TOPIC: INVESTIGATING THE SUSCEPTIBILITY TO INFESTATION OF SOME NEWLY INTRODUCED MAIZE VARIETIES IN GHANA TO *SITOPHILUS ZEAMAIS* MOTSCHULSKY (COLEOPTERA: CURCULIONIDAE)

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1.0 INTRODUCTION

Maize is an important staple crop in Ghana. Between 1986 and 1988 maize production was 571,000 tons and constituted 47% of the total land area used for cereal production. Within this same period, percentage use of the crop as food, feed and other uses averaged 84, 5 and 11 percent, respectively (CIMMYT, 1990).

Farmers' efforts to increase and stabilize maize production are frustrated by numerous constraints, ranging from low soil fertility and unavailability of improved germplasm, unrenumerative prices, uncertain access to markets and most importantly, post-harvest storage losses. Although efforts are being made to overcome some of these constraints, post-harvest storage losses appear to be very significant. Whether stored as shelled grain or unshelled on cobs with the husks removed or intact, the crop is most often attacked by various pests, most importantly the maize weevil, *Sitophilus zeamais*, Motschulsky (Coleoptera: Curculionidae).

As part of measures to reduce *S. zeamais* attack of the crop in storage, new varieties are being developed and released to maize farmers. Grains of the newly introduced improved varieties are often resistant to diseases and less susceptible to attack by *S. zeamais* than the traditional or local types. Small-scale farmers, who produce the bulk of the crop in the country, normally store maize in cribs or barns with the husks intact. This form of storage as opposed to shelled grain in bags, lessens the advantage since most of the improved varieties have relatively shorter husk cover than the traditional ones. This renders the improved varieties more susceptible to infestation in the field and further insect build-up in storage. Researchers in the country have suggested the reduction of storage infestation by *S. zeamais* to include among others, milling of grains of the newly introduced varieties into flour, soon after crib drying to safe moisture levels. This is because, in most forms before consumption, maize is mainly processed into flour. Storage of maize in the milled form, however, is likely to render the flour to infestation by another important storage pest, the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae).

This study was conducted, therefore, to: (1) determine the susceptibility of the crop as whole grain to *S. zeamais* attack; (2) determine some factors that are likely to influence susceptibility to *S. zeamais* infestation; (3) relate *S. zeamais* susceptibilities as whole grain with those of *T. castaneum* as milled flour so as to determine the effectiveness and/or advantages of maize storage as whole grain or milled flour; (4) advise maize breeders in Ghana to incorporate those advantageous characteristics that confer resistance into high yielding commercial varieties for storage as grain or milled flour; and (5) advise small-scale farmers about those varieties that are more resistant for long storage without the use of chemical protectants.

2.0 MATERIALS AND METHODS

Since the source and purity of the varieties was unknown and the quantities of grains were not enough for all the experiments, it necessary to multiply, and standardize the varieties. The following methods were employed in the standardization of the test maize varieties:

2.1 The maize varieties

Fourteen newly introduced and three local varieties were grown in a randomized complete block design with four replications. Planting was done at the onset of rains on 26th April, 1992. Three seeds were planted per hill and plants thinned to two per hill, two weeks after planting (WAP). Plots consisted of 10 metre-long rows, with inter- and intra- row spacings of 0.75 metre and 0.25 metres, respectively. In order to maintain the purity of the genotype, reciprocal crosses on each plant were made, by using pollen collected from each half of a row to pollinate ears of the other half. The systemic insecticide Furadan (Carbofuran) 5G was applied at 0.20 g per plant into the whorls of the seedlings, 2 weeks after emergence and repeated 2 weeks later to reduce insect damage to the plant. A compound fertilizer providing 60 kg N, 60 kg P_2O_5 and 60 kg K_2O ha^{-1} was applied during land preparation and supplemented 4 WAP by urea at the rate of 60 kg N ha^{-1}. Two hand weeding operations were performed and no insecticide was applied afterwards. Maize cobs, with the husks intact, were harvested on July 10, 1992 when the kennels were physiologically mature and the moisture content had reached 25 percent (wet basis). The cobs were sun-dried on black plastic sheets for 2 weeks, until moisture content of the grains reached 18 percent (wet basis), and placed into large polythene bags, measuring 100 cm by 80 cm. To kill off any insects resulting from field infestation, cobs were defrozen at -20 ^{o}C, within the bags until required for the experiments when they were removed for moisture equilibration for 2 weeks in the laboratory. Agronomic characteristics of the maize plants and the grains are shown in Tables 1 and 2, respectively.

Table 1: Agronomic characteristics of the varieties used for the study[1]

Variety	Type[2]	Mean plant height[3] (cm)	Mean Days to silking[3]	Mean Ear size[4] (cm)		Husk cover rating of cobs[4]	Mean kernel no. per cob[4]	Average yield[5] (tons/ha)	Ecological suitability for cultivation[5,6]
				Diameter	Length				
Dobidi [derived from La Posta Ejura(1)7843]	High-yielding (improved). 110-120 day maturity.	205.0de	56.5e	45.4f	13.6cdefg	2.0bc	447.3cd	5.5h	All
Aburotia CRI [derived from Tuxpeno PB C16]	High-yielding (improved). 105-day maturity.	152.5a	52.0c	47.3gh	13.1cde	2.0bc	422.5b	4.6b	CS, GS
La Posta	High-yielding (improved). 120-day maturity.	205.0de	56.5e	42.4cd	13.2cdef	2.5c	436.8bcd	5.3	All
Hi-Lysine	High-yielding (improved). Quality Protein Maize. 120-day maturity.	175.0c	56.5e	47.4hi	15.3i	2.0bc	420.2b	4.5b	All
Dorke SR	High-yielding (improved). Breeding material. Streak resistant. 95-day maturity.	162.5b	48.5b	48.5b	14.2efghi	1.5ab	450.3d	4.9d	All
Safita 2 [derived from CIMMYT's Pool 16]	High-yielding (improved) 95-day maturity.	167.5d	47.0ab	48.4i	15.2i	2.5c	438.1bcd	5.0f	GS, CS
Golden Crystal	High-yielding (improved) Grown for poultry and livestock mainly. 110-day maturity.	202.5d	55.0d	42.7de	13.3cdef	2.0bc	432.5bcd	4.6bc	F, CS, GS
Okomasa [derived from EV8343 SR BC3]	High-yielding (improved) Breeding material. Streak resistant. 120-day maturity.	205.0de	46.5a	46.9gh	14.6ghi	2.0bc	433.3bcd	5.5h	All

