THE SUSCEPTIBILITY OF DIFFERENT TYPES OF MAIZE TO POST-HARVEST INFESTATION BY <u>SITOPHILUS ZEAMAIS</u> AND <u>SITOTROGA CEREALELLA</u>, AND THE IMPORTANCE OF THIS FACTOR AT THE SMALL-SCALE FARM LEVEL[1]

PHILIP DOBIE
Centro Internacional De Mejoramiento De Maiz Y Trigo
International Maize and Wheat Improvement Center
Londres 40, MEXICO 6, D. F.

ABSTRACT: The losses caused by insects attacking stored products in rural areas of the tropics are frequently very heavy, and the introduction of new maize types in these areas have in some cases aggravated this problem. However, the considerable success achieved by maize breeders in selecting for resistance against pests and diseases of the growing plant leaves considerable scope for optimism that this approach would be successful in the storage field.

Some of the problems of encouraging the improvement of storage practises are mentioned, and the benefits which could be obtained by the introduction of maize with improved storage qualities are outlined.

The situation in Malawi, where difficulties have been encountered in the introduction of improved hybrids due to the unsuitability of their kernel type and their high susceptibility to storage pests, is discussed and some experimental results concerning the field and storage susceptibility of some varieties of Malawi maize to *S. zeamais* and *S. cerealella* are presented.

The relevant susceptibilities to infestation by the two insects of some populations of maize and their counterpart 'opaque' versions of high protein quality were assessed, and the opaque were found to be considerably more susceptible than the normal versions. However, it was found that opaque populations which had been selected for increased kernel hardness were less susceptible than their soft opaque counterparts.

The distribution of eggs laid by female *S. zeamais* when individual kernels were exposed to individual female insects for 24 hours was found to be non-random, and the kernels which were apparently avoided were selected for growing in an attempt to select for resistance to this insect.

It was found that removal of the pericarp/testa layer of the maize kernel greatly increases its susceptibility to *S. zeamais* and the relevant importance of the pericarp/testa layer, the endosperm, the embryo, and the moisture content of kernels to susceptibility to both species is discussed.

Relationships found between susceptibility and protein quality of the maize are reported, and the importance of the nutritional quality of the maize towards susceptibility is discussed.

[1]On secondment from the Tropical Stored Products Centre (Tropical Products Institute) London Road, Slough Berks., England.

INTRODUCTION: It has long been realized that the losses caused by stored products insects attacking stored crops in rural areas of the tropics are frequently very high, usually appreciable and very seldom absent. The losses occurring after harvest are as real and as tangible as losses caused by diseases and pests attacking the growing plant.

Considerable success has been achieved by maize breeders in identifying and selecting maize lines which are tolerant or resistant to pre-harvest diseases and pests, and although the gene action is often not fully understood, it has been found to be practicable to select for the responsible genes in breeding programmes. The success achieved in the pre-harvest field leaves considerable reason for optimism that similar success could be achieved in the post-harvest field.

The species, *Zea mays*, after originating as a cultivated plant in all probability in the Southern Mexican region has subsequently become dramatically and successfully distributed throughout the world. Within the Central and Southern American region there is already a very large variation in maize types, and the establishment of the species in other parts of the world has resulted in the selection of an even greater variety of types. It is this variability, and the broad-based genetic pool that causes it which results in the variability in susceptibility to storage pests which we have observed, and hopefully, it is this variability which can be exploited for the selection of less susceptible varieties.

Conventionally, maize is divided into the following types based on kernel characteristics: dent, flint, flour, sweet, popcorn, waxy and podcorn. As far as small-scale farming is concerned, sweet, popcorn, waxy and podcorn can be ignored (the first three being types grown on a fairly small scale for certain commercial purposes, and the last being a botanical curiosity). This leaves us with dent, flint and floury types to represent the maize which is grown on small farms throughout the world. These three types are essentially a broad classification based upon the distribution of hard and soft starches in the endosperm, and this classification can be misleading as there is a tremendous variability in chemistry and morphology within and across the groups. For instance, in 25 varieties and hybrids obtained from Malawi, all of which were dent types and none of which had been selected for amylose content, we found a range of between 22.3% and 45.3% of amylose in the starch. Similarly, within the same material, it was estimated that the softer kernels had approximately 1.6 times as much soft endosperm than had the harder kernels. Reference to the literature will show us that total sugar content, total carbohydrate, total protein and amino acid balance all vary in a similar manner. On the morphological side, kernel shape and size varies, the size of the embryo varies, and multi-aleurone layers are known. The maize ear (or cob) also varies in structure, with the extent of the coverage of the ear by the sheathing leaves being perhaps of most importance as far as susceptibility is concerned.

With a crop which is so varied, it is clearly reasonable to expect a varied response to infesting insects.

