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Mora, M.A.; Pedersen, J.R.

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9. ABSTRACT

Maize (Zea mays L.) with 12.5 and 14.2% initial moisture content (M.C.), both uninfested and infested with Sitophilus zeamais Motsch, was stored in variable (outdoor) and constant (indoor, 25±0.5°C, 70±4% r.h.) environments. Samples from top and bottom sections of containers (761) were analyzed every 4 weeks for 24 weeks. Moisture contents and temperatures of infested maize increased because of insect activity. Development of weevil populations outdoors was slowed by cool temperatures. Indoors, insect populations were higher than outdoors, however differences between populations in low and high initial M.C. maize were not consistent. Predominant storage fungi were Asperigillus glacus and A. restrictus groups. Weevil damage and fungal invasion decreased seed viability. Weight loss correlated highly ($P<0.01$) with weevil populations and weevil damage. No obvious changes in proximate analysis (protein, fat, fiber, and ash) were noted during the 24-week period.

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DAMAGE TO STORED MAIZE INFESTED WITH *Sitophilus zeamais* Motsch.

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MANHATTAN, KANSAS 66506

REPORT SUMMARY

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Principal Investigator: Miguel A. Mora

SUMMARY STATEMENT

Maize (*Zea mays* L.) with 12.5 and 14.3% initial moisture content (m.c.), both uninfested and infested with *Sitophilus zeamais* Motsch., was stored in variable (outdoor) and constant (indoor, 25 ± 0.5°C, 70 ± 4% r.h.) environments.

Samples from top and bottom sections of containers (76 l) were analyzed every 4 week for 24 weeks.

Moisture contents and temperatures of infested maize increased because of insect activity.

Development of weevil populations outdoors was slowed by cool temperatures. At the end of the experiment in December (winter), all weevils were dead. Maximum average weevil population outdoors was 150/kg; indoors 646/kg.

Outdoors, weevil populations in maize with 14.3% initial m.c. were double those in maize with 12.5% initial m.c. Indoors, insect populations were higher than outdoors, however, differences between populations in low and high initial moisture content maize were not consistent.

Under our test conditions, visual (visible to the unaided eye) weevil damage by number of damaged kernels is easy to determine and results are highly correlated with both weevil damage determined with X-ray and visual damage by weight.

Predominant storage fungi were Aspergillus glacus and A. restrictus groups. The relationship between fungi and weevil infestations is probably more closely related to increased moisture because of insect activity than to weevil feeding damage itself.

Weevil damage and fungal invasion decreased seed viability.

Test weight decreased with increasing weevil damage but was not significantly correlated with weevil populations or weevil damage.

Dry matter weight loss in infested maize as measured by weighing whole replicates ranged from 1.7 to 9.7%. The replicate with 1.7% weight loss had 10% by wt visual weevil damage compared with 40% by wt visual insect damage for the replicate with 9.7% weight loss.

Weight loss correlated highly ($P<0.01$) with weevil populations and weevil damage.

No obvious changes in proximate analysis (protein, fat, fiber and ash) were noted during the 24 week experiment.

Fat acidity values (FAV) were not consistently related to degree of insect damage or fungal invasion.

DAMAGE TO STORED MAIZE INFESTED WITH

Sitophilus zeamais Motsch.

Prepared by

Miguel A. Mora
and
John R. Pedersen
Grain Science and Industry
Kansas State University

Prepared for the
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at the
FOOD AND FEED GRAIN INSTITUTE
Kansas State University
Manhattan, Kansas 66506

Dr. William J. Hoover, Director
Dr. Leonard W. Schruben, Associate Director

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INTRODUCTION

Insects are a major cause of damage to stored grain. They consume grain and contaminate larger quantities of it with their bodies, exuviae, feces, silk, etc. Insect infestation in grain also causes heating and moisture increases and enhances development of microorganisms. These factors result in further damage to the grain.

Several methods have been developed to measure grain damage. A comparison of the possibilities and suitability of these methods to measure weevil damage in different storage situations was needed.

Most storage studies of weevil-infested grain are under controlled environments using small-sized samples (near 1 kg or less). Although these experiments are valuable, experiments that represent actual storage situations using larger grain masses are needed.

In this study 50 kg lots of weevil-infested maize were stored in an outdoor environment, and results were compared with those obtained in a controlled environment. The effects of grain moisture, storage environment, and location within containers upon increases in weevil population were studied. Changes produced by weevils in maize were determined by several analytical methods commonly used for grain quality determination. The purpose of this work was to study the (1) effectiveness of several methods to assess weevil damage in maize, (2) effect of environment, location of weevils in containers, and initial moisture content of maize on degree of weevil damage, and (3) relationship between methods used in assessing weevil damage.

MATERIALS AND METHODS

Insect infested and uninfested maize (Zea mays L.) was stored in two environments; a variable environment (outdoors, Kansas State University campus) where the grain was exposed to average weekly temperature of 0 to 29.4°C and average weekly relative humidity between 43 and 75% (Fig. 1), and a constant environment (indoors) with controlled temperature (25 ± 0.5°C) and relative humidity (70 ± 4%).

Weekly temperatures and relative humidities shown in Fig. 1 are averages of hourly readings taken by the Department of Physics, Kansas State University.

Outdoors, containers of maize were protected from the weather with a plastic canopy placed about 30 cm above them (Fig. 2A).

Eight 20 gal (76 l) plastic drums were used as containers in each storage environment (Figs. 2A-2B). Each drum contained 50 kg of sound yellow dent maize which had been cleaned in a Clipper 167-D seed cleaner. Four of the drums contained maize with 12.5% m.c. and 4 with 14.3% m.c. Two drums of each moisture level were infested with 500 unsexed adult maize weevils, Sitophilus zeamais Motsch., from a Mexican line reared in the Department of Entomology, Kansas State University. The other drums were used as controls.

Each drum lid had two 10 cm dia holes, one on each side of the handle, covered with 80 mesh brass gauze and filter paper. These holes allowed air exchange. Lids also had five, 5 cm holes, one centered and 4 toward the edge at cardinal points. These smaller holes were used for

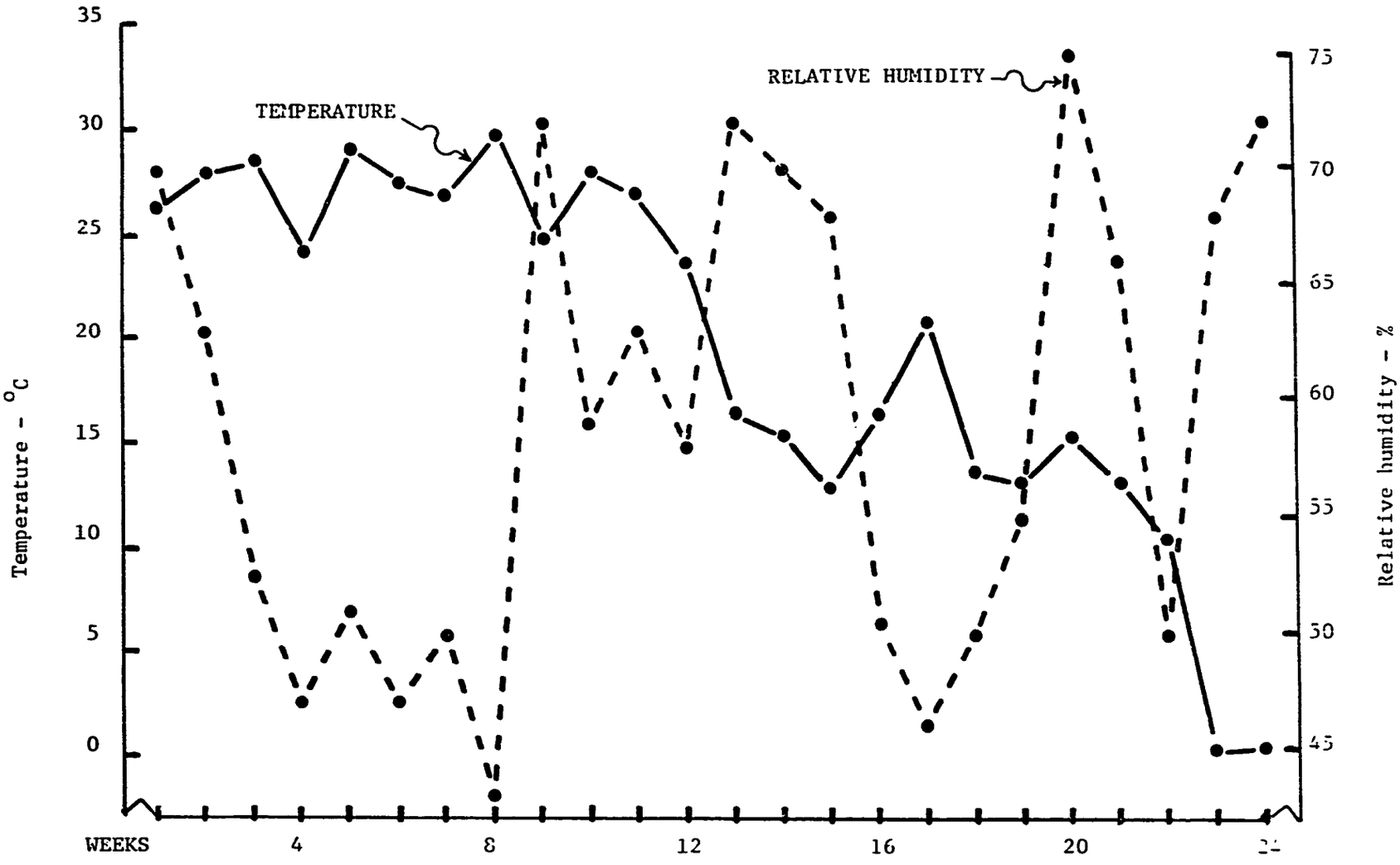
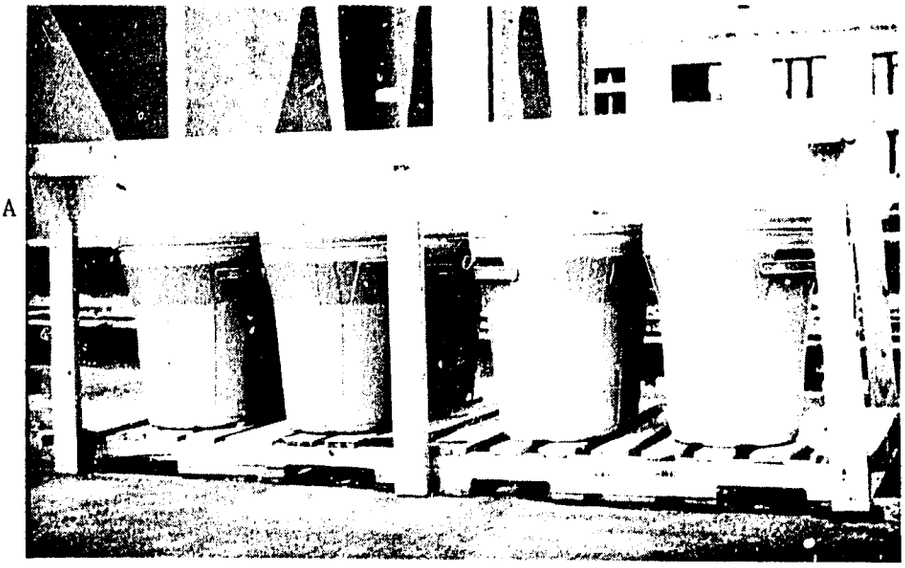


FIG. 1. Average weekly temperature and relative humidity (from hourly readings) in Manhattan, Kansas, between June 24 and December 6, 1975. Source: KSU Physics Department.

A



B

FIG. 2. Containers with maize uninfested and infested with Sitophilus zeamais, stored under variable (A, outdoor) and constant (B, indoor) environments.

sampling and were fitted with rubber stoppers (Fig. 2B).