Mexico8049	High-yielding (improved). Breeding material. 105-day maturity.	152.5a	52.0c	46.3fg	13.0defgh	2.0bc	429bc	4.9ef	All
Composite 4	High-yielding (improved) Composite variety. Subsistence farming. 120-day maturity.	215.0f	60.0f	42.1cd	14.8hi	1.5ab	420.7	4.5b	All
Kawanzie	High-yielding (improved). Grown for poultry and livestock mainly. 95-day maturity.	162.5b	46.0ab	41.9cd	12.9bcd	2.0bc	430.7bc	4.8de	GS, CS
Pool 16SR EV85	High-yielding (improved) Streak resistant 95-day maturity	167.5b	48.0ab	40.2b	12.7bc	2.0bc	425.8b	4.7cd	GS, CS
Pool 16SR [derived from CIMMYT's Pool 16]	High-yielding (improved) Streak resistant 95-day maturity.	167.5b	48.0ab	41.3c	13.2cdef	2.5bc	428.3bc	4.8de	GS, CS
Gandajika	High-yielding (improved) 105-day maturity	167.5b	47.0e	43.0de	14.3fghi	2.5bc	422.5b	4.9ef	All
Ho Local	Low-yielding (traditional). Subsistence farming. 120-day maturity.	167.5b	52.0c	39.4ab	11.9ab	1.0a	307.8a	2.5a	CS, GS
Kwadaso Local	Low-yielding (traditional). Subsistence farming. 120-day maturity.	215.0f	61.0f	38.9a	11.2a	1.0a	305.2a	2.5a	F, T
Pokoase Local	Low-yielding (traditional). Subsistence farming. 120-day maturity.	205.0ef	60.0f	39.2ab	12.0ab	1.5ab	303.9a	2.5a	CS

[1]Means followed by the same letter within a column are not significantly different from each other at $P \leq 0.05$ by Duncan's Multiple Range Test.
[2]All varieties open-pollinated.
[3]Determined from 20 randomly selected plants in the field.
[4]Determined from 20 randomly selected cobs after harvest.
[5]Data obtained from Crops Research Institute, Kumasi, Ghana.
[6]All = All Ecological zones, CS = Coastal Savanna, GS = Guinea Savanna, T = Transition zone, and F = Forest zone.

Mexico8049	High-yielding (improved). Breeding material. 105-day maturity.	152.5a	52.0c	46.3fg	13.0defgh	2.0bc	429bc	4.9ef	All
Composite 4	High-yielding (improved) Composite variety. Subsistence farming. 120-day maturity.	215.0f	60.0f	42.1cd	14.8hi	1.5ab	420.7	4.5b	All
Kawanzie	High-yielding (improved). Grown for poultry and livestock mainly. 95-day maturity.	162.5b	46.0ab	41.9cd	12.9bcd	2.0bc	430.7bc	4.8de	GS, CS
Pool 16SR EV85	High-yielding (improved) Streak resistant 95-day maturity	167.5b	48.0ab	40.2b	12.7bc	2.0bc	425.8b	4.7cd	GS, CS
Pool 16SR [derived from CIMMYT's Pool 16]	High-yielding (improved) Streak resistant 95-day maturity.	167.5b	48.0ab	41.3c	13.2cdef	2.5bc	428.3bc	4.8de	GS, CS
Gandajika	High-yielding (improved) 105-day maturity	167.5b	47.0e	43.0de	14.3fghi	2.5bc	422.5b	4.9ef	All
Ho Local	Low-yielding (traditional). Subsistence farming. 120-day maturity.	167.5b	52.0c	39.4ab	11.9ab	1.0a	307.8a	2.5a	CS, GS
Kwadaso Local	Low-yielding (traditional). Subsistence farming. 120-day maturity.	215.0f	61.0f	38.9a	11.2a	1.0a	305.2a	2.5a	F, T
Pokoase Local	Low-yielding (traditional). Subsistence farming. 120-day maturity.	205.0ef	60.0f	39.2ab	12.0ab	1.5ab	303.9a	2.5a	CS

[1]Means followed by the same letter within a column are not significantly different from each other at $P \leq 0.05$ by Duncan's Multiple Range Test.
[2]All varieties open-pollinated.
[3]Determined from 20 randomly selected plants in the field.
[4]Determined from 20 randomly selected cobs after harvest.
[5]Data obtained from Crops Research Institute, Kumasi, Ghana.
[6]All = All Ecological zones, CS = Coastal Savanna, GS = Guinea Savanna, T = Transition zone, and F = Forest zone.

Table 2: Characteristics of grains of the varieties used in the study[1]

Variety	Endosperm type & texture	1000 Grain wt (g)	Grain density (g/cm³)	Bulk density (kg/m³)	Weight of Grain components (g)				Pericarp thickness (mm)		Grain Size (cm)			Grain volume (cm³)
					Peri-carp	Tip-cap	Endo-sperm	Germ	Germ side	Side opposite germ	Length	Breadth	Depth	
Dobidi	Dent/Flint	396.2a	1.27ef	0.74f	0.09e	0.021e	1.16g	0.18b	0.09c	0.11cd	11.4f	8.5e	4.0f	7.1hi
Aburotia	Dent	287.3b	1.25cd	0.71bc	0.06bc	0.019d	1.13a	0.20c	0.09c	0.10bc	10.4bc	8.3de	3.5bcde	7.0h
La Posta	Dent	330.5d	1.24c	0.70ab	0.06bc	0.018d	1.12cd	0.20c	0.09c	0.11cd	10.4cde	8.2cde	3.5bcde	6.5de
Hi-Lysine	Dent/Floury	261.4a	1.21b	0.74f	0.07cd	0.012a	1.10b	0.21c	0.09c	0.10bc	11.5f	8.9f	3.1a	5.9b
Dorke SR	Dent	329.0d	1.24cd	0.72cd	0.07cd	0.013ab	1.11bc	0.23d	0.08bc	0.10bc	11.2f	8.5e	3.1a	6.8g
Safita 2	Dent	290.0bc	1.20b	0.70ab	0.07cd	0.013ab	1.12cd	0.20c	0.09c	0.11cd	11.0def	8.4de	3.8ef	6.4cd
Golden-Crystal	Dent	308.0c	1.26de	0.74f	0.06bc	0.015c	1.14ef	0.18b	0.09c	0.11cd	11.1ef	8.5e	3.7def	6.4cd
Okomasa	Dent	288.5b	1.20b	0.73de	0.09e	0.019d	1.16g	0.18c	0.08bc	0.09b	11.0def	8.5e	3.5bcde	6.5de
Mexico 8049	Dent	247.4a	1.18a	0.70ab	0.06bc	0.019d	1.15fg	0.17ab	0.07ab	0.11cd	10.6cde	8.4de	3.5bcde	6.3c
Composite 4	Dent	280.7b	1.20b	0.69a	0.06bc	0.022e	1.16g	0.18b	0.07ab	0.10bc	10.5cd	7.9bc	3.5bcde	6.8g
Kawanzie	Flint	250.7a	1.18a	0.69a	0.08de	0.015c	1.13de	0.16a	0.07ab	0.10bc	10.3bc	7.9bc	3.4abcd	6.5de
Pool 16SR EV85	Dent	290.2bc	1.20b	0.69a	0.07cd	0.014bc	1.15fg	0.18b	0.09c	0.11cd	10.4bc	7.8b	3.1a	6.7fg
Pool 16SR	Dent	295.3bc	1.21b	0.70ab	0.07cd	0.014bc	1.15fg	0.18b	0.09c	0.12d	11.0def	7.9bc	3.2ab	6.6ef
Gandajika-8149	Dent	330.0d	1.24c	0.71bc	0.07cd	0.015c	1.13de	0.16a	0.07ab	0.11cd	9.9ab	8.1bcd	3.3abc	7.2i
Ho Local	Dent/Floury	250.4a	1.28f	0.74f	0.04a	0.018d	1.13de	0.21c	0.06a	0.10bc	9.6a	7.4a	3.6cde	5.4a
Kwadaso-Local	Dent/Flint	255.0a	1.26de	0.74f	0.05ab	0.019d	1.02a	0.20c	0.06a	0.07a	9.5a	7.3a	3.5bcde	5.5a
Pokoase-Local	Dent/Floury	260.0a	1.25cd	0.73de	0.05ab	0.019d	1.02a	0.20c	0.07ab	0.07a	9.4c	7.4a	3.7def	5.4a