THE POTENTIAL BENEFITS OF THE INTRODUCTION OF MAIZE TYPES WITH IMPROVED STORAGE QUALITIES: The place where the highest losses of stored maize occur is undoubtedly on small farms in the tropics. Although sophisticated preventative measures against storage pests can be very easily justified where grain is stored in large quantities, very often the subsistence farmer either cannot afford to protect his grain, or perhaps there are other reasons which to him make this undesirable. Some of the problems of protecting grain on small farms are indicated below.

(1) Need for capital to buy insecticides, fumigants and building materials.

(2) Insecticides and fumigants are often not easily available locally.

(3) Dilute insecticide dusts are frequently rather unstable, and have a short 'shelf life'. As a result, locally bought insecticides are frequently old and useless.

(4) The introduction of new storage techniques may necessitate a change in storage habits. (For example, if grain is to be stored under airtight conditions, arrangements must be made to store the grain in units which will not be opened until immediately prior to consumption or sale).

(5) Frequently it will be necessary to change the pattern of construction of traditional storage structures, which often have many favourable points.

Although great advances could probably be made by introducing modified storage structures, fumigation and insecticide application to the small farm, the above factors will in practise make this impossible in the short term.

The financial problems involved in improving storage techniques can be illustrated in an example from Mexico. During an experimental extension scheme in the state of Puebla in Mexico the mean total income of 25 farming families in the project area, including income from sale of crops, off-farm wages, other non-farm income and from livestock production was found to be $504.88 (U.S.) per year during the survey period during 1967 to 1969. [1] In Table 1 are given some estimates of the cost of materials for the construction of some fairly simple storage structures, and these costs expressed as a percentage of total family income. The estimates are based upon 1974 costs reduced by 30% to allow for inflation. [2]

It can be seen from the table that to build a cylindrical mesh silo holding 10 tons of ear maize, line it with polythene, equip it with rat-guards and fumigate it with phosphine would cost 13% of the annual family income. Alternatively, to build a small concrete silo with damp-course and treat the grain with Malathion would cost 7% of the annual family income. While it can be argued that this expenditure would be easily justified, it is easy to understand a reluctance to spend a quantity amounting to more than one months total family income. Obviously the financial problem will be even greater in truly subsistence families with virtually no capital.

TABLE 1. Estimated costs of some storage structures in Mexico (1968)

	Cost $(U.S.)	% total annual family income
1) Circular mesh silo, plastic lined (Capacity 10 tons cob maize)		
20 m² wire mesh	36	
Galvanised sheet for 4 rat-guards	14	
Polythene sheet to line	12	
(Timber and roofing materials assumed to be locally available)		
Total	62	12
2) Concrete silo (Capacity 8 tons shelled maize)		
Cement	4	
Gravel	5	
Sand	5	
Steel supports	20	
Polythene for damp-course	2	
(Roofing materials assumed to be locally available)		
Total	36	7
3) Oil drums (Capacity 145 kg shelled grain)	9	2
4) Chemicals		
Malathion 4% dilute dust, kg.	1	
Phostoxin, tube of 30 pellets	3	1

Clearly, with these obstacles to improvement on the small farm, great benefits could be brought about by the introduction of maize varieties and hybrids with improved storage properties.

The problems encountered when an unsuitable maize type is introduced can be illustrated by the situation in parts of Central Africa.

In many parts of Africa, stored products insects have been a considerable problem in rural areas and in parts of Central Africa the problem has been to a certain extent accentuated.

In Malawi, the local varieties of maize tend to have rather short ears with thick, tightly-fitting husks, and the grain is a white semi-flint. A considerable improvement in yield was made possible by the introduction of hybrids which had initially been developed in Southern Rhodesia. However, the hybrids had the

the following disadvantages:

1) Poor husk cover
2) Soft, floury kernels
3) High susceptibility to storage pests

As a result, the subsistence farming community quickly became disenchanted with the new varieties. Storage losses were very obviously increased, and the soft endosperm of the kernels was not suited to the wet pounding process traditionally used by Malawi women. Also, infestation at harvest was increased to such an extent that one farmer in the Thyolo area of Malawi told me that he decided never again to grow a new hybrid after seeing the level of field infestation on his first crop. The situation which has resulted is that the hybrids have been adopted by certain progressive farmers as a cash crop, and as such have produced excellent crops for these farmers with yields well above the local average producing cash returns as high as would have been expected from tobacco or cotton. However the hybrid crop is not usually stored on the farm, but is sold soon after harvest to the National Marketing Agency. Therefore these hybrids have had very little impact on the large proportion of Malawi agriculture which is based on the small farmer who stores almost all of his crop for family consumption.

Seed sales of improved maize for the 1973-74 season totalled 350 tons, which is sufficient to plant 1 1/2% of the total maize producing land in Malawi, and of this only 165 tons was dent hybrid seed.

