INVESTIGATING THE SUSCEPTIBILITY OF SOME NEWLY INTRODUCED GHANAIAN MAIZE VARIETIES TO INFESTATION BY *SITOPHILUS ZEAMAIS* MOTSCHULSKY (COLEOPTERA, CURCULIONIDAE)

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ABSTRACT

Grains of 10 varieties of maize including 3 local varieties were analysed in the laboratory for their susceptibility to infestation by the maize weevil, Sitophilus zeamais during storage. Kawanzie was the least susceptible and Pool 16SR the most susceptible to infestation by the insect. Grains of Pool 16EV85, Gandajika 8149 and Dobidi did not differ significantly (at $P = 0.05$) from Kawanzie in susceptibility to infestation by S. zeamais. However the three local varieties namely Ho Local Two, Ho Local One and Pokoase Local were more susceptible to infestation than Kawanzie. Significant differences in susceptibility were not observed (at $P = 0.05$) between Pool 16SR, the three local varieties, Composite 4, Aburotia CRI and Dobidi.

Fat, carbohydrate, phosphorus, iron, ash, calcium or protein contents of the grains of the different varieties studied had no significant correlation (at $P = 0.05$) with susceptibility to insect infestation.

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I. INTRODUCTION

1.1 Importance of maize in the agricultural economy of Ghana

Maize (Zea mays L.) is a staple food for more than 40 percent of the population of Ghaa (Prempeh, 1971). As a food crop used by almost all the ethnic groups for various products, it contributes to the carbohydrate and protein base of food of its consumers. In 1962, the National Food and Nutrition Survey found that it provided between 90 to 95 per cent of the total calories in the diet of the people on the coastal plains.

The crop is a source of income to a large proportion of the farming population. The amount of land used for its cultivation in each farming season is greater than any food crop. Total production of maize in 1985 was 411,000 metric tonnes bringing its percentage self-sufficiency level to 79.5 as against 56 per cent for rice, another important staple. (Min. of Agric., 1986). Ninety to ninety-five per cent of the annual output is used for human consumption and five to ten per cent for poultry and livestock (Quartey, 1980).

1.2 Introduction of high-yielding maize varieties

Since the 1970 population census, the population of the country recorded an annual growth rate of 2.6 per cent, resulting in the provisional figure of 12.2 million in 1984. To increase the production of maize to feed this ever increasing population, measures including improved husbandry methods and the introduction of high-yielding varieties have been adopted.

These high-yielding varieties generally display advantageous pre-harvest agronomic characteristic much better than local varieties. Some of these characteristics include reduced growth periods, resistance to the maize streak virus and other pathogens, ability to withstand high population per unit area without lodging, uniform cob height and size, favourable plant height etc., Unfortunately, other characteristics such as tightness of husk and tip length make them more susceptible to insect infestation in the field and in store than low-yielding local varieties.

1.3 The factors that influence the susceptibility of maize to *S. zeamais* attack

Basically, two factors are known to influence the susceptibility of maize to *S. zeamais* attack. These are (a) the susceptibility of the cobs to field infestation and (b) the inherent susceptibility of the maize grains (Wheatley, 1971).

With the traditional or local maize varieties, field infestation is generally low due to complete husk cover. As a result, *S. zeamais* numbers carried into storage from the field are low. With the improved varieties, the incomplete husk cover naturally permits the insect direct access to the grain for infestation. Apart from the initial field infestation the build-up of infestation depends among other factors, on how hard or soft the maize grain is. The improved varieties have harder grains and are likely to store better than their local counterparts if field infestation could be totally eliminated. However, due to their poor husk cover, field infestation is very high and even with their hard grains, population build-up of *S. zeamais* is higher in stores in relatively shorter storage periods.

1.4 Effect of the Cultivation of these improved high-yielding varieties on Ghanaian Farmers

Most small-scale farmers in several West and Central African countries are becoming discouraged in the cultivation of these high-yielding varieties because of the high losses incurred due to *S. zeamais* during storage. This is also true of most Ghanaian small-scale farmers who produce over 70 per cent of the country's maize requirements.

1.5 Objectives

As some of the high-yielding varieties are already being cultivated or more are about to be introduced for cultivation, there is the need to look at to what extent the grains of these varieties are susceptible to attack by *S. zeamais* in storage. This study was therefore undertaken with the following objectives:-

(a) to evaluate and screen the grains of some newly introduced high-yielding or improved Ghanaian maize varieties against some local varieties, for the grains' natural resistance to the main storage pest, S. zeamais and

(b) to determine some inherent factors within the grains of these varieties which could be linked to their extent of susceptibility to S. zeamais attack.

2. REVIEW OF LITERATURE

2.1 Factors that influence the field infestation of maize by S. zeamais

The husk of the maize cob is important in the prevention of field infestation by S. zeamais. Schulten (1976) reported that field infestation declined as the extension of husks over the maize ear tip increased. Infestation also decreased when the tightness of the husks around the ears increased. Other factors involved in the prevention of field infestation are the number of husks (Eden, 1952) damage to the silk and sheaths by caterpillars, (Floyd et al, 1958; Starks et al, 1966) and damage to sheaths by birds. Giles and Ashman (1971) demonstrated in Kenya that ears with open or loose sheaths were more highly infested in the field than those with tight-fitting sheaths. Studies carried out in Mexico (Dobie, 1977) and Nigeria (IITA, 1985) indicated a close link between high weevil damage and poor husk cover (Table 1).

TABLE I

Damage to various maize varieties by Sitophilus spp.