Samples were taken through the five sampling holes at the beginning and at 4 wk intervals during a 24 wk period, using a 100 x 3.5 cm sampling probe with separated compartments. Contents of each probe were divided into two equal parts representing the top and bottom sections of drums. Composites were made of the top samples from each drum. Bottom samples were also composited.

Temperatures of top and bottom sections of each drum were recorded from thermister readings at each sampling time.

All drums were weighed at each sampling time. Percent dry matter weight loss was calculated adjusting for sample weights and moisture contents.

Live and dead weevils in each sample were counted. Results are presented as number of weevils/kg of maize.

Moisture content, wet-weight basis, was determined by the air oven method for whole maize kernels as published by the AMERICAN ASSOCIATION OF CEREAL CHEMISTS (1969) (10-15 g samples were heated at 103°C for 72 hr).

Fat acidity values (FAV) were determined by the colorimetric method of BAKER (1961) in ground air dried samples.

Percent invasion by fungi was determined on 50 kernels, surface disinfected in 2% sodium hypochlorite for 1 min, rinsed with sterile water, and plated on malt agar media with 4% NaCl and 200 ppm Tergitol. Fungi were identified after about 1 wk incubation at 25°C. Percentage of seeds invaded by each kind of fungus was determined.

Duplicate germination tests were run by placing 50 kernels in

wet paper towels wrapped in aluminum foil. After 1 wk at 25°C, all seeds with any size sound sprout were counted as viable.

Samples of 100 g were X-rayed using a General Electric Grain Inspection Unit. Number of weevil-damaged kernels per 100 g was determined by examining the radiographs. MILNER et al (1950), PEDERSEN and BROWN (1960), SHARIFI and MILLS (1979), and others have used the X-ray technique to study stored grain insects.

X-rayed samples were also used for visual (visible to the unaided eye) weevil-damage determinations. All kernels with visual weevil-damage were counted and weighed. Percent weevil-damaged kernels was determined by weight (wt) and by number (No.).

Density (test weight or weight per unit volume) was determined according to official method (USDA, 1953), only on samples taken at 4, 12, and 20 wk. Results are expressed in lb/bu.

Proximate analyses were made in the Analytical Service Laboratory, Department of Grain Science and Industry, using standard methods.

RESULTS AND DISCUSSION

Weevil Populations (Fig. 3)

No more than 6 weevils/kg were found in any samples from the top section of infested drums stored outdoors. Weevil populations increased at the bottom of infested drums to 35-39 weevils/kg by 12 wk storage. There was little increase after 12 wk in the 12.5% initial m.c. samples but weevil populations continued to increase in the 14.3% initial m.c. samples to 150/kg by 24 wk. At this time all weevils were dead probably because of low outdoor temperatures during the last weeks of storage (Fig. 1).

Infested drums stored indoors also had more weevils in the bottom samples up to 12 wk. However, by 24 wk weevil populations increased to 645/kg in the top and to 81/kg in the bottom samples with 14.3% initial m.c.

Large differences in numbers of weevils between replicates were noted. One replicate of maize with 14.3% initial m.c. stored indoors reached an infestation of 1000 weevils/kg at the top by 24 wk. The top section of the other replicate had only 291 weevils/kg, similar to the final population at the top of one of the replicates with 12.5% initial m.c. (269 weevils/kg). The other 12.5% initial m.c. replicate indoors had 101 weevils/kg in the top at 24 wk.

Large differences were observed between average weevil populations of treatments but these were not statistically significant because of the wide variations between replicates. The average weevil population data

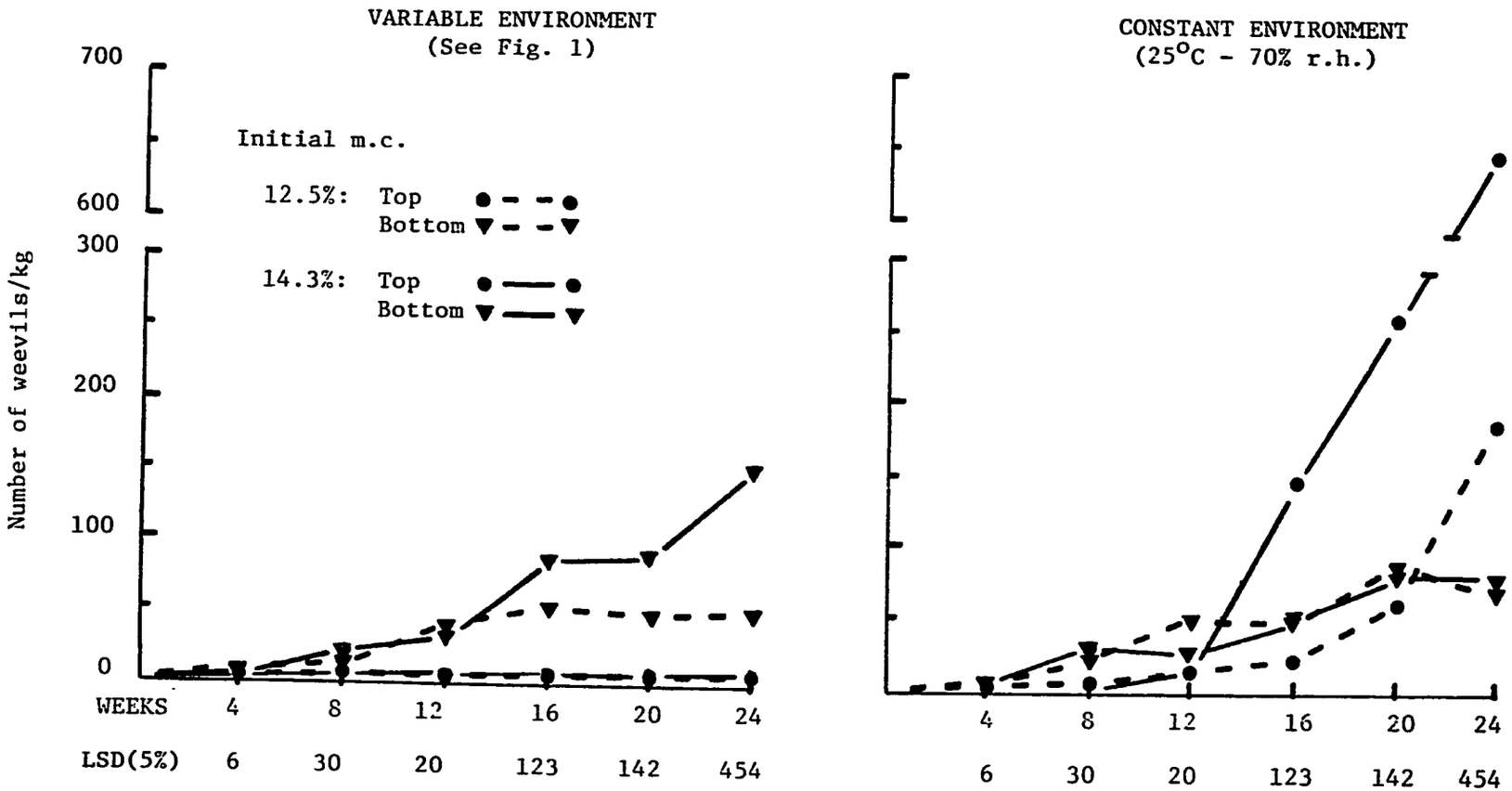


FIG. 3. Weevil populations in maize infested with Sitophilus zeamais and stored in two environments. Averages of two replicates.

seems to indicate that treatment effects were real.

Weevils used to infest test drums were placed on the upper surface of maize. In all cases initial increases of weevil populations began at the bottom of the drums. Later, in some replicates, weevils began to invade top sections of drums. This was probably due to overcrowding in bottom sections of drums as suggested by HOWE (1951).

HOWE (1951) found that Sitophilus spp. in grain have a predominant movement toward the bottom of containers and that the major factor limiting this movement is tightness of packing. This could explain the beginning of population increases at the bottom of containers in this and previous work (MORA and PEDERSEN, 1975) because maize provides ample interseed space for downward movement of weevils. However, AGRAWAL et al (1958) reported that granary weevil population increase in wheat began at the top of containers, whereas CHRISTENSEN and HODSON (1960), also working with granary weevil in wheat, noted that population increases began at the bottom of containers.

A tendency for insect infestation to initially develop at the bottom of grain masses is important since considerable damage can occur in stored grain before the infestation is detected.

The main factor controlling weevil population increase in this study was temperature. Cooling outdoor temperature inhibited weevil population increase and killed all weevils by the end of the experiment in December (winter). Indoor weevil populations increased steadily during the experiment.

Moisture Content (Figs. 4 and 5)

Moisture content of maize changed as a result of weevil activity and environment.

Except for bottom samples of infested drums, maize stored outdoors lost moisture. Loss ranged from 0.4 to 1.8% m.c. Weekly average relative humidity outdoors, varied between 43 and 75% during the storage period (Fig. 1). Maize stored under these relative humidities would have between 10 and 16% m.c. (PIXTON and WARBURTON, 1971). Environmental conditions outdoors were such that final moisture content of maize was lower than initial moisture content.

Outdoors, most insects were found in bottom samples. Moisture content of these samples began increasing after 8 wk as a result of increased insect population. By 24 wk moisture content increased to 13.3% in samples with 12.5% initial m.c. and to 15.4% in samples with 14.3% initial m.c.

In maize stored indoors, moisture content increased in all samples with 12.5% initial m.c. The moisture content of the maize with 14.3% initial m.c. change little during the experiment. Maize stored under out indoor condition would be expected to reach an equilibrium moisture content of about 13.5% (PIXTON and WARBURTON, 1971).

Indoors, moisture content increased about 2% in infested maize with both initial moisture contents.

Increase in moisture content due to insect activity has been reported by BRONSWIJK and SINHA (1971), CHRISTENSEN and HODSON (1960), and others. In results reported here, a highly significant correlation ($P<0.01$) was found between weevil population and moisture content.

