In this respect it is useful to know that for a crib 1.5 meter high by 1 meter wide, a crib length of 1 meter will store about 670kg. of maize on the cob. Put in another way, every 3 meters length of crib will store about 2 ton of maize cobs.

(d) A great advantage of cribs are that they can be built entirely using local materials. Thus the crib legs and side supports could be made from bamboo or

similar poles, the sides could be made of split bamboo, palm fonds or similar material, and the roof could be made of thatching grass.

NOTE: Drying cribs have been generally successful but in exceptionally wet years with continuous rain weather during the harvest season, it is possible for the maize to go mouldy even in the crib.

In these circumstances, the farmer could adopt alternative ways to save his crop:

1. If he anticipates really bad weather, he could leave the cobs on the stalk and break the stalk, without severing it and bend it down so that the cob faces downwards. The physiological mechanism of the plant will, under certain conditions, continue to function and dry out the grains in spite of the heavy rains. Although the cob would still be exposed to insect attack, the birds will not be able to damage the cob in the same way as when they are facing upwards. In fact farmers may well be advised to break the stalks and turn the cobs upside down soon after ripening, to evaluate this technique. If successful, this technique could be adopted even in apparently dry years as he will then reduce bird damage and at any rate be prepared if any unforeseen wet weather suddenly occurs, or if his harvesting is delayed through labour shortages or other reasons.

2. The farmer could, after placing the cobs in the crib, light a fire underneath the crib to assist in drying. Care should of course be taken to control the fire and prevent the crib from being set on fire. It is advisable too for farmers to place less cobs in the crib to allow the hot air from the fire to pass through the cobs more easily and quickly. This may mean that he will require two or three times as many cribs as would be the case normally, and this might be expensive if he depends on purchased materials for building his cribs. However, if he has suitable local materials available (poles, bamboo, palm stems, thatching grass etc.) it need not be such a costly business.

B.4.3. Insecticidal treatment

B.4.4. Rodent and their control

Rodents damage stored cereals not only by consuming it, but also by fouling large quantities with their excretions and damaging jute and plastic bags.

They do less damage to grain stored in bulk as they cannot burrow into such grain, but find grain stored in bags or in cribs particularly attractive for building their nests in which they multiply at a very great rate.

Rodent damage can be reduced if the rodents are repelled, trapped or poisoned. Ultimately, the most effective control is to make storage structure rodent-proof.

This can be achieved by the adoption of a few basic but simple practices in stores:

1. If the walls of stores are not rodent-proof, then build the store at least 1 meter off the ground to ensure that no rodent can jump to the side of the store and gnaw its way through the walls.

2. The legs of the store should preferably be made of bamboo, as the rodents cannot climb this material because of its being slippery. However, if no bamboo is available, a conical ratguard could be fitted at the top end of the legs.

3. The rat guards should at least project 23cm. beyond the diameter of the legs.

4. Ratguards will be useless if vegetation, bicycles or other items are permitted to form a ladder for the rodents to climb up to the store.

5. For proofing of larger stores and a more detailed specification for rodent proofing in general, you are referred to Appendix E of FAO Agricultural Development Paper No.90 by D.W. Hall.

B.5. Storage Techniques

We shall deal in this section with the storage of shelled maize. One ton of maize grain, when stored in the cob will occupy about 2½ times the storage space, there is thus obvious advantages in storing maize as grain.

The smaller storage space also makes it more feasible to store the grain in an air-tight container. By so doing, it is possible

by the exclusion of fresh oxygen, to eliminate insects since after they had exhausted the original supply of oxygen in the container they will not be able to survive. The smaller storage space will also make fumigation of the stored crop somewhat more convenient.

Once the maize is shelled, it needs to be dried to about 12% moisture content before it can be safely stored. There are many choices of structure in which to store the grain, each with its advantages and disadvantages.

B.5.1 In-sack storage

This is a popular method of storage although it requires a warehouse in which the sacks can be stacked. The cheapest and strongest materials for sacks is jute, sisal or kenaf. In recent times plastic lined or straight plastic sacks have been used. These are advantageous in that the crop can be stored in air-tight conditions in which the insects will, after using up the oxygen supply, die from lack of oxygen.

B.5.2 Metal silos

In this case, too, the idea is to obtain air-tight conditions and so eliminate the need for the use of insecticides. Where drums (usual 44 gallon petrol drum) are readily and cheaply available, it is an effective method. There is a tendency for the maize to "cake" in metal silos - the reason for this is that the difference in high daytime temperatures and low night temperatures causes condensation of the moisture in the localized spot in the drum, resulting in cakes of damaged spots inthe maize. It can be overcome by placing the silos under shade and so avoid high temperature fluctuations.

B.5.3. Concrete silos

As most countries now have cement industries, there is a tendency to encourage the building of concrete silos. Unfortunately, cement is often in short supply and is often very expensive, so that the decision as to whether

concrete silos should be recommended has to be very carefully considered.

The storage on a national level at key storage depots, one can visualize the justification for such concrete silos which will last for a long time, could have provision for in-bin ventilation and mechanical handling, although the initial expenditure is high. The further down the line one gets towards the individual producer, the less applicable this type of storage is, although it would be wrong to discard it entirely for use by farmers and village traders and cooperatives in cases where the materials are readily available and the necessary skill and financial resources exist for establishing such storage.

The aim is generally to make the silos air-tight and so, by the exclusion of oxygen, eliminate the need for use of insecticides during storage. Unfortunately, the sealing of concrete silos is quite a problem, especially of small scale silos in which it is usual to try to keep the cost as low as possible. In the smaller concrete silos, there is also a tendency for "caking" to develop as in metal silos and which seems to be preventable to some extent by shading of the silos. In larger installations provision could be made for passing air through the grain periodically to eliminate "wet spots" developing, but this calls for heavier capital investment.

B.5.4. Mud Silos

Basically, these are plastered cribs, the plaster material being clay or mud or termite mounds soil made into a plaster material. The advantages claimed for this type of storage are:

(a) it requires a smaller sized crib,

(b) it offers better insect control as any insecticide used is not so directly exposed to humid air and thus can be expected to break down more slowly and so retain its ability for insect control longer. In addition, damage by the grain moth is minimized in these circumstances due to the more closely packed crop restricting the movement of the moth through the grain.

(c) There is little evidence of "caking" in the case of mud silos, and

(d) finally, as they utilize local materials only, they can be constructed by even the most modest scale farmer.

Two main disadvantages are associated with the use of mud silos. Firstly, you need to have dry maize for storage in them, and they are therefore less useful in the humid tropics but more so in countries where a well defined dry season exists.

Another but lesser disadvantage is that the farmer has to shell his maize in a fairly short period of time, whereas if he uses the open crib, shelling takes place a little at a time, and is therefore never considered a major operation.

One often finds mud storage bins constructed in such a way so as to get various compartments for storing of different crops.

B.5.5 Other Storage Techniques

Many traditional and improved traditional systems of storage exist. Gourds, earthenware jars and woven baskets are

especially popular for storage of small quantities of (usually) high value grains, such as seeds.

Another system is underground pit storage, although it seems to be common only in some far and middle East countries and South America.

A Note of Caution

Whatever storage method is adopted, it is absolutely vital to always thoroughly clean the structure after the seasons use, so that there are no residual sources of insect, mould or other contamination.

B.6. Special Storage Problems

Seed Storage

Since man's discovery of the generative function of seed some 10,000 years ago, storage of seed has been the means of distributing plant populations over both time and space. In traditional agriculture, as practiced for hundreds of generations, the farmer sets aside a part of each season's production to plant the succeeding crop. Modern, progressive agriculture, however, requires the rapid and effective multiplication and dissemination of improvements in crop varieties as they are discovered. New and improved crop varieties become an important agricultural input only when seed of such varieties are available to farmers pure, in a viable condition, free of contaminating weed seed and in adequate quantities at the right place and time.

B.6.1 Requirements for Storage

The general prescription for good seed storage is to store seed under dry, cool conditions. When seeds are produced and stored in geographical areas with an unfavourable

climatic, prolonged periods of humid and hot weather, the storage problem becomes rather complex. Solutions for seed storage problems can be found and the risk of storage losses reduced by "thinking through" the problems and needs based on a working knowledge of the basic principles of storage.

B.6.2. Basic Principles of Storage

I. QUALITY IS NOT IMPROVED BY STORAGE.

The grain or seed that are taken out of storage is never higher in quality than at the time it was placed in storage - deterioration is irreversible - we cannot transform low quality seed into higher quality even through the best storage conditions. Based on this principle, some very practical procedures can be implemented:

(a) Since deterioration begins in the field, the crop should be harvested as soon after maturity as possible.

(b) When the crop harvested is not uniform in quality, segregate the obviously deteriorated portion from the best quality.

(c) Immediately after harvest, prevent further deterioration by drying to a safe storage moisture content and storing in the best storage environment available.

(d) Periodically and systematically check the condition of the seed during the storage period.

II. LIFE OF SEED IS DETERMINED BY ITS MOISTURE CONTENT.

The rate of deterioration in seed increases as seed moisture content increases. If moisture content is sufficiently high (say about 18%) biological activity in the seed mass will produce sufficient heat to injure the seed unless they are well aerated. Seed drying is a very critical operation. Moisture content of the seed has to be rapidly reduced without thermal injury. In heated air drying, it has been a long established practice to limit the temperature of the heated air to 110F. (43°C).

Seeds of most grain will store well for one year at moisture contents of 11-13% and normal warehouse temperature. For two years storage, moisture content should be decreased to 10%. Storage periods longer than two years require a further reduction in moisture content and/or a conditioned temperature of 60°F or less. Maize seed stored in a contiononed storage maintained at 50 F and 50% R.H. (relative humidity) will remain viable (germination above 90%) for twenty years.

III SEED MOISTURE CONTENT IS A FUNCTION OF RELATIVE HUMIDITY AND TEMPERATURE OF THE STORAGE ENVIRONMENT.

Seed are hygroscopic. They absorb moisture from the environment or lose moisture until equilibrium is established between the moisture content of the seed and the relative humidity of the atmosphere. Equilibrium moisture content varies among seed kinds. In general, the equilibrium moisture content of oily seed is lower than that of starchy seed at the same relative humidity and temperature.

Temperature and moisture content are the most important factors influencing the storability of seeds. Within limits, a ten degree (10 F.) decrease in temperature nearly doubles storage potential of seed, and a one (1) percent decrease in moisture content also nearly doubles the storage life of seed.

IV DAMAGED, IMMATURE AND DETERIORATED SEED LOTS DO NOT STORE WELL.

The storage potential of seed lots even of the same kind, variety and initial germination differ in proportion to the degree of deterioration of the seed. Therefore, one of the primary reasons for processing seed is to remove the impurities, immature and damaged seeds. Cleanliness and unbroken seed coats are pre-requisites to

effective insect control. Seed should be tested for purity and germination before and after processing and periodically for "aliveness" of seed during the storage period.

V EFFECTIVE SEALED STORAGE REQUIRES THAT MOISTURE CONTENT BE TWO (2) TO THREE (3) PERCENT LOWER THAN FOR OPEN STORAGE.

There is an increasing interest in sealed storage for field crop seeds that would permit safe storage in the tropics without having to control (lower) the temperature. In the vegetable seed industry, sealed storage to preserve the viability and vigor of seeds for long periods has been practical for many years. One paramount factor must be considered in sealed storage of seed. Moisture content must be lower (2-3%) than that at which seeds are normally packaged in non-moisture, vapour-proof containers. With the advent of plastic bags in the 1950's some seedmen in the United States had rather unhappy experiences packaging seeds in them at the usual moisture content. Hybrid maize, for example, was usually dried to about 13% moisture and packaged in cloth or paper bags and quality was maintained for 8 to 18 months. When seed of this moisture level was placed in plastic bags and sealed, germination declined very rapidly.

In sealed storage the atmosphere inside the bag will be in equilibrium with the moisture content of the seed and it will remain at that level. The atmosphere in a moisture, vaporproof container filled with seed maize at 13% will equilibrate at a relative humidity of about 65%. Molds can develop, multiply and be quite harmful at 65% relative humidity. Also, respiratory rate of the seed is high and remains high. In contrast, the atmosphere surrounding maize seed packaged at 13% moisture in porous containers will rise to nearly 100% at times, but it will also drop below 65%. The moisture content of the seed will slowly decrease from 13% during the dry season and may rise a little above 13% during the wet season.

B.6.3 Justification for a Seed Program

A well organized, effective seed program - industry is as important to continual agricultural programs as are the supply programs for fertilizer, pesticides, irrigation, credit, marketing, etc. Seed production, processing, storage and distribution is a complicated business and requires the skills of many trained technicians. Most countries have established good to excellent varietal testing, introduction and breeding programs and by dramatic demonstrations have shown just what can be accomplished by determined, mission orietial crop breeding and research; however, new and improved crop varieties become a significant agricultural imput only when pure, high quality seed are available and planted

by a majority of the farmers in the country. This can be best accomplished through an organized, systematic and cooperative effort involving both private and public institutions and personnel.

B.6.4. Guide for Rural Farmer

Planting seed must in any case be stored from the harvest season until the next planting season. A farmer's seed storage requirements will depend upon whether his seed is produced on his own farm or obtained from another source.

(a) If the seed is produced locally by the farmer, he should plan his complete seed program by:

1. Selecting and obtaining the basic seed required for his seed field from a reliable source.

2. Utilizing the best land and resources for the seed field.

3. Following approved cultural practices.

4. Harvesting seed crop as soon after maturity as possible, selecting and sorting according to quality.

5. Reducing moisture content immediately after harvest by an approved method.

6. Providing for special packaging or containers approved for seed storage.

(b) If the seed is obtained from an outside source, the farmer should:

1. Select a known and recommended variety and obtain a quantity to meet his requirements sometime before planting time.

2. Obtain a current germination test.

3. Provide a temporary storage in a cool and dry place, protected from rodents and insects. Depending upon the quantity and the length of storage, this can be in sealed jars or tins placed in a shaded area, sealed plastic bags on an elevated platform, or perhaps in jute or burlap bags for a relative short period of time depending upon the weather conditions.

B.2 Biological and Physical Principles in Drying/Storage

B.2.1. Sampling Techniques

The object of sampling is to provide information as a basis for future planning and action in relation to the stock of grain. The aim is to determine a mean value and the variability of the level of contamination or infestation (e.g. of mould infected produce or insect pests) or of moisture content. The information collected from a sample indicates the condition of the grain at the time the sample was taken. The results will be used to initiate the application of control measures against insect or rodent infestations, microbiological spoilage and other forms of deterioration (water, heat). These results may also be of value in determining the fitness of the grain for human consumption, animal feed and for determining its monetary value.

(i) Selection of sample

The sample must be representative of the whole population within a given context e.g. a sample of cobs taken from a crib may be representative of the maize stored in cribs in the surrounding areas if the cultural conditions and weather conditions are similar.

It may be necessary to carry out some comparative experiments in order to define the best method for sampling. The method for sampling maize in cob is different than for sampling maize in grain. They should be carefully described in order to ensure uniformity between different workers. All samples taken must be replaced by clean grain or paid in cash to the farmer.

(ii) Primary sample

The size of the primary sample should be as large as possible taking into account the following factors :

- Transportation
- Number and size of subsamples
- Cost of replacement of grain collected.

(iii) Subsamples

The primary sample may have to be divided into representative sub-samples for the various test to be carried out : e.g.

a) moisture content. The test for moisture content should be carried out as soon as

possible after removal of sample in order to ensure reliability. If this is not possible it should be put immediately into a moisture proof container for subsequent analysis.

b) damage caused by insects

c) other damages, mould broken grain etc.

d) germination tests

If the examination of subsamples cannot be made immediately, they should be fumigated in whole or in part.

(iv) Sampling in a crib - maize in cobs

1. If sampling is to be carried out regularly to estimate the effect of an insecticide or the rate of insect infestation, the same quantity of cobs must be taken each time. In order to find the best method to use, it will be worthwhile to compare various methods:

   e.g. (a) Take 100 cobs at random from the top
   (b) Take 25 cobs from 4 opposite directions in the crib
   (c) compare A & B as for moisture content, insect damage etc... If there is no significant difference the simplest method should be selected.

2. Shell the maize as soon as possible after collecting primary sample.

3. Divide into sub-samples by "coning & quartering". The grain is to be shaped into a symmetrical cone in a tray or a sheet then cut into halves or quarters using a flat piece of wood or cardboard.

4. Examine for moisture content

5. Examination of subsamples.

(v) Sampling of shelled maize

- in bags
- in drums
- mud, metal, concrete silos
- by using sampling spears of various sizes
- samples must be taken from different places inside the container, then mixed and divided into subsamples as number 4 above.

SAMPLING RECORD

SAMPLE No.

Collection of sample -
Temperature
R.H.
Weather
Date of harvest:
Date of drying or storage:
Treatment carried out and date
Estimated weight of remaining grain:

Date of sampling:
Moisture content:
Weight of sample:
Weight of sievings
Insects found:

REMARKS

CALCULATIONS

Total number of grains: a. =
Number of damaged grains: b. =
Number of undamaged grains: c. =
Weight of damaged grains: d. =
Weight of undamaged grains: e. =

$$\% \text{ damage} = \frac{100 \times b}{a}$$

$$\% \text{ weight loss} = \frac{100\,[(e \times b) - (d \times e)]}{e \times a} =$$

FAO
AFRICAN RURAL STORAGE CENTRE
(Worksheet for the building of a drying/storage crib)

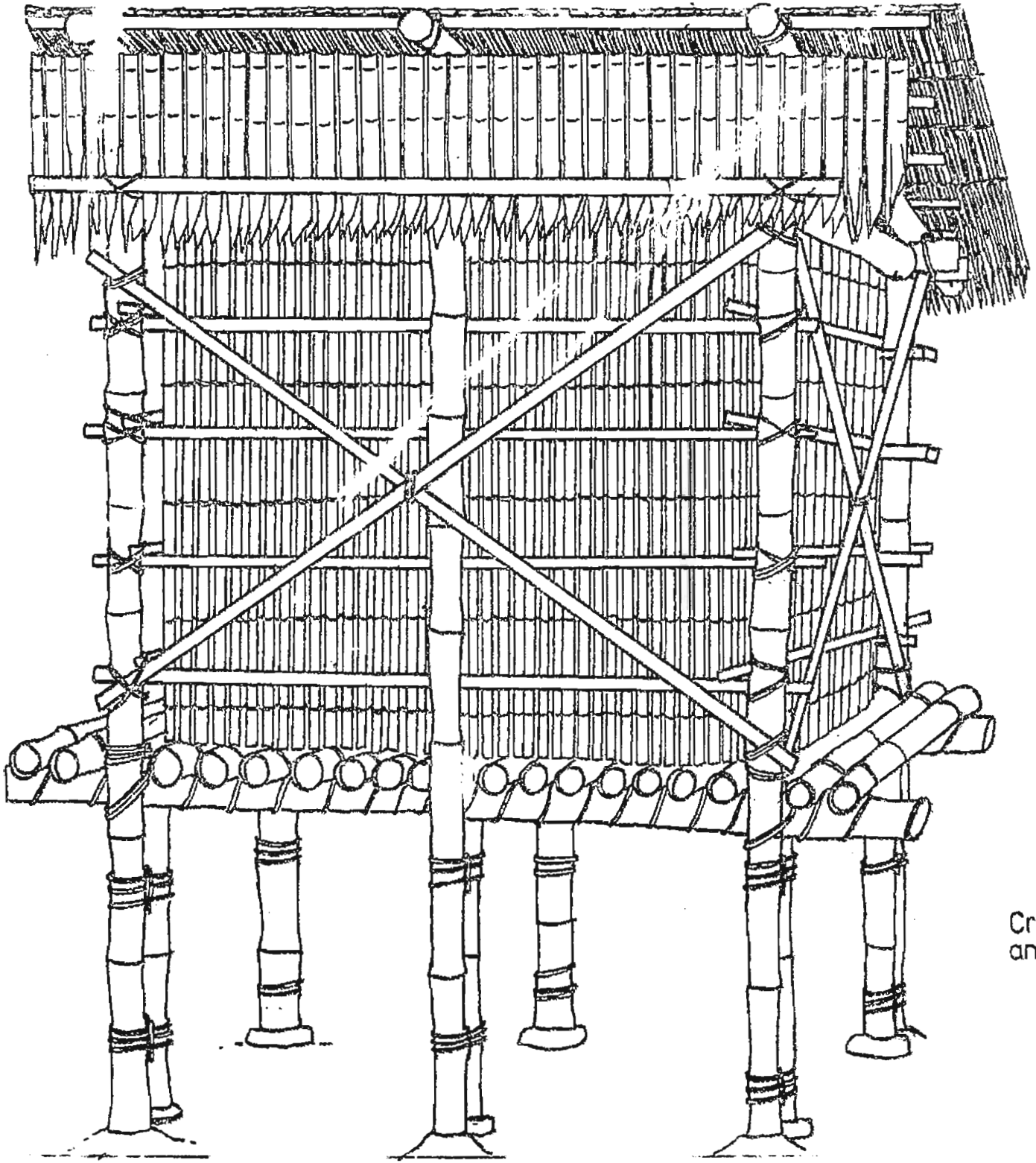
NOTE:

1. The crib illustrated is a modified version of the NSFRI crib.

2. There is no reason to use exactly the same materials as is shown in the illustrations, but users may choose whatever is most convenient.

3. Users are advised though to adopt the dimensions shown as much as possible as this will facilitate building, avoid structural failures, prevent rodent damage and ensure maximum drying efficiency.

4. In building of the Roof (step 9 onwards) the materials should match the basic crib (step 8). Since each crib is likely to be somewhat different, in practice no dimensions are given for the roof materials, but the easiest would be to build the roof straight onto the basic building.



Crib with front loading cover
and roof in position - complete

STEP 1

Collect materials, cut to length and notch where required.

a-3 vertical supports (notched at nodes at one end with V cut above node) 3.5m long

b-3 vertical supports (same as above) 3.0m. long

c-2 horizontal roof supports 2.5m long

d-2 horizontal platform supports 2.5m long

e-6 vertical platform supports 1m long

f-6 horizontal spacers (notched at nodes both ends) 1m long

g-20 25 bamboo or poles (straight and uniform in size) 1.25m long

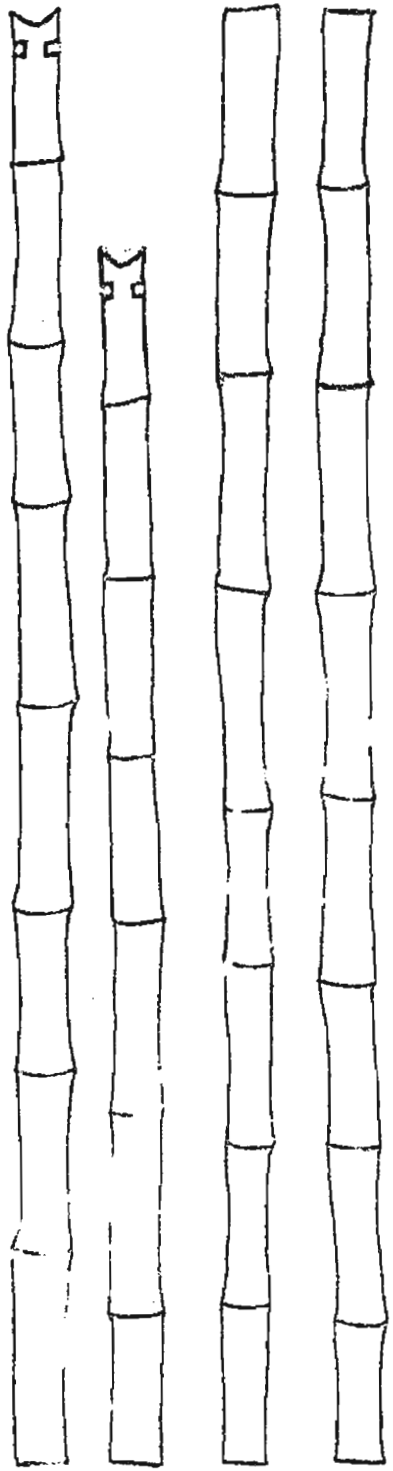
h- 8 braces (raffia or small bamboo) 2.5m long

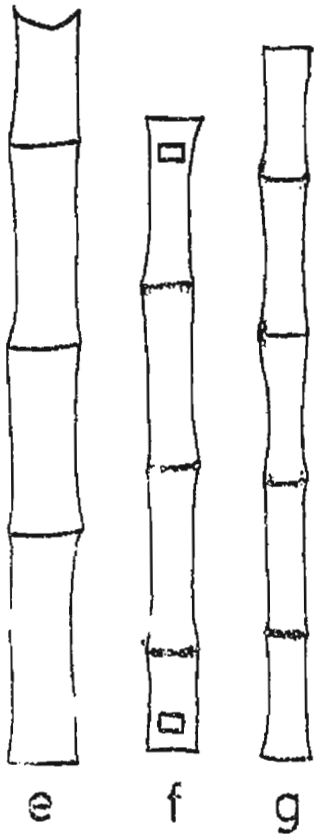
- 8 side wall supports same as h above 2.25m

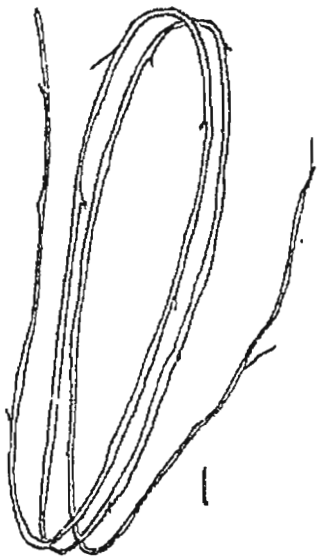
8 end wall supports same as h & i above 1.25m long

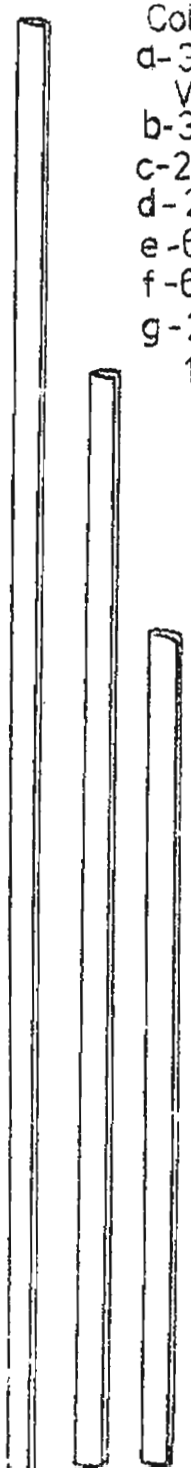
k Raffia or other strong slats (tie as pickets for crib walls) approx. 6m. long by 1.5m high