[1]Means followed by the same letter within a column are not significantly different from each other at $P \leq 0.05$ by Duncan's Multiple Range Test.
All varieties white, except Golden Crystal and Kawanzie which have yellow grains.

Grain moisture content was determined for all varieties by the method of the Association of Official Analytical Chemists (AOAC, 1984) after equilibration in the laboratory at 25 ± 2 °C and 70 ± 5% r.h. In this method, 10 grains were ground into flour. Two grams of flour were weighed into tarred aluminium dishes, in three replicates. The dishes were placed in a 135°C pre-heated oven for 1 hour, cooled to room temperature and placed in a dessicator before weighing. Heating was repeated until constant weights were attained.

2.2 Culturing of *S. zeamais*

S. zeamais used for the experiments were collected from infested cobs during field drying. These were reared for three generations in the laboratory on grains of the white local maize variety, Volta Local, (obtained from the Ghana Grains Development Board, Kumasi, Ghana), after dust and frass were sieved. Fifty adult insects, made up of 30 females and 20 males, were introduced onto 200 gram lots in 10 replicates in 1 litre Kilner jars. The tops of the jars were covered with a fine metal mesh for ventilation. After 7 days, the insects were removed and placed on fresh ten 200-gram replicates. This process was repeated consecutively for two more times, so that emerged adults from each lot were 1 week older than the previous lot. Emerged males were dissected and confirmed as *S. zeamais* using aedaegal characters described by Halstead (1963).

2.3 Culturing of *T. castaneum*

Maize flour previously sieved through a US Standard sieve No. 50, moisture equilibrated in the laboratory and deep frozen in air-tight polythene bags (measuring 30 cm x 30 cm), were used for the experiments. Twelve parts of the flour were mixed with one part of brewers yeast which had been dried at 35°C for 4 hours and milled. Fifty adults of *T. castaneum* (obtained from cultures of the (Ghana Cocoa Marketing Board Infestation Laboratory, Tema), were reared on 200 g of the mixture in 1-litre Kilner jars. Ten replicates were set up. For adequate ventilation, the tops of the jars were covered with a fine metal mesh. After 1 week the jars were sieved through a US Standard Sieve No. 50. Insects retained on top of the sieves, were aspirated and placed on ten fresh 200 gram replicates. The process was repeated two more times until enough adults were obtained for the experiments. Adults were identified by features of the eyes and antennae, described by TDRI (1984).

2.4 Varietal susceptibility of grains to *S. zeamais* attack

The varietal experiments were conducted in the laboratory at 25 ± 2 ^{O}C and $70 \pm 5\%$ r.h. The method for determining susceptibility of grains to *S. zeamais* described by Dobie (1974) was used. Sound, unbroken grains were selected and six 50-gram replicates of each variety were set up in 1-litre Kilner jars. For each replicate, 12 female and 6 male adult *S. zeamais*, 0-7 days old (as measured from emergence of the adult from the cultures) were placed and left for 1 week. This was to allow them to become "conditioned" to the test variety of maize, in the hope that any short-term changes in behaviour associated with the change in host variety could be eliminated. At the end of this week, the insects were placed on six fresh experimental 50 gram replicates for 1 week. Any insects that died at the end of the conditioning period were replaced by insects from a replicate "conditioning" treatment. After the adults had been removed from the grain, it was left undisturbed until all F_1 generation had emerged. Adults were removed daily and terminated when no F_1 adult emergence was recorded for 5 consecutive days. Susceptibility Indices (SI) were calculated using the formula SI = $\{(\log_e F) \times 100\}/MDP$, where F = number of F_1 and

MDP = development period estimated as the time from the middle of oviposition to the emergence of 50% of the F_1 generation.

2.5 Factors influencing susceptibility to *S. zeamais* attack

2.5.1 Effect of prolonged storage on susceptibility of grains

In order to determine the influence of prolonged storage on susceptibility of grains to *S. zeamais*, tests described above for varietal susceptibility were conducted on the varieties after they were stored in the laboratory for 3 or 6 months. Results were compared between treatments, and with those of Section 2.4.

2.5.2 Damaged and totally removed pericarp tissue

Susceptibility tests, as in Section 2.4, were conducted and results compared on grains damaged with those having their pericarp tissue totally removed. Fifty-gram kernels of each variety, in 3 replicates, were used for the study. Grains classified as damaged were scratched at the post-germinal side with sandpaper. To remove pericarp tissue, grains were soaked in distilled water for 4 hours until the pericarp tissue became removable with a scalpel. Grains were dried in an oven at 35°C for 24 hours and later moisture equilibrated in 9-cm diameter petri dishes for 2 weeks.

2.5.3 Nutritional and chemical factors

The composition and nutritive value of grains is known to influence the development of insects in stored grains (Dobie, 1974). Nutritional or chemical factors, thought to influence oviposition and development of *S. zeamais* were protein, total sugars, fat, phosphorus, calcium, iron, amylose, amylopectin, crude fibre and ash. For the determinations of fat, phosphorus, calcium, iron and total sugars, the methods of the Association of Official Analytical Chemists (AOAC, 1984) were used. Protein was determined by the micro-Kjeldahl method, where Nitrogen content was measured and multiplied by the factor 6.25. Percentage ash was determined by the method of the American Association of Cereal Chemists (AACC, 1983), and percentage crude fibre by the trichloro-acetic method (Entwistler and Hunter, 1949) A Technicon® autoanalyser was used for the determination of amylose (Juliano, 1971) and amylopectin values were obtained by subtracting amylose values from 100. To ascertain the relationship between the nutritional factors and development of the weevil, correlation tests were carried out between the nutritional factors and numbers of F_1, MDP and SI determined for sound unbroken kernels in Section 2.4.

2.6 Olfactory factors in influencing *S. zeamais* attack

Five experiments were conducted to study the influence of olfactory factors on susceptibility. After the tests, the relationship between numbers of F_1, MDP and SI of each test were determined with those obtained in Section 2.4. The tests were:

2.6.1 Addition of flour to grains

Ten grams of whole flour of each variety was added to sound, undamaged 50 grams of its grains. Three replicates were set up in glass vials (10 cm high x 2.5 cm diameter). Twelve females and 6 male *S. zeamais* adults were placed on the grains and removed after 1 week. To provide adequate ventilation, the top of the vials were covered with a nylon mesh and held in place by rubber bands.