Maize Varieties	Grain colour & Texture *	Weevil Damage **	Seed Germination ***	Husk cover Rating ****
8329 - 15	Y/FD	1.0	95	1.0
8425 - 10	Y/F	1.0	95	1.4
8425 - 9	Y/FD	1.3	70	1.2
Sekou 81 TZSR-W-1	W/FD	1.8	96	2.0
8321 - 18	W/FD	2.0	78	1.5
8322 - 13	Y/FD	2.0	81	1.8
IK 81 TZSR-Y-1	Y/DF	2.5	73	2.0
EV 8428 - SR	W/D	7.0	46	2.5
Western Yellow	Y/D	7.5	35	2.0
EV 8443 - SR	W/D	8.0	16	2.5
8338 - 1	W/DF	8.7	8	3.5

* W = white, Y = Yellow, D = Dent, F = Flint

** Mean of three samples taken after five months in 1 = 10 per cent, 10 = 91 - 100 per cent

*** Mean of three samples taken after four months in storage

**** 1 - tight, 5 = loose

Source: IITA Annual Report and Research Highlights 1986.
Weevil Damage : A comparison of different maize varieties pp. 77-78

In a review report by Adams (1977) of work carried out in Malawi and Kenya, weight losses caused by insect infestation in local varieties of maize was 1 - 2 per cent compared with losses in improved varieties of 5 per cent and hybrid varieties, 10 per cent. The reason for the low level of losses due to insect attack in local maize varieties was that the sheath covering the grain offered good protection against field infestation by storage insects. In comparison, the most commonly used hybrid SR 52 was highly susceptible to insect attack and because the sheaths did not completely cover the grains on the cob.

2.2 Factors that influence susceptibility to infestation in store

As mentioned, the extent of _S. zeamais_ infestation in store is influenced by the initial field infestation, and grain characteristics such as seed coat (Hall, 1975) endosper hardness (Singh and McCain, 1963, Dobie, 1974, 1977), damaged kernels (Dobie, 1977) nutritional factors (Munro, 1966). These factors are closely linked and are difficult to separate.

2.2.1 Seed-coat of grain

Schulten (1976) quoting some workers showed that the seed coat of maize may be sufficiently tough and thick in some varieties to inhibit penetration for oviposition by _S. zeamais_ Hall (1975) adds that the hardness, brittleness and resistance to splitting of the seed coat are also factors affecting susceptibility. High tannin content in the seed coat of some maize varieties has been reported to be very unattractive to insects.

2.2.2 Endosperm Hardness

It has been shown that hard flinty maize varieties are relatively more resistant to attack than soft floury varieties (Singh and McCain, 1963; Dobie, 1974). The incorporation of the opaque-2-gene in maize varieties to increase the lysine and tryptophan content of the grain renders the endosperm abnormally soft resulting in grain with a higher susceptibility to _S. zeamais_ (Gupta et al, 1970). However, if opaque varieties are selected for hard flinty kernels without changing their good nutritional characteristics, then their resistance to pests is significantly improved (Dobie, 1977).

2.2.3 Damaged Kernels

According to Dobie (1977) the same number of eggs were likely to be laid in resistant and susceptible varieties if the kernel is damaged. More eggs tend to be laid by females isolated with kernels which were damaged than with undamaged kernels even though the eggs were not necessarily laid in the damaged part of the grain. Dobie (1977) postulated that the ease with which the adult can feed may determine the rate of oviposition, and not the ability of a female to penetrate the kernel in order to lay eggs. Quoting Schoonhoven et al (1976), he further postulated that, it is possible damaged kernels release an oviposition stimulant and that adding maize flour or dough to undamaged kernels increased the rate of infestation.

2.2.4 Nutritional factors

Generally, the nutritional requirements of the stored product pests is essentially the same for man. For example, the proteins or amino acids serve in body building, the carbohydrate supply energy, and the sterols and vitamins especially those of the B-group are essential (Munro, 1966). Therefore any crop variety which is highly deficient for insect nutrition would probably be unsuitable food for man. However, some varietal differences in nutrient levels affecting stored-product insects may have practical relevance for control eg. sugar content (Singh and McCain 1963) amylose content (Peters et al 1960, 1972; Rhine and Staples, 1968), protein content (Gupta et al, 1970).

2.3 Reported Susceptibility of grains of some varieties to Infestation by S. zeamais

Earlier reports of work in Ghana concerned how the husk cover of the different maize varieties affected their susceptibility to S. zeamais attack in storage. (Rawnsley 1969; Nyanteng 1972) No assessment of the grains of the different maize varieties were carried out until Ofosu (1976) studied grains of 10 maize varieties including a local variety for their susceptibility to S. zeamais infestation under laboratory conditions. He found out that Diacal H253 was the least susceptible and the local variety Kwadaso local, the most susceptible. The varieties, Diacol 153, Composite 2O4, Mexican 17C4 and GS1 did not differ significantly (at P = 0.05) from Diacol H253. Composite 3C4, Mexican 17C1, GS2 and Composite 1C4 did not also differ significantly (at P = 0.05) from the local variety. Most of the varieties he studied were in the process of development.

Ofosu (1977) again analysed under laboratory conditions, grains of maize varieties including a local variety Kwadaso local and 4 new varieties (Composite 2, Golden Crystal, La Posta, and Mexican 17) that have been released to farmers for planting. La Posta was found to be the least susceptible to infestation by *Sitophilus zeamais* while Composite W was the most susceptible. The susceptibilities of Mexican 17, Golden Crystal and Kwadaso Local did not differ significantly (at P = 0.05)from that of La Posta. There was however a significant difference (at P = 0.05) between the susceptibilities of composite 2 and La Posta although no such difference was found between Mexican 17, Golden Crystal, Kwadaso Local and Composite 2.