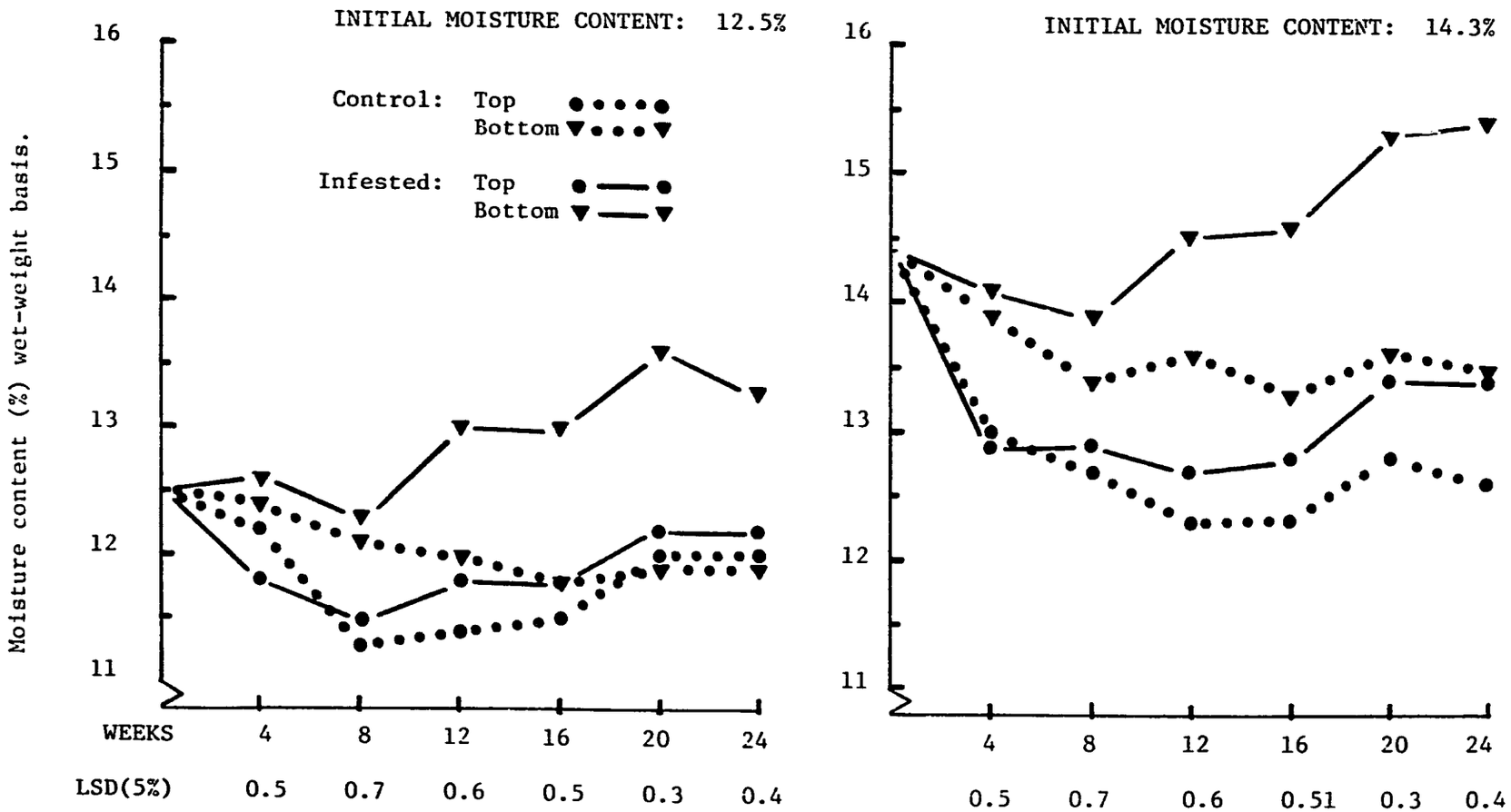


FIG. 4. Moisture content of maize infested with Sitophilus zeamais and stored in a variable environment (See Fig. 1.) Averages of two replicates.

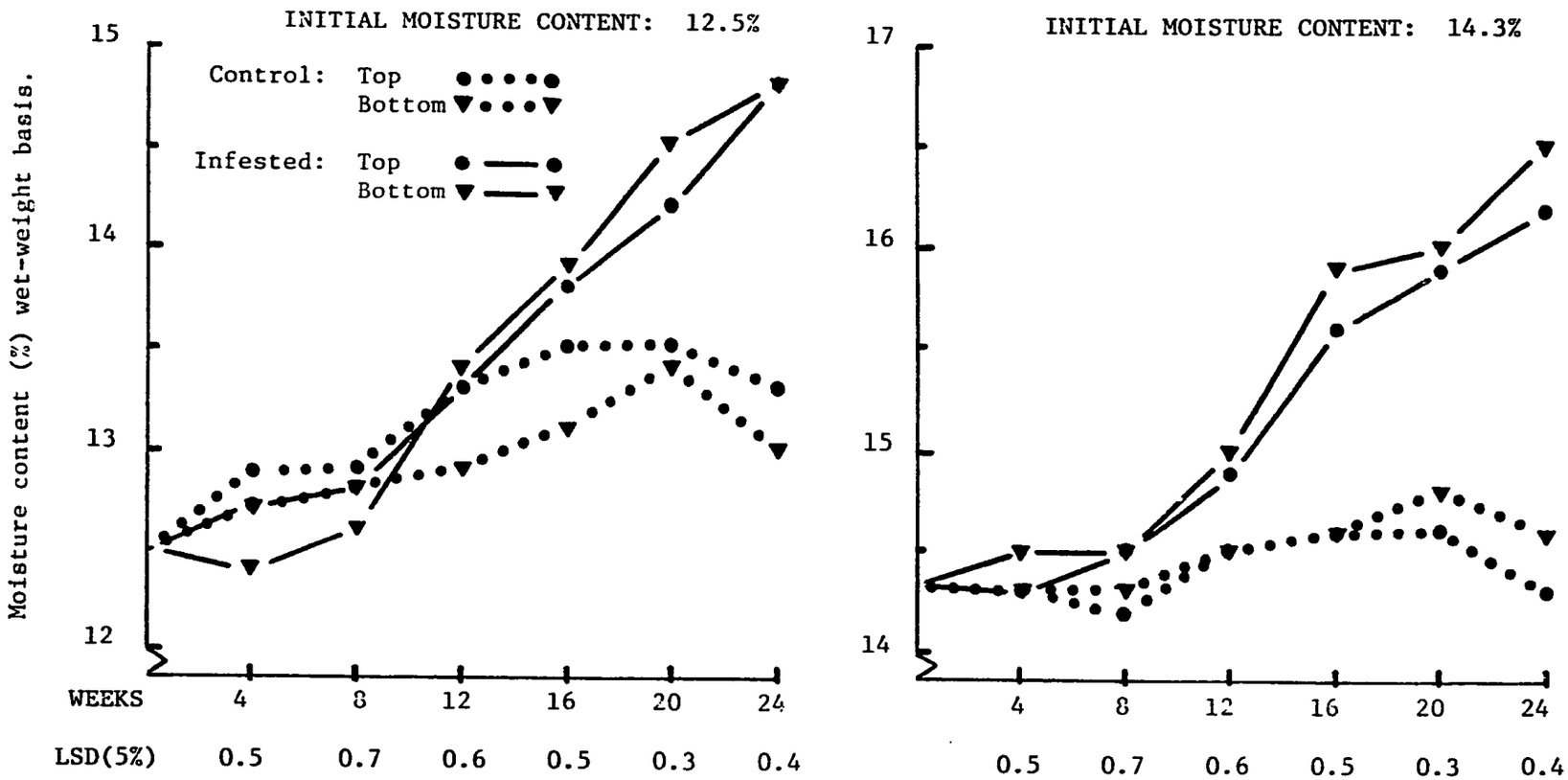


FIG. 5. Moisture content of maize infested with Sitophilus zeamais and stored in a constant environment (25°C - 70% r.h.). Averages of two replicates.

Temperature (Fig. 6)

Initial temperature of maize stored outdoors was 26.6°C. After 4 wk it increased to 36°C, then gradually decreased to 3.2-3.7°C at 24 wk. There were no differences larger than 1.4°C between top and bottom sections of between drums at any given sampling time. The average maize temperatures were: 36.2°C at 4 wk, 31.3°C at 8 wk, 16.8°C at 12 wk, 18.5°C at 16 wk, 17.1°C at 20 wk, and 3.4°C at 24 wk. Outdoors, maize temperatures varied with ambient temperatures (Fig. 1).

Indoors, temperature of control maize remained similar to room temperature while it increased to 31.7°C in top sections of infested maize with 14.3% initial m.c. At 24 wk temperature in the bottom section of these drums was 27.3°C.

Temperature of 12.5% initial m.c. infested maize stored indoors, increased to 30.1°C in the top section and to 27.0°C in the bottom.

No differences in temperature were found between bottom sections of infested drums of either moisture level, however, temperatures were significantly ($P<0.05$) lower in bottom than in top sections.

Insect activity is reported to cause increases in temperature of grain masses (BRONSWIJK and SINHA, 1971, CHRISTENSEN and HODSON, 1960, and others). Increased temperatures are used to detect insect infestations in commercial grain storage. Under our test conditions temperature was not effective in detecting early weevil infestation and damage. Amount of maize used in this experiment was probably not large enough to retain heat produced by activity of low weevil populations. Correlation coefficient between maize temperature and weevil population was significant ($P<0.05$) but low ($r=0.361$, 46 d.f.).

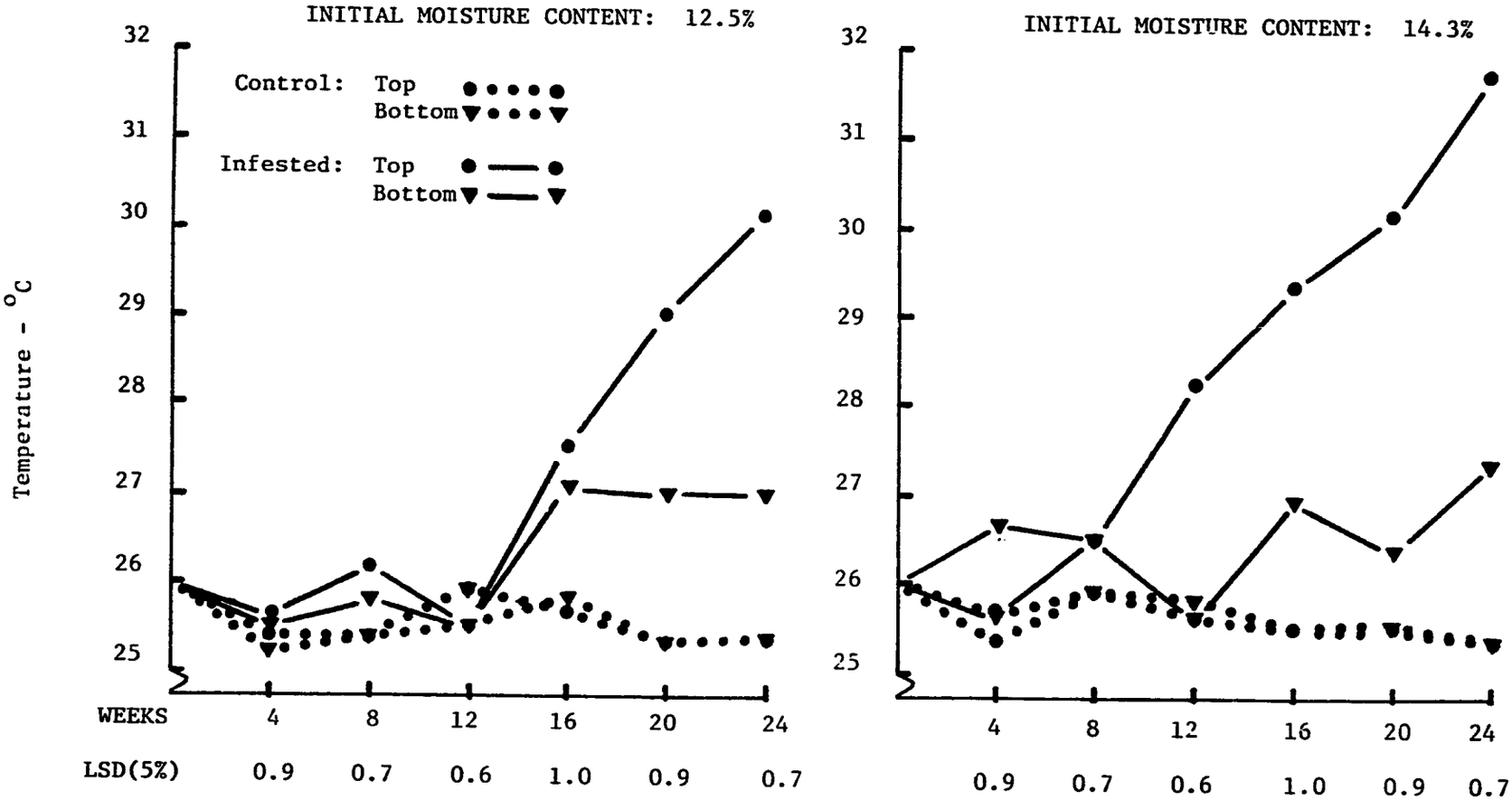


FIG. 6. Temperature of maize infested with Sitophilus zeamais and stored in a constant environment (25°C - 70% r.h.). Averages of two replicates.

X-ray Test (Fig. 7)

X-ray results are highly correlated ($P<0.01$) with weevil populations (Fig. 3).