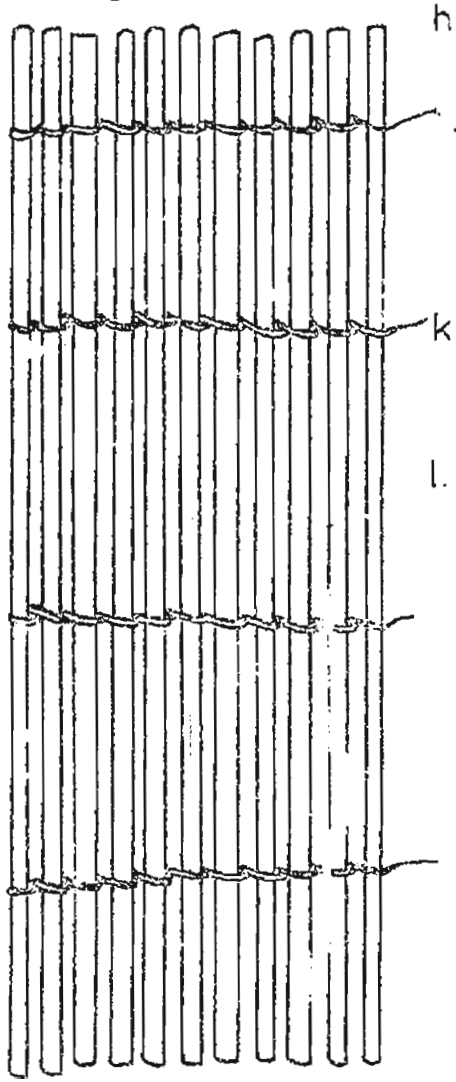
l. Rattan or other tie vine for lashing





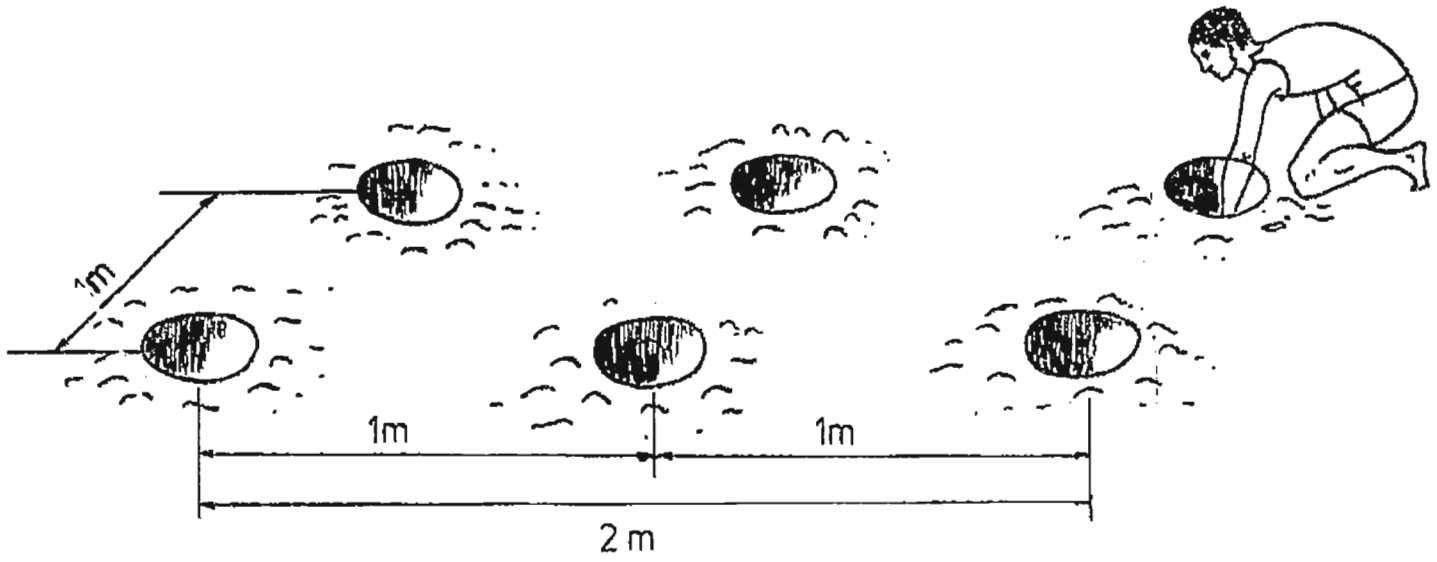


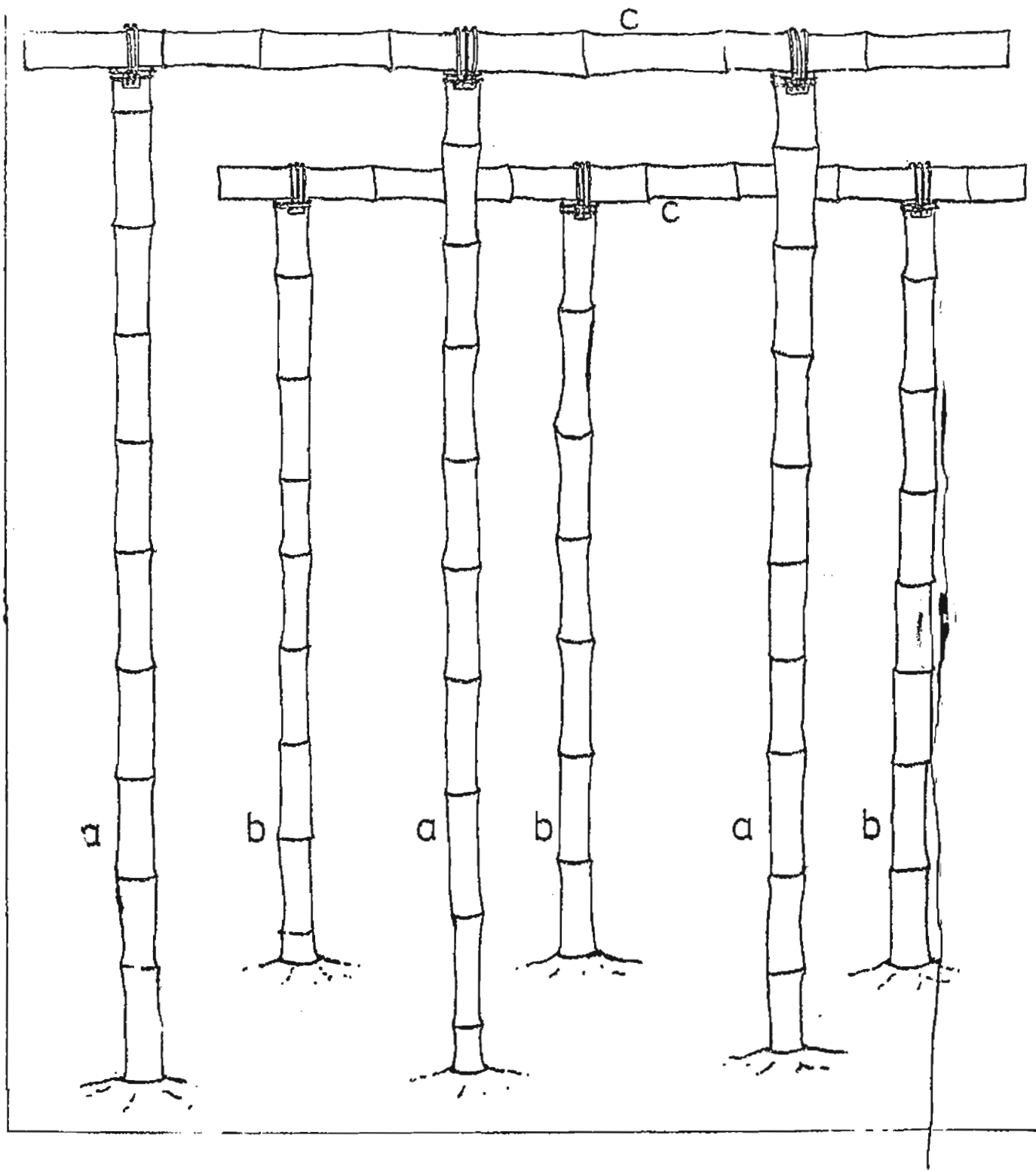




STEP 2

Dig holes for vertical supports. 6 holes .5 m. deep

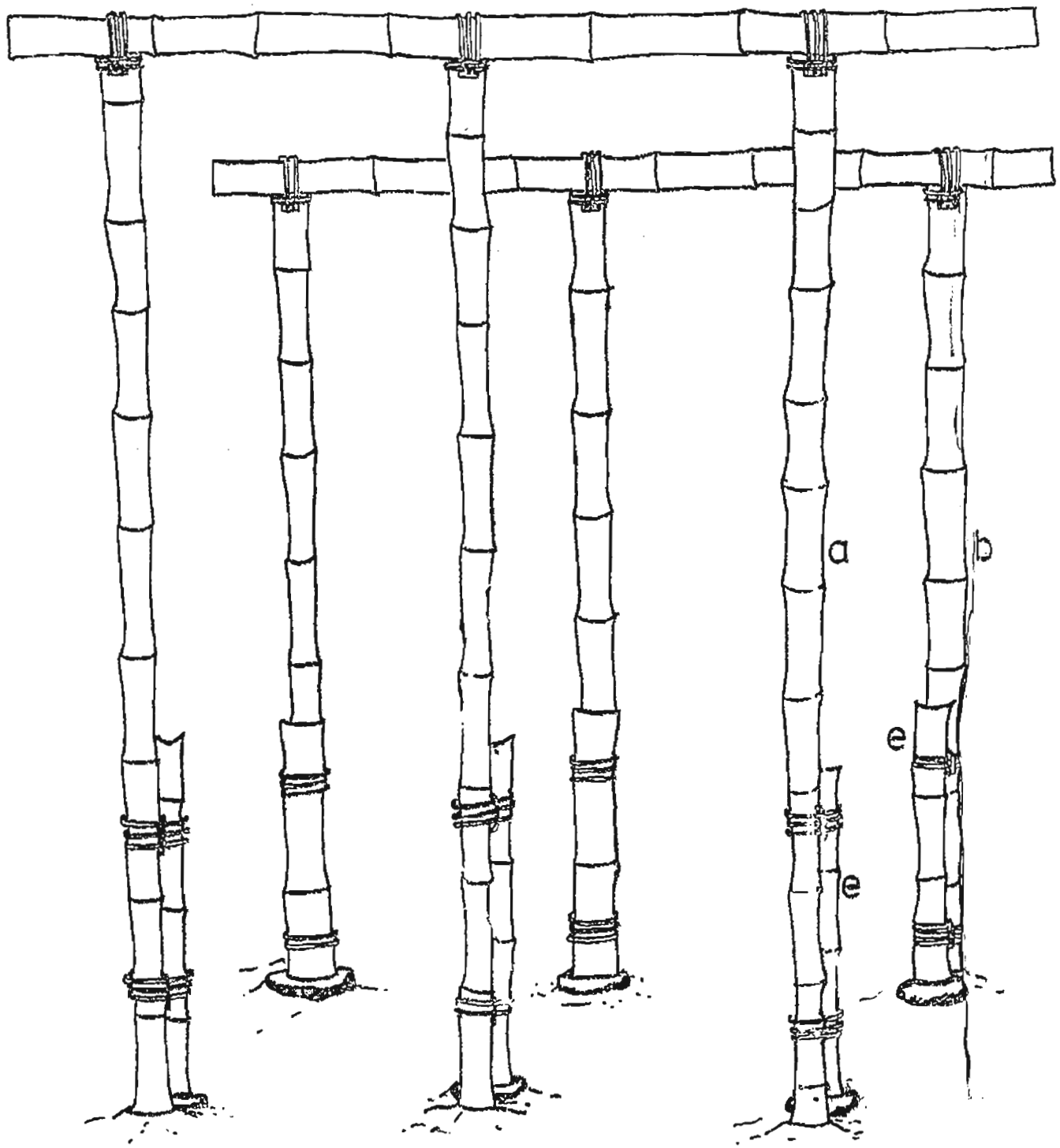




STEP 3

1 Lash horizontal roof supports c to vertical supports a & b - position opposite holes

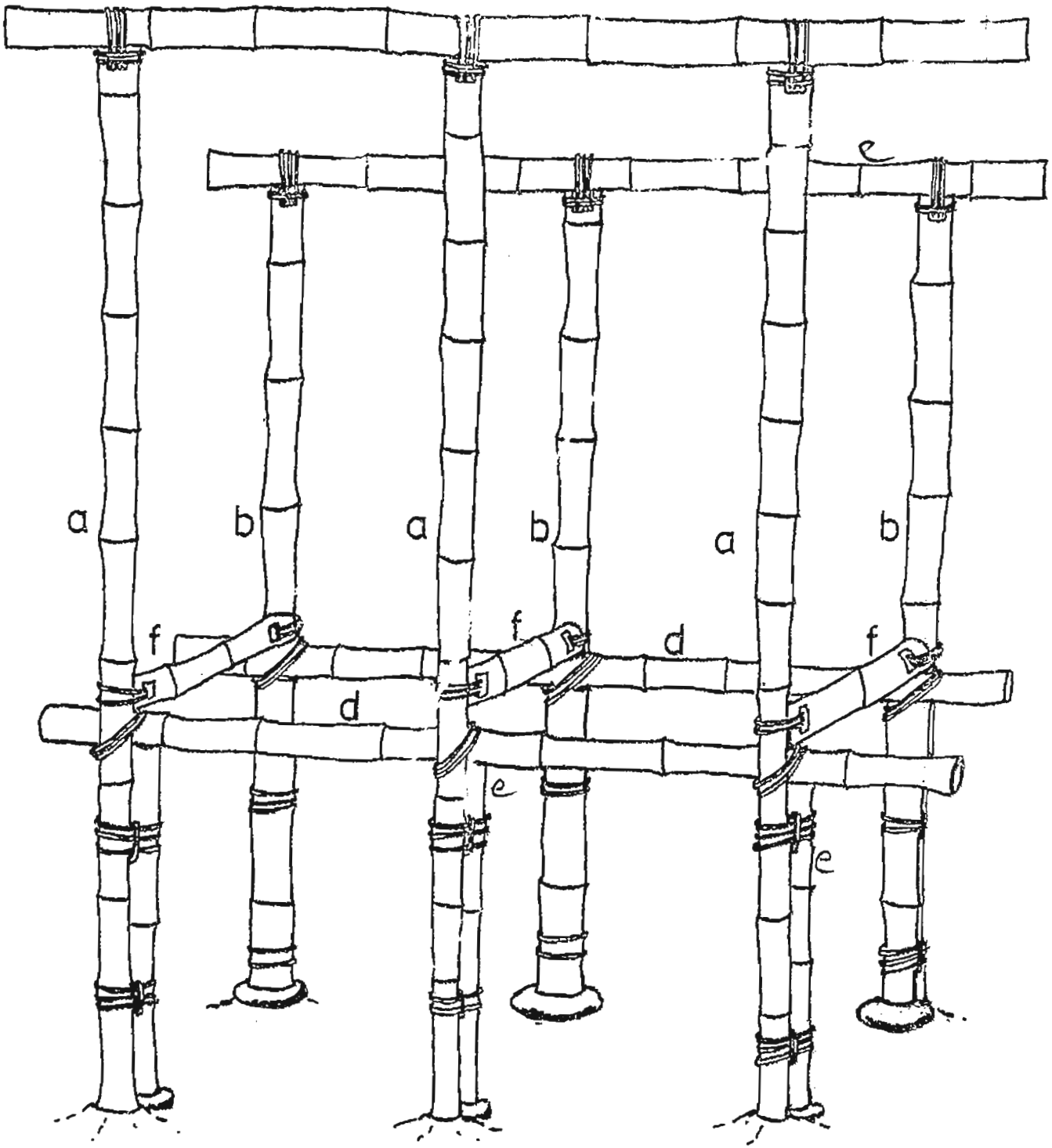
2 Place into holes and tamp fill around supports a & b after placing spacer f between vertical supports - temporarily.



STEP 4

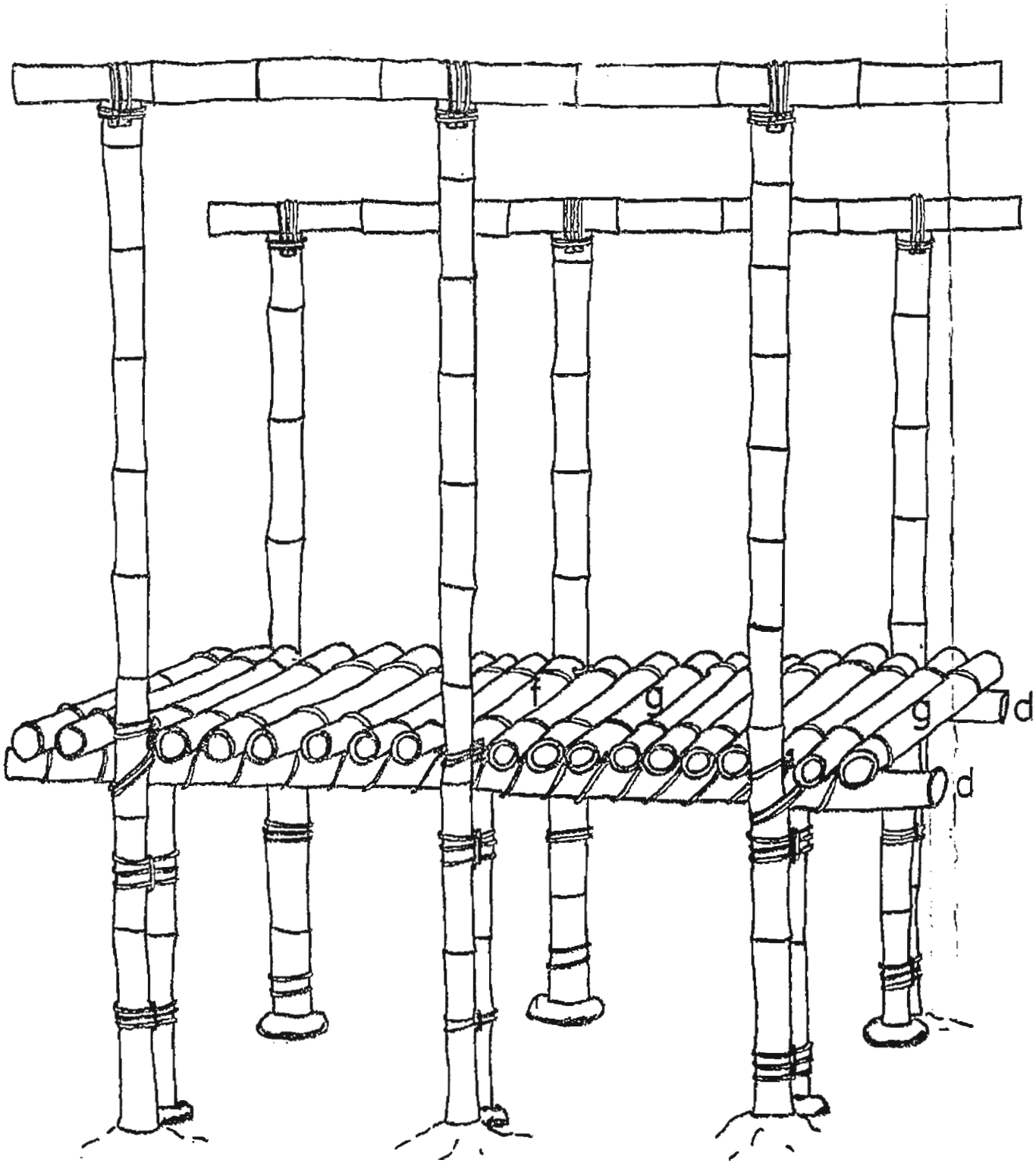
1 Lash vertical platform supports e to vertical supports a & b