2.6.2 Addition of mouldy grains

Ten mouldy grains of each variety were added to 50 grams sound grains of the same variety. The experimental set-up and procedure was same as in Section 2.6.1.

2.6.3 Addition of longitudinally halved grains

Ten sound grains of each variety were broken into two longitudinally, and added to 50 grams whole grains of the same variety. The experimental set-up and procedure was same as in Section 2.6.1.

2.6.4 Addition of germinated grains

Twenty grains of each variety were soaked in distilled water for 45 minutes. After this period, the grains were placed on moistened Whatman No. 1 filter paper in 9 cm petri-dishes for 2 days. Ten germinated kernels were removed and added to sound ungerminated grains in glass vials. The experimental set-up and procedure was same as in Section 2.6.1.

2.7 Varietal susceptibility of flour to *T. castaneum* attack

The method of determining susceptibility to *T. castaneum* is based on the modified procedure described by Rhine and Staples (1968). The grains were milled using a Seedburo Toothfeed Hand Grinder No. 5. Six 1-litre Kilner jars (replicates) containing 100-gram flour of each variety were infested with 20 adults of *T. castaneum*, which were removed one week later. Since development from egg to adult of this insect is reported to take about 20 days under optimal conditions (Howe, 1962), the jars were left undisturbed for 35 days, after removal of the parent insects, when all F_1 adults would have emerged. Emerged F_1 adults were counted after all the jars were deep-frozen at -20°C. Ten F_1 adults from each replicate were weighed on a Mettler® UM3 balance.

2.8 Data analyses

All data were analysed using the SuperANOVA or StatView 4.0 statistical packages, both of Abacus Concepts Inc., 1989 and 1992, respectively.

3.0 RESULTS AND DISCUSSION

3.1 Varietal susceptibility of grains to *S. zeamais* attack

The Susceptibility Indices obtained for grains of the 14 improved and 3 local varieties are shown in Table 3. Dobie's (1974) Index of Susceptibility is based on the assumption that the more F_1 progeny and the shorter the duration of development, the more suitable the grain is as host to *S. zeamais*. Hence the more susceptible varieties have a higher index.

Before analyses, data on F_1 progeny were log (x+1) transformed in order to satisfy the assumptions of normality for the analysis of variance (ANOVA). Highly significant differences ($P<0.01$) were observed in the mean numbers of F_1 progeny on the tested maize varieties. Mexico 8049, an improved variety, produced the lowest mean number of progeny i.e. 17.0 F_1 adults, and Hi-Lysine, another improved variety, produced 6.1 times more (Table 3). Comparing the results using contrasts, significantly ($P<0.01$) more F_1 progeny emerged from the 14 combined improved than the 3 local varieties put together. Similarly, the white-grained varieties yielded significantly ($P<0.01$) more F_1 adults than the yellow-grained types (Table 4).

An analysis of variance of MDP values gave highly significant differences ($P<0.01$) among varieties, and ranged from 30.5 to 36.5 days. When the MDP of the 14 improved and 3 local varieties were compared, no significant differences ($P>0.05$) were observed (Table 4). However, significant differences ($P<0.01$) were observed in MDP between weevils developing on white- or yellow-grained varieties. Hi-Lysine, a quality protein maize, had the lowest SI and Mexico 8049 the highest SI and the developmental period of *S. zeamais* was longest on it (Table 3). Comparing SI values of the improved varieties with those of local varieties, significant differences ($P<0.01$) were observed, although no such differences ($P>0.05$) were found between white- or yellow-grained accessions (Table 4).

The mean separation of varieties by Susceptibility Index (Table 3) showed a wide array of groupings, indicating that diverse genetic backgrounds could be responsible for susceptibility or resistance. Grains of the majority of the improved varieties could be grouped as somewhat resistant (i.e "a", "b", "c"). The most susceptible groups, "h", "i" and "j", contained two of the local varieties Kwadaso Local and Pokoase Local.

Table 3: Results of susceptibility indices of 14 newly introduced and 3 local varieties to *S. zeamais*.[1]

Maize variety	Means of 6 replicates		
	Number of F_1 adults	Median Development Period (Days)	Susceptibility index
Mexico 8049	17.0a	36.5g	7.8a
La Posta	22.5b	32.9cde	9.5b
Kawanzie	28.0c	34.4f	9.7bc
Dorke SR	32.3de	35.0f	9.9bc
Gandajika 8149	30.0cd	33.6def	10.1c
Ho Local	41.5fc	33.9ef	11.0d
Okomasa	30.3cd	30.5a	11.2d
Pool 16SR EV85	35.2e	31.4abc	11.4de
Composite 4	41.5f	32.3bcd	11.5def
Aburotia	45.0f	32.1abcd	11.9efg
Dobidi CRI	52.0g	32.7cde	12.1fgh
Pool 16SR	42.7f	30.7ab	12.3gh
Safita 2	61.5hi	32.5cde	12.7hi
Kwadaso Local	55.7gh	31.6abc	12.7hi
Pokoase Local	59.0hi	31.7abc	12.9i
Golden Crystal	81.3j	33.5def	13.1i
Hi-Lysine	103.3k	30.7ab	15.1j
Mean for improved varieties	44.5	32.8	11.3
Mean for local varieties	52.1	32.4	12.2

[1]Means followed by the same letter within a column are not significantly different from each other at $P \leq 0.05$ by Duncan's Multiple Range Test.

[2]Number of F_1 adults were transformed using log (x+1) before analysis. Retransformed means shown.

Table 4: Tests for statistical significance for pre-planned comparisons of various treatment main effects for number of F_1 weevils, Median Development Period (MDP) and susceptibility indices of 14 newly introduced and 3 local varieties to *S. zeamais*.

Treatment comparison	Statistical significance tests[1]		
	Number of F_1 adults	Median Development Period (Days)	Susceptibility index
Improved vs Local varieties	**	ns	**
White vs Yellow varieties	**	**	ns

[1]The symbols ** and ns indicate significance ($P<0.05$) and not significant ($P>0.05$), respectively.

The nature of the experiment, however, could lead to some deficiencies in finding very clear groupings in susceptibilities. One of the problems is that, laboratory conditions produce behavioural patterns in the insects which bear little resemblance to their behaviour under field or storage conditions where abnormally high population levels could be observed. Also, under the "no-choice" condition of the experiment, where weevils were confined on grains for a number of days, females must oviposit on the grains in order for the population to survive. Dobie (1974) showed that an increase in parental density resulted in a reduction in fecundity. Abnormally high larval densities will result in a reduction of progeny due to intra-specific competition within grains.