It would be misleading to suggest that the lack of farmer response to improved maize was due entirely to the storage and pounding qualities of the maize. In addition, the hybrid maize requires good husbandry and heavy fertilising, and all but the larger scale farmers need credit to buy fertiliser. However it should be noted that more than half of the improved seed sold in the 1973 season was not of the dent hybrid type, and at present much interest is being shown in newly-developed composite varieties which yield very highly and have the semi-flint grain which is much better suited to local conditions.

I am indebted to Mr. A. Bolton, Maize Breeder, Chitedze Agricultural Research Station, Malawi for much of this information.

Obviously the choice of maize for release in any area depends upon many factors including genetic adaptability to local conditions, the necessary agronomic techniques, seed supply, yield, and post-harvest factors. The purpose of the work described here is to progress towards evaluating additional criteria for predicting the suitability of a particular maize type in a particular area.

During 1973 some maize varieties and hybrids were collected from the Malawi National Variety Trials. After harvest, the maize was shelled and a random sample was taken from each variety or hybrid. Two 50g. sub-samples were placed in paper bags and sent to Bvumbwe Research Station for the counting of the emergence of field infestation, while the rest of the sample was sent to the Tropical Stored Products Centre (Tropical Products Institute), England, for laboratory work. At Bvumbwe, all emerging *Sitophilus spp* and *Sitotroga spp* were counted 70 days after harvest. In England, the inherent susceptibility of the different samples to infestation was determined in the laboratory by a technique developed at the Tropical Stored Products Centre [3]. The technique is outlined briefly below.

1) Twelve female and six male adult *S. zeamais* (0-7 days from emergence) are placed on 50 g. replicates of each test population of maize and left for 7 days. This is a 'conditioning' period, during which time it is hoped that the insects will become accustomed to the new varieties.

2) All insects are moved to new 50 g replicates of the same populations of maize, and left for 7 days. Any dead insects are replaced from a 'spare' conditioning replicate.

3) All insects are removed from the trials, and the trials are left until the first F_1 insects are observed.

4) F_1 insects are removed and counted at frequent intervals (daily where possible), until the entire F_1 generation is judged to have emerged.

5) The average development period on each replicate is estimated by determining the time from the mid-point of the oviposition period to the time when 50% of the F_1 generation have emerged.

6) The susceptibility of each replicate is expressed as an 'Index of Susceptibility' given by

$$\text{Index} = \frac{\log_e(\text{Total number } F_1 \text{ adults}) \times 100}{\text{Average development period}}$$

The indices of susceptibility (means of four replicates) are given in Table II. Also given in Table II are data referring to the softness of the grain (as measured by the percentage endosperm passing a 500 sieve after a standard grinding process,) the mean emergences of field insects emerging from the Bvumbwe samples and the percentage of ears with exposed tips as recorded at harvest. In Table III are correlations which were established for these data.

The well known correlation between the softness of the grain and susceptibility is adequately demonstrated here. A significant correlation between field infestation by *Sitophilus* and the percentage of ears with exposed tips was demonstrated but no such correlation was established for *Sitotroga*.

THE SUSCEPTIBILITY OF 'OPAQUE' MAIZE OF IMPROVED PROTEIN QUALITY: A potentially very important discovery in the world of maize genetics has been the 'Opaque-2' gene. This gene, which causes an increase in the levels of the limiting amino acids tryptophan and lysine in the grain, is very easy to handle in a breeding programme, and virtually any maize population can be converted to its opaque form. The introduction of these maize types to small-scale farming areas where maize is a staple diet would dramatically improve the

TABLE II.

Variety or Hybrid	Mean Index of Suscept-ibility	% ground kernel passing 500µ sieve	Numbers of insects emerging from fields samples: *Sitophilus* spp.	*Sitotroga* spp.	% ears with bare tips
Makanga Composite A	6.76	7.58	3.25	7.00	21.5
Salina Composite A	7.58	9.04	1.75	3.75	23.0
Chitedze Composite A	7.15	7.86	1.75	4.75	17.9
Chitedze Composite B	8.32	8.21	2.00	9.75	8.3
CCA x CCB	7.91	8.09	3.25	6.00	24.0
SR52 (ex Rhodesia)	9.831	12.41	6.75	11.75	51.4
NPP x K64r (PPx K64r)	8.78	9.76	0.25	4.00	28.5
Zambia composite Z	8.98	9.40	2.00	7.25	20.6
SV 17	6.70	9.11	1.00	4.25	11.6
SV 28	7.84	9.04	0.25	3.50	25.2
SCK 1	7.22	8.58	1.25	6.50	11.7
LH 11	7.60	8.38	0.50	9.00	12.7
R 200	9.05	9.74	3.50	12.00	30.8
Ukiriguru composite A	7.70	7.82	3.00	8.25	29.6

TABLE III. Correlations

	% ground kernel passing 500 sieve	Field *Sitophilus*	Field *Sitotroga*
Index of Susceptibility	0.77 **	0.49 **	0.37
% ears with bare tips		0.73 **	0.45

nutrition of the farming community. Unfortunately there has been considerable resistance to the introduction of opaque maize due to several considerations including:

1) Consumer rejection of the abnormally soft opaque kernel type.