2 Position flat stone under each platform support



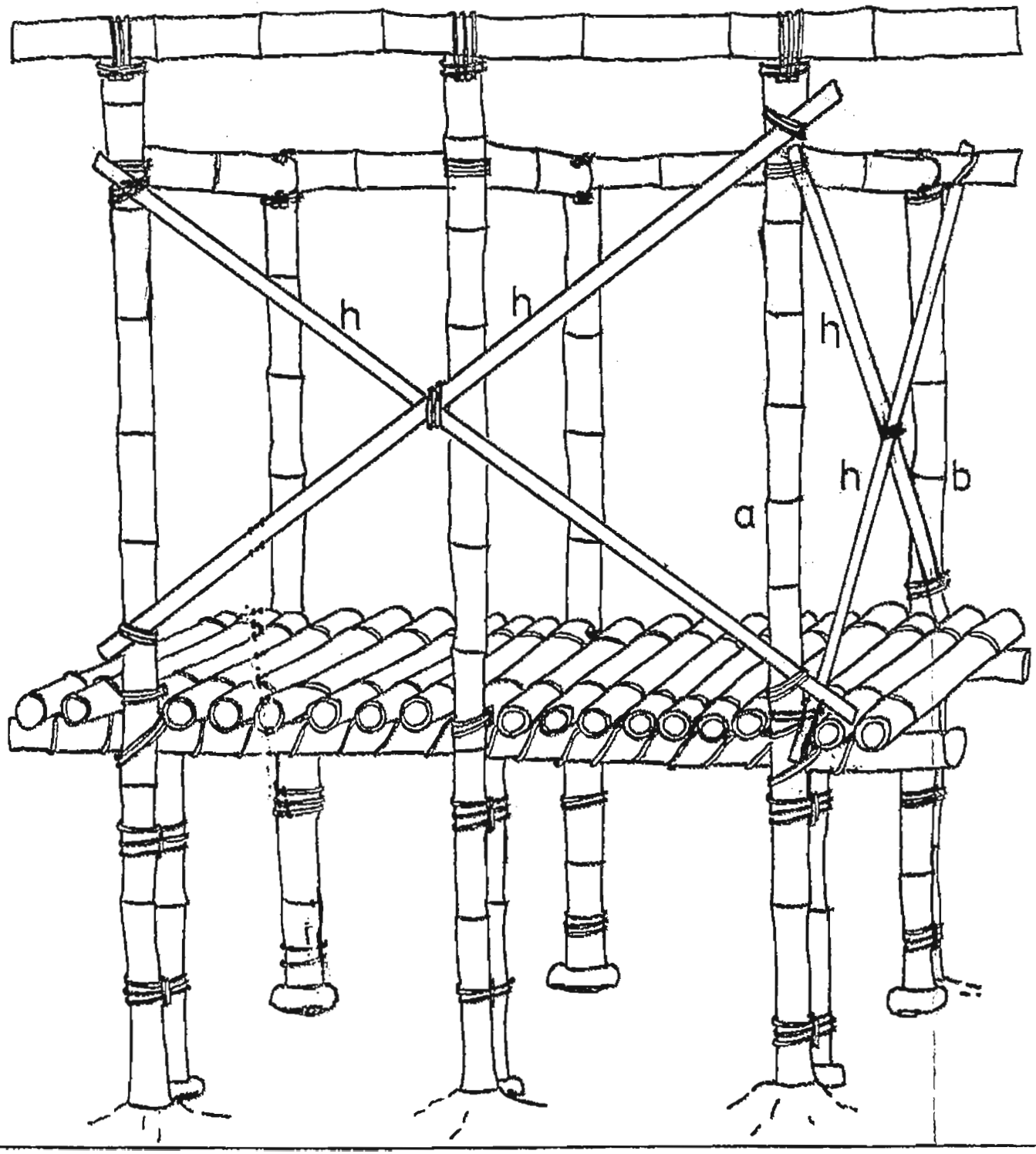
STEP 5

Lash horizontal platform supports d and spacers to vertical supports a&



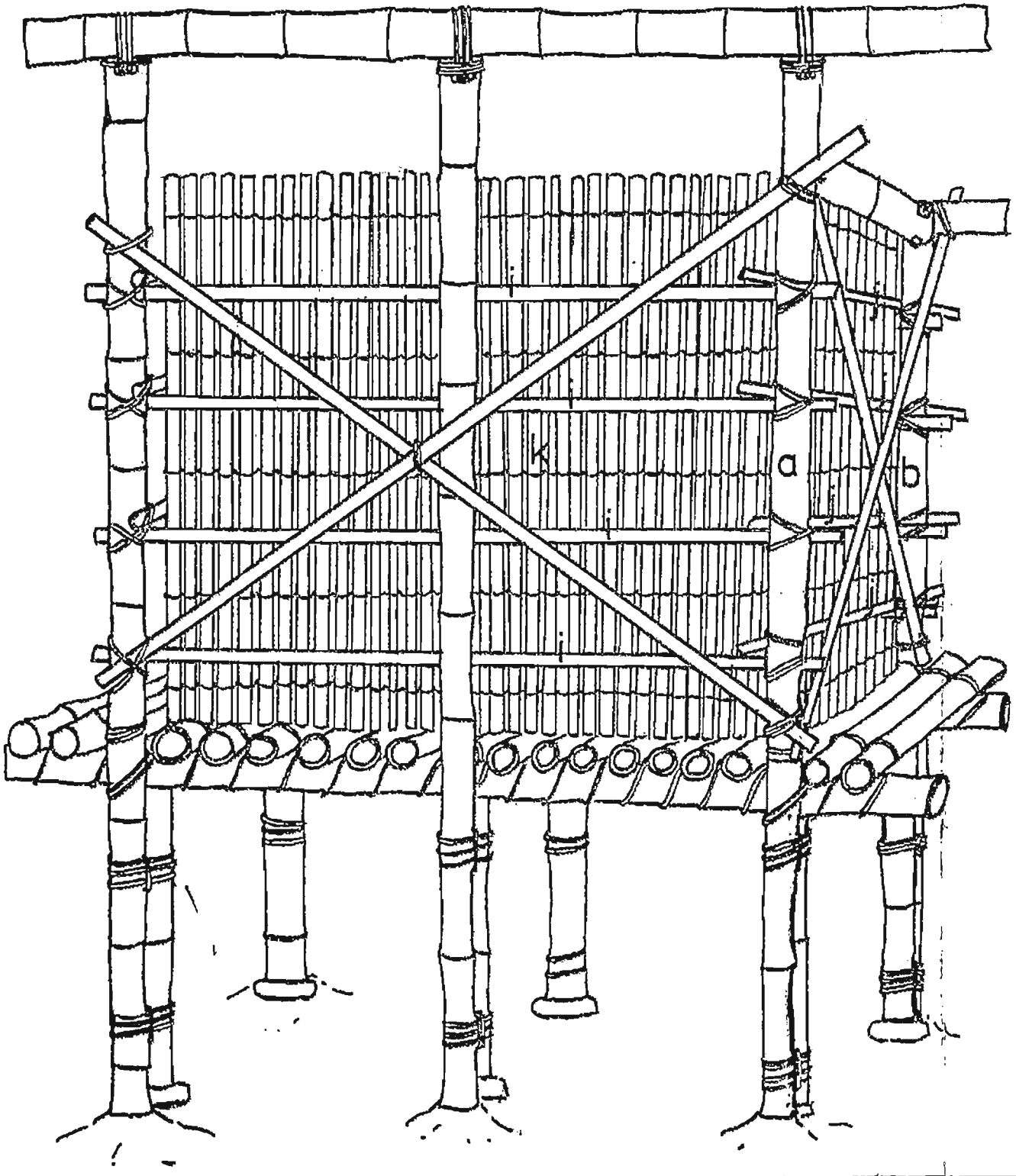
STEP 6

Lash platform pieces g
to horizontal supports d



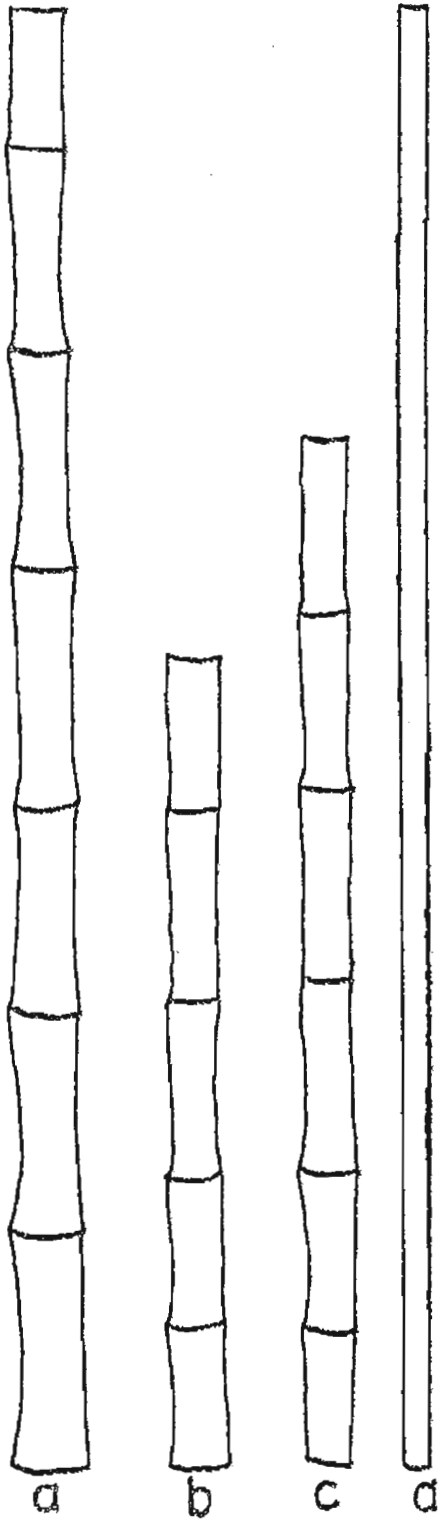
STEP 7

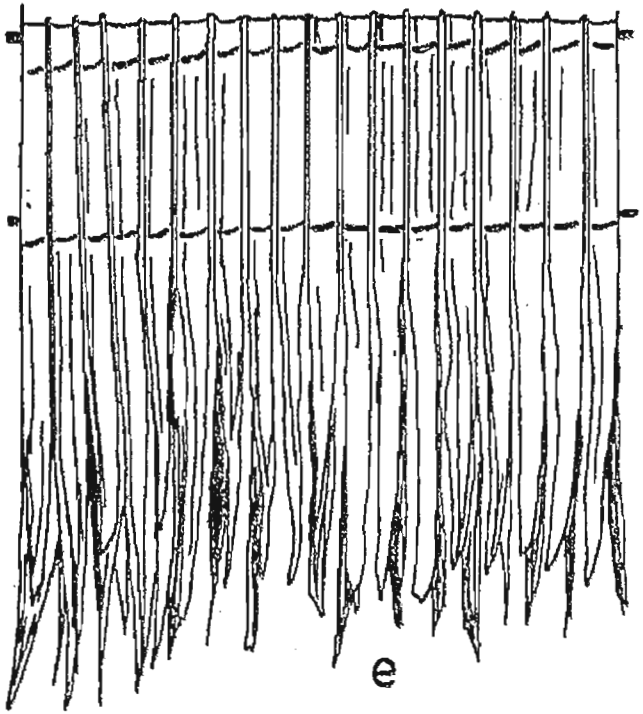
Lash X braces h to vertical supports a & b square frame before securing



STEP 8

1. Lash wall supports i & j to vertical supports a & b
2. Lash side wall k to wall supports i & j





STEP 9 - ROOF

Collect material and cut to length

a 3 horizontal roof members

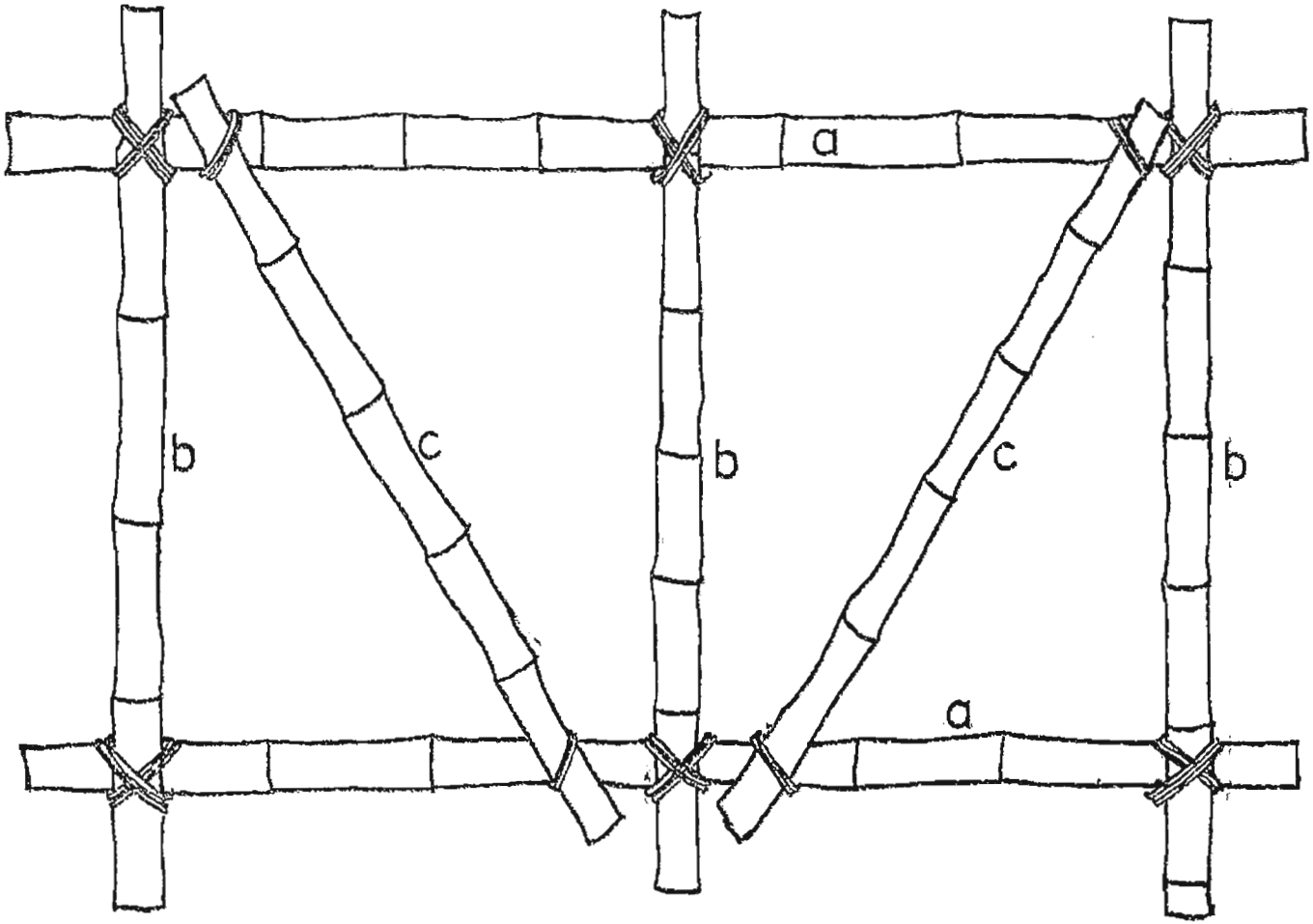
b 3 cross roof members

c 2 braces

d 7 purlins

e raffia mats or grass for thatch and front loading cover

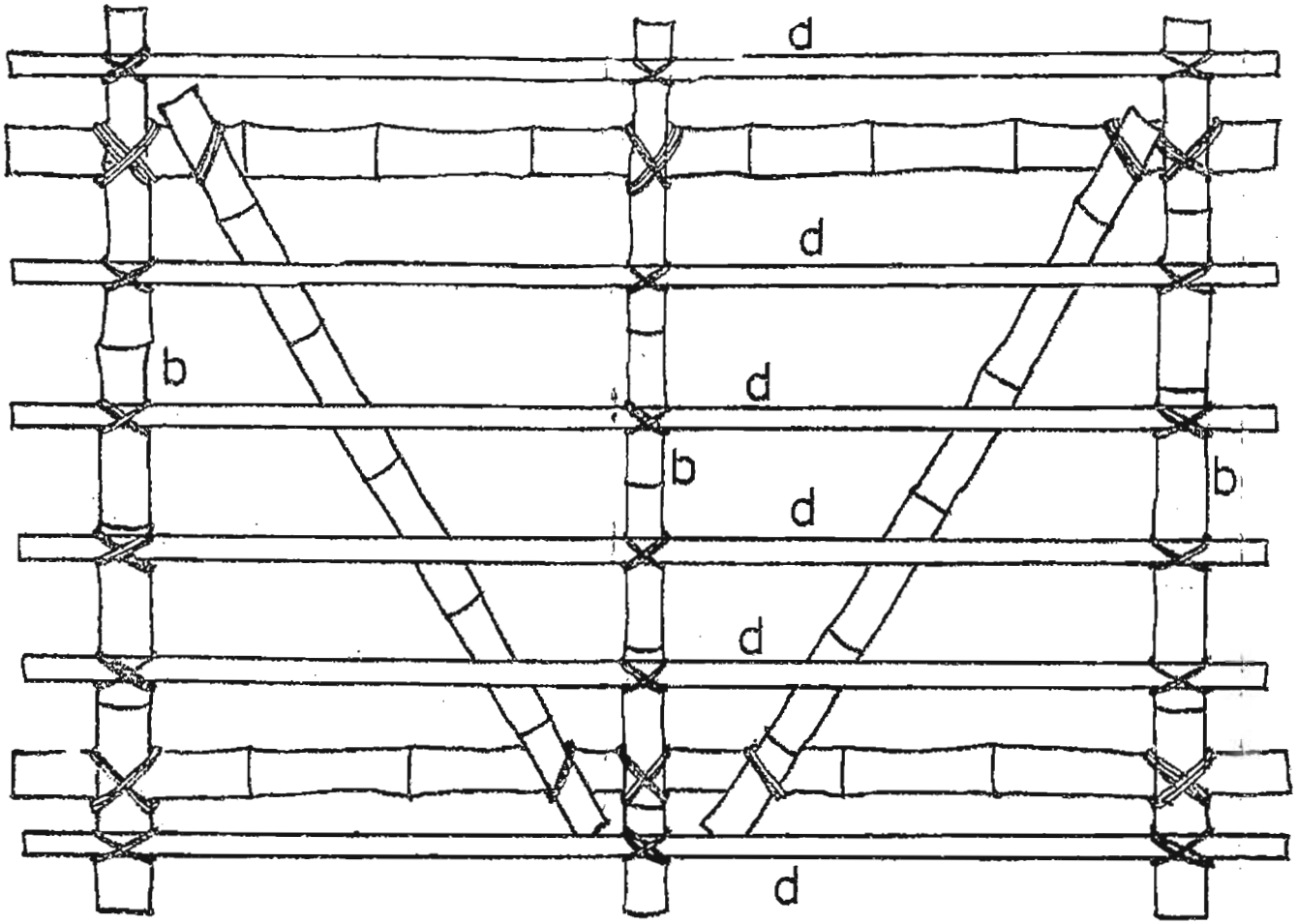
f tie vine



STEP 10

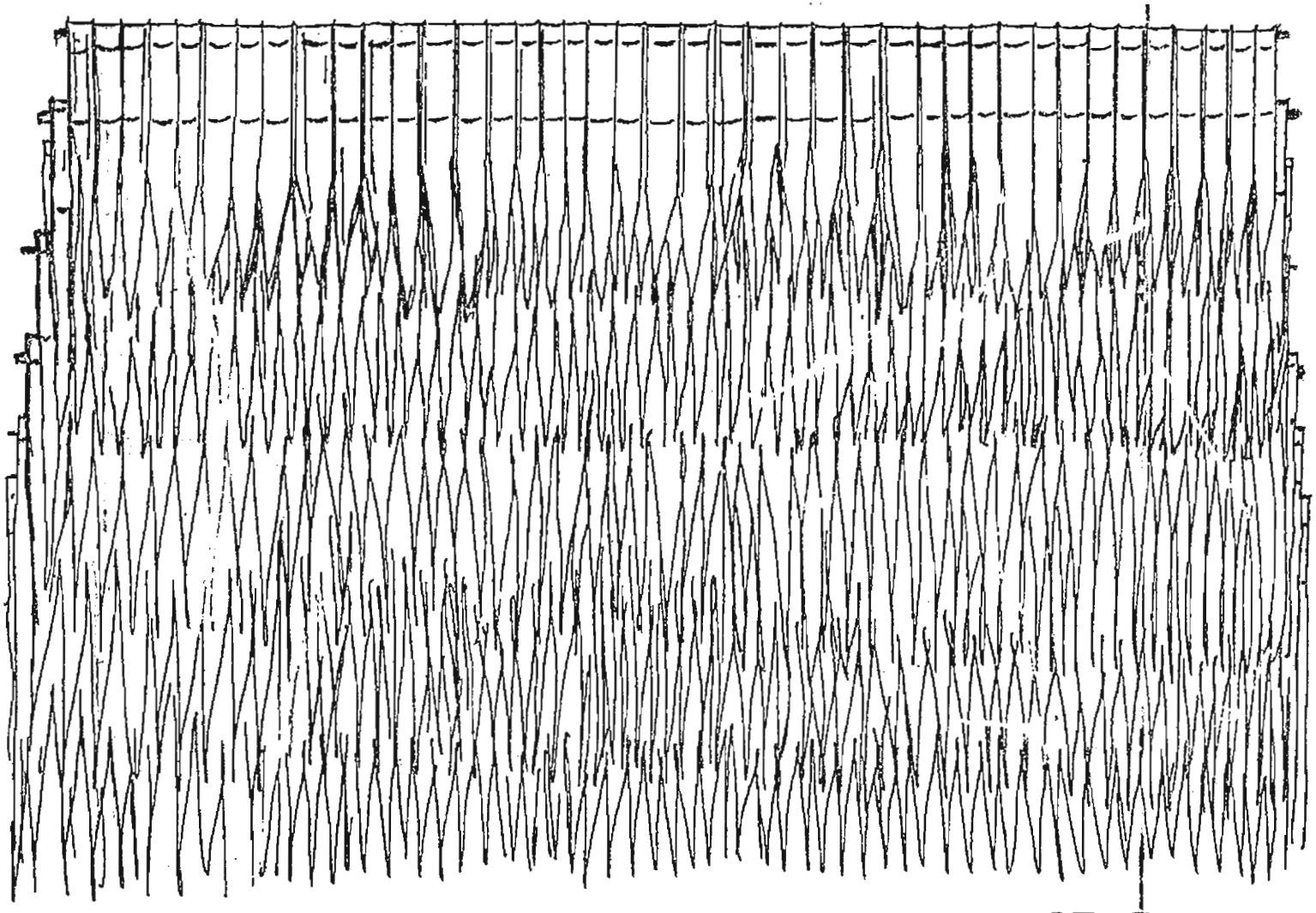
1 Lash cross roof members b to 2 of horizontal roof members a.

2 Lash braces c to horizontal roof members a



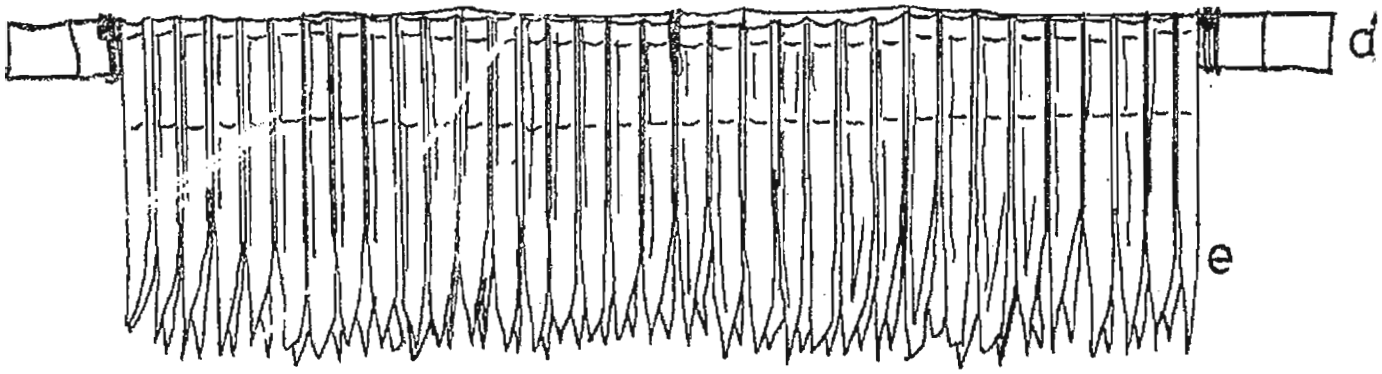
STEP 11

Lash 6 purlins d to cross roof members b



STEP 12

Lash raffia mat in overlapping layers to roof frame



STEP 13

Lash raffia mat e to horizontal roof member a to form front loading cover

MOULD DETERIORATION OF STORED FOOD CROPS AND CONTROL[1]

BY

J. O. OYENIRAN[2]

INTRODUCTION

Moulds are microscopic fungi and mould deterioration can be defined as any change resulting from the activities of moulds which renders a product unsuitable for its intended use or reduces the economic value of the material. It is also desirable to include those activities of microorganisms which may result in an increase of processing costs or which may affect amenity value.

Research on stored food crops in most countries has concentrated more on insect than on fungal deterioration (Clarke, 1968). This is partly because most stored product insects are visible to the naked eye and the damage they cause is usually conspicuous and quantitative. However, fungi, especially moulds, have been known to cause various types of deterioration and pose hazards to the life of animals and man whenever they infect stored food products. These have been extensively discussed in many reviews especially by : Christensen, 1957; Christensen and Kaufmann, 1965; Hiscocks, 1965; Raymond, 1966; and Eggins and Coursey, 1968. The various types of deterioration will be mentioned, discussed and illustrated.

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[1] Lecture delivered at the International Maize Production Training Course, IITA, Ibadan - 14th August 1974.

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Ibadan.

Types Of Mould Deterioration

1. Discolonration: Moulds cause discolouration of produce. Since they themselves are in different colours - green, yellow, black, brown etc., they impart these colours on the produce where they grow and thus change the appear nce of such produce.

   For instance, Botryodiplodia theobromae was responsible for the disease of discolouration of groundnuts widely known as "concealed damage" in Alabama while Macrophomina phaseoli caused "black nuts" in Gambian groundnuts (ilson, 1947; Pattinson & Thornton, 1961). Discoloured produce is disliked by manufacturers and consumers for a number of reasons. In the Hand Picked Selected (HPS) groundnuts in Nigeria, the more discoloured kernels present, the greater the task of picking them. Discolouration in palm kernels is often associated with high acidity, reduction in nutritional values of the cake and production of oil that is very difficult to bleach (Cornelius, 1966).

   Before the 1950's the cause of discoloured grains was not precisely known. For example wheat in storage sometimes develops dark germs, and in the grain trade these have been called "sick" wheat, a poor term, since such seeds are dead not sick. Later, studies by Christensen (1955) revealed that fungus mycelium were usually abundant on such discoloured embryos. Such discoloured grains disfigure the prepared flour by appearing as unsightly specks inside it.

   Christensen and Linko (1963) obtained samples of wheat from commercial bins and stored these in the laboratory with the same moisture contents as the samples had when received. The relationship found between moisture content, brown or damaged germs and colonies of Aspergillus per gram of grain is summarised in Table 1.

Table 1. Influence of Moisture Content upon Increase in storage Fungi and Percentage of Brown germs in hard red winter wheat stored Fourteen Months at 20° - 25°C. (68° - 77°F).

Moisture Content %	Brown Germs%	Colonies of Aspergillus per gram (IN thousands)
12.3	0	0
13.2	0	0
13.8	3	120
14.2	5	330
14.7	20	220
14.9	28	530
15.1	100	1008

Source : Christensen and Linko (1963).

2. Destruction of Viability : One reason why agricultural produce is stored is to use as seed for the next crop. Fungi kill the viability of seeds by infecting and destroying their embryo. There is a considerable body of evidence to indicate that invasion of seeds by storage fungi can drastically reduce the germinability of the seed.

Tuite and Christensen (1955) stored samples of barley seeds at 19.4% moisture content and at room temperature, some of the samples free of storage fungi and others inoculated with storage fungi. After fifteen days the sample inoculated with storage fungi germinated 72% whereas the sample free of storage fungi germinated 98%. They stated, "All of these species of the A. glaucus group as well as A. candidus and Penicillium sp. invade various parts of the seed, including the germ, and directly cause or contribute to reduction in germination.

Qasem and Christensen (1958) adjusted corn free of fungi to different moisture contents, inoculated some samples with various storage fungi, left others uninoculated, stored the samples at several temperatures and periodically tested them for germinability. The samples inoculated with Aspergillus candidus and stored at 18% moisture content and 25°C for 4.5 months germinated 9%, the controls germinated 94%.

Lopez and Christensen (1967) stored corn at 19-20% moisture content and 20°-25°C., some samples free of fungi, others inoculated with different isolated of A. flavus. After seventy-four days, the samples free of fungi averaged 97% germination, and those inoculated with A. flavus averaged 13%.

Broadbent (1968) found that mouldy maize from a government farm in Western Nigeria had germination of 7-14% while the mould free maize had 100% germination. (Table 2, SLIDE).

The normal course of events in almost all plant tissues decayed by fungi is, first invasion, then death of the invaded tissue, followed by discolouration.

Table 2. Germination And Seedling Vigour Of The Seed Maize

	Germination %	Seedling Height (CM)		
		Min.	Average	Max.
Control Maize	100	18.0	30.3	38.0
Seed Maize				
Sample 1	13.5	5.0	16.6	33.3
Sample 2	7.5	9.0	18.9	32.5

3. Effect of Flavour and Odour : Mouldiness spoils the flavour of stored produce and also that of the product manufactured from it. Mouldy raw or fried groundnuts have a very unpleasant, sour taste when consumed and these are usually spit out from the mouth as soon as chewed.

   Effect on flavour is the most objectionable character developed by mouldy cocoa beans and manufacturers claim that amounts as low as 4% mouldy beans can be detected by taste in a sample of chocolate which has passed through all the normal manufacturing processes (Wadsworth, 1955).

   Mouldy produce also has a bad odour ranging from the musty odour of mouldy grains to the foul smell of rotting grains or tubers.

4. Biodeterioration of Oilseeds and Fats - Increase in F.F.A. and Decrease in Oil Content. : Among the intermediate products of spoilage in materials that contain fats or oils are fatty acids, and the characteristic odours and flavours of these fatty acids are what make partially spoiled fats rancid. It has also long been known that deterioration of stored grains is accompanied by an increase in fatty acids. This is because many species of moulds produce lipases which could hydrolyse fats into fatty acids by the process called Lipolysis, thereby increasing the F.F.A. content of the produce. This makes the oil difficult to refine. Sometimes limits are set for amount of FFA permissible in exportable oilseeds and oilseed products.

In palm kernel trade it is 4.75%, and for every 1% above this amount there is a finacial penalty of 0.75% per ton. Moulds also lead to a reduction in the amount of oil extractable from the oilseeds.

Many instances of deterioration of oilseeds were reviewed by Eggins & Coursey (1968). These include the work of Barbosa (1962) who showed that total losses of oil content and increases in FFA of stored groundnuts in Portugal were associated with the growth of fungi, in particular, Aspergillus flavus.

Ward and Diener (1961) found that Aspergillus glaucus gp., A. tamarii and Penicillium citrinum cause lipolysis of groundnut oil and reduction in the oil content. (SLIDE 2).

In the Nigerian groundnut crop, high acidity of around 5% occurred before 1954 due to a high proportion of broken kernels which were easily attacked by moulds. The introduction of the shelling machine raised the proportion of whole kernels from 30% to 70% and this reduced the acidity to less than 1%. With a harvest of 700,000 tons, this represents a saving of about £1 million (Raymond, 1966).

Coursey and Eggins (1961) isolated a number of moulds from palm oil and showed that many of them increased the FFA of palmoil in pure culture studies. Sheridan (1961), Coursey et at (1963) isolated a number of lipolytic fungi from Nigerian palm kernels.

Some work on the effect of moulds on the biochemical property of maize has also shown that the FFA is always increased. Nagel and Semeniuk (1946) inoculated corn with pure cultures of nine species of fungi, separately and together. The moulds increased the FFA content of the grains to varying extents from 74.8 units to 384 units.