3.2 Factors influencing susceptibility

3.2.1 Effect of prolonged storage on susceptibility of grains

Results of the effect of prolonged storage on susceptibility of grains for 3 or 6 months is shown in Table 5. Correlation analyses of the log (x + 1) transformed mean numbers of F_1 adults from the same variety for the two storage periods showed no significant differences ($r = 0.98$, $P>0.05$). The mean MDP and the SI values did not change significantly after different lengths of storage time ($r =0.93$ and $r = 0.98$, $P>0.05$, respectively). Using t-tests to compare the SI values of sound grains with those stored for 3 or 6 months showed no significant results were found ($t = -0.597$ and $t = -0.069$ at $P>0.05$, respectively). These results indicate that storing kernels for a prolonged time did not change their susceptibility suggesting that varieties could maintain their resistance factors during up to a 6-month storage period.

Table 5: Influence of duration of storage on susceptibility of 14 newly introduced and 3 local maize varieties to *S. zeamais*.[1]

Maize variety	3 months storage			6 months storage		
	No. of F_1 adults	MDP (Days)	SI adults	No. of F_1 (Days)	MDP	SI
Aburotia	48.8	31.8	12.2	48.2	32.7	11.8
Composite 4	43.3	32.6	11.5	46.2	32.8	11.6
Dobidi CRI	51.6	32.8	12.0	52.7	33.0	12.0
Dorke SR	35.8	34.8	10.2	34.3	33.9	10.4
Gandajika 8149	32.6	33.6	10.3	33.0	34.3	10.2
Golden Crystal	84.5	33.8	13.1	78.0	33.3	13.1
Hi-Lysine	100.7	30.9	14.9	107.0	31.0	15.1
Kawanzie	31.2	35.1	9.7	29.0	34.8	9.6
La Posta	27.7	33.0	10.0	23.8	33.9	9.4
Mexico 8049	24.2	36.9	8.6	23.0	35.8	8.7
Okomasa	38.3	31.0	11.7	32.2	31.1	11.2
Pool 16SR EV85	33.8	31.6	11.1	34.2	31.8	11.1
Pool 16SR	43.5	31.1	12.1	43.5	31.2	12.1
Safita 2	56.7	32.9	12.2	65.5	33.5	12.5
Ho Local	41.8	33.4	11.2	43.3	32.8	11.5
Kwadaso Local	52.8	32.8	12.1	54.0	32.6	12.3
Pokoase Local	62.0	31.9	12.9	57.7	32.8	12.4
LSD (5%) for varieties[2]	9.8	1.3	0.8	6.7	1.4	0.7

[1]Values are means of 6 replicates. Each replicate is a 50-gram sample infested with 12 females and 6 males for 7 days.
[2]Number of F_1 adults were transformed using log (x+1) before analysis. Retransformed means shown.
Correlation coefficients for number of F_1 adults, MDP, and SI were 0.98, 0.93, 0.98, respectively.

3.2.2 Damaged and totally removed pericarp tissue

The results of tests showing influence of pericarp tissue damage on susceptibility of grains to *S. zeamais* are shown in Table 6. Comparison of the results obtained in this test were made to those obtained in Section 2.1 using sound unbroken grains by t-test are presented in Table 7. Local varieties produced a mean progeny of 80.2 on scratched grains as against 59.6 for those without pericarp (Table 6). No significant differences ($P>0.05$) were observed between the mean number of F_1 adults produced for all the varieties when pericarp was scratched or removed. Progeny weevils developed equally fast ($P<0.05$) on sound kernels and scratched grains. Generally, susceptibility was significantly increased ($P<0.05$) when pericarp tissue was totally removed, indicating that some resistance factor located in the pericarp tissue must have been lost. Results of this experiment support the findings of Arnasson *et al.* (1993) who reported that the maize pericarp tissue contains phenolics which confer resistance to *S. zeamais* and *Prostephanus truncatus*.

Table 6: Influence of grain pericarp tissue damage on susceptibility of 14 newly introduced and 3 local maize varieties to *S. zeamais*.[1]

Maize variety	Scratched pericarp			Totally removed pericarp		
	No. of F_1 adults	MDP (Days)	SI	No. of F_1 adults	MDP (Days)	SI
Aburotia	57.0	31.7	12.7	55.1	30.5	13.2
Composite 4	51.4	32.1	12.2	54.4	31.3	12.8
Dobidi CRI	66.8	31.9	13.1	60.3	31.2	12.8
Dorke SR	45.1	33.1	11.4	44.5	31.3	12.1
Gandajika 8149	37.2	34.5	10.8	43.1	32.6	11.6
Golden Crystal	83.7	33.1	13.3	86.7	31.8	14.0
Hi-Lysine	119.6	30.3	15.8	98.2	29.2	15.7
Kawanzie	34.4	34.3	10.2	38.4	32.9	11.0
La Posta	40.3	33.1	11.1	29.6	31.9	10.6
Mexico 8049	40.8	34.7	10.7	31.1	34.8	9.8
Okomasa	39.5	30.5	12.0	39.5	28.9	12.7
Pool 16SR EV85	45.1	31.4	12.1	45.0	29.9	12.7
Pool 16SR	48.8	30.7	12.6	52.8	29.4	13.5
Safita 2	76.7	33.0	13.1	76.5	32.1	13.5
Ho Local	44.0	31.9	11.9	51.2	30.9	12.7
Kwadaso Local	57.2	33.7	12.7	59.8	30.7	13.3
Pokoase Local	65.8	32.0	13.0	67.8	30.7	13.8
LSD (5%) for varieties	9.9	1.5	0.8	8.1	1.6	0.9
Mean for improved varieties	56.0	32.5	12.3	53.9	31.3	12.6
Mean for local varieties	80.2	32.5	12.2	59.6	30.8	13.3

[1]Values are means of 6 replicates. Each replicate is a 50-gram sample infested with 12 females and 6 males for 7 days.

Table 7: *t*-Tests for comparisons of various treatment main effects for number of F_1 weevils, Median Development Period (MDP) and susceptibility indices (SIs) on influence of grain pericarp tissue damage on susceptibility of 14 newly introduced and 3 local maize varieties to *S. zeamais* [1].

Number of F_1 weevils	Mean X-Y	Paired t-value	Prob (2-tail)
Sound vs Scratched grains	-0.099	-4.716	0.0002
Sound vs Pericarp removed grains	-0.093	-6.754	<0.0001
Scratched vs Pericarp removed grains	0.006	0.407	0.6892
MDP			
Sound vs Scratched grains	0.235	0.923	0.370
Sound vs Pericarp removed grains	1.524	7.758	0.001
Scratched vs Pericarp removed grains	1.288	8.322	0.001
SI Values			
Sound vs Scratched grains	-0.841	-4.862	0.0002
Sound vs Pericarp removed grains	-1.247	-9.566	0.0001
Scratched vs Pericarp removed grains	-0.406	-3.386	0.0047

[1]Each treatment comparison is a mean of 6 replicates; and a replicate is a 50-gram sample infested with 12 females and 6 males for 7 days.