2) Greatly increased susceptibility to storage pests.

It should be noted that two further objections to opaque maize are often quoted: opaque maize invariably yields less than a normal counterpart due to the low density of the endosperm, and opaque maize is easily damaged during mechanical shelling and handling. However these objections do not apply to small farming situations. Opaque maize is already available which will outyield most locally available varieties and mechanical handling is seldom employed on very small farms.

In many cases the soft, starchy texture of the kernals of opaque maize combined with its very obvious susceptibility to stored-products insects will be the predominant factors affecting consumer acceptability. At CIMMYT considerable progress has been made in selecting harder-kerneled maize of high protein quality from opaque populations, and experiments have been carried out to evaluate the susceptibility of normal, opaque and these 'modified' populations to infestation by *Sitophilus zeamais* and *Sitotroga* cerealella.

Tests were carried out under 'no choice' conditions using the technique described above for *Sitophilus* and the following technique for *Sitotroga*.

1) Eggs are collected from young female moths by allowing them to oviposit in the folds of black polythene folded into a concertina shape and held by a paperclip.

2) 100 eggs are placed in each of four 50g. replicates of each of the test populations of maize.

3) Emerging insects are counted and removed as for *Sitophilus*, and the average development period is also estimated in the same way.

4) The Index of Susceptibility is given by:

$$\text{Index} = \frac{\log_e (\text{\% eggs surviving to adult stage})}{\text{Average development period}} \times 100$$

This index is identical to the parameter developed by Howe [4] to describe the suitability of an environment for insect development, except that it is multiplied by 100 for convenience.

For both species the experiments were carried out at 27°C and 70% r.h.

The Indices of Susceptibility for *S. zeamais* are given in Table IV and for *S. cerealella* in Table V. The results have been arranged in descending order of susceptibility and significant differences as given by Duncan's Multiple Range Test at the 5% level are indicated by the usual convention.

For *S. zeamais* the trend for opaque forms to be more susceptible than normal forms, with the modified types lying in between, is clear. The emergence pattern for these data is shown in Figure 1, and it can be seen that selection for the slightly modifield type of opaque maize has reduced the susceptibility of the grain.

Although such a small reduction would undoubtedly have very little real effect in the field, it should be noted that this was obtained after only two cycles of selection for modified kernels. It is hoped that further progress will result in a significant reduction in susceptibility.

For *S. cerealella*, once again all normal versions have a lower susceptibility than the opaque versions but the difference is not so great as for *S. zeamais*. No differences can be postulated between opaque and modified types. The emergence pattern is given in Figure 2.

At this stage one point should be made clear. At the

TABLE IV. Indices of susceptibility of some opaque populations and their normal counterparts (*Sitophilus zeamais*).

Population	Endosperm type *	Mean Index of Susceptibility
Yellow hard-endosperm composite	O	9.84 a
CIMMYT composite	O	9.69 ab
White composite	M	9.36 abc
White composite	O	9.01 bcd
Yellow composite	M	8.99 bcde
Composite K	O	8.87 cde
Composite K	M	8.75 cde
CIMMYT composite	M	8.58 de
CIMMYT composite	N	8.26 ef
White composite	N	7.73 fg
Yellow composite	N	7.11 gh
Composite K	N	6.35 h

* O = opaque
M = modified
N = normal

TABLE V. Indices of susceptibility of some opaque corn kernel populations and their normal counterparts (*Sitotroga cerealella*)

Population	Endosperm type *	Mean Index of susceptibility
CIMMYT composite	O	13.03 a
CIMMYT composite	M	12.98 a
Yellow hard-endosperm composite	O	12.71 ab
Yellow hard-endosperm composite	M	12.66 abc
White composite	M	12.63 abc
Composite K	M	12.60 abc
Composite K	O	12.54 bc
White composite	O	12.50 bcd
CIMMYT composite	N	12.26 cd
White composite	N	12.09 d
Yellow hard-endosperm composite	N	11.69 e
Composite K	N	11.16 f