Goodman and Christensen (1952) grew cultures of four species of fungi isolated from mouldy corn - Penicillium solitum, Aspergillus flavus, A. candidus and A. amstelodami - on corn meal from which the oil originally extracted had again been added. All caused an initial increase in fatty acids in the meal containing oil. In these tests the fatty acids were produced as a result of fungus lipases acting upon the corn oil.

5. Rotting and Caking : Direct spoilage such as rotting of yams and caking of maize is usually caused by extensive mould infection and damage of these products during storage. Studies by Okafor (1966), Ogundana (1969) and Adeniji (1970) have shown that number of fungi (Aspergillus niger, Botryodiplodia theobromae, Fusarium moniliforme, Hendersonula toruloidea, Macrophomina phaseoli, Penicillium oxalicum and P. sclerotigenum) cause rotting in Nigerian yams.

   We have carried out extensive studies on maize deterioration at N. S. P. R. I. Ibadan, and these will be reviewed shortly. (SLIDE 3).

6. Absolute weight loss : Attack by moulds do cause an absolute weight loss in stored products. A dry matter loss of 12% was found in Fijian copra during a fourteen day's storage due to attack by moulds (Raymond 1966). There is also a weight loss when grain is stored, an estimated possible world loss due to this cause was about 1% (F.A.O., 1948). The loss in the tropics must be much higher.

   Nagel and Semenuik (1946) found that four of the nine moulds they tested induced marked organic matter losses in maize. The greatest loss (approximately 40%) was induced by Aspergillus flavus, A. niger, Penicillium chrysogenum I & II in the four week period. Losses of 20.1% 14.5%, 11.9%, 10.4% and 6.4% in the same period were induced by A. candidus, Penicillium pallitanus, P. rugulosum Mucor racemosus and Aspergillus amstelodami respectively.

7. Preparation of the material for attack by other predators. : Mould damage in stored products prepares such materials for attack by other agents of deterioration, especially insects and mites. It is difficult in many foods to separate the deterioration due to insects from that caused by fungi, but that the two are interrelated is in no doubt. What is in doubt sometimes is the exact sequence of events and the relative damage caused by the two agents (Raymond, 1966).

   Christensen and Hodson (1960) showed that both insects and fungi are associated in their deterioration of grains and each enhances the activity of the other. Sikorowski (1964) reviewed the whole subject and pointed out that storage insects can live, develop and reproduce entirely on certain fungi and they undoubtedly play an important part as carriers in the spread of fungi.

8. Production of Mycotoxins : Toxin production is the most serious effects of microbiological deterioration of stored products. A number of fungi are known to produce metabolites into the stored products on which they grow, so that when these products are consumed, they cause diseases known as mycotoxicoses. This is a wide subject on which very much has been written (see Forgacs and Carll, 1962; 1966; Coveney, et al. 1965; Wogan, 1965; Forgacs 1966, Bamburg et al. 1969). Some notable examples of mycotoxicotes are :

(i) Ergotism, a disease of cattle in central Europe caused by Claviceps purpurea
(ii) Facial eczema of sheep in New Zealand caused by Pithomyces chartarum
(iii) Yellow Rice Disease of man in Japan caused by Penicillium citrinum, P. islandicum and P. citreoviride
(iv) Alimentary Toxic Aleukia (ATA) of man and cattle caused by Fusarium sporotrichiodes, F. poae, and F. tricinctum
(v) The complex known as Moldy Corn Toxicoses caused by Penicillium rubrum, Chaetomium globosum, Aspergillus ochraceus and other moulds.
(vi) Lastly and most significantly - Aflatoxicosis of poultry and livestock caused by Aspergillus flavus. (Table 3 - Slide 4).

This last mentioned toxin disease, Aflatoxicosis, has been receiving world-wide attention since 1960 when it was reported to have been caused the death of about 100,000 turkeys in Britain (Sergeant, et al. 1961). These turkeys were fed with meals containing a particular batch of Brazillian groundnut cake which was infected with Aspergillus flavus. The toxic substance was hence called AFLATOXIN. Our studies in Nigeria have recalled the presence of aflatoxin in Nigerian groundnuts and livestock feed maize. (see Aflatoxin Bibliography 1960 - 1967).

STUDIES ON THE DETERIORATION OF STORED PRODUCTS (MAIZE)

Your course here is primarily concerned with maize production and for this reason I shall concentrate my discussion of this section and most of the rest of the lecture on maize deterioration by moulds.

Maize is an important staple food crop in Nigeria; about a million tons are produced annually in Nigeria (Anon 1966). Most of the maize produced by the local farmers is sold to middlemen (traders) and consumers at harvest, while the farmer stores a little quantity, limited by storage facilities. While the farmer usually stores his maize on the cob with the sheath on (until recently when modern crib storage was introduced by my department), the middlemen usually store their maize shelled and in bags. A few, especially the government departments, store in sillos. In recent years demand for maize by livestock

Table 3 . Some Toxic Moulds and their Toxins

Ammanita phalloides	Phalloidin
Aspergillus chevalieri	Xanthocillin
A. flavus	Aflatoxin
A. fumigatus	Gliotoxin
A. nidulans	Sterigmatocystin
A. ochraceus	Ochratoxin
A. oryzae	Maltoryzine
Fusarium graminearum	Xearalenone
Penicillium citrinum	Citrinin
P. cyclopium	Cyclopiazonic acid
P. frequentans	Citromycetin
P. islandicum	Islanditoxin
P. notatum	Xanthocillin
P. rubrum	Rubratoxin
P. rugulosum	Citreoviridin
P. toxicarium	Citreoviridin
P. urticae	Patulin
Pithomyces chatarum	Sporidesmin

feed industry had become so high that most farmers' maize is bought around harvest time and stored shelled in bags.

The problem of mould attack becomes serious with shelled maize that is stored soon after harvest, without extra drying. The reasons for this will be discussed later under the causes of mould deterioration of grains

Studies have been carried out on maize obtained at different stages on the trading channel and these will be highlighted shortly but first let us look briefly at our methods of grain analysis for moulds.

1. Methods of grain analysis for moulds : Several methods are known for isolating moulds from grains. They range from simple ones like placing grains on moistened filter paper in dishes (Sinha & Wallace, 1965) to very laborious ones like dissecting grains before plating (Clarke, 1968). Two popular methods however are : the direct-plating (Christensen & Dreschner 1954); and dilution-plating (Christensen 1946; 1957; Clarke 1968) of grains. These are the two methods studies could be fully understood, these methods will be described briefly.

i. Direct-plating method - A sample of grains is obtained. Two sub-samples are taken from the sample. One is surface- sterilized by washing in Milton's reagent (1% sodium hypochlorite + 16.5% sodium chloride) for three minutes and thrice in sterile water for two minutes each. Fifty grains of unsterilized and fifty of sterilized lots are embedded in cool molten Malt Extract Agar in Petri dishes at five grains per plate using flamed forceps. The plates are all incubated at room temperature (26-28°C) for five days after which the plates are examined. The number of grains from which moulds develop are recorded and the species of mould developing from each of them are identified.

ii. Dilution-plating method - A sample of ten grams of grains is weighed out aseptically. It is macerated in a blender bottle with 90 mls. of sterile watery (0.2%) agar using a high-speed homogenizer. The suspension obtained here is 1/10th concentration of the original sample or simply 10^{-1} dilution. From this, a series of dilutions (up to 10^{-7}) is then prepared, each dilution containing 1/10th of the weight of product present in the immediately preceding dilution. One ml. amounts from each from each dilution from 10^{-2} to 10^{-7} are pipetted into three replicate Petri dishes to which cooled (45°C) molten culture media are then added. The plates are swirled several times to thoroughly mix the produce with the medium. Two types of culture media are used, namely Malt Extract Agar to which antibiotics, Penicillin and Streptomycin are added (MPS) and Harrold's Agar, made up of Malt Extract Agar and 40% sucrose (M40Y). A set of the MPS and all the M40Y plates are incubated at room temperature while another set of the MPS plates are incubated at 37°C. The plates are left for three days after which the mould colonies developing on each plate are marked and recorded. Averages on three replicate plates are recorded as the number of colonies per gram of grain at that particular dilution, medium and temperature. Averages of the number of colonies growing on all media, at all temperatures used are taken as the total number of colonies per gram of produce , and is regarded as a measure of the mouldiness of the sample.

2. Results of studies on maize : Several studies have been carried out in NSPRI laboratory at Ibadan on mould deterioration of maize during storage at various stages (Broadbent, 1968[a]; 1968[b]; Broadbent & Oyeniran, 1968; Oyeniran 1973[a], 1973[b], 197-). These studies could be divided broadly into two categories : (a) studies on samples obtained from the field (farms, storage sites, markets, silos etc.) and (b) studies on experi experimental samples (e.g. grains stored at certain moisture contents).

Our concern in this lecture is the first category because deterioration in such samples can be described as natural while in the other it can be termed induced or manipulated.

The studies in the category we are considering cannot also be fully reviewed because a lot of work is involved but highlights of their findings can be given along the following lines to bring out the essentials as regards the type of deterioration that occurs in maize under different storage conditions.

First, let us look at the total list of moulds isolated from maize during storage. (Table 4.).

Table 4. Checklist of moulds isolated from maize in field studies at NSPRI, Ibadan.

1. *Aspergillus candidus Link
2. *Aspergillus chevalieri Mang. Thom & Church
3. *Aspergillus flavus Link ex Fr.
4. *Aspergillus fumigatus Fresenius
5. Aspergillus melleus Yukawa
6. *Aspergillus niger Van Tieghem
7. *Aspergillus tamarii Kita
8. *Aspergillus terreus Thom.
9. Aspergillus versicolor Vuill. Tirab.
10. Absidia corymbifera (Cohn) Sacc. & Trotter
11. Mucor hiemalis Wehmer
12. Mucor pusillus Lindt
13. Mucor racemosus Fres.
14. Rhizopus arrhizus Fischer
15. Syncephalastrum racemosum Cohn Schroeter
16. Botryodiplodia theobromae Pat.
17. Drechslera rostrata (Drechst.) Richardson & Fraser
18. *Fusarium moniliforume Sheld.
19. *Paecilomyces varioti Bainier
20. *Penicillium citrinum Thom
21. Penicillium coryophilum Dierckx
22. Penicillium decumbes Thom
23. Penicillium fumiculosum Thom
24. Penicillium janthinellum Biourge
25. Penicillium steckii Zaleski
26. Penicillium [illegible] Sopp

**From Broadbent 1968[a,b.] , Oyeniran 1973, a.b., 197-

*Toxin-producing strains are known for these species. (Coveney et al 1966; Forgacs & Carll, 1966; Scott De B. 1965).

The list contains twenty-six species of which more than half are Aspergillus and Penicillia, about 1/5 are Phycomycetes while the rest are imperfect fungi. Their occurrence in maize under different conditions of storage shall be examined.

The samples of maize studied can be grouped as follows :

A. Stored Maize on the cob soon (less than 30 days) after harvest.

1. With low (less than 15%) mois.ure content.
2. With high (more than 15%) moisture content.

B. Stored maize on the cob long (more than 30 days) after harvest.

3. With low moisture content.
4. With high moisture content.

C. Stored shelled maize soon after harvest.

5. With low moisture content.
6. With high moisture content.

D. Stored shelled maize long after harvest.

7. With low moisture content.
8. With high moisture content.

These eight groups represent the possible conditions of storage to which the samples of maize obtained from the various sources could be classified. Let us now examine some results obtained as grouped under each condition (Tables 5 and 6).

Table 5. : Deterioration of Maize under Different Conditions of Storage*

Class	Shelled of Unshelled	Storage method	Length of storage (days)	Moisture content (%)	Number of mould colonies per gram of maize	Aflatoxin cont. Microgram/ Kilogram
1	Unshelled	Under kitchen roof	7	14.9	-	>100
	Unshelled	Under kitchen roof	5	19.3	1.9×10^5	< 100
2	Unshelled	Under kitchen roof	10	16.5	-	>100
	Unshelled	Heaped on the floor	10	21.5	-	100-1000
	Unshelled	Modern Crib	0	23.1	5.8×10^5	< 100
	Unshelled	Under kitchen roof	45	13.6	-	< 100
3	Unshelled	Modern crib	60	13.0	6.7×10^5	100-1000
	Unshelled	Under kitchen roof	30	15.7	5.3×10^5	< 100
	Unshelled	Heaped on the floor	30	24.8	-	100-1000
4	Unshelled	Wide crib	30	26.5	-	100-1000
	Unshelled	Modern crib	30	16.6	3.5×10^6	100-1000
	Shelled	Silo after drying	15	13.4	6.1×10^6	100-1000
5	Shelled	Bag storage	30	14.7	6.5×10^7	>1000
6	Shelled	Casual-Market	7	24.2	1.0×10^6	< 100
	Shelled	Bag storage	30	15.8	1.1×10^7	>1000
	Shelled	Bag storage	30	18.5	2.9×10^7	100-1000
7	Shelled	Heaped on the floor	30	14.6	2.0×10^7	>1000
	Shelled	Bag storage	60	11.8	2.0×10^6	>1000
	Shelled	Bag storage	70	10.6	1.8×10^6	>1000
8	Shelled	Heaped on the floor	30	16.9	1.0×10^7	100-1000
	Shelled	Bag storage	30^+	16.2	2.0×10^7	>1000
	Shelled	Bag storage	30^+	16.2	9.9×10^6	>1000

*Data from : Oyeniran, J. O. 1973 ab, 197-

Table 6. : The Occurrence Of Mould Species In Maize Under Different Conditions of Storage.

Mould Species	UNSHELLED				SHELLED			
	1	2	3	4	5	6	7	8
1. *Aspergillus candidus	.	-	3	-	-	-	-	-
2. *Aspergillus chevalieri	.	-	-	-	-	-	-	-
3. *Aspergillus flavus	.	+	++	++	+++	+++	+++	+++
4. *Aspergillus fumigatus	.	+	-	++	-	+	-	+
5. Aspergillus melleus	.	-	-	-	-	-	++	-
6. *Aspergillus niger	.	+	+	+	-	-	+	+
7. *Aspergillus tamarii	.	+	+	-	-	++	++	++
8. *Aspergillus terreus	.	-	-	-	-	+	+	-
9. Aspergillus versicolor	.	-	-	-	-	-	-	-
10. Absidia corymbifera	.	-	-	-	+	++	++	++
11. Mucor Hiemalis	.	-	-	-	-	-	+	-
12. Mucor pusillus	.	+	-	++	++	++	+	++
13. Mucor racemosus	.	-	-	-	-	-	-	-
14. Rhizopus arrhizus	.	-	-	-	-	+	+	-
15. Syncephalastrum racemosum	.	-	-	+	-	-	+	-
16. Botryodiplodia theobromae	.	+	-	-	-	-	-	-
17. Drechslera rostrata	.	-	-	-	-	-	+	-
18. *Fusarium moniliforme	.	++	+	++	-	++	++	-
19. *Paecilomyces varioti	.	+	-	+	+	-	-	-
20. Penicillium citrinum	.	+	-	-	++	++	++	++
21. *Penicillium coryophilum	.	-	-	++	-	-	-	-
22. Penicillium decumbens	.	+	-	-	-	-	-	-
23. Penicillium funiculosum	.	-	-	-	-	-	-	-
24. Penicillium janthinellum	.	+	-	-	-	-	-	-
25. Penicillium steckii	.	-	-	-	-	+	-	-
26. Penicillium variabile	.	-	+	-	-	-	-	-

+++ heavy occurrence; ++ moderate occurrence;
+ light occurrence; - no occurrence.
* Toxin producing strains are known for these species (Coveney, et al 1966; Forgacs & Carll, 1966; Scott De B. 1965).

From the analysis of tables 5 and 6 it can be seen that maize is liable to heavy mould deterioration when stored as shelled grains at high moisture content. It does not matter whether these are stored in silos or bags or heaped on the floor, similar levels of deterioration takes place. On the contrary, shelled maize that is dried soon after shelling is less liable to deterioration.

Generally, maize on the cob soon after harvest bears a low level of mould attack as shown in group A of Table 5. However, those which are heaped together at high moisture, on the floor of the house or stored in a very wide crib are also prone to severe deterioration, just a little less than the shelled grains under similar conditions. Unshelled maize which is stored in conditions of effective drying, whether gradual as occurs in the modern crib or rapid as occurs in traditional kitchen roof storage, are much less prone to mould attack.

I think the analysis given has shown clearly what amount of deterioration takes place under each storage condition as well as the levels of aflatoxin content possible in each case. Let us now consider in some detail the factors that cause mould deterioration generally and of maize in particular.

Causes Of Mould Deterioration Of Stored Products

1. The role of Moisture : The primary cause of mould deterioration is moisture, which as we all may know is an essential pre-requisite for microbiological activity. A word or two on the theory of moisture in stored produce explained by Mackay (1967) will therefore be appropriate at this point. Moisture in stored produce is divided into two classes :

    (a) Chemically-bound water :-part of the composition of the commodity itself.
    (b) Physically-bound water :-This can be subdivided into (i) Adsorbed water - also held by strong physical forces to the commodity and, (ii) Absorbed water - held loosely onto the surface of the commodity.

Moisture content of stored produce therefore refers to the physically-bound water. It is usually expressed on a wet-weight basis as the ratio in percentage of the weight of (physically-bound) water to the total weight of the material containing that water.

However, it is not the moisture content as such that is the controlling factor in biological deterioration, it is the Ralative Humidity (R.H) of the air within and around the commodity. This is the ratio in percentage of the weight of water which would be contained in that sample if it were saturated at the same temperature.

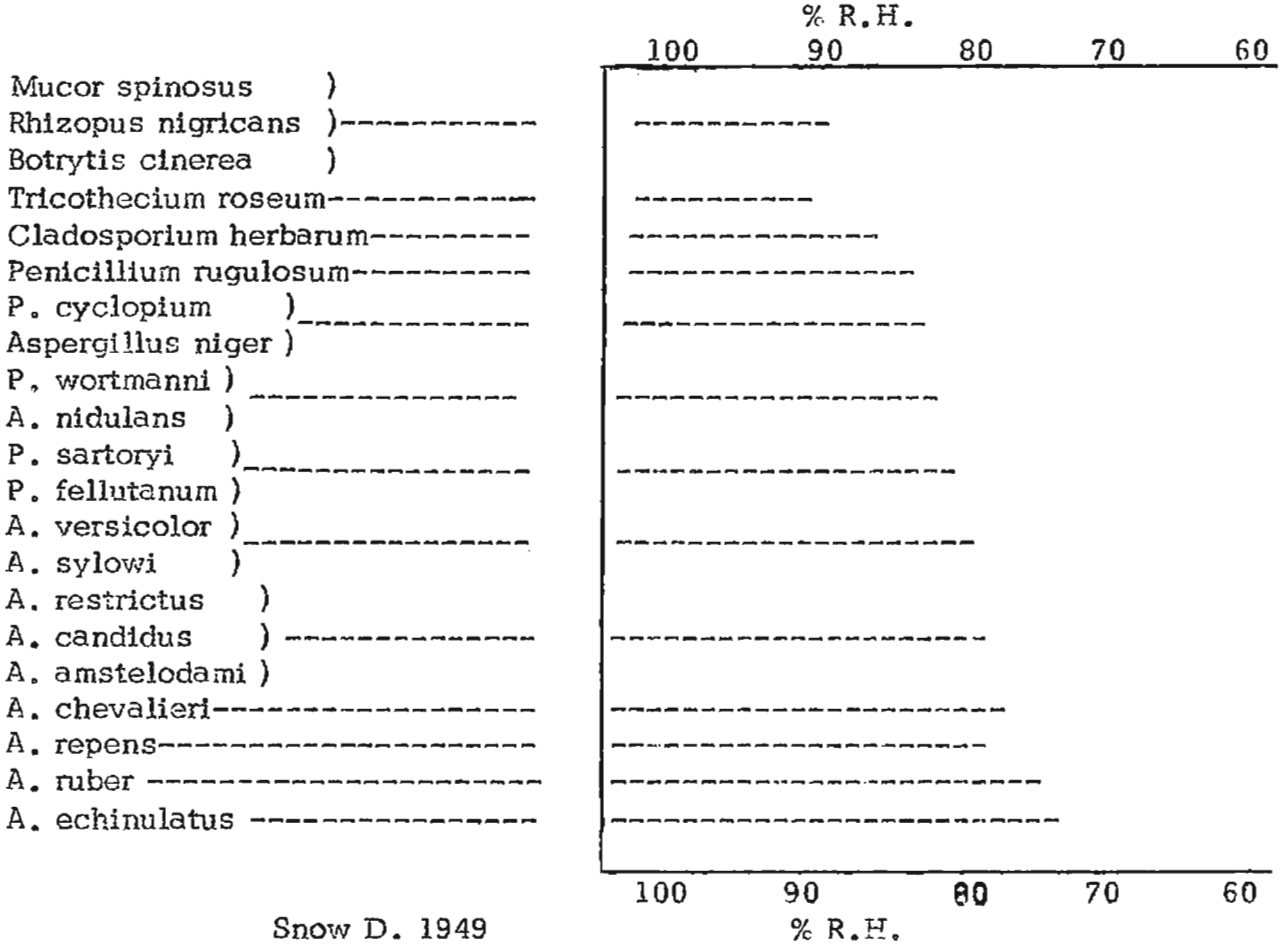
Biological activity occurs only in the presence of moisture and limits of R.H. can can be specified within which biological agencies causing deterioration can develop.

Germination occurs at	95% R.H. or over
Bacteria grow	" 90% " " "
Fungi "	" 70% " " "
Mites infest	" 60% " " "
Insects infest	" 30-95% R.H.

Even though R.H. is the controlling factor, attention is usually focussed on the moisture content because R.H. is difficult to measure while moisture content is not. Both are related and from a measurement of the moisture content of a commodity, the equilibrium R.H. can be reduced.

It is known that microbiological activity is reduced to a minimum at R.H. 70% or less. (Table 7, Slide 5).

Table 7. The Range of Humidity For Spore Germination on Nutrient Gelatin at 25°C



Snow D. 1949

Seventy percent R.H. has therefore been regarded as a "safe" limit and commodities with moisture contents in equilibrium with R.H. 70% are relatively safe from microbiological deterioration. Such moisture contents for a few commodities are shown. (Table 8, Slide 6).

Table 8. Moisture Content Equilibrium (at 70°C) Values Of Produce at Relative Humidity 70%

Commodity	Moisture Content
Maize	13.5
Wheat	13.5
Sorghum	13.5 (16)
Millet	16.0
Paddy	15.0 (4)
Rice	13.0
Cowpeas	15.0 (13.5)
Beans	15.0
Groundnut (Shelled)	7.0
Cottonseed	10.0
Cocoa Beans	7.0
Copra	7.0 (5.8)
Palm Kernels	5.0 (5.7)

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I shall now describe a few specific ways by which moisture plays its role in causing microbiological deterioration.

(i) Moisture Migration - In bulk storage of grains, especially in silos, when differences of temperature exist from one part to another, moisture is formed between the warmer and the cooler portions of the bulk, and this starts mould activity (Illustrate).

(ii) Condensation - In bulk grain storage bins, condensation occurs on the inner side of the top during cool weather especially at night following hot weather during the day, or in the fall following summer in temperate climates. Warm air will move from the warm centre of the bulk and when it gets to the cool grain near the surface, condensation will occur and mould attack will set in. (Illustrate).

(iii) Leakage. - Wherever there is a leakage in the storage structure it is possible for water to drip into the commodity stored and thereby cause deterioration.

(iv) Hot Spots.- This is an interesting phenomenon in bulk storage of grains. It is usually started by a concentration of insect activity which causes heating, sometimes to considerable temperatures. When the hot air from such a pocket moves to cooler grains, condensation occurs and mould and bacteria develop round this pocket caking the grains. The microorganisms increase the temperature of the pocket and when the area becomes too hot for the insects, they move out, causing further damage. (Illustrate).

(v) Moisture Absorption - Most stored products are hygroscopic; that is, they will exchange moisture with the atmosphere of storage until an equilibrium is reached. This means that when stored in an atmosphere of high relative humidity, literally, 'damp atmosphere', dry produce will gain moisture, and vice versa. This means that the relative humidity of storage is essential and as such an occasional check is necessary on the moisture content of produce stored in atmospheres with fluctuating relative humidities. It is also possible for produce stored in bags to absorb moisture through the floor if placed directly on the floor of the store.

(vi) Mechanical or other damage. - When produce is mechanically damaged or wounded by other agents such as insects or rodents, they become more liable to mould attack which automatically begins on the wounded or damaged surface or spot. This is because such exposed surfaces are damper and act more or less like a culture medium for moulds to grow. This is common with all produce; grains, tubers, cocoa beans, groundnuts etc. Some examples of damaged grains which have developed moulds are shown. This is the reason why some storage moulds are found on grains at harvest, in addition to a few field fungi which naturally attack them at that stage.

Control Of Mould Deterioration in Grains

1. As much as possible retain maize on the cob in a condition where rapid or gradual, but effective drying by heat or aeration is possible; otherwise provide artificial drying if storage as shelled grains is desired. The rachis tends to afford some protection to the grains when unshelled.
2. Cool artificial dried grains before bulk storage to avoid moisture migration. For the same reason sufficient shades should be provided for metal silos to prevent fluctuations in temperature inside the grain bulk.
3. If possible, store dried grains in air tight conditions to keep away from fluctuating atmospheric relative humidity which could lead to increase in moisture content, e.g. store in polythene bags, or polythene-lined sacks.
4. Prevent pockets of heavy insect activity which could lead to localised moisture increases and mould growth in bulk of grain by proper application of insect-control measures.

5. Avoid mechanical damage on produce.
6. Keep away produce from wetting and moisture absorption. Use dunnage for bagged produce stacked in stores.
7. Chemical Control. This is mentioned just for information not as a recommendation. It has not met with much success primarily because of the toxicity of most fungicidal chemicals. The few that showed signs of success, e.g. Propionic acid and Ascobic acid were expensive and had bad smells. Therefore no attempt at chemical control of moulds is being made by my department yet.
8. Other possible measures of mould control are refrigeration or cool temperature storage and irradiation, both of which are also limited by their costs.

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INSECTICIDES AND FUMIGANTS IN CROP STORAGE[1]

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INSECTICIDES AND FUMIGANTS IN CROP STORAGE

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Definition

Insecticides are selective poisons whose lethal effects are markedly greater on insects than on other forms of life, or insecticides are toxic products used to kill insects i. e. it is an insect killer.