Research workers in Nigeria's IITA (1985) studying 11 newly developed maize varieties indicated that a yellow flint-dent hybrid (8329 - 15) suffered less than 10 per cent kernel damage compared with 70 per cent for a locally grown variety (Western Yellow). Among the white maize hybrids 8321n - 18 ranked the best with less than 20 per cent damage compared with 80 per cent for 8338 - 1 a dent-flint variety. The results are summarised in Table 1.

2.4 Biology of *S. zeamais*

S. zeamais Motschulsky belongs to the order Curculionidae within the large family of Coleoptera. It is the most important primary pest of stored maize in Ghana (Rawnsley, 1969). The infested maize stores are the principal sources of infestation of the standing crop in the field and of the stored maize. *S. zeamais* flies readily and can cover distances of 400 to 800 metres (Schulten,1976). The threshold temperatures for flight activity is between 20 and 21°C (Taylor, 1971). Slightly exposed ears induce flight activity to and within the crop.

The adult insect, normally between 3.5 to 4.0 mm long can live between 5 - 12 months under favourable conditions. The female is capable of laying 300 - 500 eggs within this period and 50% may be laid in the first 4 - 5 weeks. The white oval eggs are individually deposited by the long ovipositor of the female in small cavities chewed into cereal grains. As the ovipositor is withdrawn, glands associated with it secrete a gelatinous material that fills the remainder of the oviposition cavity not occupied by the egg. Eggs are laid at temperatures of between 15°C and 35°C with an optimum around 25°C. (Anon, 1984).

The egg hatches into a white legless larva which begins to feed inside the grains excavating a tunnel mostly within the endosperm and this is responsible for the grain damage. There are 4 larval instars prior to pupation.

Pupation is most favourable at 25°C and 70% R.H. It normally takes 25 days although may be extremely protracted at low temperatures (eg. 98 days at 18°C and 70% R.H.)

The newly developed adult remains inside the kernel for a few days before chewing an escape hole through the seed-coat In different maize varieties, total development periods of S. zeamais have been shown to vary from 31 to 37 days under optimal conditions at 27°C and 70% R.H. (Anon, 1984). The size of the adult at emergence depends on the size of the grain kernel it emerged from. For example, in small grains like millet, or sorghum, the size will be small but in maize which is its preferred food, it will attain its maximum size (Christeinsein, 1974).

2.4.1. Recognition and Identification of S. zeamais

S. zeamais closely resembles S. oryzae (the rice weevil) and are almost indistinguishable from each other externally. Both have a characteristic rostrum and elbowed antennae which are often carried in an extended position when the insect is walking. Both species may have 4 reddish orange circular markings on the elytra.

Until a few years ago, *S. zeamais* and *S. oryzae* were thought to be a single species known as the rice weevil. Males of both species may be recognized by their shorter and thicker snouts which are also somewhat straighter than those of females. The lateral and dorsal surface of the male snout is covered by irregular pits, producing a rough appearance. The pits on the female snout are avoided, regularly spaced, and the surface between the pits is smooth with a shiny appearance. (Anon, 1984).

It is now possible to distinguish between *S. zeamais* and *S. oryzae* using their genitalia after dissection. (Halstead, 1964, Proctor, 1971). In males of *S. oryzae* the surface of the aedaegus is completely smooth. In females, the "prongs" of the Y-shaped sclerite are rounded and the gap between them is narrower than their combined width. But in *S. zeamais*, the aedaegus of the males has a central ridge between two depressions. In the females, the "prongs" of the Y-shaped sclerite are pointed at the end and the gap between them is wider than their combined width.

Arrangements or patterns made by the pronotal pits on the prothorax can also be used to differentiate between the two species. With *S. zeamais* the pits are roundish in shape and cover the entire surface of the prothorax. In the case of *S. oryzae*, they are slightly oblong and leave an unpunctuated median zone. Counted in a straight line from the front to the rear side, their number exceeds 20 for *S. zeamais* and is less than 20 for *S. oryzae* (Fisher, 1987).

There may also be considerable variation in the biology and behaviour of these species living in different geographical areas. (Christensein, 1977).

2.5 Factors that affect the rate of increase of a pest such as *S. zeamais*

A lot of factors influence the rate of increase of a pest population. One of these is the food upon which the pest is feeding. In many crops, some varieties are less suitable than others for insect development. Such varieties are described as being resistant or less suitable to insect attack. The factors that influence the population increase of insect pests on a food crop according to Dobie (1984) may be due to:-

(a) a high rate of egg-laying,
(b) rapid growth rate and development, and
(c) a low death rate (i.e. few insects dying before they reach sexual maturity and produce progeny.

To reduce the rate of population increase, a resistant variety should:-

(a) cause a reduction in the rate of egg-laying and/or
(b) extend the development period and/or
(c) cause high mortality of the developing insects:-

The rate of egg-laying can be reduced by:-

(i) varieties that have mechanical barriers that present access of insects to the material upon which they feed, thus reducing the number of eggs laid and the insects productivity.
(ii) Varieties that repel the insects or that are unattractive to them.
(iii) Varieties that are for some reason unsuitable for oviposition (eg. too hard for species that chew holes in which to lay eggs).

The development period can be extended by:-

(i) hard-textur . varieties that are difficult to ingest or digest.
(ii) varieties that are partially toxic to the insect pests
(iii) varieties that are nutritionally inadequate for the development of the pest.

The death rate can be increased by:-

(i) varieties that cannot be penetrated by the larvae which hatch from the eggs, so that the larvae are unable to feed.
(ii) varieties that are nutritionally inadequate for or toxic to the feeding insects.