* O = opaque
M = modified
N = normal

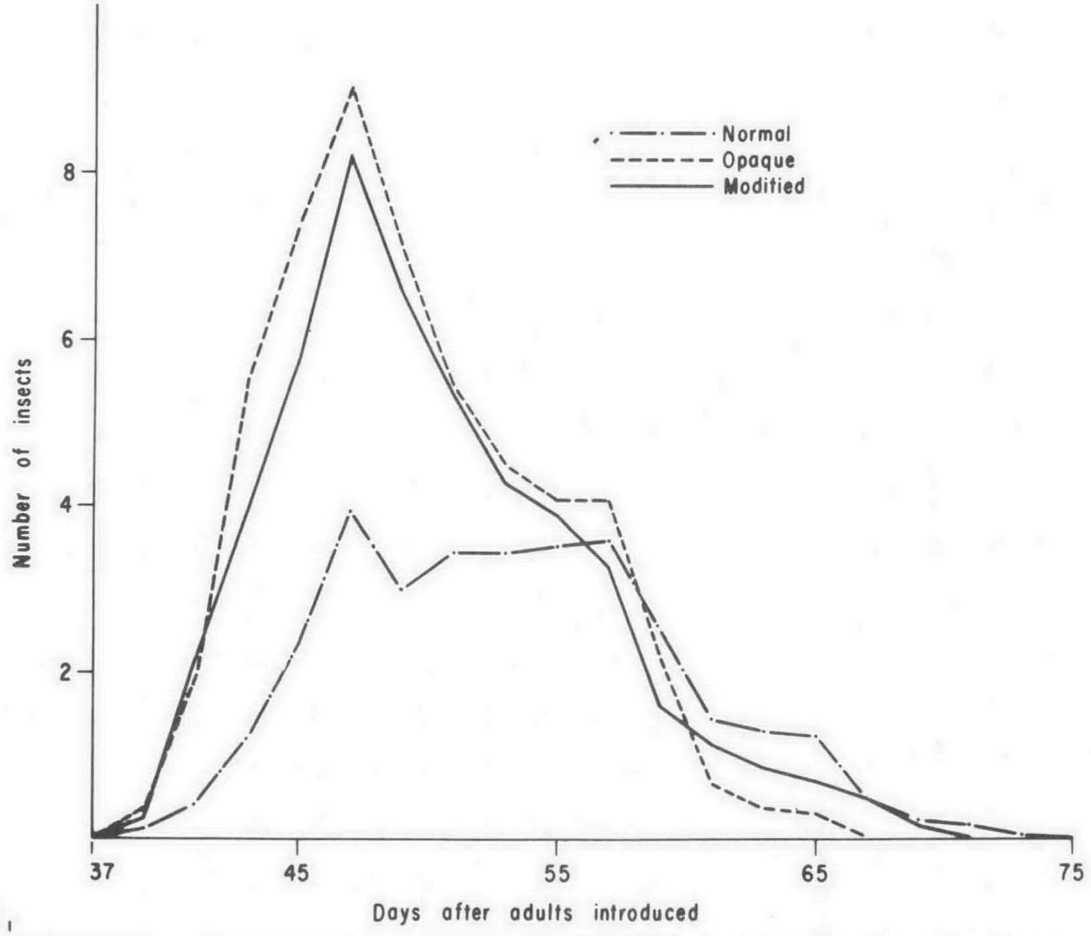

FIGURE 1. Emergence pattern of *Sitophilus zeamais* from Opaque, Normal and Modified maize

present stage of investigation we have not found any indication that the nutritional quality of opaque maize affects its susceptibility but that it is the soft nature of opaque maize which is the problem. We will return to this point later in this paper.

OVIPOSITION BY <u>SITOPHILUS ZEAMAIS</u> ON DIFFERENT TYPES OF MAIZE: 80 kernels of each of nine populations of maize were placed individually in cells in a plastic grid along with 10-15 glass balls of a diameter of about 6 mm. One female *S. zeamais* (of unselected age) was placed in the cell with each kernel and left for 24 hours. The kernels were then stained using acid fuchsin [5] and the numbers of egg-plugs in each kernel were counted.

The results are given in Table VI along with the expected number of kernels if the eggs are laid at random in the kernel. In all cases the actual distribution differs from the Poisson distribution, and the interpretation of these results is either that the capacity to lay eggs was not randomly distributed throughout the sample of female *S. zeamais*, or that the insects had a greater tendency to lay eggs in some kernels than in others. These results confirm some data, obtained previously [6] when similar distributions were found when *S. zeamais* were allowed to oviposit in culture. In culture, assuming movement of the adults, all grains should have an equal chance of receiving any egg, and so the results