The product as prepared by manufacturers is called formulation. This usually contains a diluent, or a stabiliser which prevents a chemical breakdown or denaturing. The active ingredient is the insecticidal content of the formulation.

Classification

Insecticides can be classified in two ways :

(a) According to their chemical nature
(b) According to their type of insecticidal action or mode of action.

Both methods are based on properties of the active ingredient. Members of a single chemical class can each have different modes of action and insecticides with the same mode of action can belong to different chemical classes

I. Classification according to chemical properties

ORGANOCHLORINE COMPOUNDS OR CHLORINATED HYDROCARBONS e. g. BHC, DDT.

The insecticidal activity of these compounds seem to depend on the arrangement of chlorine atoms in the molecule. They are all fairly stable compounds of low volatility so that they tend to be among the persistent insecticides; i.e. their insecticidal effect lasts longer than other insecticides. They have many properties in common, and insects which become resistant to one often easily become resistant to all; the insects develop a strain which is no longer killed by the insecticides.

(b) ORGANOPHOSPHORUS COMPOUNDS or organophosphoric esters :

These substances are Esters or organic salts of phosphoric acid or its derivatives. Examples include : Bromophos, Iodofenphos, Malathion and dichlorvos.

II Classification According to type of Insecticidal action or Mode of Action.

As already mentioned above, insecticides can be classified according to their type of insecticidal action or mode of action. Insecticides achieve their poisoning effect on insects in a variety of ways.

(a) Stomach Poison

Insects may actually eat the insecticides where it has been applied as a deposit on their normal food source and so become poisoned. Such an insecticide that must be swallowed by the insect before it can be effective is called stomach poison or stomach insecticide.

(b) Contact Poison

Certain insecticides can be absorbed through the insects' 'skin' or cuticle as the insects move over the surface of an insecticidally treated surface. These are called contact posion or contact insecticides. Most contact insecticides are also stomach insecticides.

SYSTEMIC INSECTICIDES

Systemic Insecticides are those that may be absorbed by plants and taken up in the sap stream of the plant and conveyed by this means to other parts of the plant other than where it is applied. Sap feeders and biting insects are more readily affected by systemic insecticides.

FUMIGANTS

Some insecticides are sufficiently volatile to give rise to vapours which are insecticidally active in the vapour phase. Many insecticides give rise to vapours of this sort in addition to excercising a stomach or contact effect.

Such insecticides, whose main effect on insects is caused by vapour, are called Fumigants. The contact insecticides and fumigants are the two main types of chemicals used in the control of insect pests of stored products. Contact insecticides confer long-term protection, usually referred to as the residual effect, but often tend to be somewhat specific in their effect upon insect species and to produce resistance more than the fumigants.

Fumigants provide no residual effect but unlike contact insecticides, have the power to penetrate through loosely packed commodities, stacks or bulks and to become absorbed into individual grains or kernels, killing all stages of insect life within the grain.

FORMULATION

The product as prepared by the manufacturer is called formulation. This contains, as already mentioned, a diluent, a stabiliser to prevent breakdown or denaturing and, most important of all, the active ingredient (a.i. for short) which is the insecticidal content of the formulation. Insecticides may be applied in either solid or liquid form.

1. For solid application we have dusts and granules.

   Dusts : In these formulations the solid insecticide is finely powdered or else made into a solution which is absorbed on particles of powder and diluted with a finely powdered inert material such as take or Kaolin. Though their use is limited by wind and heavy rain, they are commonly used on stored products.

b. Granules : In this type of formulation the insecticide is mixed with other materials to form larger grains the size of a pea. These grains serve to protect the active ingredient which is inside and allow its release slowly when applied to stored produce or grains.

2. For liquid application there are solutions, emulsifiable concentrates (or water miscible liquids) and wettable powders.

a. Solution : The active ingredient is made into concentrated solution of some convenient strength. At times, a stabilizer can be added to prevent chemical decomposition.

b. Emulsifiable Concentrates or Water miscible liquids - In this case the active ingredient is dissolved in some appropriate solvent and an emulsifier is added. This is in turn mixed with a large volume of water so that it disperses evenly throughout the water in minute droplets and forms an emulsion or suspension.

c. Wettable Powders - The active ingredient is dissolved in some suitable carrier material. The resultant very fine dust is not soluble in water but is treated with a dispersing agent so that the fine particles disperse evenly when mixed with water, in a manner resembling an emulsion.

Other types of formulation include concentrated solution similar to emulsifiable concentrates being diluted in mineral oils instead of water. These are called " oil miscible liquids". Certain very concentrated formulations are made for application with hot oil vapour droplets as carriers instead of water or mineral oil. These are called "fogging concentrates."

NOTES ON some Insecticides used in storage in Nigeria.

1. GAMMA BHC. It is commonly known as lindane. Gamma BHC has a strong stomach poison action, high contact toxicity and some fumigant activity on a wide range of insects. It is used mainly as dust in storage but it may also be formulated as a wettable powder, or emulsifiable concentrate. Two hundred and sixteen packs of gamma BHC are available for sale in form of dust under the trade names gammalin "A" and Lindane in Nigeria Dosage-10 p.p.m. or 4 ozs. to a bag of maize grain on the cob or shelled.

11.. MALATHION - It has a high insecticidal activity and low order of mammalian toxicity and lack of any pronounced residue or off flavours making malathion one of the most useful insecticidal chemicals for pest control. It is used widely for controlling insects on stored food. It induces vomiting if swallowed by operators. Dosage - 10-20 p.p.m. on stored grains. In Nigeria, there is the problem of insects that have become resistant to malathion e. g. Tribolium castaneum, an important pest of groundnut and grains.

PYRETHRUM - This is a natural insecticide of vegetable origin, a derivative of a flower which is one of the chrysanthemum (Pyrethrum). It is effective in controlling the most common insect species attacking stored products. It has a "knock down" effect on insects but it does not necessarily kill them. Pyrethrum is practically non-toxic to man and thus very safe to use on food or in situation where food is likely to become contaminated. Storage pests have not developed resistance to pyrethrum under normal conditions of use.

Recommended application rates :-

1.139g of (.2% pyrethrins
1% piperonly butoxide) to 90kg maize.

GARDONA - (tetrachlovinphos) It is an organophosphorus insecticide of low toxicity. Gardona acts insecticidally by inhibition of acetyl cholinesterase activity in the insect body following both contact and ingestion. It has been found to be effective against the adult and larval forms of lepidopterous, dipterous and to a lesser extent coleopterous pests. Gardona has a low order of toxicity whether administered by oral, dermal or respiratory ways.
Dosage - 10-15 ppm (3% dust on stored grains.)

BROMOPHOS - (or Nexion) It is a relatively new organo-phosphorus insecticide with a low mammalian toxicity. It is reported to be effective against a wide range of stored products insects.

PIRIMIPHOSMETHYL - It is a fast acting, organophosphorus insecticide also with a low mammalian toxicity. It has a wide spectrum of insecticidal activity and may become a replacement of malathion against resistant strains of insects. Dosage :- 10ppm on stored grains. In our trials in Nigeria with the control of insect infestation of maize stored in cribs using 1% Bromophos, 5% Gardona, 2% Pirimiphosmethyl and 5% Iodofemphos dusts, at a dose of 20 ppm each, they were all effective in controlling insect infestation in the crib for eight months with less than 20% insect damage, Bromophos was effective for seven months. The rate of breakdown of the insecticides was very rapid within the first month. It broke down to less than 5ppm in the first month and to less than 2.5ppm by the third month. This makes these insecticides much safer than Gamma BHC dusts currently in use where farmers must not use grains dusted until after two to three months. Lower doses of the insecticides would be tested this season so as to work out a recommendation for general use on grains in Nigeria. Lower doses are known to have been effective in central Africa. (Where 225gm of 2% dust per cubic meter i.e. 6ppm, cob weight and 11ppm, shelled basis).

III METHYL BROMIDE CH_3Br.

Also known as Bromomethane Methyl Bromide, it has high insecticidal properties used for space fumigation and for the fumigation of plants and plant products in stores, mills and ships. It is a soil fumigant used for the control of nematodes, fungi and weeds. It is highly toxic to man, operators must wear respirators and use should be restricted to trained personnel. It is packed in glass ampoules (up to 50ml) in metal cans and cylinders for direct use. A warning gas (chloropictin) is sometimes added.

Methyl Bromide is detected (for leakages) in practice by the halide lamp. It is the most widely used fumigant on all export produce in Nigeria e. g. Cocoa, groundnuts. It can also be used on cereal products, dried fruits and seeds.

Dosage : 11/2 - 31 Ibs. per 1,000 cu. ft. for twenty-four hours or 1 Ib. per 10 tons Cocoa beans.

IV. ALUMINIUM PHOSPHIDE (PHOSTOXIN) AlP.

Aluminium phosphide forms dark grey or yellowish crystals. Though stable when dry, it reacts with moist air or with acids liberating phosphine. Phosphine is a gas with a carbide - like odour. It is highly insecticidal and a potent (powerful) mammalian poison.

Commercial formulations include phostoxin in the form of tablets, 3gm each liberating 1gm phosphin or pellets (0.6gm or $\frac{1}{5}$ of tablet). These formulations are inserted by probe into the material to be fumigated e.g. grain, the moisture content of which should be more than 10%. Phostoxin evolves a non-flammable mixture of phosphine, ammonia and carbondioxide. Fumigation is from 3-10 days and should only be undertaken by trained personnel. Adequate airing after this period may be checked by a gas detector. The residue is non-poisnous. It is used extensively for fumigation of grain both in bags and bulk at a dosage of 4-8 tablets per ton and two tablets per ton of cocoa.

(1) (Describe the application of insecticide in cribs)
(2) (Describe the use of phostoxin tablets for grains and methyl Bromide for cocoa beans including post-fumigation protection of grains.

In work done in the Nigerian Stored Products Research Institute, fumigation of maize in an aluminium silo using a 1 :1 carbon tetrachloride : ethylene dichloride mixture at a rate of 1 gallon to 5 tons was reasonably effective against S. zeamais and T. castaneum (Cornes and Oyeniran, 1967).

It was also found that ethylene dibromide did not penetrate the maize grain efficiently, giving effective control only in the top half when fumigiation was carried out in polythene-lined sacks. (Cornes, Adeyemi and Qureshi, 1967). A similar observation was made by Cornes and Adeyemi (1969) that ethylene dibromide apparently gave a good control of adult insect, during a fumigation trial of cowpea in polythene lined

hessian sacks, but penetration was inadequate and control of the early stages of C. maculatus was only achieved at the top of the bags where the fumigant was applied. They concluded that ethylene dibromide was unsuitable for use against C. maculatus when applied in the manner.

PROBLEMS RELATING TO THE USE OF INSECTICIDES

1. Danger to Personnel handling insecticides : As well as being very lethal to insects, insecticides are also highly poisonous to warm blooded animals including man.

Danger to personnel handling insecticides depends on the degree of mammalian toxicity of the chemical, the circumstances under which it is sold, the concentration at which it must be used, the way it is prepared for use and is employed and the local facilities for personnel handling the insecticide to wash immediately after use.

Toxicity is expressed in terms of the necessary dosage to kill fifty percent of a large population of the species of animal under consideration (i.e. LD50 figure). Mammalian toxicity may occur by absorption of the chemical through the skin, through intake of small ouantitites of the chemical over a period of time, or through the exposure of the human body to a single large dose of the chemical (either inhaled or ingested). Pest control personnel handling contact insecticides should wear protective clothing to minimise the risk of dermal absorption and wear face masks and gloves during treatment followed by immediate and thorough washing.

GENERAL PRECAUTIONS FOR HANDLING OF INSECTICIDES

1. Operators must not work alone
2. All operators must be trained in basic first aid with emphasis placed on artificial respiration techniques for gas poisoning.
3. Operators, in the case of fumigation, should wear respirators or gas masks with the appropriate canister for the specific gas.
4. Protective clothing and gloves should be worn by operators.
5. Operators should not smoke or touch food at anytime during and after use of insecticides until their hands are thoroughly washed.
6. All cases of suspected poisoning should be reported immediately to a physician and all relevant information on the insecticide should be supplied.

2. DANGER FROM INSECTICIDE RESIDUE

The danger varies with the insecticide used, the absorptive properties of the produce, the handling and processing to which the produce is subjected after treatment and before being eaten by man or animals, and in the case of storage, the time between treatment and consumption of the produce.

3. SPECIFICITY OF TOXICITY OF INSECTICIDES TO INSECTS

Chemicals used in the control of pests have a certain degree of specificity. The general purpose insecticide, which is effective against all pests under all conditions, does not exist. Not only that, different species of insect vary in their susceptibility or resistance to insecticides, but within a species the different stages of egg, larva, pupa and adult may vary in their reactions, e.g. sitophilus spp., and Bruchidae are relatively susceptible to Lindane while Tribolium spp are relatively susceptible to DDT and all species of insects susceptible to fumigants.

4. DEVELOPMENT OF RESISTANCE TO INSECTICIDES BY INSECTS

During the past few years there have been indications that stored product insects are showing resistance to the range of insecticides in use. Under practical storage conditions this includes Tribolium spp against DDT, Sitophilus oryzae and S. zeamais against Lindane and Tribolium casteneum against malathion.

THE RATE AT WHICH RESISTANCE DEVELOPS DEPENDS UPON THE FOLLOWINGS.

a. Incidence of resistance in the genetic make up of starting population.
b. Dosage rate of insecticidal application.
c. Frequence or uniformity of the treatment.
d. Life history of the pest in relation to exposure to insecticidal treatment.

If insects are exposed to insecticidal treatment at all stages of thier life cycle, they are likely to develop resistance more rapidly than insects exposed at one stage of their life cycle.

5. TAINT OR DAMAGE TO GERMINATION

The use of insecticides, in addition to the presence of chemical residues which may be toxic in produce, may result in an odour or flavour which detracts from its quality; the ability of the grain or kernel to germinate may also be impaired.

INSECTICIDE CALCULATIONS[1/]

Objectives: To know the meaning of terms commonly used in insecticide calculations; to be able to compute accurately the amount of insecticide in wettable powder, granular and emulsifiable concentrate forms; and to treat a given area at a given rate of active ingredient.

Materials: paper and pencil

Teaching aids: Conversion table from pounds per US or imperial gallon to kilograms per liter
Graph for determining amount of granular materials required for various plot sizes.

INTRODUCTION

Insecticide recommendation rates are often expressed as kilograms of active ingredient per hectare (kg/ha a.i.) or as percent concentration (% a.i.) of active ingredient in the final diluted insecticidal solution. These rates have been carefully studied and tested to give optimum results. Therefore you should apply insecticide at the correct dosage by diluting the exact amount of the concentrated form of insecticide with a predetermined volume of water or other diluent, or by spreading the exact amount of granules required over a specific area of the crop. To achieve this, it is necessary to calculate the exact amount of insecticide material needed.

PRESENTATION

A. *Common terms used in insecticide calculations*

1) Expressions of concentrations — Each insecticide possesses an *active ingredient* (a.i.), the principal chemical compound (toxicant) that acts on the insect. When in its pure form, the toxicant may be a solid or a liquid. Because the insecticide is highly toxic, the manufacturer has to dilute it before making it available to farmers.

In commercial *solid formulations* (*dust, wettable powder WP, and granules*), a certain weight of the toxicant is mixed or impregnated with a certain weight of inert powders or granules. The concentration of the a.i. is thus expressed as percentage of the weight of a.i. in the total weight of the commercial solid formulation, or:

$$\% \text{ a.i. of dust, WP, or granules} = \frac{\text{weight of a.i.} \times 100}{\text{total weight of dust, WP, or granules}}$$

Examples: Sevin 85 WP means that there are 85 grams of 1-naphthyl-N-methylcarbamate in every 100 grams of commercial 85% wettable powder;

Basudin 10% granules means that for every 100 grams of the commercial Basudin granules there are 10 grams of pure diazinon or diethyl (2-isopropyl 6-methyl 4-pyrimidinyl) phosphorothioate.

In commercial *liquid formulations* (emulsifiable concentrate EC), a certain weight of the toxicant is dissolved in a certain volume of its solvent with an emulsifying agent. The concentration of the a.i. is then expressed in two ways:

a) Percentage

$$\% \text{ a.i. in EC} = \frac{\text{weight of a.i.} \times 100}{\text{volume of EC}}$$

b) Pounds per gallon or grams per liter

Examples: Endrin 20% EC means that for every 100 cc of commercial Endrin 20% EC there are 20 grams of pure endrin or 1, 2, 3, 4, 10, 10-hexachloro 6,. 7-epoxy 1, 4, 4a, 5, 6, 7, 8a-octahydro-exo-1,4 exo-5, 8-dimethanonaphthalene (or 200 grams per liter).

2. Diluent — Diluent is any liquid (water, oil) used to reduce the amount of insecticide in any concentrate or technical material to a desired lower concentration.

3. Volume of spray — The volume of spray material is affected by the size of the foliage of the crop and the size of the individual droplet deposited on the leaf. Most fruit crops having large foliage require a large or high volume of spray material in order to obtain a thorough coverage. *High-volume spray* usually requires 400 liters or more of spray material per hectare. Obviously it requires a large volume of water and suitable equipment for transporting the spray solution.

This may create a problem where water is not readily available. In such cases it may be desirable to use a low-volume spray which would require less water and reduce the transportation requirements. But with smaller volume of liquid a finer droplet size is required to get an adequate coverage of the foliage. With recent advances in the design of spray nozzles, it is possible to produce smaller droplets with sizes from 80 microns or less (1 micron = 0.001 mm) in diameter, without requiring expensive equipment.

These nozzles are capable of producing a fine deposit on leaves, thus eliminating the need for

1/ From Xuan, Vo-Tong, and Ross, Vernon E. Training Manuel for Rice Production IRRI. 1972. pp. 96-104

large volume of liquid. *Low volume spray* usually denotes a spray volume of 4 liters to less than 400 liters per hectare of crop. Equipment recently developed can effectively spray 4 liters per hectare. This equipment is called *ultra low volume spray* (ULV).

Most insecticide recommendations are given in kilograms of active ingredient per hectare; in this case the volume of spray is to be determined by the type of spraying equipment available and its corresponding calibration. However, when the recommendation is given in percentage of active ingredient in the spray (i.e. percent of the weight of toxicant in the total weight of the diluted spray), the volume of spray is always specified. In summary:

If recommendation is given in:	Volume of spray is:
kg/ha a.i.	dependent on sprayers and their calibrations
% a.i.	specified

4. Specific gravity — In the preparation of a spray solution, a certain quantity of solid formulations (dust, WP, or granules) is weighed. But liquid formulation (EC) cannot be conveniently weighed in the same manner. Its volume is measured instead. Therefore insecticide manufacturers always indicate on the label the concentration of their emulsifiable products. Some manufacturers, instead of giving concentration in percentage or pounds per gallon or grams per liter (see above), indicate the specific gravity of their products. In simplest terms, specific gravity is an expression of the relationship between the weight of a given volume of any liquid and the weight of an equal volume of water. Therefore when the specific gravity is known, it is possible to obtain a certain weight of a liquid by measuring a corresponding volume of this liquid. An emulsifiable liquid insecticide is "weighed" by determining its volume instead of by actually weighing it on a balance.

B. *Calculations*

As discussed above, there are two types of insecticide recommendations. Separate procedures for calculations are, therefore, required for each type.

1) When the recommendation is in percentage of active ingredient (% a.i.) This type of recommendation calls for a certain unit weight of active ingredient in 100 units weight of spray volume. For example, 0.05% Azodrin spray solution contains 0.05 gram of active Azodrin in 100 grams of spray volume. The volume of spray is therefore composed of two fractions: (1) volume of the toxicant and (2) volume of the diluent. Note that it is the weight, not the volume, of both the toxicant and the diluent that is involved in the computation of this type of recommendation. The weight of a liquid diluent is determined by multiplying its volume by its specific gravity. When water is used as diluent, its weight is approximately equal to its own volume (kg is equivalent to liter; gram is equivalent to cubic centimeter) because its specific gravity is approximately 1. Formula 1, 2, and 3 under this section are based on water as the diluent.

Conversion Tables

Pounds per US or imperial gallon to kilograms per liter

US		Imperial	
lb/US. gal	kg/liter	lb/Imp. gal	kg/liter
1	0.12	1	0.10
2	0.24	2	0.20
3	0.36	3	0.30
4	0.48	4	0.40
5	0.60	5	0.50
6	0.72	6	0.60

If an insecticide is to be diluted in oil or any liquid other than water, formulas 1, 2, and 3 should not be used. Refer to: "Scientific guide to pest control operations (2nd ed.) by L.C. Truman and W.L. Butts. Cleveland, Ohio: Pest Control Magazine, pp. 43-45."

a. For wettable powder (WP)

Steps	Key points
1 Assemble pertinent data	The following data must be given: a) Specified volume of spray, liters per hectare. If volume is given in gallons, multiply gallons by 3.8 to obtain liters; b) Recommended concentration (% a.i. desired); c) Concentration of the commercial WP, % a.i.
2 Compute the total weight of toxicant in the specified volume of spray	$\text{Weight of toxicant} = \frac{\text{\% a.i. desired} \times \text{specified spray volume (liters)}}{100}$
3 Compute the weight of WP to satisfy the required weight of toxicant (Formula 1)	$\text{kilograms of WP required} = \frac{\frac{\text{\% a.i. desired} \times \text{specified spray volume (liters)}}{100}}{\frac{\text{\% a.i. in commercial WP}}{100}}$ or simply $\text{WP required (Kg)} = \frac{\text{\% a.i. desired} \times \text{specified spray volume (liters)}}{\text{\% a.i. in commercial WP}}$

(Instructor: Proceed to "Application" and give example to apply this formula before discussing next formula.)

b. For emulsifiable concentrates (EC)

Steps	Key points
1 Assemble pertinent data	The following data must be given: a) Specified volume of spray (liters per hectare). Convert gallons into liters (1 gal = 3.8 liters); b) Recommended concentration (% a.i. desired); c) Concentration of commercial emulsifiable concentrates (1) % a.i. (use formula 2 below) (2) pounds per gallon (convert to kilograms per liter before using formula 3 below)
2 Compute the total weight of toxicant to be mixed in the specified spray volume	$\text{Weight of toxicant required} = \frac{\text{\% a.i. desired} \times \text{specified spray volume (liters)}}{100}$
3 Compute the volume of commercial EC to satisfy the required weight of toxicant	a) If concentration of EC is % a.i.: $\text{Volume of toxicant required} = \frac{\text{\% a.i. desired} \times \text{specified spray volume (liters)}}{100} \Big/ \frac{\text{\% a.i. in commercial EC}}{100}$ or simply
(Formula 2)	$\text{liters of EC required} = \frac{\text{\% a.i. desired} \times \text{specified spray volume (liters)}}{\text{\% a.i. in commercial EC}}$
	b) If concentration of EC is in kg/liter a.i.
(Formula 3)	$\text{EC required (liters)} = \frac{\text{\% a.i. desired} \times \text{specified spray volume (liters)}}{100 \times \text{concentration (kg/liter) a.i. in commercial EC}}$

(Instructor: Proceed to "Application" and give examples to apply these formulas before discussing next formula.)

2) When the recommendation is in kilograms of active ingredient per hectare (kg/ha a.i.)

a. For wettable powders (WP), dust and granules

Steps	Key points
1 Assemble pertinent data	The following data must be given: a) Area to be sprayed (hectares, or square meters). Convert to kg/ha if rate is given in lb/acre (multiply lb/acre by 1.12 to obtain kg/ha). b) Concentration of toxicant in WP, dust, or granules (% a.i.); c) Recommended rate (kg/ha a.i.)
2 Compute the weight of WP, dust or granules required per hectare	$\text{Weight of WP, dust or granules} = \frac{\text{Recommended rate (kg/ha)}}{\text{\% a.i. in WP, dust or granules}} \times 100$
3 Compute the weight of WP, dust, or granules required per area concerned (Formula 4)	a) If area is in hectare: $\text{Weight of WP, dust, or granules required} = \frac{\text{Recommended rate (kg/ha)} \times \text{Area (ha)} \times 100}{\text{\% a.i. in WP, dust, or granules}}$ b) If area is in square meters: $\text{Weight of WP, dust, or granules required} = \frac{\text{Recommended rate (kg/ha)} \times \text{Area (sq m)}}{\text{\% a.i. in WP, dust} \times 100 \text{ or granules}}$

(Instructor: Proceed to "Application" and give examples to apply formula 4 before discussing next formula.)

b) For emulsifiable concentrates (EC)

Steps	Key points
1 Assemble pertinent data	The following data must be given: a) Area to be treated (hectare or square meter) b) Recommended rate (kg/ha a.i.). Convert to kg/ha if rate is given in pounds per acre (multiply lb/acre by 1.12 to obtain kg/ha). c) Concentration of commercial EC (1) % a.i. use formula 5 (2) kg/liter (If concentration is given in lb/gal, first convert it to kg/liters before using formula 6. Multiply lb/gal by 0.12 to obtain kg/liter).
Compute the volume of commercial EC required per hectare	a) If concentration of EC is % a.i. $\text{Liters of EC per hectare} = \frac{\text{Recommended rate (kg/ha)}}{\text{\% a.i. in commercial EC}} \times 100$ b) If concentration of EC is kg/liter a.i. $\text{Liters of EC per hectare} = \frac{\text{Recommended rate (kg/ha)}}{\text{kg/liter a.i. in commercial EC}}$
4 Compute the volume of commercial EC required per area concerned	a). If concentration of EC is % a.i.: (Formula 5) $\text{Liters of EC required} = \frac{\text{Recommended rate (kg/ha)} \times \text{Area (ha)} \times 100}{\text{\% a.i. in commercial EC}}$ or if area is in square meter: (Formula 6 bis) $\text{Liters of EC required} = \frac{\text{Recommended rate (kg/ha)} \times \text{Area (sq m)}}{\text{\% a.i. in commercial EC} \times 100}$ b) If concentration of EC is kg/liter a.i.: (Formula 6) $\text{Liters of EC required} = \frac{\text{Recommended rate (kg/ha)} \times \text{Area (ha)}}{\text{kg/liter a.i. in commercial EC}}$ If area is in square meter: (Formula 6 bis) $\text{Liters of EC required} = \frac{\text{Recommended rate (kg/ha)} \times \text{Area (sq m)}}{\text{kg/liter a.i. in commercial EC} \times 10{,}000}$

APPLICATION

Formula 1

$$\text{WP required (Kg)} = \frac{\text{\% a.i. desired} \times \text{specified spray volume (liters)}}{\text{\% a.i. in WP}}$$

Example: To control leafhoppers, 2,000 liters of 0.09 percent carbaryl is to be prepared. The wettable powder Sevin to be used contains 85% carbaryl. What is the required weight of Sevin?