Outdoors, weevil damage determined by X ray increased steadily at the bottom of drums to near 80 damage kernels/100 g by 16 wk. There was no further damage increase in the 12.5% initial m.c. maize. Damage continued to increase in maize with 14.3% initial m.c. to 130 weevil-damaged kernels/100 g by 24 wk. Only minor weevil damage was found in top sections of drums stored outdoors.

Indoors, minor weevil damage was also found in top samples during 8 wk. At this time there were 30 damage kernels/100 g in bottom samples with 12.5% initial m.c. maize and 50 in the bottom samples with 14.3% initial m.c. After 8 wk, weevil damage began increasing in top sections. At 24 wk there were 136 and 288 damaged kernels/100 g in 12.5% and 14.3% initial m.c. maize, respectively. Final damage shown by X ray in top sections was about 2.5 and 3.7 times the damage in their respective bottom sections. Increased weevil damage in top samples corresponds to increased weevil populations.

The X-ray technique is excellent to detect weevil damage. In the present study was used to confirm results obtained by other means. However, the cost of equipment installation and operation may limit its usefulness.

Visual Weevil Damage (Figs. 8 and 9)

Visual weevil damage is expressed as percent by weight (Fig. 8) and by number (Fig. 9). These results are alike and agree with the X-ray

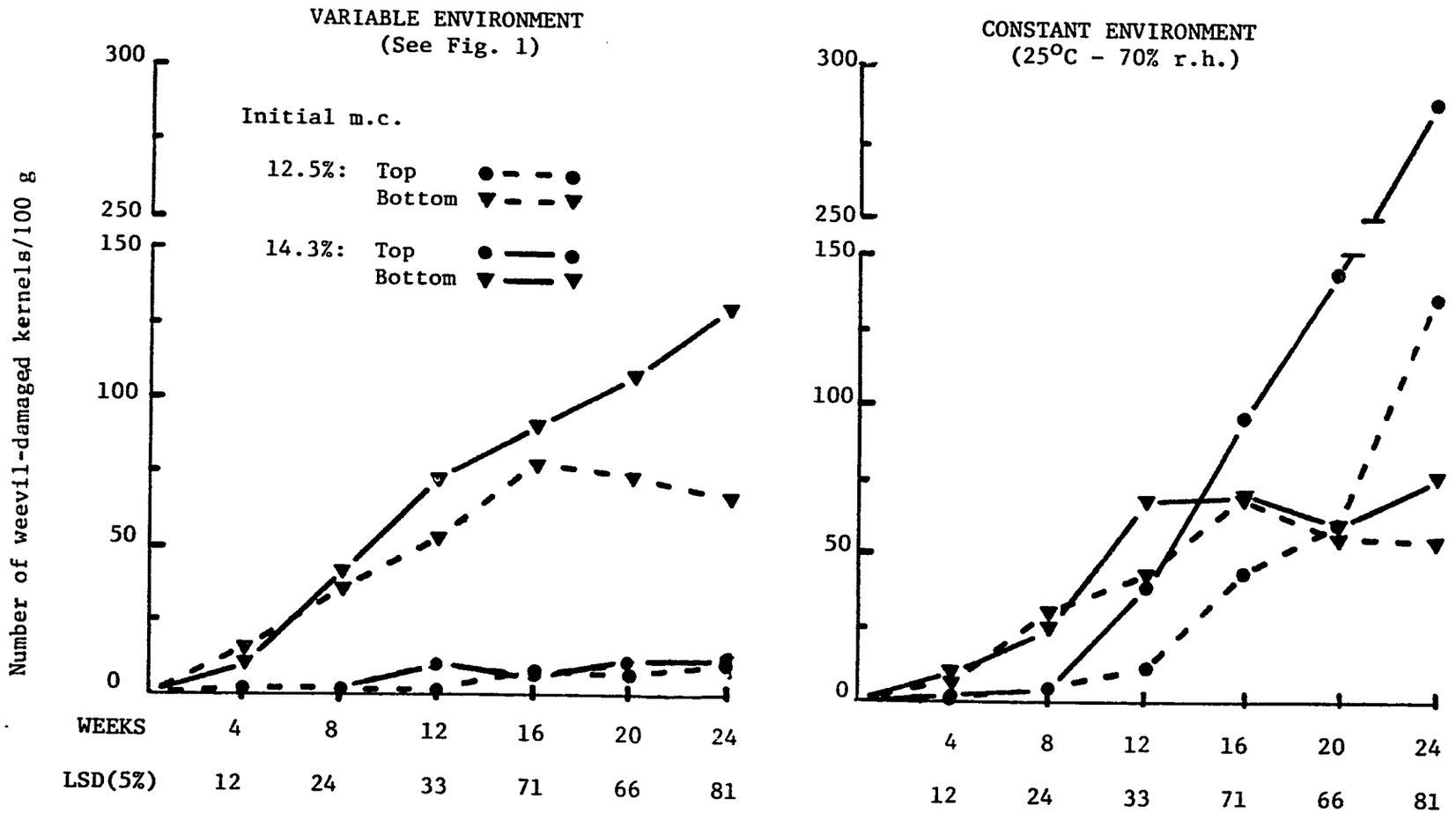


FIG. 7. X-ray results of maize infested with Sitophilus zeamais and stored in two environments. Averages of two replicates.

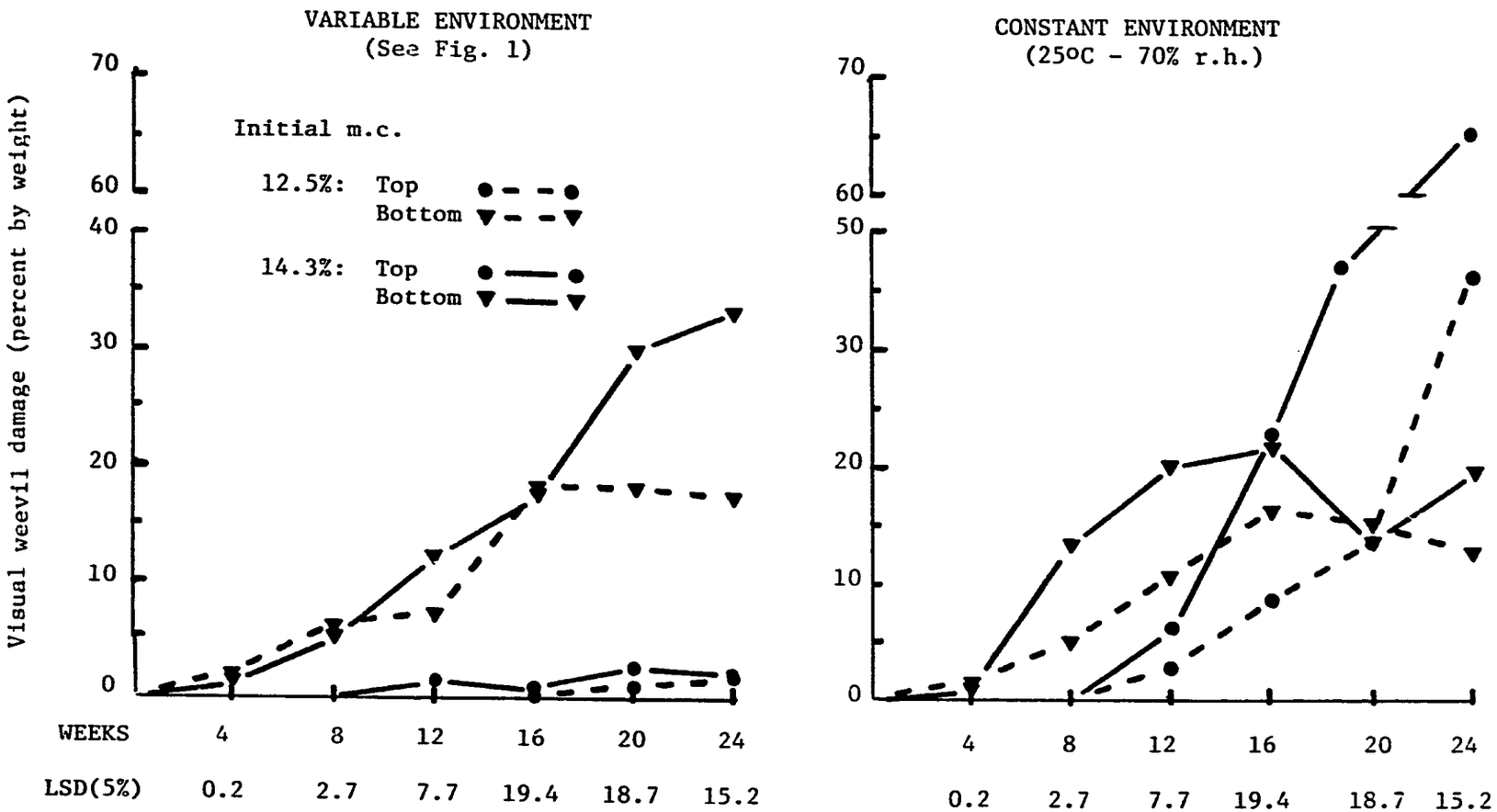


FIG. 8. Visual weevil damage (percent by weight) of maize infested with Sitophilus zeamais and stored in two environments. Averages of two replicates.

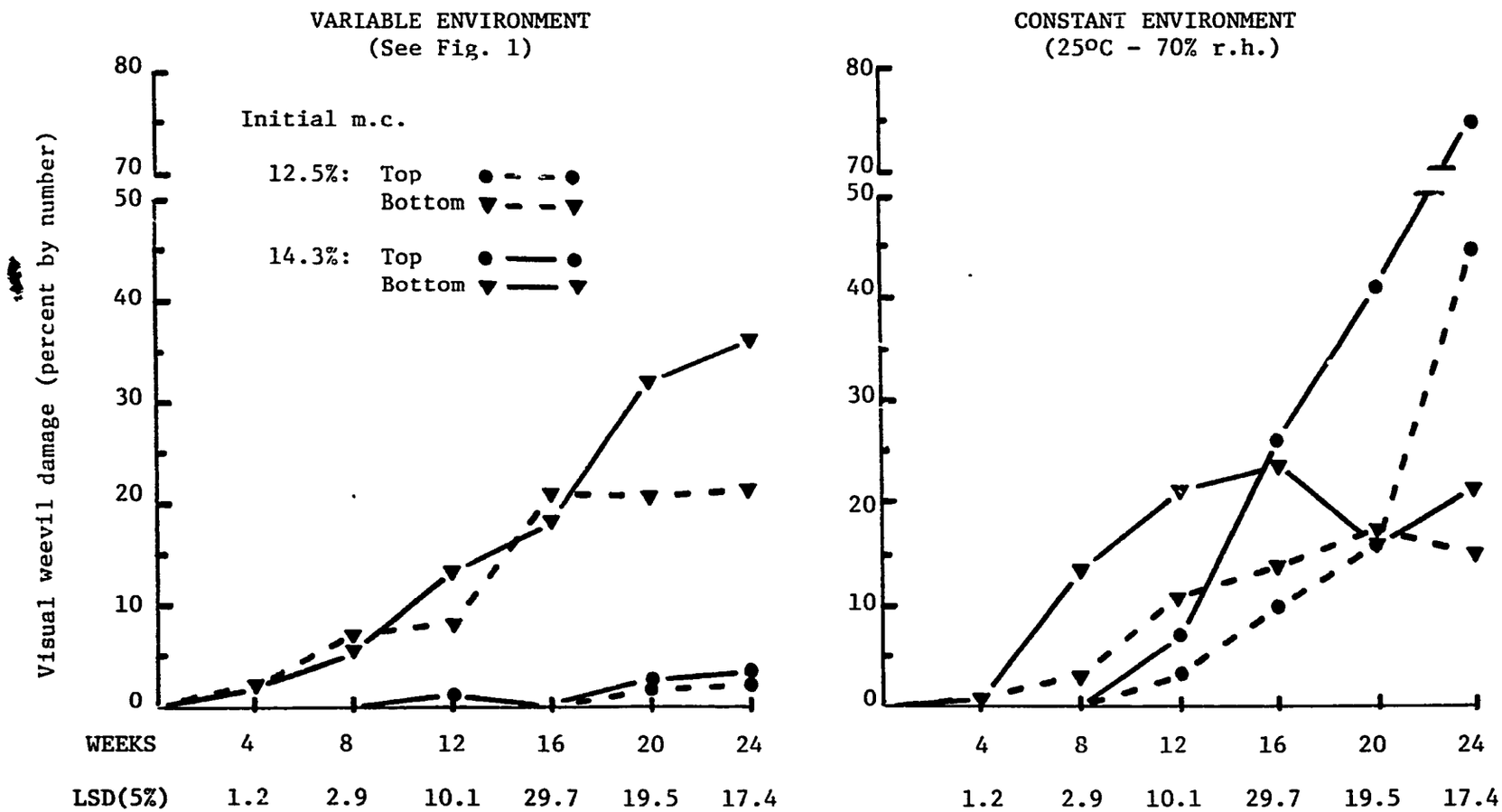


FIG. 9. Visual weevil damage (percent by number) of maize infested with Sitophilus zeamais and stored in two environments. Averages of two replicates.

data (Fig. 7). Correlation between visual weevil damage results and X ray are highly significant ($P<0.01$). However correlation coefficients between X-ray and visual weevil damage ($r=0.644$ and 0.646, 94 d.f.) were lower than the correlation coefficient between visual damage by weight and by number ($r=0.995$, 94 d.f.).