[2]Comparison of these treatments were conducted on log(x+1) transformation

3.2.3 Nutritional or chemical factors

The nutritional or chemical factors of the maize varieties are shown in Table 8. Correlations between the nutritional or chemical factors in the maize varieties with developmental parameters in Table 9 revealed that except for iron levels which showed a significant negative correlation ($P<0.05$) and a positive correlation ($P<0.05$) with MDP and SI values, respectively, none of the tests were significant ($P>0.05$).

Considering the high variation of the physical characteristics of the maize varieties studied, as recorded in Tables 1 and 2, it is also likely that their chemical and nutritional characteristics may vary. Dobie (1977) reported that the protein content of the grain (including the embryo) was in some way highly negatively correlated with the Index of Susceptibility to *S. zeamais*. Generally, maize bearing the "opaque-2" gene as in the variety: High Lysine, produce soft, floury endosperm rich in tryptophan and lysine, the two amino acids which are normally absent in maize. It is widely known that the soft nature of maize grains renders them more susceptible to *S. zeamais* attack and the tryptophan and lysine content also satisfies insect nutritional requirements. These effects were, however, not detected in the present study. Other important factors affecting the development of insects in stored food grains are temperature, atmospheric humidity and grain moisture content.

Table 8. Major nutritional or chemical composition of 14 newly introduced and 3 local maize varieties[1].

Variety	Protein %	Total sugars %	Fat %	Phosphorus %	Calcium %	Iron %	Amylose %	Amylopectin %	Crude Fibre %	Ash %
Aburotia	11.1	4.8	11.5	308.5	43.6	5.3	30.7	69.3	2.5	3.7
Composite 4	11.7	4.7	11.6	327.9	39.7	4.7	30.7	69.3	2.5	3.5
Dobidi CRI	11.4	4.0	10.5	304.9	45.4	4.1	31.1	68.9	2.9	3.7
Dorke SR	11.3	4.3	12.7	300.0	42.2	4.5	30.9	69.1	3.3	3.3
Gandajika	11.7	3.9	11.1	314.5	50.9	4.1	31.5	68.5	3.2	3.7
Golden Crystal	11.6	3.6	10.5	313.6	40.0	4.3	31.0	69.0	2.6	3.7
Hi Lysine	11.7	4.3	13.1	307.8	44.0	5.1	30.5	69.5	2.7	3.6
Kawanzie	10.6	5.0	13.2	309.8	47.0	4.6	30.4	69.6	2.9	3.9
La Posta	11.4	5.0	10.6	322.7	51.6	3.8	31.1	68.9	2.5	3.5
Mexico 8049	11.4	3.6	11.6	326.5	42.1	3.7	31.3	68.7	2.7	3.8
Okomasa	11.5	3.8	11.7	323.9	47.1	4.9	30.9	69.1	3.0	3.8
Pool 16SR	10.8	4.8	10.3	328.7	40.8	5.4	30.7	69.3	2.4	3.6
Pool16SR EV85	11.4	3.8	13.4	308.0	43.3	4.3	30.7	69.3	2.9	3.1
Safita	11.0	4.9	13.2	328.8	45.4	4.0	31.0	69.0	3.0	3.5
Ho Local	10.6	3.5	9.8	304.2	52.2	5.2	30.4	69.6	2.4	3.3
Kwadaso Local	11.2	3.4	10.1	300.5	51.5	5.4	30.7	69.3	2.6	3.5
Pokoase Local	11.0	3.9	9.4	324.1	48.2	4.9	30.5	69.5	2.5	3.7

[1] Values are means of triplicate determinations on dry-weight basis (except for amylose, 2 replicates). See text for the methods used for the determinations.

Table 9: Correlation between developmental parameters of *S. zeamais* with major nutritional/chemical constituents of 14 newly introduced and 3 local maize varieties[1].

Variety	Protein %	Total sugars %	Fat %	Phosphorus %	Calcium %	Iron %	Amylose %	Amylopectin %	Crude Fibre %	Ash %
No. of F_1 adults	0.21ns	-0.09ns	0.01ns	-0.18ns	-0.20ns	0.32ns	-0.33ns	-0.33ns	-0.22ns	0.01ns
MDP	-0.12ns	-0.10ns	0.06ns	-0.12ns	-0.02ns	-0.55*	0.38ns	0.38ns	0.26ns	0.11ns
SI	0.12ns	-0.03ns	-0.06ns	-0.12ns	-0.14ns	0.51*	0.19ns	0.19ns	-0.28ns	0.01ns

[1]Correlation coefficients followed by ns, * indicate that the values are not significantly different (P>0.05) or significantly different (P<0.05), respectively.

3.3 Olfactory factors

3.3.1 Addition of flour to grains

Significantly more ($P<0.01$) F_1 adults emerged from grains to which flour had been added compared with untreated grain. This resulte relatively high susceptibility of the treated grain. Median developm periods of F_1 emergents were equal (Tables 10 and 11). Similar re were reported by Schoonhoven *et al.* (1976) when flour or dough added to resistant or susceptible maize kernels.

Influence of flour addition was thought to result in higher attractic maize grains resulting in unhindered feeding by weevils, which in enabled females to lay relatively more eggs. Tipping (1986) citing Hon *al.* (1969) have reported the presence of *S. zeamais* attraction stimulan maize grains. Oviposition stimulants of this insect have also been fc in maize (Maeshima *et al.*, 1985). It is also thought that by adding flo grains, high levels of feeding and/or oviposition stimulants are rele by the flour thereby resulting higher oviposition on the maize grains.

Table 10: Effect of flour addition on susceptibility of 14 newly introduced and 3 local varieties to *S. zeamais*.

Maize variety	Means of 3 replicates[1]		
	Number of F_1 adults	Median Development Period (Days)	Susceptibility index
Aburotia	55.2	32.1	12.5
Composite 4	53.5	31.7	12.5
Dobidi CRI	59.2	30.6	13.3
Dorke SR	43.1	35.8	10.5
Gandajika 8149	37.0	33.5	10.8
Golden Crystal	89.3	34.3	13.1
Hi-Lysine	110.8	30.1	15.7
Kawanzie	32.8	36.3	9.5
La Posta	31.3	33.4	10.3
Mexico 8049	26.9	37.8	8.7
Okomasa	40.8	29.1	12.7
Pool 16SR EV85	45.4	31.9	12.0
Pool 16SR	51.8	30.8	12.8
Safita 2	66.6	33.0	12.7
Ho Local	48.3	34.1	11.3
Kwadaso Local	64.5	33.0	12.6
Pokoase Local	67.3	32.6	12.9
LSD (5%)	9.6	2.4	1.0

[1]Each replicate is a 50-gram sample infested with 12 females and 6 males for 7 days.

Table 11: *t*-Tests comparing developmental parameters of *S. zeamais* on 14 newly introduced and 3 local maize varieties with and without addition of maize flour[1].