Data given:

Concentration of commercial Sevin 85% a.i. WP
Specified spray volume = 2,000 liters
Recommended concentration = 0.09% a.i.

Calculation:

$$\text{Kg of Sevin} = \frac{0.09 \times 2000}{85} = 2.117 \text{ kg of Sevin 85 WP}$$

Formula 2

$$\text{Liters of EC required} = \frac{\text{\% a.i. desired} \times \text{specified spray volume (liters)}}{\text{\% a.i. in commercial EC}}$$

Example: 500 gallons of 0.04 percent endrin spray is needed to control rice stem borers. What is the volume of commercial Endrin 19.5% EC required?

Data given:

a) Concentration of commercial Endrin 19.5% EC
b) Specified spray volume = 500 gal x 3.8 liters/gal. = 1900 liters
c) Recommended concentration = 0.04% a.i.

Calculation:

$$\text{Liters of Endrin required} = \frac{0.04 \times 1900}{19.5} = 3.897 \text{ liters}$$

Formula 3

$$\text{Liters of EC required} = \frac{\text{\% a.i. desired} \times \text{specified spray volume (liters)}}{100 \times \text{kg/liter a.i. in commercial EC}}$$

Example: 500 liters of 0.05% Accothion spray is to be prepared to control stem borers and leafhoppers. If Accothion 500—E, an emulsifiable concentrate containing 500 grams active ingredient per liter, is used, calculate the required volume.

Data given:

a) Concentration of Accothion 500-E = 500 g/liter = 0.5 kg/liter
b) Specified spray volume = 500 liters
c) Recommended concentration = 0.05% a.i.

Calculation:

$$\text{Liters of Accothion 500-E required} = \frac{0.05 \times 500}{100 \times 0.5} = 0.50 \text{ liters}$$

Formula 4

$$\text{Weight of WP, dust, or granules required} = \frac{\text{Recommended rate (kg/ha)} \times \text{Area (ha)} \times 100}{\text{\% a.i. in WP, dust or granules}}$$

or

$$\text{Weight of WP, dust, or granules required} = \frac{\text{Recommended rate (kg/ha)} \times \text{Area (sq m)}}{\text{\% a.i. in WP, dust, or granules} \times 100}$$

Example: Basudin 10G granules containing 10% active ingredient is used to control pink stem borers at a rate of 2 kg/ha a.i. How many kilograms of Basudin 10G are needed for a 2,500 sq m plot?

Data given:

a) Concentration of Basudin 10G = 10% a.i.
b) Recommended rate = 2 kg/ha a.i.
c) Area to be treated = 2,500 sq m

Calculation:

$$\text{Weight of Basudin 10G required} = \frac{2 \times 2500}{10 \times 100} = 5 \text{ kg}$$

Formula 5

$$\text{Liters of EC required} = \frac{\text{Recommended rate (kg/ha)} \times \text{Area (ha)} \times 100}{\% \text{ a.i. in commercial EC}}$$

or

$$\text{Liters of EC required} = \frac{\text{Recommended rate (kg/ha)} \times \text{Area (sq m)}}{\% \text{ a.i. in commercial EC} \times 100}$$

Example: When the recommendation calls for 2 kg/ha of gamma-BHC to control rice stem borers, and an emulsifiable concentrate containing 20% gamma-BHC is available, how many liters of this formulation is needed to treat 8,000 sq m?

Data given:

a) Area to be treated = 8,000 sq m
b) Concentration of commercial gamma-BHC emulsifiable concentrate: 20%
c) Recommendation: 2 kg/ha a.i.

Calculation

$$\text{Liters of 20\% gamma-BHC required} = \frac{2 \times 8000}{20 \times 100} = 8 \text{ liters}$$

Formula 6

$$\text{Liters of EC required} = \frac{\text{Recommended rate (kg/ha)} \times \text{Area (ha)}}{\text{kg/liter a.i. in commercial EC}}$$

or

$$\text{Liters of EC required} = \frac{\text{Recommended rate (kg/ha)} \times \text{Area (sq m)}}{\text{kg/liter a.i. in commercial EC} \times 10{,}000}$$

Example: To ntrol rice bugs and leaffolders methyl parathion should be applied at a rate of 1.5 kg/ha a.i. Folidol emulsifiable concentrate, containing 6 lb (US)/gal of methyl parathion, is available. How many liters of Folidol are needed to treat 3.5 hectares?

Data given:

a) Area to be treated = 3.5 ha
b) Recommended rate = 1.5 kg/ha
c) Concentration of methyl parathion in Folidol = 6 lb (US)/gal x 0.120
= 0.720 kg/liter

Calculation:

$$\text{Liters of Folidol required} = \frac{1.5 \times 3.5}{0.72} = 7.29 \text{ liters}$$

EVALUATION

1) Insecticide recommendations are usually expressed in two ways. What are they?
2) What is an active ingredient?
3) Explain the expression "Sevin 85% wettable powder."
4) Explain the expression "Dimecron 50% emulsifiable concentrate."
5) Explain the expression "Folidol 6 lb/gal emulsifiable concentrate."
6) What is a diluent?
7) What is a high-volume spray? And a low-volume spray? And an ultra low-volume spray?
8) How is an emulsifiable concentrate "weighed"

during the preparation of an insecticide spray? Why?

9) Explain the expression "a 0.04% Malathion spray solution."

10) Why are formulae 1, 2 and 3 not applicable to diluents other than water?

11) Commercial Sevin wettable powder contains 85% a.i. How many kilograms of this Sevin are needed to make 200 liters of 0.09% spray solution?

12) Dimecron 50 emulsifiable concentrate is to be used in controlling stem borers and whorl maggots at a rate of 1.75 kg/ha a.i. Compute the volume of Dimecron 50 needed to treat an area 1,250 sq m.

13) Accothion 500-E contains 500 g a.i. per liter of emulsifiable concentrate. An experiment with a total area of 600 sq m is to be protected against insect pests with this insecticide as a 0.05% spray solution. How many milliliters of Accothion 500 E are required to mix with 5 gallons of water to be used in a knapsack sprayer?

14) Furadan granules contain 8% a.i. How many kilograms of Furadan are required to apply to an area of 8,000 sq m at a rate of 2 kg/ha a.i.?

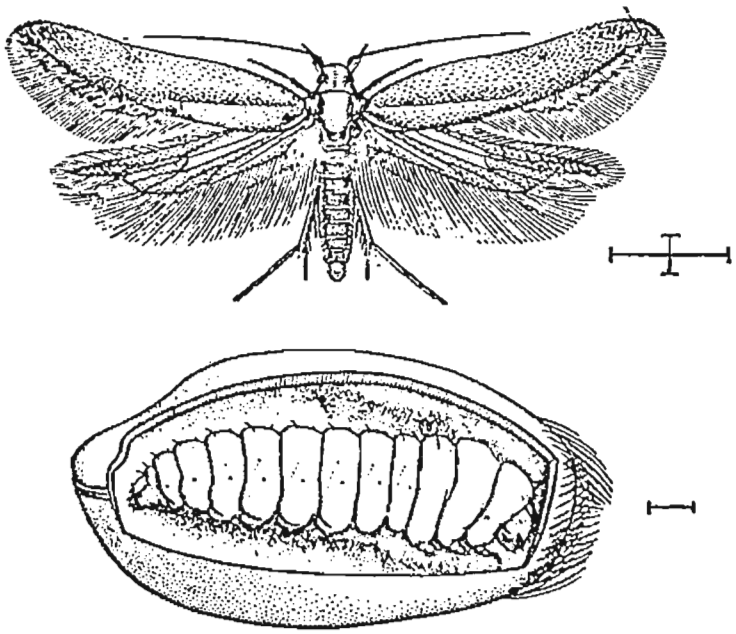
15) Folidol contains 6 pounds/gal (US) of active ingredient as methyl parathion. How many liters of Folidol are needed to prepare sufficient spray solution to treat an area of 2.4 hectares at a rate of 1.25 kg/ha a.i.?

EXAMPLES OF USE OF INSECTICIDES IN THE TROPICS

CHEMICAL	HOW USED	FORMULATION USED
Lindane - The gamma isomer of benzene hexachloride (BHC) Lindane is the refined form of BHC	1. Cob maize (in the sheath) in cribs	Dust
	2. Maize on the cob with sheath removed	Dust
	3. Maize in bags	Dust
	4. Maize seeds	Dust
	5. Groundnuts (unshelled)	Dust
	6. Beans and cowpeas admixed with dust	Dust
	7. Paddy - Layer dusting to prevent insects crawling under sheets covering stacks	Dust
	8. Wheat stacks dust layer by layer	Dust
	9. Unthreshed sorghum or millet, sandwich treatment	Dust
	10. Sorghum seed	Dust
	11. Bagged decorticated Groundnuts	Wettable powder
	12. Spraying of godowns for rice storage	Wettage powder
Malathion (premium grade deodorized. An organophosphorus compound	1. Grains	Dust or liquid
	2. Interior surface in contact with grain	Liquid
	3. Warehouse disinfestation	Dust and liquid
	4. Shelled groundnuts	Liquid
	5. Wheat stacks dust layer by layer	Dust
	6. Outside of sacks	Dust
Methyl bromide Monobromomethane CH_3Br. A fumigant	1. Grain 2. Rice 3. Groundnuts 4. Cocoa beans 5. Animal feed 6. Tobacco 7. Beans 8. Copra 9. Wheat	
Phostoxin or Phosphine (PH_3) Hydrogen phosphide A Fumigant	1. Grain in bags and bulk 2. Maize and wheat bran in bags, in rail trucks and also in stores under plastic sheeting 3. Shelled groundnuts	
Ethylene dibromide	Grain - used as surface spray after phostoxin	
Ethylene dichloride Coarbon tetrachloride mix 3:1 EDC/CT A fumigant	Fumigant of grain not for use as seed.	

CHEMICAL	HOW USED	FORMULATION USED
Carbon tetrachloride + Carbon disulphide $CC/4/CS_2$ mix 4:1	Grain	
Pyrethrum - natural insecticide, the most important constituent are Pyrethrins. Virtually non-toxic to man.	1. Cocoa 2. Fogging cocoa sheds 3. Copra 4. Malathion + pyrethrins used on maize 5. Pyrethrins + piperonyl butoxide used on maize 6. In heavy oil for spraying large moth infestations. 7. Against Ephestia cautella.	

SITOTROGA CEREALELLA



ANGOUMOIS GRAIN MOTH — *Sitotroga cerealella*

Fig. 9

Order	Lepidoptera
Family	Gelechiidae
Species	Sitotroga cerealella
Common name	Angoumois grain moth
Identification	Small pale yellowish brown moths. Forewing with one or two small black dots; hind wing with obvious fringe of long hairs, apex sharply pointed. Labial palps curved.

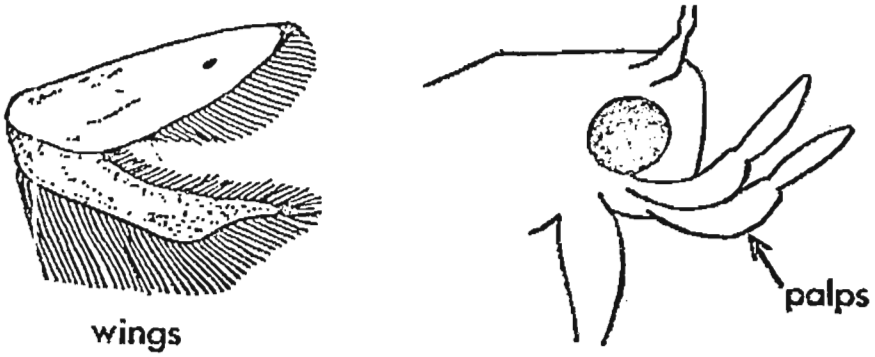


Fig. 10

Products attacked

Paddy rice, sorghum, maize, barley and wheat.

Type of damage and importance

Primary pest, causing damage very similar to that brought about by weevils. (Already indicated for Lepidoptera that only larvae cause damage.) The loss in weight of individual grains of maize attacked by this species is just over 10%.

Fig. 11

Sitotroga cerealella: adults on maize.

Habits and life history

Commonly infests produce before harvest. In store it is abundant only in the surface layers of bulk stored grain. The female lays eggs on the surface of grain and the larva hatches and bores into the grain where it remains until fully grown. At this stage it has eaten out a considerable proportion of the grain and now eats a channel to the surface, leaving a thin layer of the seed coat intact. The pupa is formed, and then the adult stage appears and pushes open the thin area of seed coat prepared by the larva and leaves a characteristic 'trap door' in the grain. Only the larvae feed on stored produce, the adults being short-lived. The developmental period from egg to adult is about five weeks at 30°C.

Temperature and relative humidity conditions for development

Temperature °C		Optimum
Max.	Min.	R.H.%
35	16	75
R.H.%		Optimum
Max.	Min.	Temperature °C
80	25	32

Distribution

Cosmopolitan.

CORCYRA CEPHALONICA

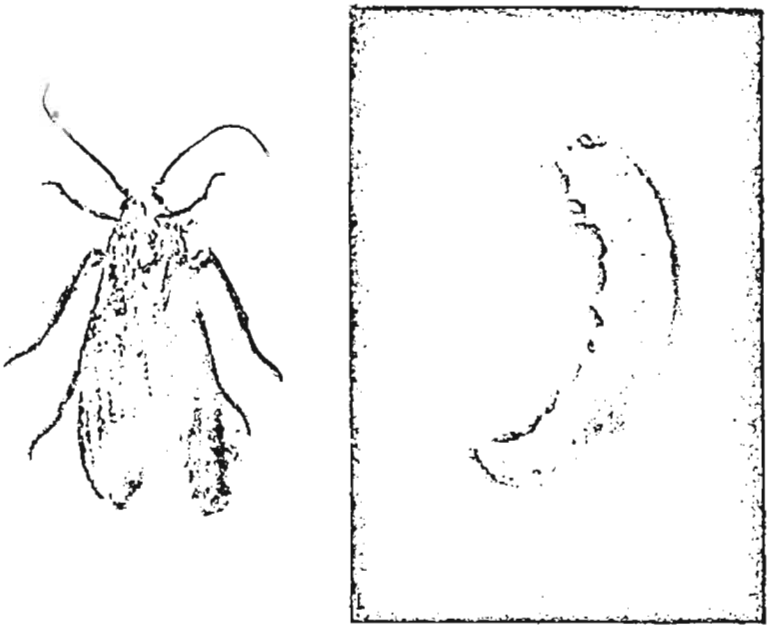


Fig. 12

Order	Lepidoptera
Family	Galleriidae
Species	Corcyra cephalonica
Common name	Rice moth
Identification	Forewing uniformly coloured pale buff brown, without spots but with the veins slightly darkened. Cocoons are dense white and very tough and therefore distinct from those of other species described here. Labial palps straight. Note the larva's conical 'prolegs' on abdominal segments.

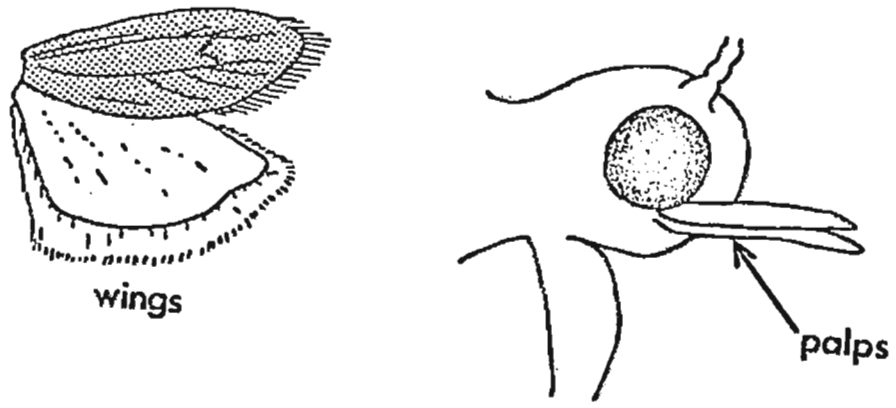


Fig. 13

Products attacked

Rice, sorghum, millet, sesame, groundnuts, cocoa and copra.

Type of damage and importance

Primary pest causing aggregation of the infested produce.

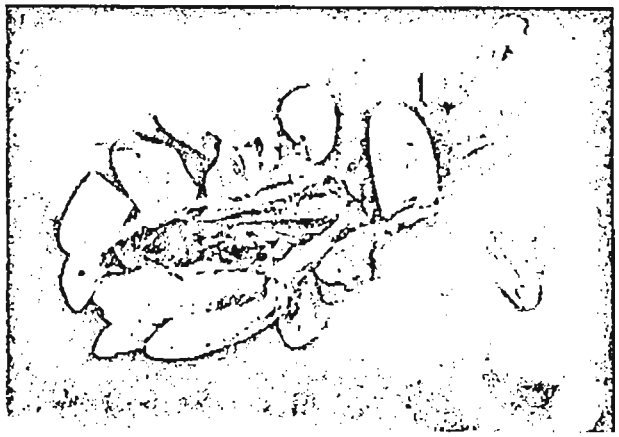


Fig. 14

Corcyra cephalonica: rice aggregate opened to show pupal case.

Habits and life history

This species has not been studied in detail. Infestation is characterised by aggregations caused by the presence of webbing to which grains of produce and frass adhere, and which may ultimately contain the cocoon which is prepared by the mature larva. This is very tough and white in colour, and is most distinctive when seen attached to bag surfaces. The adult moths are short-lived and do not feed, and as many as 150 eggs may be laid within a few days of emergence from the pupa. The developmental period from egg to adult is 4 - 5 weeks within the optimum temperature range.

Temperature and relative humidity conditions for development

The temperature optimum for this species is in the range 28° - 32°C, and the minimum relative humidity for complete development is about 30%. Development is not completed at temperatures lower than 18°C.

Distribution

Cosmopolitan. In the U.S.A. it has been reported as a pest of cocoa and confectionery, while in other countries it is better known as a pest of rice and other cereals.

CADRA CAUTELLA

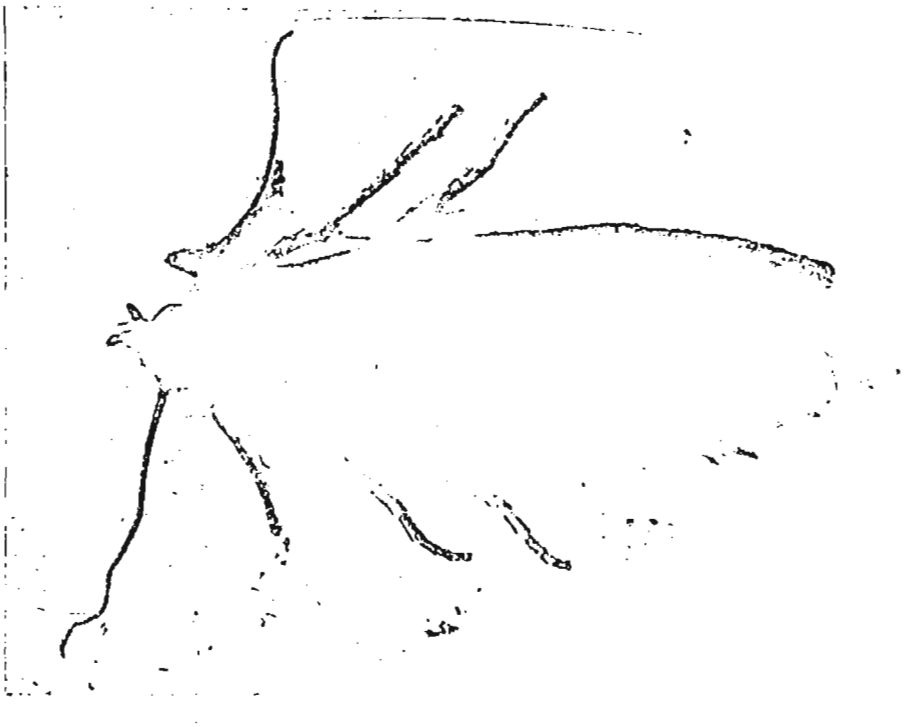
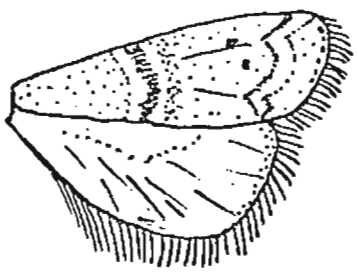
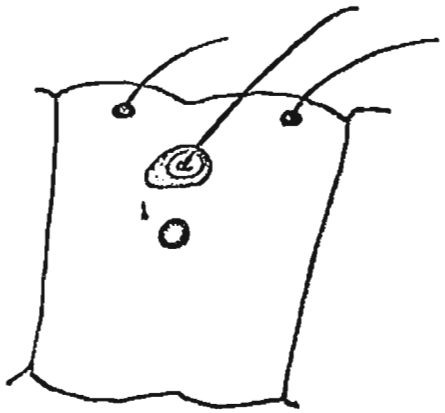


Fig. 15

Order	Lepidoptera
Family	Phycitidae
Species	(Cadra) (Ephestia) cautella
Common name	Tropical warehouse moth
Identification	Forewing dull greyish brown with obscure markings, but with an outer pale band and an inner broad dark band with a broad pale band on its inner edge. Larvae have setae arising from pigmented spots on the cuticle.



wings



larval segment

Fig. 16

Products attacked

Cereals, oilseeds (including groundnuts and palm kernels), cocoa, spices, animal feeding stuffs and bones.

Type of damage and importance

Primary pest; webbing and frass produced in the infested product are nuisance factors.

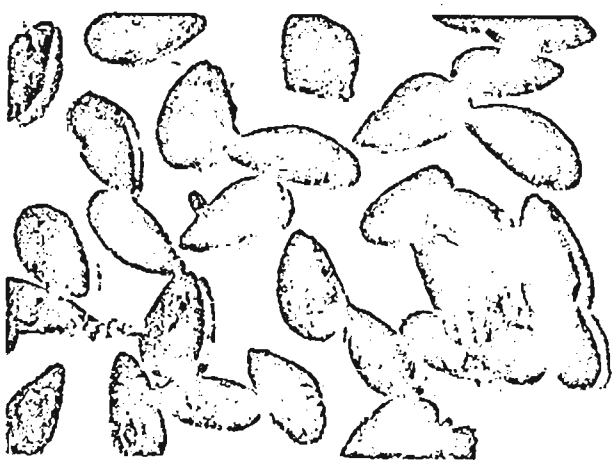


Fig. 17 Ephestia cautella: damage to cotton seed.

Habits and life history

The adult moth avoids strong light and rests in dark places during the daytime; it has a flight rhythm giving periods of active flight during 5 - 7 p.m. and at 6 a.m. when daily fluctuations in temperature and humidity occur. The eggs are laid in the produce, often by simply dropping them through the holes between fibres of jute bags, or freely on the surface of produce. The adult moths, which do not feed, live for less than 14 days and the eggs (up to 300 per female) are normally laid within three or four days of emergence. The larva moves freely through the produce and contaminates it with webbing and frass; it feeds (in the case of cereals, largely on the embryo) until it is mature. The larva then enters a wandering phase during which a fine thread is trailed after it and a silken cocoon is eventually spun: many larvae wandering over the surface of a stack may completely obscure the bag surfaces with silken webbing
In due course, the pupa (within its cocoon) gives rise to an adult. At the optimum conditions, the eggs hatch in three days and development from the egg to the adult takes about 25 days.

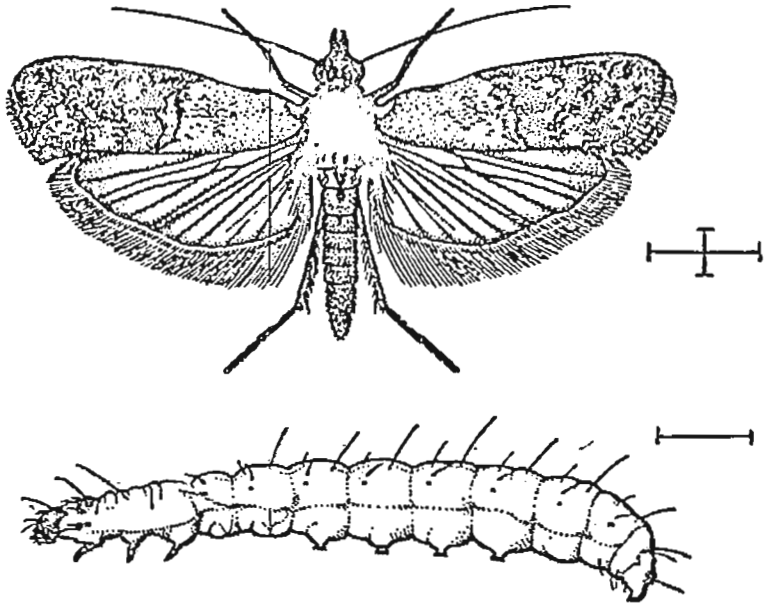
Temperature and relative humidity conditions for development

Temperature °C		Optimum
Max.	Min.	R.H.%
38	15	70
R.H.%		Optimum
Max.	Min.	Temperature °C
100	45	28

Distribution

Cosmopolitan.

PLODIA INTERPUNCTELLA



INDIAN MEAL MOTH — *Plodia interpunctella*

Fig. 18

Order	Lepidoptera
Family	Phycitidae
Species	Plodia interpunctella
Common name	Indian meal moth
Identification	Forewing with basal one-third a pale yellowish buff colour, remainder reddish brown. Larvae without pigmented spots on the cuticle.