Outdoors, visual damage was similar in bottom samples of maize with 12.5 and 14.5% initial m.c. during the first 16 wk (17.5% by wt). By 24 wk visual weevil damage increased to 33.2% by wt in bottom samples with 14.3% initial m.c. No increase in damage was found in the 12.5% initial m.c. maize after 16 wk.

Visual weevil damage was no more than 2.8% by wt in top samples of maize stored outdoors.

Maize stored indoors had more weevil damage than maize stored outdoors. Indoors, weevil damage increased first in the bottom sections of drums but after 12 wk weevil damage at the top began increasing. At 24 wk weevil damage was approximately 3 times greater in top than bottom sections of both 12.5% and 14.3% initial m.c. maize. At 24 wk the top sections of 14.3% initial m.c. maize had 65% by wt weevil damage, nearly twice the damage of the 12.5% initial m.c. maize (36% by wt).

Percentages of visual weevil damage determined by number are about 1.1 times the percentages of damage by weight.

Percent visual weevil damage by number is easy to determine and results are comparable to those obtained by X-ray and weevil damage by weight. The latter method is used in official grain grading in the United States.

Fungal Invasion (Fig. 10)

The most common storage fungi found were from the *Aspergillus glaucus* and *A. restrictus* groups. They are reported together here and referred to as *A. glaucus*.

No appreciable increase of fungal invasion was found in maize with 12.5% initial m.c. stored outdoors. Moisture content of these samples was always below 13.8%.

In the 14.3% initial m.c. maize stored outdoors, percentage of kernels invaded by *A. glaucus* increased after 4 wk. At 16 wk there was 93% invasion at the bottom of the infested drums. It remained approximately at that level throughout the experiment. At the top, fungal invasion increased to 73% by 12 wk, then decreased to 35% by 24 wk.

In control drums with 14.3% initial m.c. maize stored outdoors *A. glaucus* had increased to 21% in the top section and 40% in the bottom by 24 wk.

Indoors, *A. glaucus* invaded not only the maize with 14.3% initial m.c. but also weevil infested samples with 12.5% initial m.c. No increased fungal invasion was found in samples with 14.3% initial m.c. after 16 wk (ca. 58% invasion). Final fungal invasion of these 14.3% initial m.c. samples was 35% at the top and 58% at the bottom.

In control maize with 14.3% initial m.c. stored indoors, fungal invasion began increasing at 8 wk and was 42 and 54% by 24 wk in bottom and top sections, respectively.

No significant correlation was found between fungal invasion and weevil population. A low, significant ($P<0.05$), correlation coefficient between fungi and weevil damage was recorded, however.

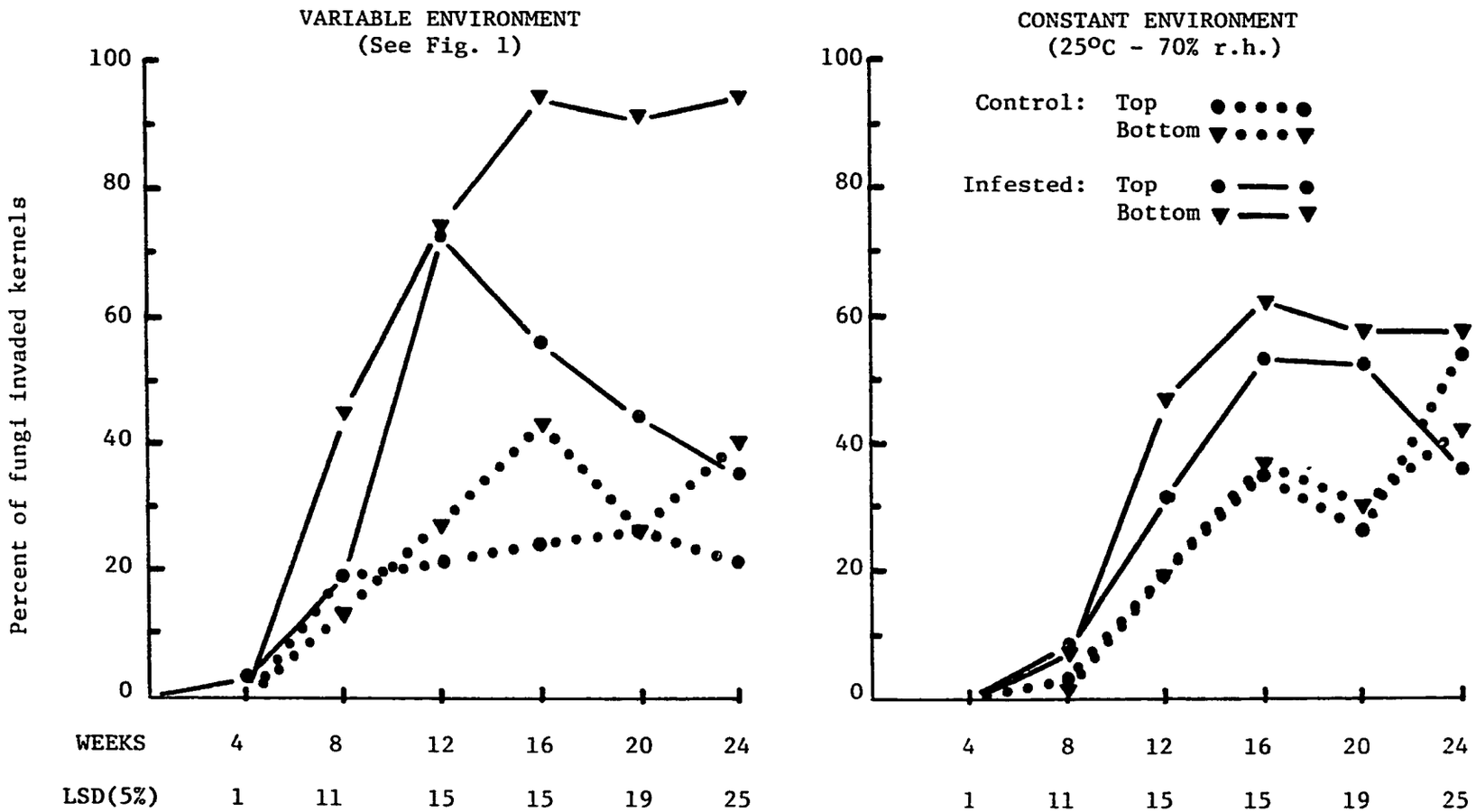


FIG. 10. Aspergillus glaucus - A. restrictus invasion of maize infested with Sitophilus zeamais and stored in two environments with an initial moisture content of 14.3%. Averages of two replicates.

The only other storage fungus found at significant levels of invasion was Aspergillus flavus. It increased to 40 and 52% invasion at 20 and 24 wk respectively in the top section of one of the indoor replicates with 14.3% initial m.c.

Field fungi invasion generally decreased as storage time increased and no relation to treatments was noticed. Percentage invasion decreased from an initial 60-85% to 5-25% at the end of the experiment.

Penicillium spp. were found at the beginning in 20-30% of kernels, however, invasion decreased to 6% or less by 24 wk.

Aspergillus flavus grew in maize with 16.2% m.c. This agrees with observations by QASEM and CHRISTENSEN (1960). However, CHRISTENSEN and KAUFMANN (1969) report a minimum of 18% m.c. for growth of this fungus in maize; LOPEZ and CHRISTENSEN (1967), 18.5% m.c.; and KOEHLER (1938), 18.3% m.c. These authors worked with sound grain whereas maize in our experiment had over 50% by wt weevil damaged kernels. This probably allowed easier penetration by fungi along with less effective surface disinfection of maize kernels for the fungal invasion tests. AGRAWAL et al (1957) found that weevil-damaged grain had more fungal invasion than sound grain at similar moisture content.

Fat Acidity Value (FAV)

There was relatively little increase in fat acidity. FAV between 22 (maximum for sound maize, BAKER et al, (1959) and 50 were found in bottom samples of infested maize stored outdoors and bottom and top samples of infested maize stored indoors. Increased FAV were noted after 12 wk outdoors and after 20 wk indoors.

These results correspond with those reported by BAKER et al (1959) who found little correlation between insect damage and FAV. BOTTOMLEY et al (1952) found little increase in fat acidity in maize invaded by A. glaucus.

Germination (Figs. 11 and 12)

Germination of control maize with 12.5% initial m.c. was always 90% or higher except for the 24 wk sample from the top of maize stored indoors (85% germination).

Germination did not change in the top samples of infested maize with 12.5% initial m.c., stored outdoors. However, in the bottom section it decreased to 75% by 24 wk. In control samples and samples from top of infested drums, final germination was between 57 and 71%. At the bottom of infested drums the germination decreased to 10% by 24 wk.

Indoors, germination of top and bottom samples of infested drums with 12.5% initial m.c. decreased to about 43% by 24 wk. In maize with 14.3% initial m.c. germination of top and bottom samples also decreased to about 50% in control and to 0% in infested maize.

Highly significant ($P<0.01$) negative correlations were found between fungal invasion, weevil damage and germination. Reduced viability in grain due to insects and fungi has also been reported by HOWE (1973), TUITE and CHRISTENSEN (1957), and others.