Treatment comparison[2]	Mean X-Y	Paired t-value	Prob (2-tail)
F_1 (With vs Without Flour)	-0.086	-7.231	<0.0001
MDP (With vs Without Flour)	-0.266	-0.943	0.3598
SI (With vs Without Flour)	-0.529	-3.853	0.0014

[1]Each treatment comparison is a mean of 3 replicates, and a replicate is a 50-gram sample infested with 12 females and 6 males for 7 days.
[2]Comparison of F_1 adults conducted on log(x+1) transformation.

3.3.2 Addition of mouldy grains

The influence of adding mouldy grains to sound ones on the susceptibility of *S. zeamais* has been shown to result in the production of significantly ($P<0.01$) more F_1 adults compared with those without mouldy grains (Table 3). Although this did not result in the prolongation of developmental periods of the weevil, Susceptibility Indices were significantly influenced ($P<0.05$). (Tables 12 and 13).

Water content of grains usually increases when grains are mouldy and also infested by stored-product pests. This high moisture content renders the grains more suitable for further invasion and development of mould. Studies carried out by Sinha and Sinha (1991) on the relationship between infestation of wheat by *S. oryzae* and the development of *Aspergillus flavus*, have shown a close connection between the weevil and *A. flavus*. The probability of infection of the crop increased when *S. oryzae* was present. Confirmation of the presence of the fungus was shown by the presence of highly toxic aflatoxin B_1 and B_2 produced by the fungus in lots infested by *S. oryzae*.

Table 12: Effect of addition of mouldy grain on susceptibility of 14 newly introduced and 3 local varieties to *S. zeamais*.

Maize variety	Means of 3 replicates[1]		
	Number of F_1 adults	Median Development Period (Days)	Susceptibility index
Aburotia	53.5	30.9	12.9
Composite 4	52.1	31.7	12.5
Dobidi CRI	57.4	30.4	13.3
Dorke SR	35.7	36.4	9.8
Gandajika 8149	35.1	34.2	10.3
Golden Crystal	88.7	34.7	13.0
Hi-Lysine	100.7	29.7	15.6
Kawanzie	34.5	35.4	10.0
La Posta	28.4	32.5	10.3
Mexico 8049	31.0	37.7	9.1
Okomasa	40.3	29.3	12.5
Pool 16SR EV85	42.5	31.8	11.8
Pool 16SR	51.4	30.7	12.8
Safita 2	67.5	34.8	12.1
Ho Local	44.3	34.5	11.0
Kwadaso Local	65.6	33.9	12.3
Pokoase Local	66.7	31.2	13.4
LSD (5%)	12.7	3.0	1.3

[1]Each replicate is a 50-gram sample infested with 12 females and 6 males for 7 days.

Table 13: *t*-Tests comparing developmental parameters of *S. zeamais* on 14 newly introduced and 3 local maize varieties after addition of mouldy grain[1].

Treatment comparison[2]	Mean X-Y	Paired t-value	Prob (2-tail)
F_1 (With vs Without Mouldy grain)	-0.074	-4.866	0.0002
MDP (With vs Without Mouldy grain)	-0.224	-0.698	0.4955
SI (With vs Without Mouldy grain)	-0.459	-2.808	0.0126

[1]Each treatment comparison is a mean of 3 replicates, and a replicate is a 50-gram sample infested with 12 females and 6 males for 7 days.
[2]Comparison of F_1 adults conducted on log(x+1) transformation.

Table 14: Effect of addition of longitunally halved grains on susceptibility of 14 newly introduced and 3 local varieties to *S. zeamais*.

Maize variety	Means of 3 replicates[1]		
	Number of F_1 adults	Median Development Period (Days)	Susceptibility index
Aburotia	57.6	34.1	11.9
Composite 4	51.3	32.0	12.3
Dobidi CRI	59.6	33.3	12.3
Dorke SR	44.5	36.2	10.5
Gandajika 8149	41.5	34.9	10.7
Golden Crystal	82.2	35.7	12.4
Hi-Lysine	91.3	31.8	14.4
Kawanzie	33.4	33.6	10.4
La Posta	29.0	33.9	10.0
Mexico 8049	23.7	36.9	8.5
Okomasa	41.1	30.0	12.3
Pool 16SR EV85	42.4	34.3	11.0
Pool 16SR	55.3	32.1	12.6
Safita 2	68.3	34.1	12.4
Ho Local	48.0	34.9	11.1
Kwadaso Local	67.2	34.9	12.1
Pokoase Local	67.5	33.8	12.5
LSD (5%)	10.8	3.6	1.5

[1]Each replicate is a 50-gram sample infested with 12 females and 6 males for 7 days.

Table 15: *t*-Tests comparing developmental parameters of *S. zeamais* on 14 newly introduced and 3 local maize varieties after addition of longitudinally halved grains.[1]

Treatment comparison[2]	Mean X-Y	Paired t-value	Prob (2-tail)
F_1 (With vs Without Halved grains)	0.080	5.337	0.0001
MDP (With vs Without Halved grains)	-1.206	-4.123	0.0004
SI (With vs Without Halved grains)	-0.147	-0.847	0.2048

[1]Each treatment comparison is a mean of 3 replicates, and a replicate is a 50-gram sample infested with 12 females and 6 males for 7 days.

[2]Comparison of F_1 adults conducted on log(x+1) transformation.

3.3.4 Addition of germinated grains

When germinated grains were added to ungerminated maize and tested for *S. zeamais* susceptibility, no significant differences (P>0.05) were observed in the number of F_1 adults and length of development among the varieties, when compared with untreated controls (Tables 15 and 16). These results are contrary to those reported by Schoonhoven *et al.* (1976) after conducting studies on the conditions that modify expression of resistance of maize grains to the maize weevil, These workers concluded that weevil progeny numbers/line differed significantly among lines and among germination periods (0, 12, 24, 36 and 48), but interaction was not significant. For all lines, increasing germination time decreased resistance, and weevils tended to develop faster in germinated grain but weighed less upon emergence, indicating changes in the endosperm. It is not known what factors in the germinated kernels induced a relatively high susceptibility of grains. Gernerally, germinated grains have higher moisture content than ungerminated grains, which could have contributed in raising the moisture content of all grains in the jars, which in turn, increased grain susceptibility to *S. zeamais*. Moisture content is widely known to be an important factor determining oviposition and development of *S. zeamais* on maize grains. Rossetto (1966) also reported that germination of rice seeds reduce their resistance to insects. Studying the resistance of 1700 rice accessions this author found that germination induced fungal infection of grains and also that *S. zeamais* could penetrate tight husks when they germinated and showed fungus infections.

Table 16: Effect of addition of germinated grains on susceptibility of 14 newly introduced and 3 local varieties to *S. zeamais*.