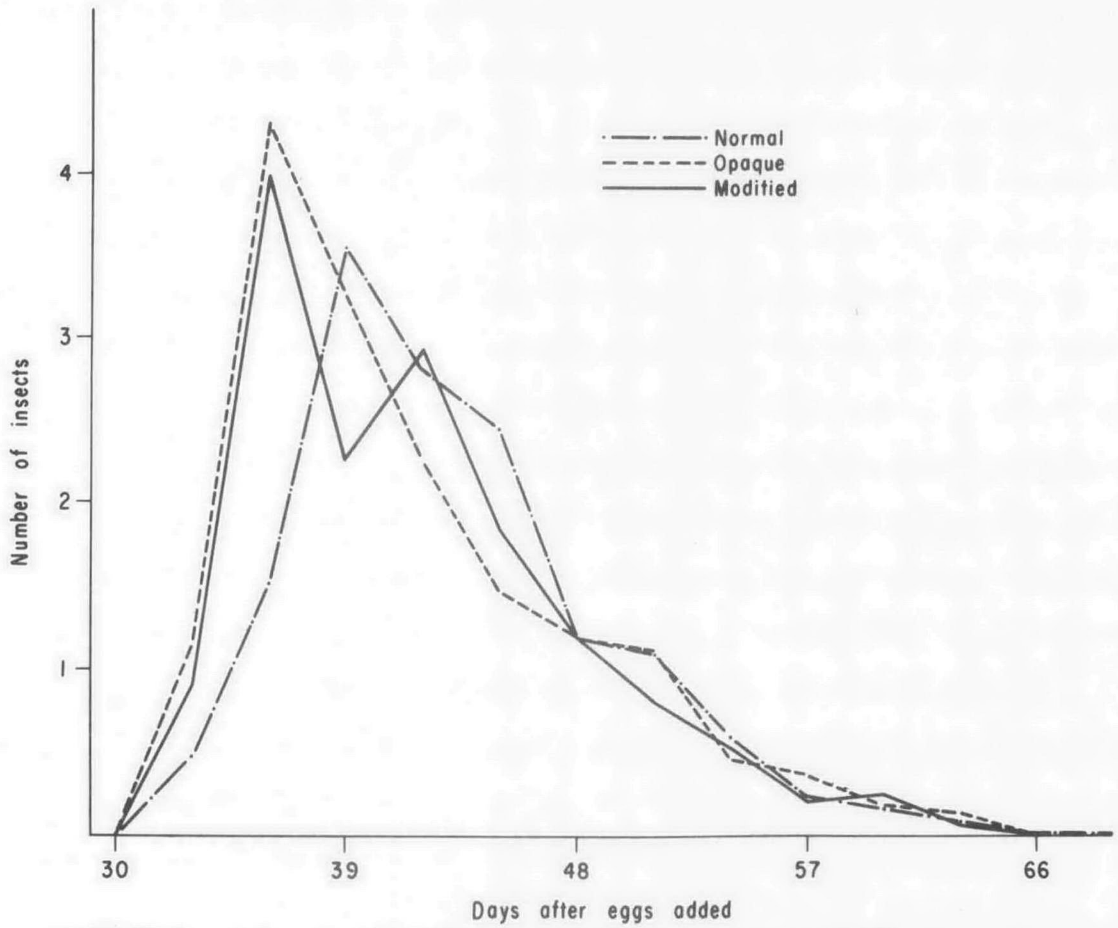

FIGURE 2. Emergence pattern of *Sitotroga cerealella* from Opaque, Normal and Modified maize

TABLE VI. Oviposition on different types of maize

Population	*	0	1	2	3	4	5	> 5
1	O	44	9	6	9	4	2	0
	E	24	28	16	6	2	0	
2	O	49	10	2	4	7	3	1
	E	15	24	20	11	5	2	1
3	O	53	5	10	4	2	0	0
	E	40	25	8	0	0	0	0
4	O	48	9	6	6	3	2	1
	E	30	28	13	4	1	0	0
5	O	54	10	6	4	2	0	0
	E	19	26	18	9	3	1	0
6	O	48	9	7	2	4	2	2
	E	28	27	13	4	1	0	0

*Observed frequency; *Poisson expectation obtained can only be explained by immobility of the ovipositing females in culture or by the tendency of the insects to avoid certain kernels. The two sets of data together suggest that certain kernels are avoided. If this is the case, then the 'avoided' kernels could very well be a source of resistance to weevil infestation if the factor causing rejection of the kernel is easily transferable to other maize.

At CIMMYT, a preliminary attempt is being made to select these kernels over several maize generations in order to investigate the possibility of increasing resistance to attack by *S. zeamais* during storage.

IMPORTANCE OF THE PERICARP/TESTA LAYER: One hundred twenty kernels of two populations of maize were soaked in water until they were soft, and the pericarp/testa layer was removed from each one using a scalpel. The kernels were then dried and placed as three 40 kernel replicates in plastic boxes measuring 4 x 4 x 1.5cm.

For each replicate a control replicate was set up using 40 intact kernels of the same population.

Into each box were placed 6 female and 3 male *S. zeamais* (all between 14 and 21 days from emergence,) and these were left to lay eggs for one week. The insects were then removed, and later emerging F_1 insects were removed and counted daily.

The total numbers of emerging insects are given in Table VII. Considerably more insects emerged from the grain without the pericarp/testa layer.