Test Weight (density) (Fig. 13)

Density loss found in all control samples was less than 0.9 lb/bu. There was little density change at the top of infested drums stored outdoors. In bottom samples density decreased from 58.5 to 54.9 lb/bu in

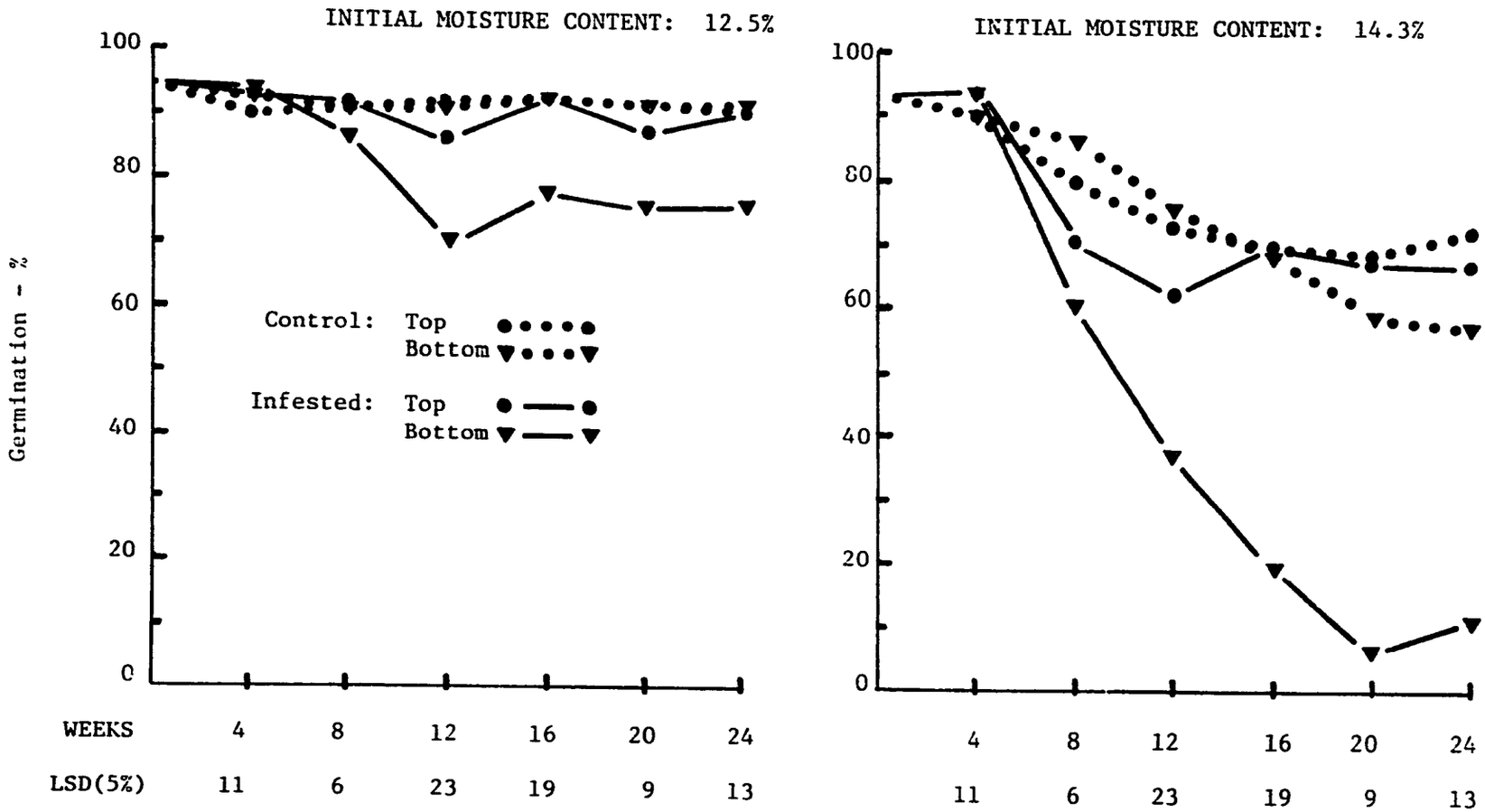


FIG. 11. Viability of maize infested with Sitophilus zeamais and stored in a variable environment (See Fig. 1). Averages of two replicates.

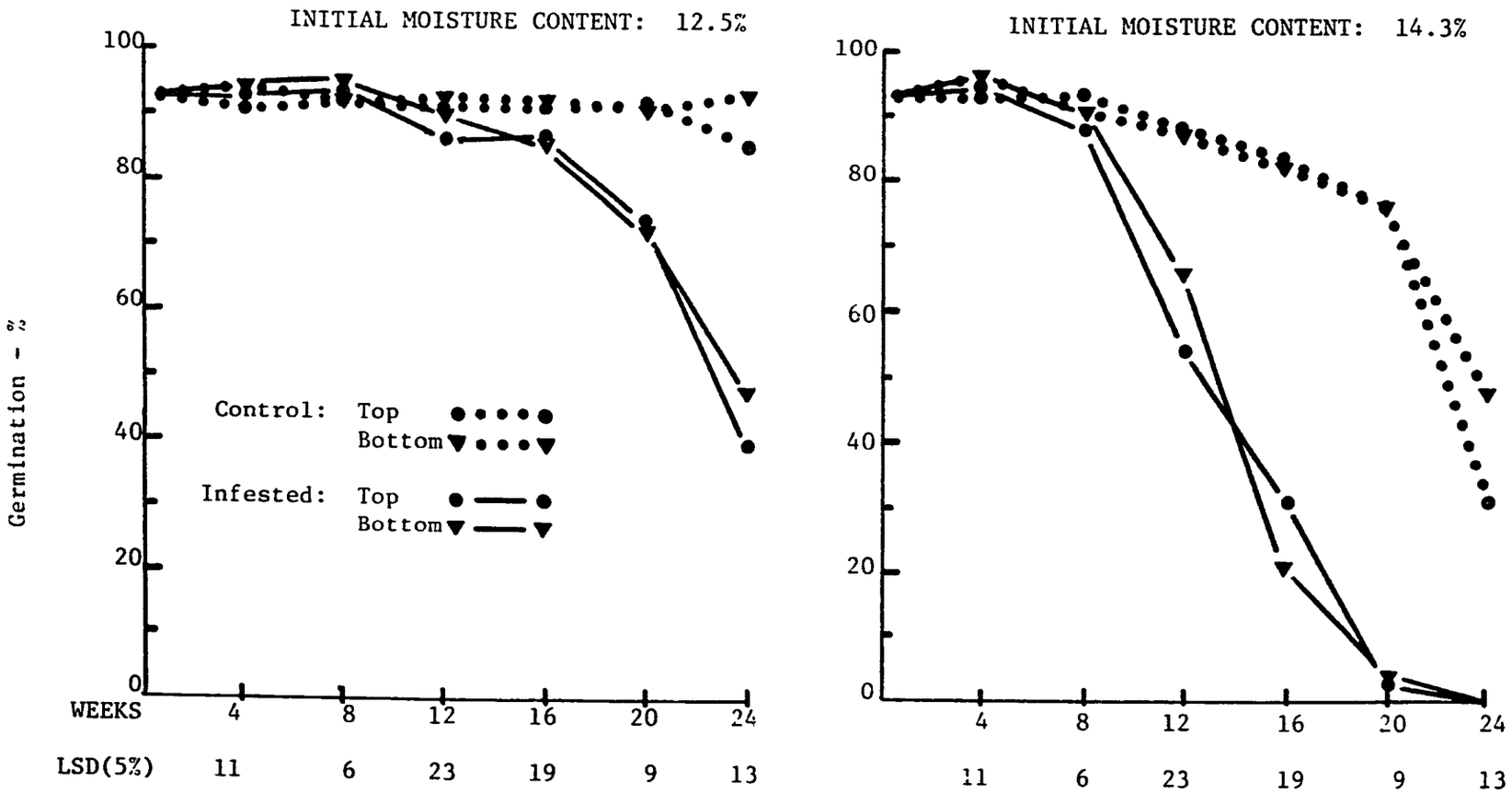


FIG. 12. Viability of maize infested with Sitophilus zeamais and stored in a constant environment (25°C - 70% r.h.). Averages of two replicates.

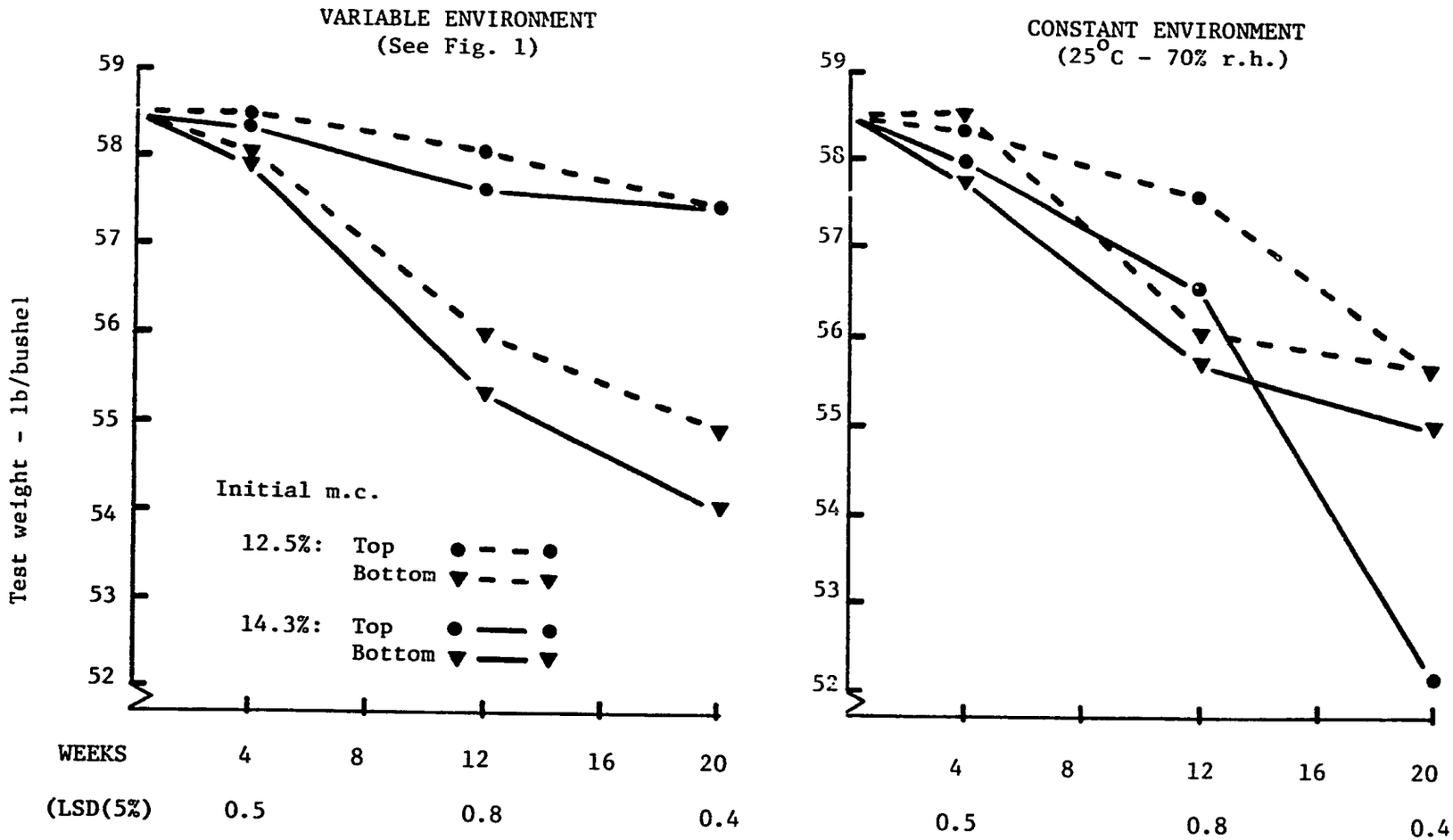


FIG. 13. Test weight (density) of maize infested with Sitophilus zeamais and stored in two environments. Averages of two replicates.

12.5% initial m.c. maize and from 58.2 to 54.0 lb/bu in the 14.3% initial m.c. maize.

Indoors, test weight decreased in top and bottom of infested samples of 12.5% and 14.3% initial m.c. maize. At 20 wk, test weight for top and bottom section of 12.5% initial m.c. maize was 55.7 lb/bu (initial 58.4 lb/bu). At 20 wk, bottom samples of 14.3% initial m.c. had a density of 54.9 lb/bu while density at the top had decreased to 52.1 lb/bu.

Although test weight decreased with increased weevil populations and weevil damage, the correlation between these variables was not significant.

Under our test conditions density could not be used to estimate weevil damage.

Dry Matter Weight Loss (Fig. 14)

There was less than 1% dry matter weight loss in any of the control drums.