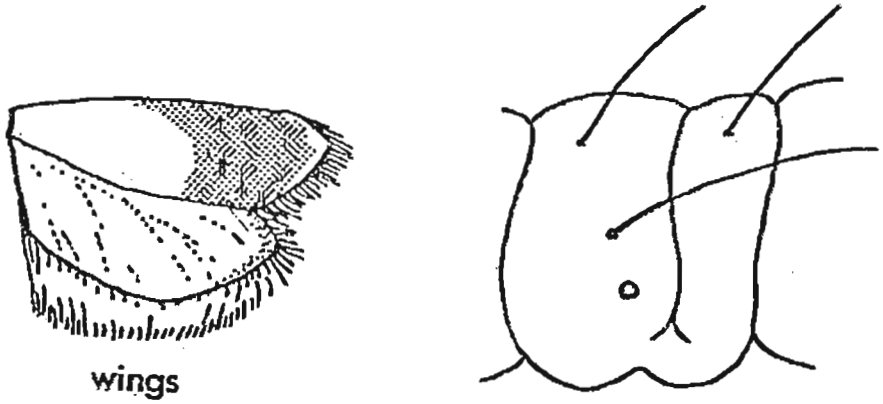


Fig. 19

Products attacked
Cereals, groundnuts, and dried fruit.

Type of damage and importance
Primary pest; webbing and frass produced in the infested product are nuisance factors.

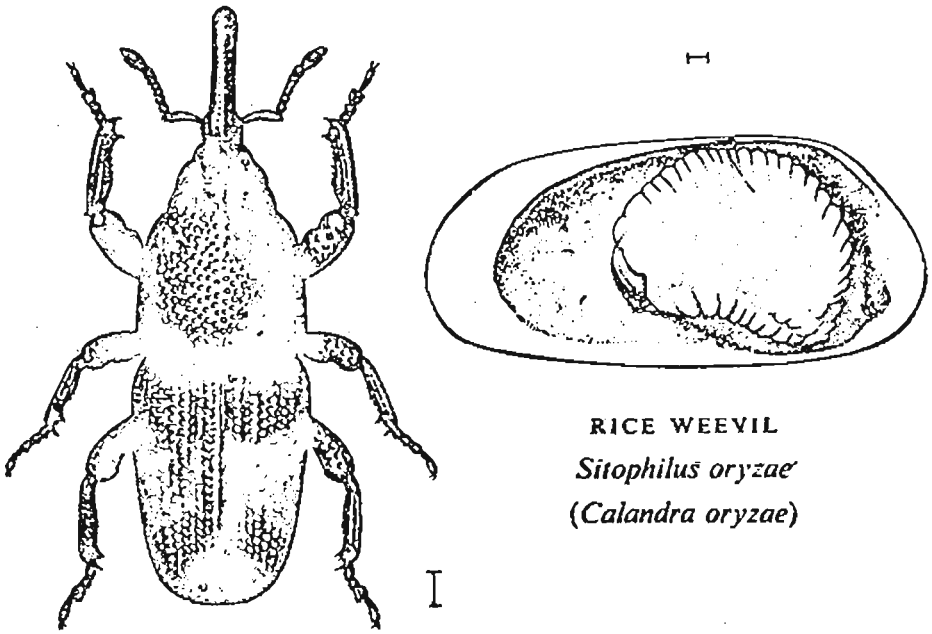
Fig. 20
Plodia interpunctella: larval damage to groundnuts.

Habits and life history
The habits and life history are similar to those of Ephestia cautella. The larvae feed first on the embryo of the grain and, while eating spin a silken thread on which accumulate the larval droppings and particles of the produce. As many as five hundred eggs may be laid by the female, the number varying with the food source during its larval life. The development from egg to adult at 30°C and 70% relative humidity takes about 26 days. The life cycle is complicated by the fact that the development of a proportion of larvae is, with some strains of this moth and under certain temperature conditions, prolonged by a pre-pupal resting stage or diapause. At this stage, the insect's metabolism, with particular reference to respiration, is very low and the normal rates of application of control chemicals (especially fumigants) may be ineffective.

Temperature and relative humidity conditions for development
The optimum temperature for development is 29°C and the optimum relative humidity 75%. Complete development is not possible at a temperature less than 10°C

Distribution
Cosmopolitan.

SITOPHILUS ORYZAE AND SITOPHILUS ZEAMAIS



RICE WEEVIL
Sitophilus oryzae
(Calandra oryzae)

Fig. 21

Order	Coleoptera
Family	Curculionidae
Species	Sitophilus oryzae
	Sitophilus zeamais
Common names	Rice weevil (S. oryzae)
	Maize weevil (S. zeamais)
Identification	Adults 2.5 - 4.5 mm long. Distinguished from all other beetles by having a well defined snout, and the antennae elbowed and clubbed. Hindwings present; punctures on prothorax round and very dense; elytra usually with four reddish spots. (Separation of the two species is very difficult, but in general S. oryzae is smaller than S. zeamais - there are however exceptions to this rule).

Products attacked

S. oryzae - rice, sorghum, wheat, maize, paddy (limited).
S. zeamais - maize, wheat, rice, paddy (limited).

Type of damage and importance

Primary pest of cereals causing hollowing out of grains.

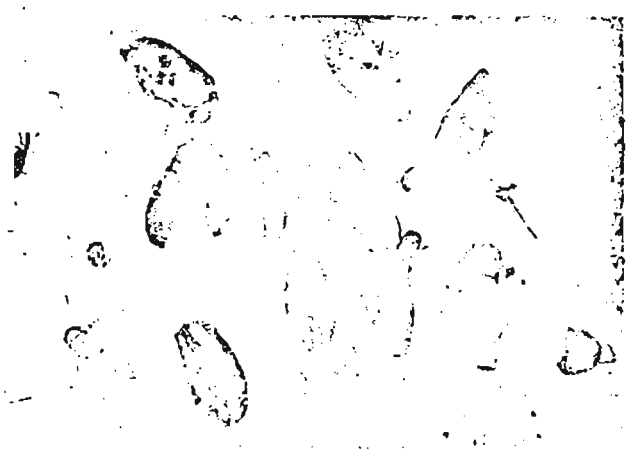


Fig. 22

Sitophilus oryzae: adult and larvae removed from grain.

Habits and life history

S. oryzae is more common on small cereal grains and has a higher temperature tolerance than S. zeamais. The adults generally avoid strong light, and are very active if disturbed. Both species can fly, and so can attack cereals in the field before harvest, but flight activity is more pronounced in S. zeamais. Under optimum conditions, 100 - 150 eggs are laid by the female over a period of many weeks. (A peak in egg-laying activity occurs about three weeks after emergence from the pupa). Each egg is laid in a minute hole chewed in the grain by the female, and is sealed in the hole by a secretion. The legless larva remains inside the grain where it feeds and eventually pupates. When development is complete, the adult bites its way out of the grain leaving behind an emergence hole. Both adults and larvae feed, and the adults may live for up to five months.

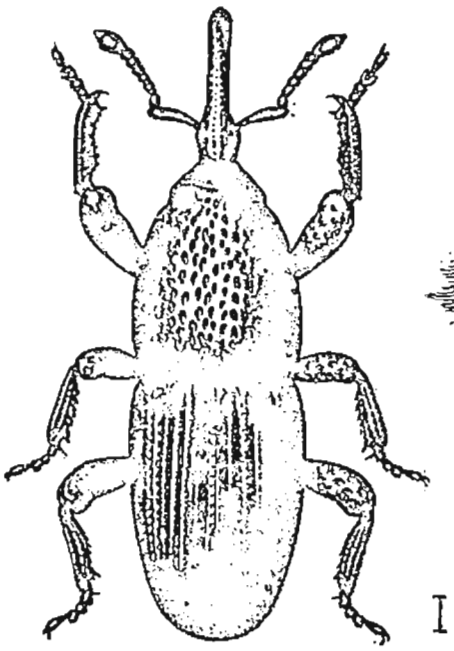
Temperature and relative humidity conditions for development

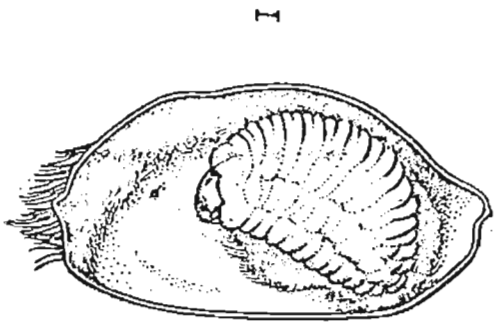
Temperature °C		Optimum
Max.	Min.	R.H.%
34	17	70
R.H.%		Optimum
Max.	Min.	Temperature °C
100	45	28

Distribution

Cosmopolitan.

SITOPHILUS GRANARIUS





GRANARY WEEVIL
Sitophilus granarius
(Calandra granaria)

Fig. 23

Order	Coleoptera
Family	Curculionidae
Species	Sitophilus granarius
Common name	Granary weevil
Identification	The adult is 3 - 4 mm long, possessing a well defined snout and elbowed antennae as in the two preceding Sitophilus species. Distinguished from them by absence of hind wings, and by punctures on prothorax which are oblong-oval.

Products attacked

Wheat, and other cereals.

Type of damage and importance

Primary pest of cereals, causing hollowing out of grains.

Fig. 24

Sitophilus granarius: adults on wheat.

Habits and life history

The adult of this species possesses only vestigial hind wings, and is therefore confined to stored grain and does not attack field crops. Both adults and larvae feed and the adult may live for as long as eight months. The female may lay between 30 and 250 eggs, these being deposited in a hole excavated in the grain and plugged with a gelatinous secretion. In general, there is a preference for the larger grains, which tend to be used for egg-laying. The small white legless larva remains in the grain, and pupates after passing through four instars. When development is complete, the adult chews its way to the grain surface.

Temperature and relative humidity conditions for development

The optimum temperature for the development of this species is in the range 26° - 30°C, and complete development does not take place at a temperature below 15°C.

Distribution

This species is primarily a pest of cereals stored under temperate conditions. It occurs in the highlands of Kenya as a pest of wheat, and may be present on imported cereals in other countries. It is not well established in those countries with a tropical climate.

RHIZOPERTHA DOMINICA

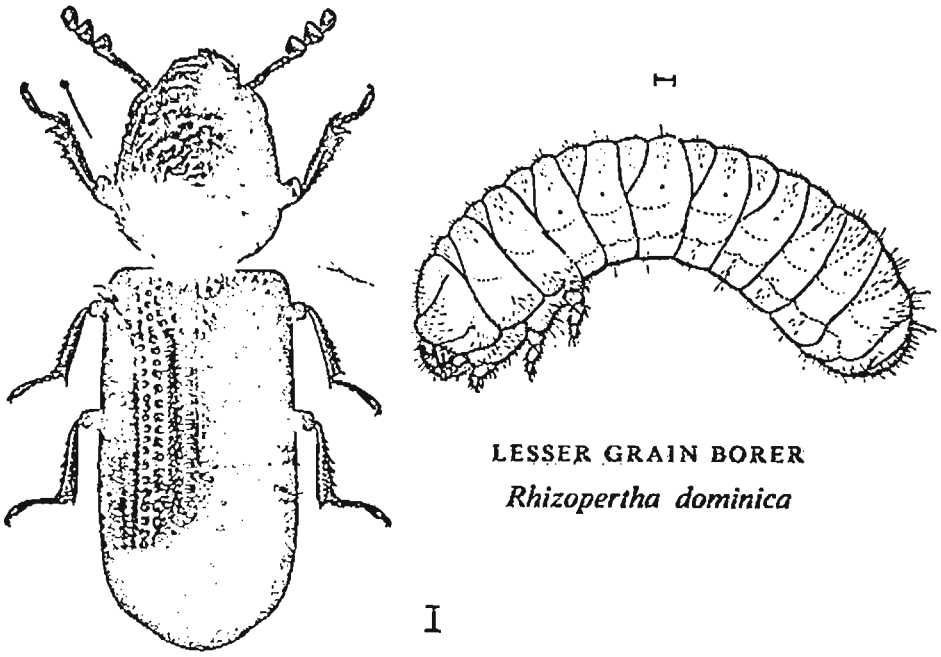


Fig. 25

Order	Coleoptera
Family	Bostrychidae
Species	Rhizopertha dominica
Common name	Lesser grain borer
Identification	Body cylindrical about 3 mm long; colour brown; head deflexed and more or less concealed from above by prothorax which is roughened by ridges and tubercles; elytra with well-defined rows of punctures; antennae with a large, loose, 3-segmented club.

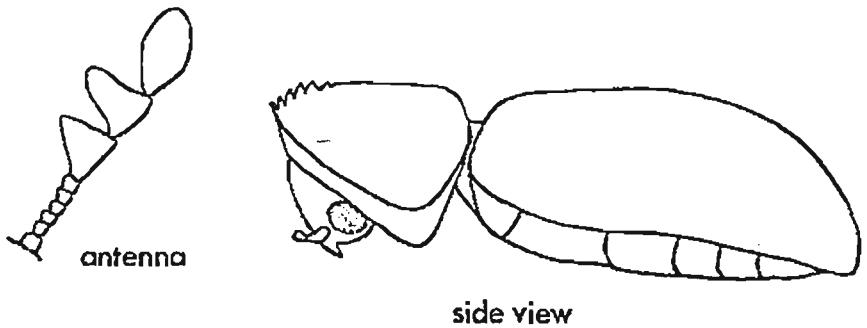


Fig. 26

Products attacked

Cereals, cassava, development possible in cereal flours.

Type of damage and importance

A primary pest of cereals (able to attack paddy rice more readily than Sitophilus oryzae); damage irregular compared with that caused by the weevils (Page 25).

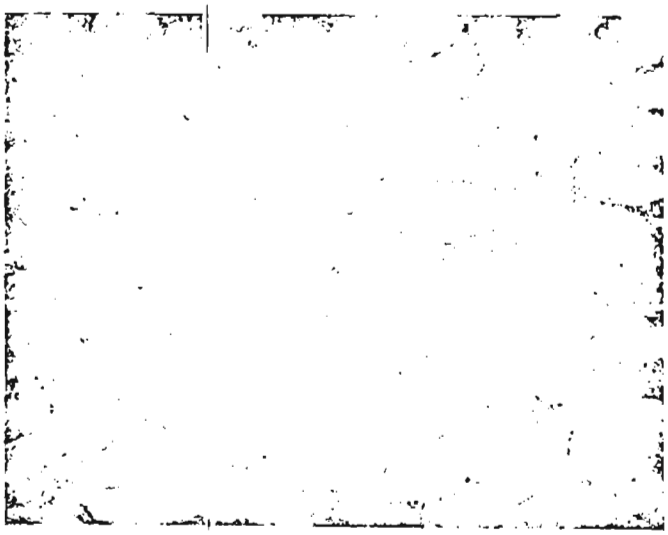


Fig. 27

Rhizopertha dominica: adults on wheat.

Habits and life history

This species belongs to a group which includes many timber borers, and both adults and larvae are voracious feeders. The adults are long-lived. The eggs are laid on the surface of, or among, cereal grains. Up to 550 eggs are laid per female over a period of three to six weeks; daily egg production is very erratic with no definite peak in egg-laying activity. The larva emerges and eats its way into a grain where it feeds in a somewhat haphazard manner. Unlike Sitophilus spp., the larvae have legs and can crawl; they actively feed in grain dust and attack grains externally. When fully grown, the larva pupates, usually inside the grain. Both adults and larvae feed on stored produce.

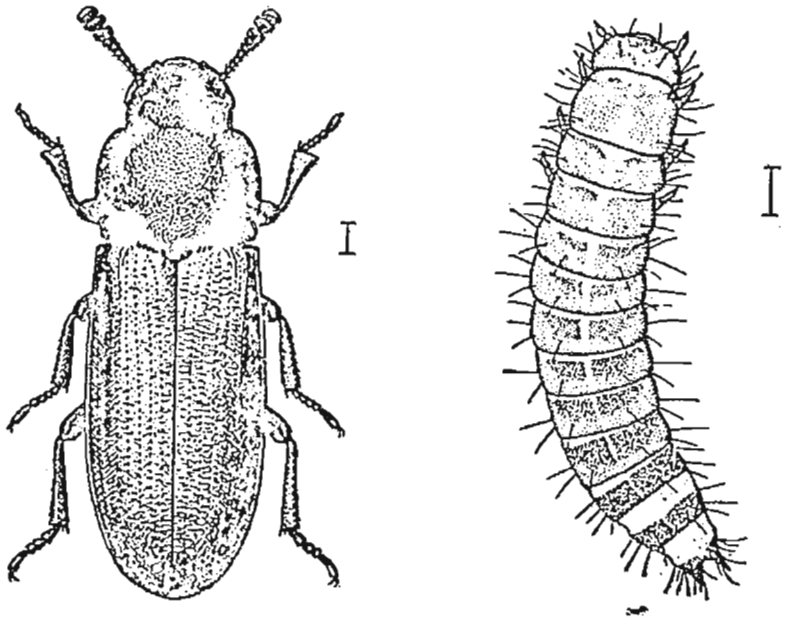
Temperature and relative humidity conditions for development

Temperature °C		Optimum
Max.	Min.	R.H.%
39	18	50-60%
R.H.%		Optimum
Max.	Min.	Temperature °C
70	25	34

Development from egg to adult under optimum conditions takes 25 days; in comparison, development is prolonged to 84 days at 23°C and 70% relative humidity.

Distribution

Cosmopolitan.



FLOUR BEETLE — *Tribolium castaneum*

Fig. 28

Order	Coleoptera
Family	Tenebrionidae
Species	Tribolium castaneum
	Tribolium confusum
Common names.	The rust red flour beetle (T. castaneum)
	The confused flour beetle (T. confusum)
Identification.	Flat beetles; 3 - 4 mm long; elongate bodies, brown in colour.
	T. castaneum - antennae with distinct three-segmented club; eyes partly divided by backwardly produced side margin of head, and having 3 - 4 facets at narrowest point.
	T. confusum - antennae gradually thickened towards apex; eyes more-strongly-divided than in preceding species and having not more than two facets at narrowest point.

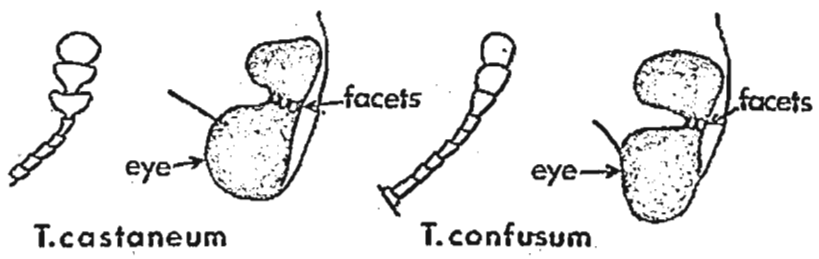


Fig. 29

Products attacked

T. castaneum - oilseed cake, groundnuts, cereals and milled cereal products.
T. confusum - cereals and milled cereal products.

Type of damage and importance

Secondary pests of sound, dry cereal grains; important pests of other products. Preference shown for the embryo of cereal grains.

Fig. 30

Tribolium castaneum: larval damage to groundnuts.

Habits and life history

Up to 450 eggs are laid by the female over a period of many months. The eggs are laid at random in the produce and hatch into slender cylindrical larvae. Pupation takes place in the food, without the formation of a cocoon, and the emerged adults may live for as long as 18 months. Both adults and larvae feed on the produce. The egg to adult developmental period for T. castaneum is about 20 days under optimum conditions, but development is markedly affected by the food source, and may be greatly extended where the food or the environmental conditions are not completely satisfactory. Thus on groundnuts at 25°C and 70% relative humidity, the egg to adult developmental period may be as long as 141 days compared with 35 days on wheat bran

Temperature and relative humidity conditions for development

T. castaneum

Temperature °C Max.	Min.	Optimum R.H.%
40	20	70

R.H.% Max.	Min.	Optimum Temperature °C
90	10	35

T. confusum

Temperature °C Max.	Min.	Optimum R.H.%
38	20	70

R.H.% Max.	Min.	Optimum Temperature °C
90	10	33

Distribution

Both species are cosmopolitan, but T. castaneum prefers slightly warmer conditions and may be more common in the tropics.

ALPHITOBIUS DIAPERINUS AND ALPHITOBIUS LAEVIGATUS

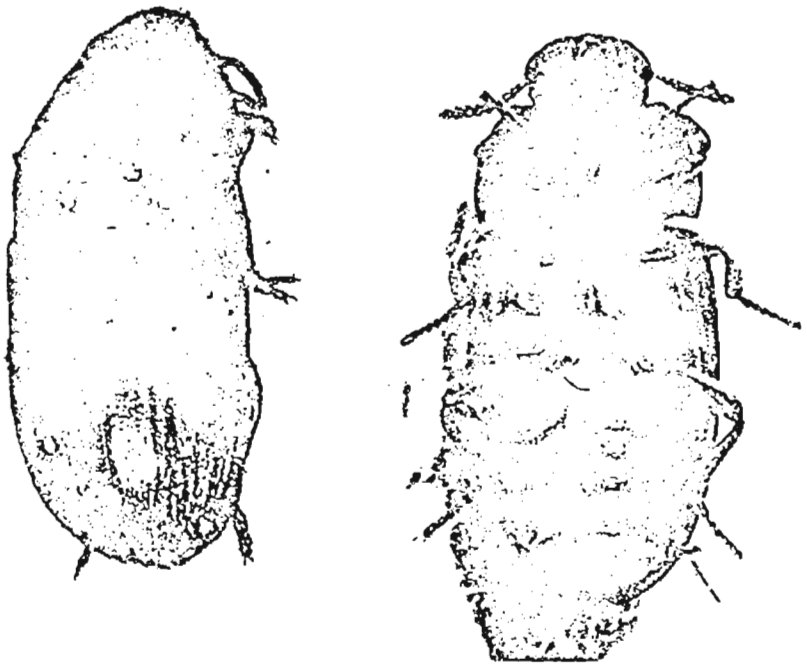


Fig. 31 Alphitobius diaperinus: dorsal and ventral views

Order	Coleoptera
Family	Tenebrionidae
Species	Alphitobius diaperinus
	Alphitobius laevigatus
Common names	Black fungus beetles
Identification	Black or dark brown beetles, 5 - 7 mm long with body somewhat broader than Tribolium spp. Eyes strongly divided; in A. diaperinus the eye at the narrowest point is composed of 3 - 4 facets; in A. laevigatus a single facet.

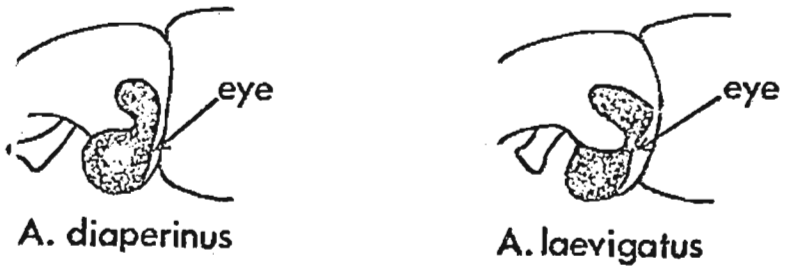


Fig. 32

Products attacked

Grain residues, damp grain and milled products.

Type of damage and importance

Both A. diaperinus and A. laevigatus are regarded as minor pests, their presence indicating poor storage conditions and incipient mould growth.

Habits and life history

The habits and life history of these species do not appear to have been studied in any detail. The egg to adult developmental period is 35 days under optimum conditions, and the adult is long-lived.

Temperature and relative humidity conditions for development

The optimum temperature for development is 35°C and the optimum relative humidity is in the range 80% - 95%.

Distribution

Cosmopolitan.

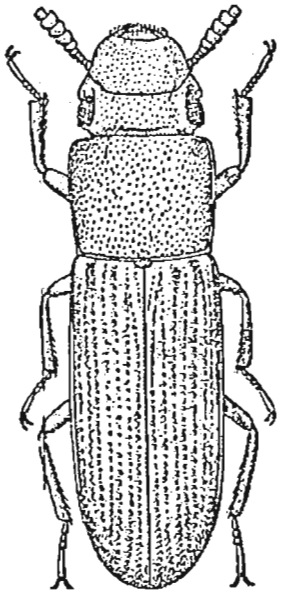


Fig. 33

Order	Coleoptera
Family	Tenebrionidae
Species	Latheticus oryzae
Common name	Long-headed flour beetle
Identification	Light brown beetle with elongate body 2 - 3 mm in length. The head is longer than in Tribolium spp., which it resembles. The antennae are shorter than the head, and have a compact five-segmented club.

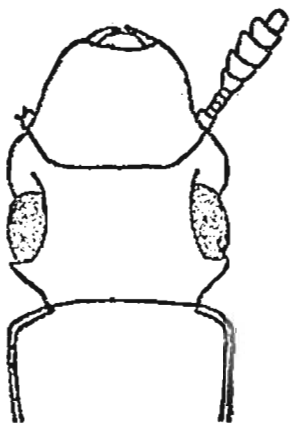


Fig. 34

Products attacked

Rice and rice products, cereal flours and cassava flour.

Type of damage and importance

Secondary pest of whole cereal grains; important pest of milled products.

Habits and life history

The habits and life history of this species are almost identical with those of Tribolium spp. The eggs are laid at random in the produce, and hatch into larvae which pupate in the food without forming a cocoon. Both adults and larvae feed on the produce, and the adults are long-lived.

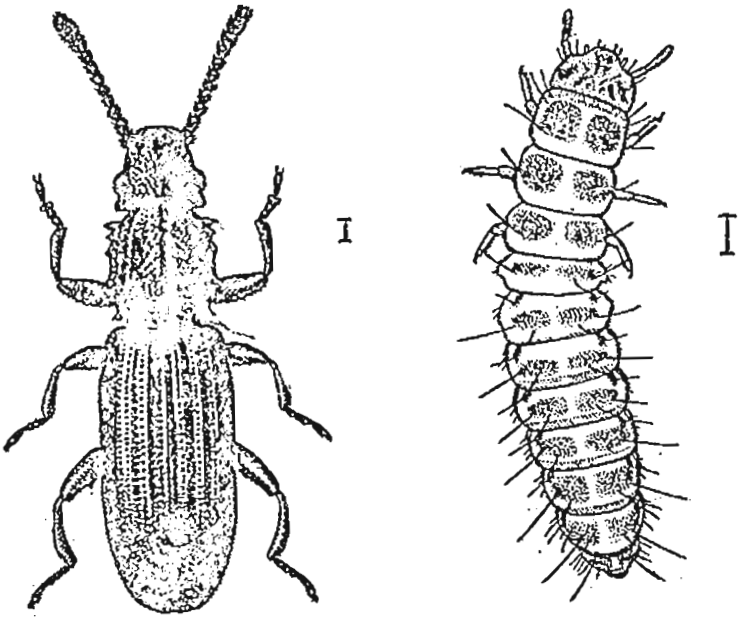
Temperature and relative humidity conditions for development

The optimum temperature for development is about 35°C and the optimum relative humidity 70%. Development is not completed at temperatures below 26°C or at relative humidities below 30%.