Generally, the numbers of eggs laid, the potential for these eggs to develop into adults, and the time taken to complete development may all differ on samples of different maize varieties.

3. MATERIALS AND METHODS

3.1 The maize varieties

The maize varieties studied are shown in Table 2 with their characteristics. They were labelled V_1 , V_2 up to V_{10}.

TABLE 2

Characteristics of the maize varieties studied in
Susceptibility tests to *S. zeamais*

Variety	Alternative name	Country of origin	Precise Location where grown *	Variety or Hybrid **	Current status ***	Ecological zones where grown ****	Plant Height	Days to 50% silking	Days of Maturity	Grain Description *****	Type of Farming variety used for ******
V_1 Ho Local one	Nil	Ghana	Ho(Volta Reg.)	Nil	T.V	G.S	200-210cm	58	100	W/F Floury	S
V_2 Pokuase local	Nil	Ghana	Pokuase(G. Accra Reg.)	Nil	T.V.	G.S	200-205cm	60	120	W/D Floury	S
V_3 Pool 16 EV 85	Nil	Nigeria Pooled from many Countries	F and T	OPV	TV,BM,N.C.A	ALL	165-170cm	47-49	95	W/D	Neither S or C
V_4 Composite 4	Nil	Ghana	Throughout but mainly F and T	OPV	TV,BM,N.C.A	All	210-220cm	60	120 +	W/D	S
V_5 Gandajika 8147	Nil	Mexico	Throughout but mainly F and T	OPV	T.V,BM, N.C.A	All	165-170cm	51-53cm	105	W/D	Neither S or C
V_6 Pool 16 SR	Nil	Nigeria Pooled from Many Countries	F and T	OPV(streak resistant)	T.V,BM N.C.A.	All	160-165cm	45-47	95	W/D	Neither S or C but for Research
V_7 Kawanzie	Nil	Ghana	F and T	OPV	IV,BM,CA	All	160-165cm	45-47	95	Y/F	S but mainly for livestock
V_8 Ho local two	Nil	Ghana	Ho,Peki(Volta Reg,)	NIL	T.V	G.S.	200-210cm	58	120	W/FD Floury	S
V_9 Dobidi	Ejura (1) 7843	Ghana Mexico	F and T	OPV	IV, BM	All	200-210cm	55-58	120	W/D	S and C with improved techniques
V_{10} Aburotia CRI	Tuxpeno P.B. C16	Mexico	F and T	OPV	IV, BM	All	150-155cm	51-53	105	W/D	S and C with improved techniques

* F = forest zone of Ghana, T = Transition zone of Ghana.
**OPV = Open - pollinated Variety
*** TV = Traditional Variety, BM = Breeding Material
NCA = Not Commercially Available, CA = Commercially Available
**** GS = Guinea Savanna
***** W = White, D = Dent, Y = Yellow, F = flint
****** S = Subsistence, C = Commercial farming
farming.

These varieties were made up of seven improved or high-yielding ones; - Pool 16 EV 85, Composite 4, Gandajika, Pool 16 SR, Kawanzie, Dobidi and Aburotia CRI and three local varieties :- Ho Local One, Ho Local Two and Pokaase Local. These were collected from the maize warehouse of the Grains Development Project, Crops Research Institute, Kumasi.

Upon receipt of the maize varieties, "Phostoxin" was used to fumigate them in a large PVC storage tank. The pellet of "Phostoxin" was placed in a paper envelope in order to prevent breakdown residues from contaminating the maize. All varieties were later removed from the storage tank and placed in an oven at 50°C for 7 days (Nwana and Akibo-Betts, 1982) to disinfest any mites that would not have died after fumigation. Mites are known to parasitise on eggs of S. zeamais and their parasitic effect could decrease the number of S. zeamais adults emerging from the maize varieties. This would affect results in the determination of Susceptibility Index.

3.2 Adjustment of grain moisture content to 13.0%

Seven days before the experiment to determine the Susceptibility Index, the moisture contents of the grains of all the varieties were adjusted to 13.0% by addition of water since moisture content is known to affect fecundity of S. zeamais (Schulten, 1976). The volume of water required to adjust to the final moisture content of 13.0% was added while gently shaking the maize container. The volume of water was calculated for the formula:-

$$\text{Wt. of water to be added in grains} = \frac{\text{Wt. of grain x required \% m.c. - initial \% m.c}}{\text{100 - required \% m.c.}}$$

(Boxall, 1986)

where m.c = moisture content

since 1g of water occupies approximately 1cm^3, the volume of water was measured from the corresponding weight calculated.

3.3 Culturing of S. zeamais

A 500cm^3 Kilner jar containing 100g of a Susceptible maize variety (Golden Crystal) was set up. The maize was previously fumigated with "Phostoxin" and sterilized at 50°C for 7 days.

Sitophilus spp. was collected from an infested maize bag obtained from the Infestation Control Laboratory of the Ghana Cocoa Marketing Board, Tema. A male and a female were identified using characters described by Anon (1984) and the pair was placed on the maize sample in the Kilner jar to breed. Seven days later, the pair was removed and new adults emerged after 25 days. Four males and 8 females of the emerged insects were removed, dissected and identified as Sitophilus zeamais by characters described by Halstead (1964). The remaining emergedinsects were used to set up new cultures to be used for the Susceptibility experiments.

3.4 Determination of Susceptibility Index

The Susceptibility Index was determined in the laboratory from August 1987 to June 1988. Laboratory temperatures were 26°C (minimum) and 30°C (maximum). Relative humidities averaged between 75% at 0900 hours and 70% at 1500 hours.

Within this period, three trials were conducted and for each trial, each variety was replicated six times.