Weight loss of infested maize of both initial moisture contents stored outdoors amounted to about 2.2% by 24 wk.

Indoors, maize at both moisture levels had similar weight losses up to 12 wk. After 12 wk, weight loss of 14.3% initial m.c. maize was greater than loss in 12.5% initial m.c. maize. By 24 wk weight loss was 5.2% for 12.5% initial m.c. maize and 7.8% for 14.3% initial m.c. maize.

At 24 wk, data indicated possible differences in dry matter weight loss between controls and infested maize, and between maize stored outdoors and indoors. Statistical analyses used here showed significant differences only at earlier sampling dates and at 24 wk for high initial

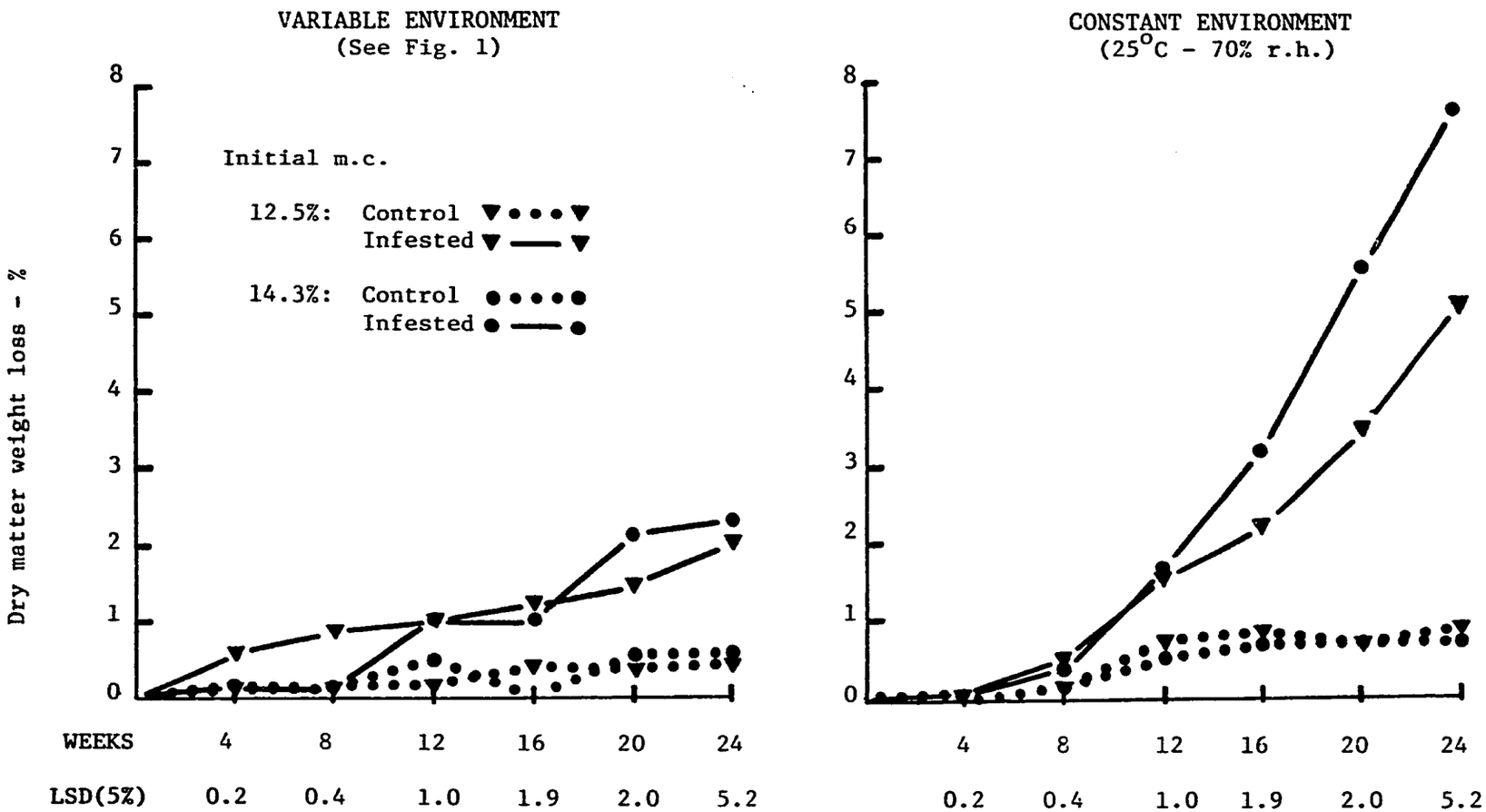


FIG. 14. Dry matter weight loss of maize infested with Sitophilus zeamais and stored in two environments. Averages of two replicates.

moisture maize stored indoors.

Highly significant correlations ($P<0.01$) were found between dry matter weight loss, weevil populations and weevil damage.

There are large variations in the weight losses reported in the literature. Part of this is due to lack of uniform methods in determining weight loss. HOWE (1965) cites several variations in methods for determining losses. Estimates may not consider differences in moisture, presence of insects and dust or, as SHAHJAHAN (1974) did, may include insect damaged kernels in the loss.

Dry matter weight loss, as measured here, does not include weight of insects and dust or damaged kernels.

In this study, maximum weight loss was 9.7% in one replicate with 14.3% initial m.c. stored indoors. This maize had a very heavy infestation (586 weevils/kg), 40% by wt visual weevil damaged kernels, and 0% germination.

Weight loss measured by actual weighing of the total mass of grain is accurate but impractical in most storage situations.

Correlations (Table 1)

Correlations between results of the various tests were calculated using part or all data depending on the nature of the test and the design of the experiment.

Weevil populations had significant correlations with temperature ($P<0.05$) non-significant correlations with *A. glaucus* and test weight, and highly significant correlations ($P<0.01$) with all other tests.

Moisture content had highly significant correlations ($P<0.01$)

TABLE 1. CORRELATIONS BETWEEN TESTS IN MAIZE UNINFESTED AND INFESTED WITH *Sitophilus zeamais* AND STORED UNDER TWO ENVIRONMENTS DURING 24 WEEKS

Moisture content (m.c.)	Temp.	Weevil damage: X-ray	Weevil damage: visual by Wt.	Weevil damage: visual by No.	*Aspergillus glaucus* *Aspergillus restrictus*	Germ.	Test wt.	Dry matter wt. loss	
0.499** b	0.361* d	0.557** b	0.792** b	0.810** b	0.139 b	-0.577** b	-0.021 f	0.885** i	No. insects
	0.576** c	0.572** b	0.693** b	0.768** b	0.585** a	-0.671** a	-0.625** e	0.017 i	m.c.
		0.271 d	0.454** d	0.454** d	0.275** c	-0.088 c	-0.908** g	0.568** j	Temp.
			0.646** b	0.644** b	0.813** b	-0.606** b	-0.014 f	0.922** i	X-ray
				0.995** b	0.273** b	-0.738** b	-0.030 f	0.913** i	Dmg by wt.
					0.266** b	-0.729** b	-0.030 f	0.881** i	Dmg by No.
						-0.839** a	-0.059 e	0.454** h	*A. gl.*
							-0.007 e	-0.697** h	Germ.
								0.122 k	Test wt.

Data used:

a = All samples; 190 d.f.
b = All infested; 94 d.f.
c = All outdoors; 94 d.f.
d = Indoor-infested; 46 d.f.
e = All samples of 4, 12, and 20 wk; 94 d.f.
f = Infested of 4, 12, and 20 wk; 46 d.f.
g = Indoor-infested of 4, 12, and 20 wk; 22 d.f.
h = Averages by drums; all; 94 d.f.
i = Averages infested; 46 d.f.
j = Averages indoor-infested; 22 d.f.
k = Averages of 4, 12, and 20 wk; infested; d.f.

Significance level: * = 0.05; ** = 0.01.

with all tests except dry matter weight loss.

All correlations between weevil damage, *A. glaucus*, germination, and dry matter weight loss were also significant ($P<0.01$).

Proximate Analysis

In a review of literature, HOWE (1965) reported studies where there were changes in chemical composition of grain due to insect infestation and also cases where no changes were found. In the present study small changes were observed in proximate analysis results throughout the experiment, but they did not appear to be related to treatments.

CONCLUSIONS

1. Weevil population increases began at the bottom of drums. When populations were large at the bottom weevils invaded top sections of drums.
2. Cooling outdoor temperatures reduced weevil population increase and finally killed all weevils in December (winter).
3. Weevil populations indoors increased to higher levels than outdoors.
4. Outdoors, weevil populations in maize with 12.5% initial m.c. were less than those in maize with 14.3% initial m.c. Indoors, effect of initial moisture on weevil populations was not well defined.
5. Replicates had large differences in weevil populations.
6. Moisture content of maize varied according to weevil infestation and surrounding environment.
7. Outdoors, maize temperatures were affected more by ambient temperatures than by increasing weevil populations.
8. Weevil damage determined by X ray increased with increasing weevil populations. Visual weevil damage reported by weight and by number was highly correlated with X-ray results and weevil populations.
9. Under test conditions, visual weevil damage by number proved to be very reliable.
10. *Aspergillus glaucus* and *A. restrictus* groups were the predominant storage fungi and found only in maize over 14.3% m.c.
11. Fat acidity was not effective in estimating weevil damage.

12. Both, weevils and fungi, were responsible for decreased viability. Germination had a high ($P<0.01$) negative correlation with weevil damage and *A. glaucus* invasion.
13. Test weight decreased with increased weevil damage but no significant correlation was found between test weight and weevil damage or between test weight and weight loss.
14. Maximum dry matter weight loss was 9.7% in one replicate with 40% by wt weevil damage. Lowest weight loss in infested maize was 1.7% in one replicate with 10% by wt weevil damage. Highly significant correlations were found between weight loss, weevil populations and weevil damage.
15. No obvious changes in proximate analysis results were noted during the experiment.

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APPENDIXES

APPENDIX 1. NUMBER OF WEEVILS (LIVE AND DEAD)/kg IN MAIZE INFESTED WITH

Sitophilus zeamais

	Outdoors (Variable)				Indoors (25°C - 70% r.h.)			
	Initial m.c.				Initial m.c.			
	12.5%		14.3%		12.5%		14.3%	
WEEKS	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
4	2*	5	0	1	0	5	0	1
	1**	9	1	8	1	2	1	1
8	6	15	5	27	3	20	1	4
	0	9	3	16	2	21	9	54
12	1	45	4	41	7	57	2	15
	0	32	4	29	16	43	24	39
16	0	40	9	50	16	33	14	27
	5	66	6	155	26	55	276	63
20	1	53	5	60	63	105	91	17
	4	41	25	115	61	70	428	156
24	0	30	3	91	101	52	291	90
	5	69	0	210	269	83	1000	172