Distribution

Cosmopolitan.

ORYZAEPHILUS SURINAMENSIS AND ORYZAEPHILUS MERCATOR



SAW-TOOTHED GRAIN BEETLE — *Oryzaephilus surinamensis*

Fig. 35

Order	Coleoptera
Family	Silvanidae
Species	Oryzaephilus surinamensis
	Oryzaephilus mercator
Common names	Saw-toothed grain beetle (O. surinamensis)
	Merchant grain beetle (O. mercator)
Identification	Narrow flattened beetles, 2.5 - 3.5 mm long; prothorax with six large teeth on each side, and three ridges on dorsal surface; antennae with a compact club; elytra completely cover the abdomen. The two species may be separated on the length of the temple behind the eye.

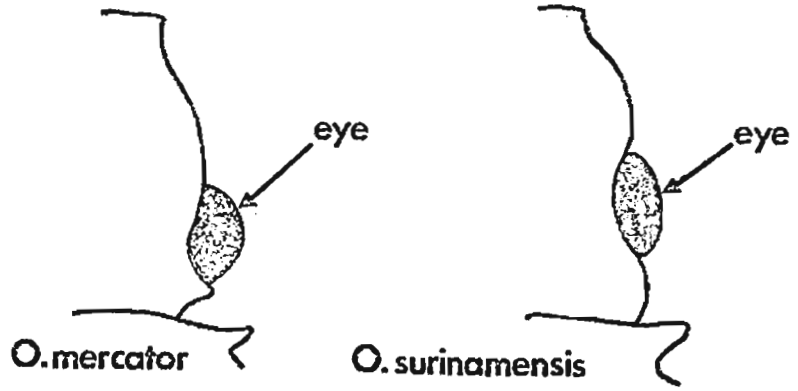


Fig. 36

Products attacked

O. surinamensis - cereals and milled cereals.

O. mercator - mainly oilseeds and dried fruit but also rice, rice bran, spices and dried fruit.

Type of damage and importance

Both species are secondary pests of whole grains causing only superficial damage; important pests of milled products, copra and oilseed cake.

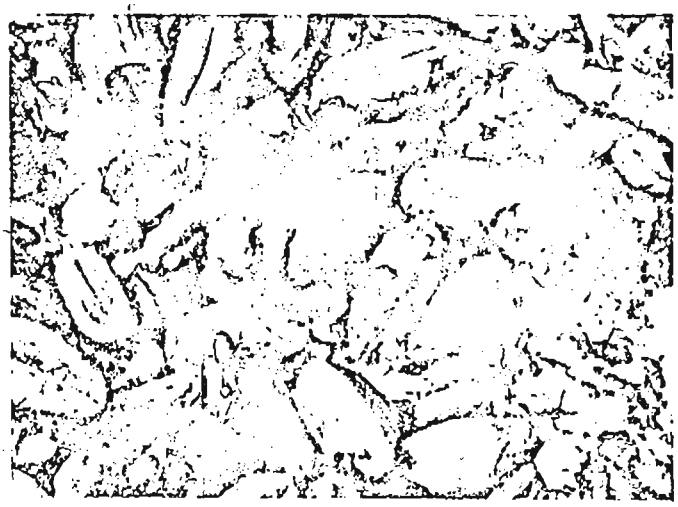


Fig. 37

Oryzaephilus sp. on previously damaged grain.

Habits and life history

The habits and life history are similar for both species. About 300 eggs are laid loosely in the produce by the female over a period of 10 weeks, and hatch into slender pale cream larvae, with two slightly darker patches on each segment. The larvae are active and move about freely until fully grown, when they construct a silken cocoon in which to pupate. Both adults and larvae feed on stored produce, and the adults may live for as long as three years. The egg to adult developmental period under optimum conditions is about 25 days.

Temperature and relative humidity conditions for development

O. surinamensis

Temperature °C Max.	Min.	Optimum R.H.%
38	18	90
R.H.% Max.	Min.	Optimum Temperature °C
90	10	35

O. mercator

Temperature °C Max.	Min.	Optimum R.H.%
38	18	70
R.H.% Max.	Min.	Optimum Temperature °C
90	10	30

Distribution

Both species are cosmopolitan.

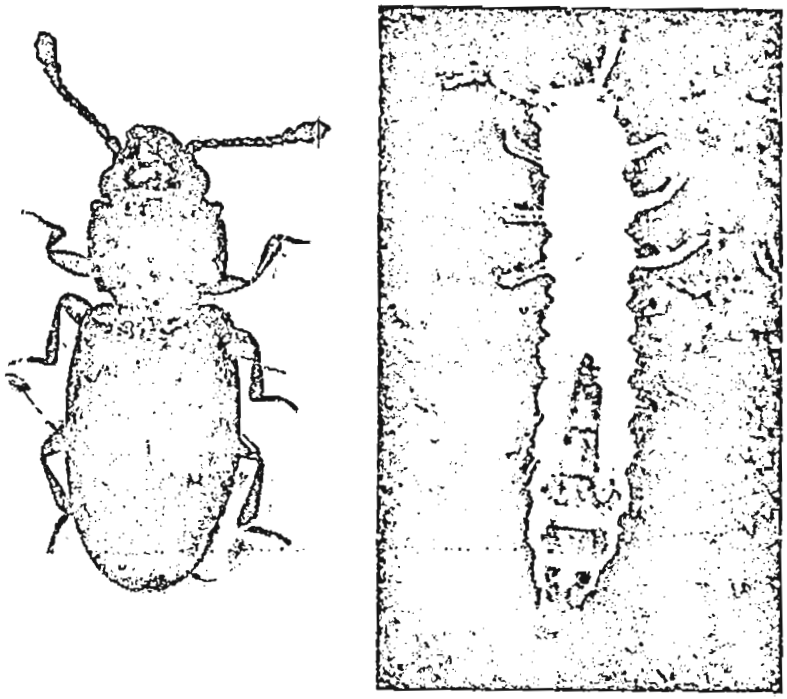


Fig. 38

Order	Coleoptera
Family	Silvanidae
Species	Ahasverus advena
Common name	Foreign grain beetle
Identification	Small beetle (2 - 3 mm long), rather smaller than Oryzaephilus spp.; prothorax with one tooth on apical angle, but without rows of teeth on sides; no dorsal ridges.

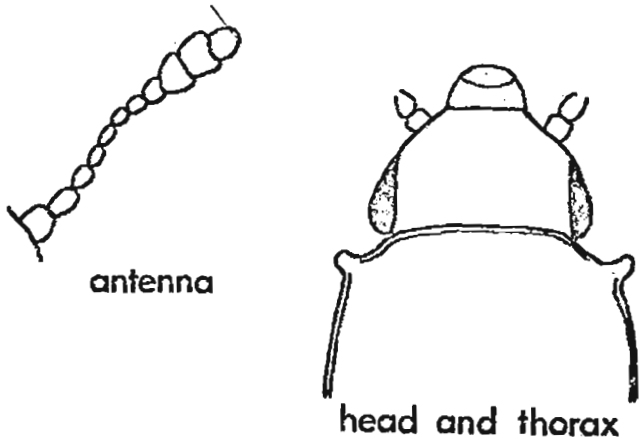


Fig. 39

Products attacked

Cocoa, palm kernels, coffee, groundnuts, copra, spices, mouldy cereals and other mould-damaged products.

Type of damage and importance

It does not damage clean dry produce, but feeds on debris, moulds, and dead insects. Its presence is taken as a warning of conditions likely to lead to mould growth.

Fig. 40

Ahasverus advena: damage to groundnuts.

Habits and life history

The habits and life history of this species have not been studied in detail. The insect is a strong flier, and moves freely from store to store. The egg to adult developmental period under optimum conditions is about 30 days.

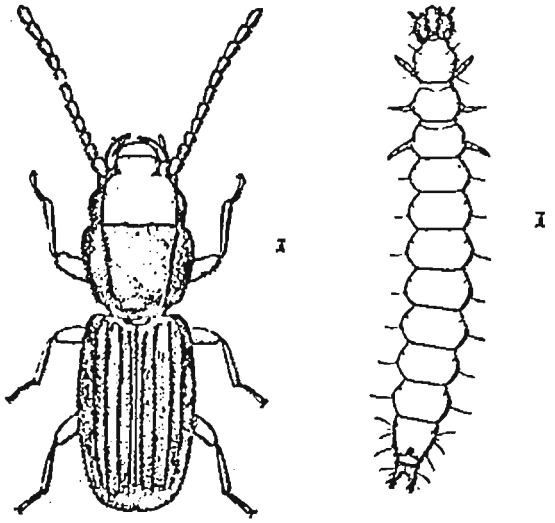
Temperature and relative humidity conditions for development

The optimum temperature for development is 30°C and the optimum relative humidity 70%. Development is not completed at relative humidities below 60%.

Distribution

Cosmopolitan.

CRYPTOLESTES FERRUGINEUS



RUST RED GRAIN BEETLE — Cryptolestes ferrugineus

Fig. 41

Order	Coleoptera
Family	Cucujidae
Species	Cryptolestes ferrugineus and other Cryptolestes spp.
Common name	Flat grain beetles
Identification	Body very flat, 1.5 - 4 mm long and light brown in colour; prothorax with lateral ridges; antennae filiform and usually more than half the length of the body. A number of species are to be found in association with stored products, but identification of all these species is too difficult for the layman.

Products attacked

Cereals, oilseeds, milled cereal products, cocoa, cowpeas.

Type of damage and importance

Secondary pests of dry whole grain; of importance as pests of damaged grain and milled products.

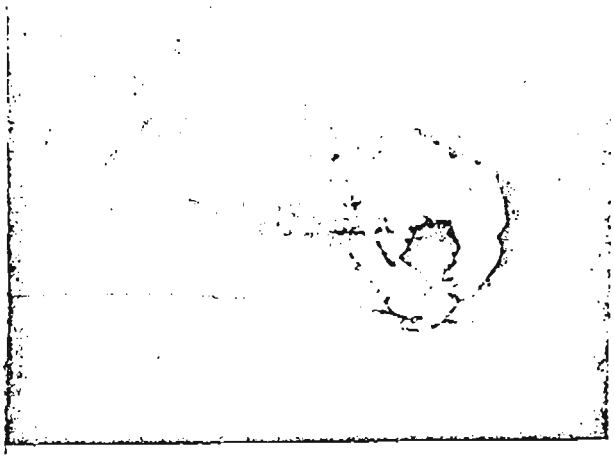


Fig. 42

Cryptolestes ferrugineus: damage to wheat grains.

Habits and life history

These small beetles are scavengers, and are only capable of breeding in produce which is dusty, contains broken grains, and has a high moisture content or is already infested with insects. Normally regarded as secondary pests, Cryptolestes spp. are able to attack wheat in which there is some fault in the seed coat, (this fault usually occurring in the region of the embryo which is preferred to the endosperm as a food). Eggs are laid in the produce, often in cracks or splits in the grains, and hatch into larvae which are long, slender and straw-coloured, with a darker twin-pointed appendage at the posterior end. When fully grown, they spin cocoons of a somewhat sticky substance to which particles of food adhere. Both adults and larvae feed, but the growth of moulds in the endosperm of the cereal, converts it into a more suitable larval food. Under optimum conditions, the developmental period from egg to adult is 23 days, and the adults are long-lived (6-9 months).

Temperature and relative humidity conditions for development

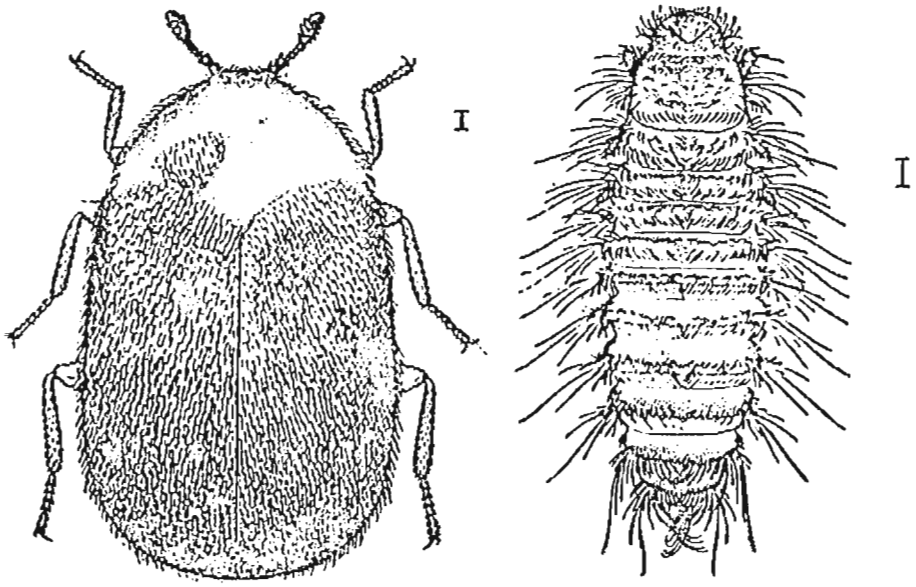
C. ferrugineus

Temperature °C		Optimum
Max.	Min.	R.H.%
42	20	70
R.H.%		Optimum
Max.	Min.	Temperature °C
90	40	33

Distribution

Varied; a few species cosmopolitan.

TROGODERMA GRANARIUM



KHAPRA BEETLE — *Trogoderma granarium*

Fig. 52

Order	Coleoptera
Family	Dermestidae
Species	Trogoderma granarium
Common name	Khapra beetle
Identification	Small oval beetles, 1.5 - 3.0 mm in length; densely covered with hairs. Elytra cover the abdomen; antennae with distinct club. Larvae straw-coloured with numerous tufts of hairs.

Products attacked

Groundnuts, groundnut cake, cereals, pulses, and spices.

Type of damage and importance

Damage to produce is of a primary nature. This can be regarded as the most important pest from a phyto-sanitary point of view. Legislation has been introduced in East and South Africa to restrict its movement; its presence on produce for export calls for immediate fumigation, and in some cases, (in the U.S.A., for example) will lead to non-acceptance by the importing country.

Fig. 53
Trogoderma granarium: adults, larvae, and pupae on wheat.

Habits and life history

The adult beetle is short-lived (about 14 days), does not feed, and is not capable of flight. The species is atypical of the family Dermestidae in that the larvae do not usually feed on materials of animal origin, but prefer cereals and oilseeds. Between 50 and 80 eggs are laid by the female on the produce, and egg to adult development takes 25 days under optimum conditions. The larvae which hatch, move and feed freely within the produce. Under unfavourable conditions, many mature larvae enter a resting stage or diapause, and leave the food to cluster in crevices in the store fabric. They may remain hidden for periods of up to four years, development continuing when food supplies become available and the temperature is favourable. In the resting stage they may be difficult to kill with contact insecticides.

Temperature and relative humidity conditions for development

Temperature °C Max.	Min.	Optimum R.H.%
41	24	25
R.H.% Max.	Min.	Optimum Temperature °C
73	3	37

Distribution

Though virtually cosmopolitan, this species is favoured by hot dry climates. It is reputed, however, to be absent from many African countries including Kenya, Uganda, Central and Southern Africa.

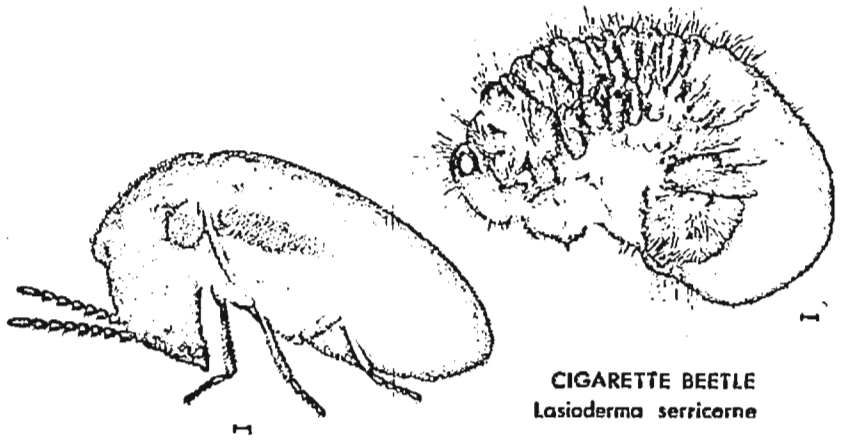


Fig. 59

Order	Coleoptera
Family	Anobiidae
Species	Lasioderma serricorne
Common name	Cigarette beetle
Identification	Small oval or nearly globular beetle, 2.0 - 2.5 mm long, with the prothorax more or less covering the deflexed head; elytra cover the abdomen and are not striate; antennae serrate with segments 4 - 11 enlarged.

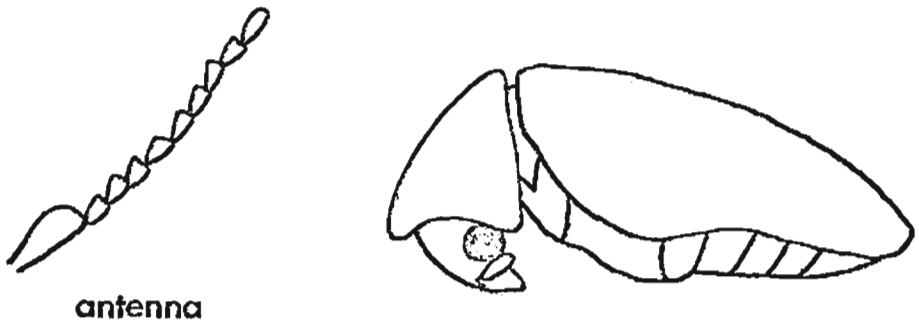


Fig. 60

Products attacked

Tobacco, cocoa, coffee, spices, pulses, cereals.

Type of damage and importance

A major pest of tobacco and cocoa. A secondary pest of other commodities; infest pulses following attack by Bruchid beetles.

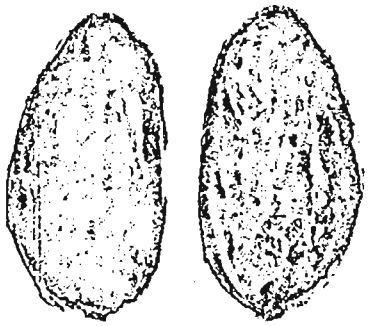


Fig. 61

Lasioderma sericorne: damage to cocoa beans.

Habits and life history

The female lays about 100 eggs over a period of 6 - 20 days depending on the temperature. Egg laying activity reaches a peak at an early stage, and then falls off rapidly. Eggs take 5 - 6 days to hatch at 35°C, and about 22 days at 20°C. The larval developmental period is significantly affected by the nature of the food supply, being about 19 days in wholemeal flour, up to as long as 48 days in crushed cocoa beans, even under optimum conditions of temperature and humidity. At the completion of the larval stage, a cocoon is formed, and the adults which ultimately emerge live for about 2 - 4 weeks and do not feed.

Temperature and relative humidity conditions for development

Temperature °C		Optimum
Max.	Min.	R.H.%
37	20	70
R.H.%		Optimum
Max.	Min.	Temperature °C
100	22	30

Distribution

Cosmopolitan.

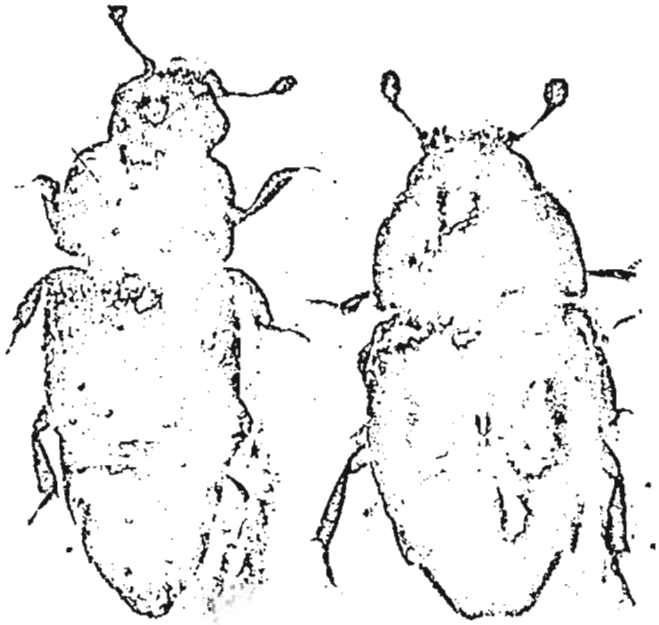


Fig. 62 C. dimidiatus C. hemipterus

Order	Coleoptera
Family	Nitidulidae
Species	Carpophilus dimidiatus and other species
Common names	Corn sap or dried fruit beetles
Identification	Small oval beetles, 2 - 4.5 mm long, with short elytra so that two or three abdominal segments are exposed from above; antennae with a compact three-segmented club. Elytra brown in colour often with a pale yellowish spot at the apex. Identification of individual species should be left to the specialist.

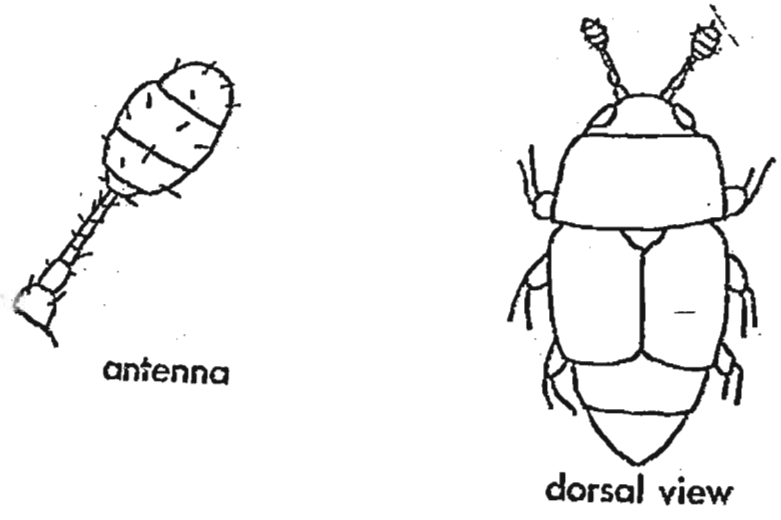


Fig. 63

Products attacked

Palm kernels, copra, cocoa, dried fruit and mouldy produce of any kind.

Type of damage an importance

Of minor importance, unless present in large numbers, when their presence can be taken as a warning of the development of excessive mould growth. Damage, including superficial channelling and tunnelling, is most severe in underdried copra.

Fig. 64

Carpophilus sp. : adults and larvae on dried figs.

Habits and life history

C. dimidiatus normally feeds in decaying fruit and vegetation, but is quite frequently observed in warehouses. It rarely damages cereal commodities which are dry and in good condition. Both adults and larvae feed, but damage is primarily caused by the larvae. The egg to adult developmental period under optimum conditions is about 15 days. The adult is long-lived, and a strong flier so that it is able to move from store to store.

Temperature and relative humidity conditions for development

The optimum temperature for C. dimidiatus is 33°C, and complete development only takes place when the relative humidity lies between 70% and 100%.

Distribution

Cosmopolitan.

PTINUS TECTUS AND OTHER RELATED SPECIES

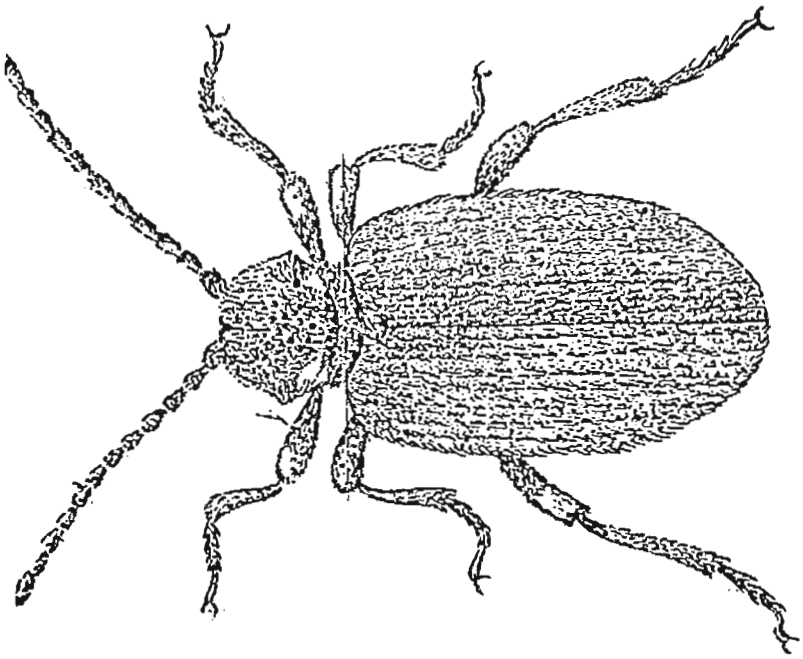


Fig. 65 Ptinus tectus

Order	Coleoptera
Family	Ptinidae
Species	Ptinus tectus and other species
Common name	Spider beetles
Identification	Because of their long legs, stout hairy bodies (2.5 - 4.0 mm long), and long antennae, they superficially resemble small spiders. About 24 species of spider beetle are associated with stored products, so that identification should be left to the specialist.

Products attacked

Debris from various commodities such as dried fruit and cereals.

Type of damage and importance

Since spider beetles feed on debris of all kinds (including rat and mouse droppings and insect and other animal remains), they are therefore scavengers. They are common in damp situations in temperate climates.

Fig. 66

Ptinus tectus: damage to paper sacks (note cocoon at bottom right).

Habits and life history

The eggs are laid in the food, approximately 70 - 120 eggs being laid by each female. The larvae which hatch pass through four instars before constructing cocoons within which pupation takes place. The adult insect is most active after dark, and generally avoids the light. Although its activity is reduced by low temperatures, it can still survive at temperatures as low as 2°C. Both adults and larvae are voracious feeders, and sometimes damage packaging material and wood.

Temperature and relative humidity conditions for development

Optimum conditions for the development of spider beetles are a temperature range of 20° - 25°C and a relative humidity of 80% - 90%. Development cannot be completed at temperatures higher than 28°C, or lower than 10°C, or at a relative humidity below 50%.

Distribution

Confined to temperate and sub-tropical climates.