TABLE VII. Effects of pericarp/testa layer.

	with pericarp/testa						without pericarp/testa					
REP.	1	2	3	4	5	6	1	2	3	4	5	6
Number of adults produced	26	22	20	23	48	15	73	69	56	82	78	74
Average development period (days)	37	36	40	37	40	40	38	37	38	37	35	35

These data show that the pericarp/testa layer provides a very significant barrier to oviposition. Schoonhoven [7] has shown that damaging the pericarp/testa with sand-paper also increases the susceptibility of maize. Although this shows that there are non-endosperm characteristics which could affect the susceptibility of maize, by affecting oviposition, it should be noted that we have not yet been able to demonstrate any case where differences in oviposition between maize types have affected susceptibility. However, the evidence of the importance of the pericarp/testa layer in susceptibility combined with the evidence given in the previous section of non-random oviposition among kernels suggest that an attempt to select maize which reduces the potential for *S. zeamais* to lay eggs may be profitable.

FACTORS AFFECTING SUSCEPTIBILITY: The relative susceptibilities of 17 populations, of normal, opaque and modified maize to infestation by both *S. zeamais* and *S. cerealella* were assessed. As not all of the determinations were carried out at the same time it was necessary to include a common control variety in all experiments. The control variety was Caccahuacintle, a soft high altitude Mexican variety, and all results are expressed as a Relative Index of Susceptibility given by-:

$$\frac{\text{Index of susceptibility of tested variety}}{\text{Index of susceptibility of control variety measured during the same experiment}}$$

In an attempt to discover which factors are responsible for the differences in susceptibility of these populations, the following physical and chemical factors were measured.

1) Percentage endosperm passing a sieve after a standard grinding process. (This is a measure of the softness of the kernels).

2) The weight in grams of a 2 litre volume of each population, corrected for moisture content and expressed as dry weight.

3) The percentage of kernels completely free of glumes.

4) The average weight in grains per kernel.

5) Total protein content of the grain.

6) The tryptophan content of the grain.

7) The 70% r.h. equilibrium moisture content of the grain.

The results of these determinations are given in Table VIII.

A preliminary simple regression matrix was prepared for the data, (Table IX) and scatter diagrams of the relationships between each variable and the Relative Indices of Susceptibility to *S. zeamais* and *S. cerealella* were drawn. As a result the following conclusions were made.

1) The percentage of kernels without glumes and the mean weight of the kernels cannot be shown to have any relationship upon susceptibility.

2) The percentage endosperm passing a sieve after grinding is linearly related to the weight of a 2 litre volume of maize, so that only the latter factor needs to be used to measure grain softness.

3) The percentage of tryptophan in the grain is negatively and linearly correlated with susceptibility to both insects, but also is correlated linearly with the 2 litre weight. Therefore any increase in susceptibility associated with an increase in tryptophan can be explained in terms of grain softness.

4) Susceptibility to both insects is negatively and linearly associated with total protein content.

The two most interesting variables can be fitted to the

TABLE VIII. Factors potentially affecting susceptibility.

	1	2	3	4	5	6	7	8	9
	% endosperm passing 500μ sieve after grinding	weight of 2 litres of maize	Total protein	% tryptophan in whole kernel	% kernels without glumes	Mean weight per kernel	70% equilibrium moisture content	Relative index of susceptibility	
Population		(g)	(%)			(g)		Sitophilus	Sitotroga
1	20.67	1384	11.25	0.044	40	0.2564	13.24	0.515	0.925
2	36.01	1180	11.00	0.094	38	0.2625	12.71	0.809	1.040
3	23.72	1277	10.63	0.084	36	0.2227	13.19	0.805	1.045
4	22.23	1377	10.88	0.039	32	0.3049	13.67	0.653	0.969
5	33.46	1214	10.63	0.092	32	0.2597	12.82	0.858	1.054
6	24.51		10.69	0.083	34	0.2398	13.78	0.819	1.050
7	20.57	1341	10.88	0.068	40	0.2703	13.35	0.707	1.003
8	28.91	1222	10.63	0.093	20	0.2762	12.98	0.821	1.037
9	26.08		10.63	0.080	46	0.2618	13.19	0.853	1.047
10	22.05	1361	10.19	0.048	14	0.2849	13.62	0.753	1.017
11	41.29	1156	9.50	0.101	34	0.2545	12.87	0.883	1.080
12	27.99	1279	10.31	0.090	28	0.2653	13.30	0.781	1.076
13	36.01	1180	11.00	0.094	38	0.2625	12.71	0.784	1.034
14	20.57	1341	10.88	0.068	40	0.2703	13.35	0.781	0.947
15	24.79	1389	10.75	0.054	22	0.2938	13.78	0.807	1.032
16	34.99	1218	10.88	0.095	42	0.2670	12.87	0.867	1.032
17	27.39		10.69	0.080	60	0.2349	13.45	0.870	1.017
18	35.38	1211	9.88	0.101	36	0.2591	12.82	0.870	1.056
19	26.41	1319	9.63	0.078	36	0.2298	13.46	0.852	1.069