* Rep. 1 - **Rep. 2

APPENDIX 2. MOISTURE CONTENT (%, WET-WEIGHT BASIS) OF MAIZE UNINFESTED AND INFESTED WITH *Sitophilus zeamais*

	Outdoors (Variable)				Indoors (25°C - 70% r.h.)			
	Initial m.c.				Initial m.c.			
	12.5%		14.3%		12.5%		14.3%	
WEEKS	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
				UNINFESTED				
4	12.2*	12.5	12.9	14.0	13.0	14.1	14.4	14.3
	12.3**	12.4	13.2	13.8	12.8	12.6	14.3	14.3
8	11.3	11.9	12.5	13.6	12.8	13.1	14.3	14.3
	11.3	12.3	12.9	13.3	13.0	12.6	14.2	14.3
12	11.4	11.8	12.1	13.8	13.3	13.0	14.5	14.6
	11.4	12.2	12.6	13.5	13.2	12.9	14.5	14.5
16	11.4	11.7	12.1	13.2	13.5	13.2	14.6	14.6
	11.5	11.8	12.6	13.4	13.4	13.0	14.6	14.6
20	12.1	11.9	12.9	13.7	13.6	13.4	14.7	14.8
	11.9	12.0	12.7	13.6	13.5	13.3	14.5	14.8
24	12.1	11.8	12.7	13.4	13.3	13.0	14.4	14.7
	12.0	12.1	12.6	13.6	13.3	13.1	14.5	14.6
				INFESTED				
4	11.5	12.4	11.9	14.1	12.5	12.4	14.3	14.4
	12.1	12.8	13.0	14.1	12.8	12.5	14.4	14.5
8	11.4	11.8	12.9	13.7	12.6	12.4	14.3	14.7
	11.2	12.7	12.9	14.0	13.0	12.8	14.8	14.4
12	11.6	13.1	12.6	14.5	13.2	13.4	14.8	14.4
	11.9	13.0	12.8	14.6	13.4	13.5	15.1	15.6
16	12.0	13.1	12.7	14.5	13.7	13.8	15.3	16.1
	11.6	13.1	13.0	14.7	13.9	14.0	16.0	15.7
20	12.2	13.5	13.4	15.4	14.1	14.5	15.6	16.0
	12.2	13.7	13.4	15.3	14.4	14.6	16.2	16.1
24	12.2	13.0	13.3	15.3	14.5	14.8	16.2	16.6
	12.2	13.6	13.6	15.4	15.1	14.9	16.2	16.4

* Rep. 1 - **Rep. 2

APPENDIX 3. TEMPERATURE (^{o}C) OF MAIZE UNINFESTED AND INFESTED WITH

Sitophilus zeamais

	Outdoors (Variable)				Indoors ($25^{o}C$ - 70% r.h.)			
	Initial m.c.				Initial m.c.			
	12.5%		14.3%		12.5%		14.3%	
WEEKS	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
				UNINFESTED				
4	34.1*	33.8	35.3	36.6	25.6	25.4	25.1	25.4
	35.4**	35.7	34.7	34.2	25.1	25.0	25.4	25.7
8	30.7	29.8	32.0	31.8	25.4	25.6	26.1	16.0
	31.7	32.0	31.5	31.2	25.3	25.1	25.6	25.7
12	17.1	16.0	15.4	15.6	26.0	25.2	25.3	25.5
	16.8	16.7	16.9	16.8	25.8	25.7	25.8	26.0
16	18.0	18.2	18.6	18.5	25.7	25.5	25.8	26.0
	18.0	17.9	18.6	18.2	25.7	26.0	25.1	15.0
20	16.6	16.7	17.1	17.2	25.2	25.1	25.6	25.7
	16.1	16.0	16.7	16.1	25.3	25.4	25.1	15.4
24	3.6	3.1	3.8	3.2	25.3	25.2	25.4	25.5
	2.8	3.4	3.6	3.7	25.2	25.4	25.1	15.0
				INFESTED				
4	35.0	35.1	34.3	36.3	25.4	25.0	25.4	26.3
	34.8	35.2	36.9	38.2	25.8	26.0	27.1	26.0
8	33.2	31.9	32.3	32.3	25.7	25.4	26.9	27.0
	33.7	33.3	32.3	32.0	26.7	26.2	26.1	16.0
12	16.9	17.1	17.2	17.0	25.3	25.9	27.1	25.4
	17.0	17.0	17.8	17.6	25.6	25.7	29.2	27.2
16	17.8	18.4	19.3	19.2	27.4	27.2	27.5	26.8
	18.0	17.9	19.0	18.9	27.5	27.0	31.1	27.0
20	17.2	17.0	17.6	17.7	28.0	26.8	29.1	25.8
	17.8	18.0	17.7	17.8	30.0	27.1	31.0	26.9
24	2.9	3.0	3.3	3.4	30.1	27.0	31.1	27.2
	3.4	3.8	3.5	3.6	30.2	27.0	31.1	27.2

* Rep. 1 - **Rep. 2

APPENDIX 4. WEEVIL-DAMAGED KERNELS/100 g AS DETERMINED BY X RAYS IN MAIZE INFESTED WITH *Sitophilus zeamais*

	Outdoors (Variable)				Indoors (25°C - 70% r.h.)			
	Initial m.c.				Initial m.c.			
	12.5%		14.3%		12.5%		14.3%	
WEEKS	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
4	1*	12	0	11	0	5	2	9
	1**	19	1	13	2	8	3	14
8	0	41	3	47	3	30	3	49
	2	29	2	45	5	29	5	50
12	1	64	7	56	13	32	19	58
	2	42	13	89	10	53	57	77
16	10	92	8	68	43	71	39	87
	12	62	7	114	46	65	153	67
20	4	74	14	103	37	55	91	49
	10	73	9	111	82	56	196	71
24	5	61	11	114	113	62	238	74
	15	73	14	145	159	46	337	79

* Rep. 1 - **Rep. 2

APPENDIX 5. PERCENT BY WEIGHT OF VISUAL WEEVIL-DAMAGED KERNELS IN MAIZE INFESTED WITH *Sitophilus zeamais*

	Outdoors (Variable)				Indoors (25°C - 70% r.h.)			
	Initial m.c.				Initial m.c.			
	12.5%		14.3%		12.5%		14.3%	
WEEKS	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
4	0.0*	1.2	0.0	0.9	0.0	0.3	0.0	0.6
	0.0**	1.8	0.0	1.9	0.0	0.3	0.0	0.6
8	0.0	7.0	0.0	4.3	0.0	4.1	0.0	13.3
	0.0	4.6	0.0	5.6	0.0	5.7	0.0	11.0
12	0.0	8.6	0.6	7.9	2.9	6.9	3.2	17.2
	0.0	5.2	1.6	16.3	2.0	13.5	8.4	22.8
16	0.0	21.0	1.2	15.2	7.1	15.8	7.0	25.2
	0.0	14.8	0.3	19.7	10.4	16.4	36.8	18.3
20	0.6	17.2	3.6	30.9	9.3	16.0	22.4	12.0
	1.3	18.0	1.4	27.7	17.5	14.6	51.1	16.8
24	1.8	14.7	2.4	33.5	28.3	15.6	66.2	19.1
	1.0	19.3	3.1	32.8	43.4	9.3	63.2	19.1

* Rep. 1 - **Rep. 2

APPENDIX 6. PERCENT BY NUMBER OF VISUAL WEEVIL-DAMAGED KERNELS IN MAIZE INFESTED WITH *Sitophilus zeamais*

	Outdoors (Variable)				Indoors (25°C - 70% r.h.)			
	Initial m.c.				Initial m.c.			
	12.5%		14.3%		12.5%		14.3%	
WEEKS	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
4	0.0*	1.4	0.0	1.1	0.0	0.0	0.0	0.7
	0.0**	2.1	0.0	0.0	0.0	0.7	0.0	0.7
8	0.0	7.9	0.3	4.9	0.0	0.3	0.0	13.9
	0.0	5.4	0.3	5.9	0.0	5.4	0.0	12.6
12	0.0	10.1	0.6	9.1	3.6	5.1	3.6	18.1
	0.0	5.7	1.6	17.5	2.1	15.4	9.2	23.9
16	0.0	25.0	0.3	15.2	8.3	7.8	7.7	26.2
	0.0	16.6	0.3	21.6	11.5	19.4	43.0	20.7
20	0.7	19.9	3.7	34.1	10.1	16.8	25.2	12.4
	2.0	21.0	1.7	29.2	20.3	16.9	56.7	25.2
24	1.4	19.4	3.1	35.9	34.3	17.1	73.1	21.1
	2.4	22.7	4.0	36.3	54.0	12.1	76.1	20.8

* Rep. 1 - **Rep. 2

APPENDIX 7. *Aspergillus glaucus* - *A. restrictus* INVASION (%) IN MAIZE UNINFESTED AND INFESTED WITH *Sitophilus zeamais*

	Outdoors (Variable)				Indoors (25°C - 70% r.h.)			
	Uninfested		Infested		Uninfested		Infested	
WEEKS	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
			14.3% initial m.c.					
4	0*	0	2	0	0	0	0	0
	0**	0	4	2	0	0	0	0
8	24	18	16	34	4	2	14	2
	14	8	22	56	2	0	2	12
12	20	38	92	98	30	28	42	46
	22	16	54	50	8	10	20	48
16	28	62	52	94	32	32	54	62
	20	23	38	92	38	22	52	62
20	30	34	36	92	24	42	76	64
	22	18	52	90	28	18	28	48
24	20	36	30	90	68	44	50	56
	22	44	40	98	40	40	20	60
			12.5% initial m.c.					
20							2	14
							26	40
24			SEE NOTE				52	34
							60	90

* Rep. 1 - **Rep. 2

Samples not presented on table had between 0 and 8% invasion.

APPENDIX 8. GERMINATION (%) OF MAIZE UNINFESTED AND INFESTED WITH

Sitophilus zeamais

	Outdoors (Variable)				Indoors (25°C - 70% r.h.)			
	Initial m.c.				Initial m.c.			
	12.5%		14.3%		12.5%		14.3%	
WEEKS	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
				UNINFESTED				
4	90*	92	90	89	91	92	95	95
	94**	90	90	91	91	93	92	94
8	92	91	79	84	92	92	92	95
	89	90	79	80	92	91	93	88
12	92	91	75	69	90	90	86	84
	90	91	68	81	91	93	86	84
16	91	93	69	67	91	93	75	76
	91	93	68	68	91	90	90	87
20	90	91	68	50	92	91	72	71
	90	91	67	68	90	89	80	81
24	91	89	70	49	85	93	40	45
	88	92	71	65	84	92	61	51
				INFESTED				
4	94	95	91	93	94	96	92	97
	92	92	92	95	95	91	95	95
8	90	92	72	62	91	95	93	93
	84	86	67	58	92	94	83	88
12	90	86	71	20	85	89	76	62
	82	69	52	53	87	90	72	70
16	91	79	69	20	85	87	51	18
	92	75	67	18	86	83	11	23
20	88	81	67	8	75	73	5	2
	86	68	66	4	70	70	1	5
24	91	92	62	14	52	62	0	0
	91	67	70	5	25	32	0	0

* Rep. 1 - **Rep. 2

Avg initial germination: 93%

APPENDIX 9. TEST WEIGHT (lb/bu) IN MAIZE INFESTED WITH *Sitophilus zeamais*.

	Outdoors (Variable)				Indoors (25°C - 70% r.h.)			
	Initial m.c.				Initial m.c.			
	12.5%		14.3%		12.5%		14.3%	
WEEKS	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
4	58.5*	58.1	58.5	58.3	58.6	58.5	58.0	58.0
	58.5**	57.9	58.1	57.5	57.9	58.4	58.0	57.5
12	58.5	55.6	58.5	55.5	57.6	56.1	57.2	55.7
	57.8	56.4	56.9	55.2	57.7	56.1	56.1	55.1
20	57.9	55.0	57.6	54.1	56.1	55.7	55.4	54.9
	57.4	54.8	57.5	54.0	55.3	55.7	49.7	54.9

* Rep. 1 - **Rep. 2
Avg initial test weight: 58.5 lb/bu.

APPENDIX 10. DRY MATTER WEIGHT LOSS (%) IN MAIZE INFESTED WITH *Sitophilus zeamais*

	Outdoors (Variable)				Indoors (25°C - 70% r.h.)			
	Initial m.c.				Initial m.c.			
	12.5%		14.3%		12.5%		14.3%	
WEEKS	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
4	0.6	0.6	0.2	0.2	0.1	0.1	0.2	0.0
8	0.7	1.0	0.0	0.3	0.4	0.6	0.5	0.2
12	0.7	1.3	1.0	0.9	1.3	1.8	1.5	2.0
16	1.3	1.2	1.1	0.9	2.4	2.0	2.6	3.9
20	1.0	2.0	2.5	1.8	3.4	3.6	4.1	7.2
24	1.7	2.4	2.4	2.2	4.7	5.6	5.8	9.7