The method described by Dobie (1974) was used. In this method, the number of F_1 generation of S. zeamais emegging from 50g maize variety, the development period of S. zeamais in grains of each variety were combined into a single parameter known as the Susceptibility Index.

$$\text{ie. Susceptibility Index} = \log_e \frac{(\text{No. of } F_1 \text{ adults}) \times 100}{\text{Development period}}$$

The Development Period was calculated from the middle of the oviposition period to the time of the emergence of 50% of the F_2 generation. The greater the Susceptibility Index, the higher a variety is susceptible to infestation by S. zeamais.

3.6 Proximate analyses of maize varieties

Proximate analyses of the maize varieties were carried out. This was done in order to find out if there was any correlation between the Susceptibility Indices and protein, carbohydrate, fat, ash, phosphorus, iron and calcium contents of the grains. As moisture content of the varieties was uniform, it could not be responsible for any differences in susceptibilities.

4. RESULTS AND DISCUSSIONS

The Susceptibility Indices obtained for the ten maize varieties studied are shown in Table 3. The smaller the Susceptibility Index, the lower a variety is susceptible to infestation by *S. zeamais*.

TABLE 3

Susceptibility Indices of 10 maize varieties

S. zeamais

Maize Variety	Means of 3 trials		
	Number of F_1 adults	Development Period (days)	Susceptibility Index
V_7 Kawanzie	21	34.05	8.00 a
V_3 Pool 16 EV 85	19	31.75	8.19 ab
V_5 Gandajika 8149	30	33.20	10.13 abc
V_9 Dobidi	52	32.60	10.41 abcd
V_{10} Aburotia CRI	45	32.10	10.63 bcd
V_8 Ho Local Two	39	33.53	11.32 cd
V_1 Ho Local One	40	33.85	11.39 cd
V_4 Composite 4	42	32.35	11.54 cd
V_2 Pokoase Local	56	31.70	12.61 d
V_6 Pool 16 SR	53	30.50	13.02 d

Susceptibility Indices followed by the same letter (a to d) are not significantly different from each other at P = 0.05

The Susceptibility Indices were analysed using Duncan's New Multiple Range Test (Steel and Torrie, 1960) (Appendix 1 - 3). Significant differences were found in Susceptibility Indices, indicating that some of the maize varieties studied were more susceptible to infestation by S. zeamais than other varieties. Among the varieties, Kawanzie was the least susceptible and Pool 16SR, the most susceptible. Grains of Pool 16 EV 85, Gandajika 8149 and Dobidi did not differ significantly (at $P = 0.05$) from Kawanzie. However, the three local varieties, Ho Local Two, Ho Local One and Pokoase Local were more susceptible than Kawanzie. These local varieties, Composite 4, Aburotia CRI and Dobidi were as susceptible as Pool 16 SR.

Results of proximate analyses carried out on the 10 varieties are shown in Table 4

TABLE 4

Proximate analysis of ten maize varieties in Susceptibility Tests to S. zeamais

Maize Variety	Susceptibility Index	% Ash	% Fat	% Protein	% Carbohydrate	Phosphorus (mg/100g)	Iron (mg/100g)	Calcium (mg/100g)
V_1 Kawanzie	8.08	1.3	3.9	9.5	72.29	622.6	5.4	39.0
V_3 Pool 16 EV 85	8.19	1.4	3.5	10.6	71.47	285.8	4.5	42.0
V_5 Gandajika	10.14	1.4	3.6	10.5	71.47	329.3	4.8	45.0
V_9 Dobidi	10.41	1.4	4.6	10.3	70.65	304.1	3.0	29.5
V_{10} Aburotia CRI	10.63	1.3	1.8	10.9	72.96	187.0	5.1	97.0
V_8 Ho Local Two	11.33	1.5	6.2	8.4	70.88	373.8	3.7	32.0
V_1 Ho Local One	11.38	1.2	4.4	9.8	71.59	219.5	5.2	68.0
V_4 Composite 4	11.55	1.3	2.9	9.5	74.30	622.6	5.4	39.0
V_2 Pokoase Local	12.61	1.7	2.9	11.9	70.48	366.7	3.6	68.0
V_6 Pool 16 SR	13.02	1.2	3.3	9.9	73.56	295.1	3.5	40.0

To determine the degree of association between Susceptibility Index and the various grain components of the proximate analysis, a simple linear correlation analysis was conducted (Appendix 4 - 10). Coefficient of correlation (r) was calculated as follows:-

$r = + 0.42$ for % Ash content
$r = - 0.07$ for % fat content
$r = - 0.08$ for % protein content
$r = + 0.025$ for % carbohydrate content
$r = - 0.07$ for phosphorus content
$r = + 0.32$ for calcium content
$r = - 0.04$ for iron content

As the tabular r value for (10-2) degrees of freedom was 0.632 at $P = 0.05$, no significant positive or negative correlation could be established for the various grain components and Susceptibility Index for the maize varieties studied.

It is possible that for these varieties, ash, fat, protein, carbohydrate phosphorus, iron and calcium contents of the grains are not the factors important in the Susceptibility to S zeamais. Dobie (1974) found that grain hardness was the most important factor affecting susceptibility. Experiments carried out by Dobie (1974) have shown that the pericarp/testa layer of the grain may form an important barrier to oviposition by S. zeamais The softer the grains the more they are susceptible to attack by S. zeamais. Although this was not investigated in the present study, it could have been responsible for the differences in susceptibility in the varieties studied. Other workers (Gupta et al, 1970) have found some nutritional components in the grain as responsible for susceptibility. For example, a negative correlation has been found between protein content and susceptibility. Incorporation of the opaque - 2 - gene in maize varieties, which increases the lysine and tryptophan content of the grains, causes a higher susceptibility to Sitophilus spp. Very probably this increase in susceptibility is caused by the soft nature of the opaque maize and further delection can decrease this susceptibility.