Maize variety	Means of 3 replicates[1]		
	Number of F_1 adults	Median Development Period (Days)	Susceptibility index
Aburotia	49.6	35.2	11.1
Composite 4	48.4	32.2	12.1
Dobidi CRI	57.9	30.7	13.2
Dorke SR	39.3	34.5	10.7
Gandajika 8149	42.5	33.5	11.3
Golden Crystal	75.1	33.7	12.9
Hi-Lysine	86.7	29.6	15.2
Kawanzie	37.8	31.0	11.7
La Posta	26.6	34.2	9.7
Mexico 8049	26.7	36.4	9.1
Okomasa	43.6	28.6	13.2
Pool 16SR EV85	39.9	33.9	10.9
Pool 16SR	50.4	31.2	12.8
Safita 2	63.8	32.9	12.7
Ho Local	53.5	35.7	11.2
Kwadaso Local	60.4	32.1	12.8
Pokoase Local	67.1	31.0	13.6
LSD (5%)	12.6	4.5	2.0

[1]Each replicate is a 50-gram sample infested with 12 females and 6 males for 7 days.

Table 17: *t*-Tests comparing developmental parameters of *S. zeamais* on 14 newly introduced and 3 local maize varieties after addition of germinated grains.[1]

Treatment comparison[2]	Mean X-Y	Paired t-value	Prob (2-tail)
F_1 (With vs Without Germinated grains)	-0.032	-0.687	0.5017
MDP (With vs Without Germinated grains)	-0.024	-0.057	0.0004
SI (With vs Without Germinated grains)	-0.547	-2.461	0.2048

[1]Each treatment comparison is a mean of 3 replicates, and a replicate is a 50-gram sample infested with 12 females and 6 males for 7 days.

[2]Comparison of F_1 adults conducted on log(x+1) transformation.

3.4 Varietal susceptibility of flour to *T. castaneum* attack

The main criterion used for susceptibility of the varieties to *T. castaneum* was the number of progeny weevils, along with their fresh weights. By the nature of the experiments where all F_1 adults were counted on day 35 after removal of the parental adults, it was not possible to determine the duration of development of the insect on each variety.

Small but significant differences ($P<0.05$) were observed in the number of F_1 progeny among varieties (Table 18). Significant differences were also observed between the 14 new and 3 local varieties. White- and yellow-grained varieties produced similar numbers of F_1 adults ($P>0.05$). When compared with normal maize, the opaque-2 variety, Hi-Lysine produced significantly more eggs. Analysis of variance of F_1 adult weights gave no significant differences ($P>0.05$) among varieties. Mean weights ranged from 1.16 mg in Gandajika to 1.482 mg in Mexico 8049, both improved varieties.

Successful development of *T. castaneum* is highly dependent on the degree of maize breakage. Arbogast (1991) compared the fecundity, developmental periods, and survival and population increase in whole corn, cracked corn and corn meal and reported that the number of eggs per female was highest in the maize meal medium, and lowest on whole maize. The degree of association between the number of F_1 *T. castaneum* emerging from the milled grains with number of F_1 *S. zeamais* that emerged from whole grains was not significant suggesting that the factors that are responsible for the final F_1 adult numbers may be different or not operating in the same way for the milled flour or grains of the same variety. Further experiments would need to be conducted to explain the factors responsible for the difference in susceptibility of maize to the two insects.

Table 18: Mean number F_1 and the weights of *T. castaneum* adults emerging from flours of 14 newly introduced and 3 local maize varieties.

Varieties	Mean number of F_1 adults[1]	Mean F_1 adult weight[2]
Mexico 8049	26.5	1.48
La Posta	29.6	1.39
Kawanzie	22.3	1.16
Dorke SR	20.3	1.43
Gandajika 8149	26.0	1.16
Ho Local	31.0	1.30
Okomasa	26.9	1.32
Pool 16SR EV85	29.9	1.41
Composite 4	29.6	1.31
Aburotia	26.5	1.30
Dobidi CRI	22.3	1.33
Pool 16SR	31.1	1.34
Safita 2	22.2	1.45
Kwadaso Local	31.0	1.23
Pokoase Local	37.5	1.37
Golden Crystal	25.9	1.42
Hi-Lysine	37.4	1.48
LSD (5%)[3]	6.8	0.24

[1] Values are means of 6 replicates. Each replicate is a 100-gram flour sample. All F_1 were counted after parental adults were removed on day 35 after removal of parental insects.

[2] Determined from 10 randomly selected adults from each replicate.

[3] Computed for F_1 on log(x+1) transformed values. Retransformed values shown.

In breeding for resistance, the first step will be to screen commercial and locally adapted varieties to separate susceptible from resistant ones. According to the intensity of the programme, this may proceed from recommending the less susceptible or more resistant varieties, if available, to searching for resistance in exotic varieties and related wild species, if resistance could not be found near at hand. Number of F_1 adults and median developmental periods, which determine Susceptibility Indices are factors that favour permanence of resistance in maize varieties. In assessing results of susceptibility trials, the significance of any results obtained must be determined in conjunction with other known characteristics of the variety. Crosses must be made between resistant and susceptible varieties and select those progenies that segregate jointly for these two characters as well as other desirable characteristics. Obviously, interest is to be shown in those resistance factors that are specific and have no detrimental effect on human and animal nutrition.

This study has also confirmed various factors which have been previously identified as responsible for conferring resistance on maize grains. The importance of factors such as pericarp damage, nutritional or chemical, and addition of flour, mouldy, broken and germinated grain to sound grain, have been observed in the relatively high susceptibility of maize varieties in the experiments conducted. These are factors coupled with the environmental conditions are encountered during storage of the crop in open cribs or barns, e.g. mechanical damage of grains at harvest, or mouldiness caused by rain or improper drying of the crop after harvest. Maize storage is a multi-faceted activity requiring pre- and post-harvest activities. It is a complex mix of maize cultivation practices, maize cob structure, inherent grain properties, and the food processor, which operates within a complex environmental and economic matrix.

Results of this study have shown that clear differences exist in the susceptibility or resistance of maize grains or flour to *S. zeamais* or *T. castaneum*, respectively. Since the degree of association is not significant, a susceptibility test either for *S. zeamais* or *T. castaneum*, will be necessary in discriminating maize varieties when the target storage method is maize grains or flour.

Developing a sound control strategy for storage insects have been beset with discipline-oriented approaches. Plant breeders would tend to emphasize on the varietal differences, most especially yield and other favourable agronomic characters. Obviously, the potential yield of any variety is the most important consideration in deciding whether or not to grow it. Before the insect susceptible factor prevents the maize from being grown, the increase in yield must far exceed the increase in loss due to changing to a new variety. Other factors may play important roles in the choice of a new variety. For example, small-scale farmers who store their produce in cribs or barns for example, will stress on factors such as long and tight husk cover, which are important in determining the extent to which husks can protect the ears before harvesting as well as the progress of infestation.

Developing high-yielding maize varieties that are insect resistant will considerably minimise the overall cost of production and storage of maize. This will reduce the likely hazards of consuming maize indiscriminately treated with insecticides, which pose environmental hazards and cause resistance in insects. For the small-scale farmer, an important feature in controlling the crop in storage will be developing an integrated control approach. The major feature of this approach is purposefully manipulating the environment, including the choice of resistant hostplant, to make it unfavourable to the pest species and/or more favourable to its natural enemies. Varietal resistance can provide the basis on which to use an integrated control system. This may be most effective when used as an adjunct to cultural, chemical and biological control methods.

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