TABLE IX. Correlation Matrix

	1	2	3	4	5	6	7	8	9
1	1.000								
2	0.924	1.000							
3	0.508	0.402	1.000						
4	0.822	0.917	0.326	1.000					
5	0.171	0.232	0.024	0.251	1.000				
6	0.214	0.356	0.188	0.495	0.454	1.000			
7	0.811	0.925	0.197	0.835	0.425	0.399	1.000		
8	0.663	0.658	0.363	0.768	0.089	0.276	0.415	1.000	
9	0.096	0.080	0.138	0.065	0.389	0.209	0.082	0.036	1.000

The factor numbers above are as inciated in Table VIII.

following equations using multiple regression techniques.

Relative index of susceptibility to *S. zeamais* $= 2.4374 - 0.0006X_1 - 0.0794\ X_2$

Relative index of susceptibility to *S. cereallea* $= 1.8730 - 0.0003X_1 - 0.0471\ X_2$

Where X_1 = weight of 2 litres of maize
and X_2 = total protein content.
The coefficients have the following t -values:

(*S. zeamais*) $b_1 : t = 3.07$
$b_2 : t = 2.42$

(*S. cerealella*) $b_1 : t = 3.04$
$b_2 : t = 3.32$

The apparent relationship of susceptibility to protein content may, of course, really indicate a relationship with some other factor that is in turn associated with protein. Further work is continuing to clarify this situation.

DICUSSION: The problems of storing crops on small scale farms in tropical areas are frequently treated with a considerable degree of complacency. Very few reliable assessments of the quantities of food lost under these circumstances have been published, and perhaps this is one of the main reasons why many administrators of farming research show little interest after the crop has been harvested. It is the purpose of this contribution to suggest that the problem of insect attack of stored grain can be tackled by intelligent selection of the type of maize to be stored as well as by improving storage conditions on the farm.

The feasability of selecting maize which is resistant to storage insects should be investigated more fully, and if possible factors other than hardness of the endosperm should be selected so that resistant soft material will be available for the areas where soft maize is popular. If, however, characteristics of the pericarp/testa layer can be exploited to increase resistance, then this may be a difficult factor to handle in a breeding programme. The pericarp/testa layer is derived from cytoplasmic maternal tissue, and so it is not heritable from the seed.

The value of the husk covering the ear is clearly great. Giles and Ashman [8] have shown the value in reducing the level of infestation at harvest, and also showed that a lower level of infestation at harvest considerably reduced the subsequent degree of infestation in the store. Improvement of husk qualities are usually possible by selection within a population, and with improvement of the husk greater protection against damage by birds and late ear rots could be expected.

The negative correlation between susceptibility and protein content will be the subject of further research. Obviously a higher protein content is beneficial to human nutrition, and is therefore of great interest if a high protein reduces susceptibility to insects. Protein quality appears to be completely independent of kernel hardness.

While protein content appears to affect susceptibility, protein quality, as expressed by the quantity of tryptophan present is inextricably associated with kernel hardness. At present there is no evidence to suggest that high quality maize is nutritionally superior for infesting insects. Progress in breaking the linkage between protein quality and softness will probably result in a reduction in susceptibility to infesting insects.

REFERENCES:

[1] Anon. The Puebla Project 1967-69. Report of Centro Internacional de Mejoramiento de Maíz y Trigo, México.

[2] Anon. Indicadores Económicos. Banco de México, S. A., 2 4 (March 1974).

[3] Dobie, P. Laboratory assessment of the inherent susceptibilities of 25 varieties of Malawi maize to Post-harvest infestation by *Sitophilus zeamais* Motsch. Report L33 of the Tropical Products Institute, London (March 1973).

[4] Howe, R. W., A parameter for expressing the suitability of an environment for insect development. J. stored Prod. Res. 7 (1971) 63-65.

[5] Frankenfeld, J. C., Staining method of detecting hidden weevil infestation in grains. U. S. Patent No. 2,525,789 (1950).

[6] Dobie, P., The laboratory assessment of the inherent susceptibility of maize varieties to Post-harvest infestation by *Sitophilus zeamais* Motsch. (Coleoptera, Curculionidae) J. stored Prod. Res. (Currently in press).

[7] Schoonhoven, A. V., E. Horber, R. B. Mills, and C. E. Wassom, Resistance in corn kernels to the maize weevil. Proc. NCB Entomological Society of America (1972).

[8] Giles, P. H., and Ashman, F.A., A study of pre-harvest infestation of maize by *Sitophilus zeamais* Motsch. (Coleoptera, Curculionidae) in the Kenya highlands. J. stored Prod. Res. 7 (1971) 69-83.