5. CONCLUSION

It is obvious from the values of Susceptibility Indices that the grains of the high-yielding or improved varieties are less susceptible to infestation in storage by S. zeamais. Therefore, they will suffer less damage in storage than the local varieties if the level of field infestation of both types are the same. In practice this does not happen in the field due to the poor husk cover of the improved varieties and there is the need to study further how the field infestation affects storability of the grains of the different varieties. This would then give a true indication of which variety really stores better or is less susceptible to attack by S. zeamais.

It is also necessary to develop high-yielding varieties with a good husk cover and low inherent susceptibility of the grains in order to reduce field infestation and storage losses. Since to a large extent a better husk cover tends to be correlated with smaller maize ears, yeild would have to be sacrificed for the sake of reduction of insect damage. It is possible that yields could still be the same by way of increasing the number of ears on the plant.

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9.0 APPENDICES

APPENDIX I

ANALYSIS OF VARIANCE OF SUBSCEPTIBILITY TESTS OF DIFFERENT MAIZE VARIETIES TO S. ZEAMAIS

Source of Variation	Sum of squares	Degrees of freedom	Mean squares	F ratio
Treatments (Between means)	96.5947	9	10.7327	5.5349
Blocks (within replicates)	12.7965	3	4.2655	2.1997
Error	52.3557	27	1.9391	
Total	161.7469	39		

for TREATMENTS: F values from the Statistical Tables is 2.25

Therefore, $5.5349 > 2.25$ or (calculated) > (observed) values and results are SIGNIFICANT

for BLOCKS, F values from the Statistical Tables is 2.96

Therefore $2.1997 \angle 2.96$ or (calculated) < (observed) and results are INSIGNIFICANT

APPENDIX 2

CALCULATING STANDARD ERRORS AND DIFFERENCES BETWEEN MEANS OF MAIZE VARIETIES IN SUSCEPTIBILITY TESTS TO S. ZEAMAIS

STANDARD ERRORS

	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
V_1		0.9846	0.9846	0.9846	0.9846	0.9846	0.9846	0.9846	0.9846	0.9846
V_2	3		"	"	"	"	"	"	"	"
V_3	6	8		"	"	"	"	"	"	"
V_4	2	2	7		"	"	"	"	"	"
V_5	5	7	2	6		"	"	"	"	"
V_6	4	2	9	3	8		"	"	"	"
V_7	7	9	2	8	3	10		"	"	"
V_8	2	4	5	3	4	5	6		"	"
V_9	4	6	3	5	2	7	4	3		"
V_{10}	3	5	4	4	3	6	5	2	2	

$$\text{Standard Error (S.E.)} = \sqrt{\frac{\text{Error mean}}{\text{Square}}} \; x \; \sqrt{\frac{1}{x} \; x \; \frac{1}{y}}$$

where r_x and r_y is no of replicates for x and y respectively.

Therefore S.E. for V_1 and V_6 will be $\sqrt{1.9391} \; x \; \sqrt{\frac{1}{4} + \frac{1}{4}}$

$$= \underline{\underline{0.9846}}$$

APPENDIX 3

APPLYING DUNCAN'S NEW MULTIPLE RANGE TEST TO TEST FOR SIGNIFICANCE IN MEANS OF SUSCEPTIBILITY INDICES OF THE MAIZE VARIETIES

EXAMPLE A: Comparing means of V_7 and V_3, the difference between their means is 8.19 - 8.08 = 0.11

Q from statistical Tables is 3.23 at 39 or approx 40 Degrees of Freedom and 2 (difference between means of V_7 and V_3 from Appendix 2) at P = 0.05 But S.R = S.E. x Q = 0.9846 x 3.23 = 3.1799.

Therefore since $0.11 < 3.1799$ or calculated value is less than observed value, the difference between means V_7 and V_3 is NOT SIGNIFICANT.

EXAMPLE B: Comparing means of V_7 and V_8, the difference between their means is 11.33 - 8.08 = 3.2475

Q from statistical Tables is 2.34 at 39 or approx. 40 Degrees of Freedom and 6 (difference between means of V_7 and V_8 from Appendix 2) at P. = 0.05. But S.R. = S.E. x Q = 0.09846 x 2.34 = 2.3037.

Therefore since $3.2475 > 2.3037$ or calculated value is than observed value, the difference between means V_7 and V_8 is SIGNIFICANT.

APPENDIX 4

CALCULATION OF COEFFICIENT OF CORRELATION BETWEEN SUSCEPTIBILITY INDEX (X) AND ASH CONTENT (Y) OF MAIZE

X	Y	$x = X - \bar{X}$	$y = Y - \bar{Y}$	x^2	y^2	xy
8.08	1.3	-2.65	-0.07	7.0225	0.0049	0.1855
8.19	1.4	-2.54	0.03	6.4516	0.0009	-0.0762
10.14	1.4	-0.59	0.03	0.3481	0.0009	-0.0177
10.41	1.4		0.03	0.1024	0.0009	-0.0096
10.63	1.3	-0.10	0.07	0.0100	0.0049	-0.0070
11.33	1.5	0.60	0.13	0.3600	0.0169	-0.0780
11.38	1.2	0.65	0.17	0.4225	0.0289	-0.1105
12.55	1.3	0.82	0.07	0.6724	0.0049	-0.0574
12.61	1.7	1.88	0.33	3.5344	0.1089	0.6204
13.02	1.2	2.29	0.17	5.2441	0.0289	-0.3893
$\Sigma X=107.34$	$\Sigma Y=14.7$			$\Sigma X^2=24.1680$		$\Sigma xy=0.9352$
$X=\frac{\Sigma X}{N}$	$\bar{y}=\frac{13.7}{10}$				$\Sigma y^2=0.2010$	
$=\frac{107.34}{10}$						
$= \underline{10.73}$	$=1.37$					

∴ From the formula

$$r = \frac{\Sigma xy}{\sqrt{(\Sigma_x{}^2).(\Sigma_Y{}^2)}}$$

$$r = \frac{0.9352}{\sqrt{(24,1680)(0.2010)}}$$

$$= \frac{0.9352}{\sqrt{4,858}}$$

$$= \frac{0.9352}{2.2040}$$

∴ r= $\underline{0.42}$

APPENDIX 5

CALCULATION OF COEFFICIENT OF CORRELATION BETWEEN SUSCEPTIBILITY INDEX (X) AND FAT CONTENT (Y) OF MAIZE

X	Y	$x=X-\bar{X}$	$y=Y-\bar{Y}$	x^2	y^2	xy
8.08	3.9	-2.65	0.19	7.0225	0.0361	-0.5033
8.19	3.5	-2.54	-0.21	6.4516	0.0441	0.5334
10.14	3.6	-0.59	-0.11	0.3481	0.0121	0.0649
10.41	4.6	-0.32	0.89	0.1024	0.7921	-0.2848
10.63	1.8	-0.10	-1.91	0.0100	3.6481	0.1910
11.33	6.2	0.60	2.49	0.3600	6.2001	1.4940
11.38	4.4	0.65	0.69	0.4225	0.4761	0.4485
11.55	2.9	0.82	-0.81	0.6724	0.6561	-0.6642
12.61	2.9	1.88	-0.81	3.5344	0.6561	-1.5228
13.02	3.3	2.29	-0.41	5.2441	0.1681	-0.9389
$\Sigma X=107.34$ $\bar{X}=\frac{\Sigma X}{N}$ $=\frac{107.34}{10}$ $=10.73$	$\Sigma Y=37.1$ $\bar{Y}=\frac{\Sigma Y}{N}$ $=\frac{37.1}{10}$ $=3.71$			$\Sigma x^2=24.1680$	$\Sigma y^2=12.6890$	$\Sigma xy=1.1824$

∴ From the formula

$$r = \frac{\Sigma xy}{\sqrt{(\Sigma x^2)(\Sigma y^2)}}$$

$$r = -\frac{1.1824}{\sqrt{(24.1680)(12.6890)}}$$

$$= \frac{-1.1824}{17.5719}$$

$$r = -0.07$$

APPENDIX 6

CALCULATION OF COEFFICIENT OF CORRELATION BETWEEN SUSCEPTIBILITY INDEX (X) AND PROTEIN CONTENT (Y) OF MAIZE

X	Y	$x=X-\bar{X}$	$y=Y-\bar{Y}$	x^2	y^2	xy
8.08	9.5	-2.65	-0.63	7.0225	0.3969	1.6695
8.19	10.6	-2.54	0.47	6.4516	0.2209	-1.1938
10.14	10.5	-2.59	0.37	0.3481	0.1369	-0.2183
10.41	10.3	-0.32	0.17	0.1024	0.0289	-0.0544
10.63	10.9	-0.10	0.77	0.0100	0.5929	-0.0770
11.33	8.4	0.60	-1.73	0.3600	2.9929	-1.0380
11.38	9.8	0.65	-0.33	0.4225	0.1089	-0.2145
11.55	9.5	0.82	-0.63	0.6724	0.3969	-0.5166
12.61	11.9	1.88	1.77	3.5344	3.1329	3.3276
13.02	9.9	2.29	-0.23	5.2441	0.0529	-0.5267
$\sum X=107.34$ $\bar{X}=\frac{107.34}{10}$ $=\underline{\underline{10.73}}$	$\sum Y=101.3$ $\bar{Y}=\frac{101.3}{10}$ $=\underline{\underline{10.13}}$			$\sum x^2=24.1680$	$\sum y^2=8.0610$	$\sum xy=1.1578$

from the formula

$$r = \frac{\sum xy}{\sqrt{(\sum x^2)\ (\sum y^2)}}$$

$$= - \frac{1.1578}{\sqrt{(24.168)(8.061)}}$$

$$= \frac{-1.1578}{13.9577}$$

$$= \underline{\underline{-\ 0.08}}$$

APPENDIX 7

CALCULATION OF COEFFICIENT OF CORRELATION BETWEEN SUSCEPTIBILITY INDEX (X) AND CARBOHYDRATE CONTENT (Y) OF MAIZE

X	Y	$x=X-\bar{X}$	$y=Y-\bar{Y}$	x^2	y^2	xy
8.08	72.29	-2.65	0.32	7.0225	0.1024	-0.848
8.99	91.47	-2.54	-0.5	6.4516	0.25	1.27
10.14	71.47	-0.59	-0.5	0.4516	0.25	0.295
10.41	70.65	-0.32	1.32	0.1024	1.7424	-0.4224
10.63	72.96	-0.1	0.99	0.01	0.9801	-0.099
11.33	70.88	0.6	1.09	0.36	1.1881	0.654
11.38	71.59	0.65	-0.38	0.4226	0.1444	-0.247
11.55	74.30	0.82	2.33	0.6724	5.4289	1.9106
12.61	70.48	1.88	-1.49	3.5344	2.2201	2.7636
13.02	73.56	2.29	1.59	5.2441	2.5281	3.6311
$\Sigma X=107.34$ $\bar{X}=10.73$	$\Sigma Y=719.65$ $\bar{Y}=71.97$			$\Sigma x^2=24.168$	$\Sigma y^2=14.8345$	$\Sigma xy=8.9179$

From the formula

$$r = \frac{\Sigma xy}{\sqrt{(\Sigma x^2)\ (\Sigma y^2)}}$$

$$r = \frac{8.9179}{\sqrt{(24.168)\ (14.8345)}}$$

$$= \frac{8.9179}{358.52019}$$

$$= 0.0248741$$

$$= \underline{\underline{0.025}}$$

APPENDIX 8

CALCULATION OF COEFFICIENT OF CORRELATION BETWEEN SUSCEPTIBILITY INDEX (X) AND PHOSPHORUS CONTENT (Y) OF MAIZE

X	Y	$x=X-\bar{X}$	$y=Y-\bar{Y}$	x^2	y^2	xy
8.08	622.60	2.72	258.46	7.3984	66801.57	-684.92
8.19	285.80	-2.61	-78.24	6.8122	6121.50	198.73
10.41	304.10	-0.39	-60.04	0.1521	3604.80	19.21
10.63	187.00	-0.17	-177.14	0.02899	31378.58	17.71
11.33	373.80	0.53	9.66	0.2809	93.32	5.80
11.38	219.50	0.58	144.64	0.3364	20920.73	-94.02
11.55	622.60	0.75	258.46	0.5625	66801.57	211.94
12.61	366.70	1.81	2.56	3.2761	6.55	4.81
13.02	295.10	2.22	69.04	4.9284	4766.52	158.10
$\Sigma X=97.2$ $\bar{X}=\frac{97.2}{9}$ $=10.8$	$\Sigma Y=3277.3$ $\bar{Y}=\frac{3277.3}{9}$ $=364.14$			$\Sigma x^2=23.7758$	$\Sigma y^2=200495.14$	$\Sigma xy=162.64$

From the formula

$$r = \frac{-162.64}{\sqrt{(23.7758)\ (200495.14)}}$$

$$= \frac{-162.64}{2183.33}$$

$$= \underline{\underline{-0.07}}$$

APPENDIX 9

CALCULATION OF COEFFICIENT OF CORRELATION BETWEEN SUSCEPTIBILITY INDEX (X) AND IRON CONTENT (Y) OF MAIZE

X	Y	$x=X-\bar{X}$	$y=Y-\bar{Y}$	x^2	y^2	xy
0.08	5.40	-2.72	1.02	7.3984	1.0404	-2.7744
8.19	4.50	-2.61	0.12	6.8121	0.0144	-0.3132
10.41	3.00	-0.39	-1.38	0.1521	1.9044	0.5382
10.63	5.50	-0.17	0.72	0.0289	0.5184	-0.1224
11.33	3.70	0.53	0.68	0.2809	0.4624	-0.3604
11.38	5.20	0.58	0.82	0.3364	0.6724	0.4756
11.55	5.40	0.75	1.02	0.5625	1.0404	0.7650
12.61	3.60	1.81	-0.78	3.2761	0.6084	-1.4118
13.02	3.50	2.22	-0.88	4.9284	0.7744	-1.9536
$\Sigma X=97.2$ $\bar{X}=\frac{97.2}{9}$ $=10.8$	$\Sigma Y=39.40$ $Y=\frac{39.4}{9}$ $=4.38$			$\Sigma x^2=23.7758$	$\Sigma y^2=7.0356$	$\Sigma xy=-5.1570$

From the formula

$$r = \frac{xy}{\sqrt{(\Sigma x^2)\ (\Sigma y^2)}}$$

$$r = \frac{-5.1570}{\sqrt{(23.7758)\ (7.0356)}}$$

$$= \frac{-5.1570}{12.9336}$$

$$= 0.40$$

APPENDIX 10

CALCULATION OF COEFFICIENT OF CORRELATION BETWEEN SUSCEPTIBILITY INDEX (X) AND CALCIUM CONTENT (Y) OF MAIZE

X	Y	$x=X-\bar{X}$	$y=Y-\bar{Y}$	x^2	y^2	xy
8.08	39.00	-2.72	-5.95	7,3984	35.4025	16.1840
8.19	42.00	-2.16	-2.95	6.8121	8.7025	7.6995
10.41	29.56	-0.39	-15.39	0.1521	236.8521	6.0021
10.63	47.00	-0.17	2.05	0.0289	4.2025	-0.3485
11.33	32.00	0.53	-12.95	0.2809	167.7-25	-6.8635
11.38	68.00	0.58	23.05	0.3364	531.3025	13.3690
11.55	30.00	0.75	-5.95	0.5625	35.4025	4.4625
12.61	68.00	0.81	23.05	3.2761	531.3025	41.7205
13.02	40.00	2.22	-4.95	4.9284	24.5025	-10.9890
$\Sigma X=97.2$ $\bar{X}=\underline{97.2}$ $=\underline{\underline{10.8}}$	$\Sigma Y=404.56$ $\bar{Y}=404.56$ $=\underline{\underline{44.95}}$			$\Sigma x^2=23.7758$	$\Sigma y^2=1575.3721$	$\Sigma xy=62.3116$

From the equation

$$r = \frac{\Sigma xy}{\sqrt{(\Sigma x^2)\ (\Sigma y^2)}}$$

$$r = \frac{62.3116}{\sqrt{(23.7758)\ (1575.3721)}}$$

$$= \frac{62.3116}{193.5348}$$

$$= \underline{\underline{0.32}}$$