THE EFFECT OF TEMPERATURE AND RELATIVE HUMIDITY ON THE OVIPOSITION AND MORTALITY OF *Sitophilus oryzae* (L.)

by

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Temperature and Humidity Effects on _S. oryzae_ (L.)

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ABSTRACT

The present investigation was undertaken to study the effect of temperature and relative humidity on the oviposition and mortality of the rice weevil, Sitophilus oryzae (L.) under controlled laboratory conditions. Studies carried out at 25° and 30°C and 52°/o, 75°/o, 90°/o and 100°/o R.H. on the oviposition of the weevil on wheat over a period of the first four weeks after emergence revealed that no significant difference existed in the number of eggs laid at the two temperatures.

A direct relationship was found to exist between the relative humidity and the number of eggs laid by a female per unit of grain; the highest number of eggs being laid at 100°/o R.H.

No significant difference existed in the number of eggs laid per week per unit of grain during the experimental period of four weeks.

The effect of six temperatures ranging from 5°C to 40°C and six relative humidities varying from 0°/o to 100°/o was studied in all possible combinations on the mortality of the weevil using wheat and rice separately as food and also in the absence of food. The temperature of 40°C in combination with all the experimental relative

humidities gave complete mortality of the pest but at 5°C, the highest mortality of 50°/o was obtained in combination with 0°/o relative humidity.

There existed an inverse relationship between the relative humidity and the mortality of the weevil; the highest mortality being obtained at the 0°/o R.H. and the lowest at 90°/o and 100°/o R.H. On the other hand, direct relationship existed between the temperature and the mortality of the weevil.

The type of food provided did not show any significant difference regarding the effect of temperature and relative humidity on the mortality of the weevil but the absence of food brought a significant increase in the percentage mortality.

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INTRODUCTION

The rice weevil, Sitophilus oryzae (Linnaeus.) is one of the most destructive insect pests of stored grain. It was first recorded in 1763 by Linné from the samples of rice obtained by him from Surinam and he gave this pest the specific name of oryza for the reason that it was found breeding in rice (8). This insect has generally been known in literature as Calandra oryzae (L.) though the generic name Sitophilus also remained in use. In the year 1959, the International Commission on the Zoological Nomenclature decided to change the generic name from Calandra to Sitophilus (40).

Earlier, Richards (33) and Birch (1) working independently in England and Australia respectively, found that two strains of this insect were met with in cultures and a comprehensive study of the insect made by these authors revealed that all parts of the body of the large strain were significantly larger than those of the corresponding sex of the small strain. Floyd and Newsom (11) reported that two different species of rice weevils had been confused under the name Sitophilus oryzae (L.), a large one and a small one. According to these authors, European workers in general applied this name to the small one and the Japanese workers to the large one and they accepted the latter view using the name Sitophilus oryzae (L.) for the large one and Sitophilus sasakii (Tak.) for the small one. They proposed "lesser rice weevil", as common name for the latter species.

The present investigations have, however, been carried out on Sitophilus oryzae (L.). This insect is a small reddish brown beetle, about 3.2mm. long, with head prolonged into a long slender snout at the end of which is a pair of stout mandibles or jaws. It is further characterized by being marked on the back with four light reddish or yellowish spots. The pest is world-wide in distribution being found wherever grain is stored but is generally serious in a temperate or subtropical climate (8). Both adults and larvae feed voraciously on a great variety of grain. The losses incurred by this pest to stored grain have been reviewed by Parkin (27) and discussed by Cotton (8), Floyd and Oliver (12) and Irabagan (17) in detail. For instance, according to Cotton (8), 10 percent of the corn crop is destroyed each year by this pest and to the grain trade as a whole it is believed to cost the United States of America between 60 to 75 million dollars annually. These losses might be very high in the subtropical countries, especially in the underdeveloped areas, where information on losses is very largely lacking. This state of affairs necessitates a detailed study of all the stored grain pests in general and Sitophilus oryzae (L.) in particular. Any effort made in this direction is sure to contribute much in solving the food problem of the present hungry world increasing at a tremendous rate. Millions of mouths living under conditions of starvation at the present time can be fed properly by merely averting losses of food grain caused by this pest in stores.

Before undertaking any effective control measure it is essential to have the biological and ecological knowledge of the conditions favouring increase and spread of insect infestations. Parkin (28) has stated that the problem remained neglected in United Kingdom and Australia during the first quarter of the 20th century and research work on pests of stored grain was undertaken under the pressure of the first World War. However, a good deal of research work has been carried out in the advanced countries of the world during the past 30 years.

Inspite of the tremendous improvement made during the recent years in the knowledge of pests of stored grain, there are a number of problems which yet remain to be investigated. This certainly holds good in the less developed countries of the world, particularly the Middle East, where there has always been a strong need and justification to study each problem under local conditions.

The rice weevil has certain temperature, humidity and food requirements which directly affect its abundance. The present studies were undertaken to investigate the effect of different temperatures and humidities on the oviposition and mortality of this pest and the results obtained are reported in the following pages.

REVIEW OF LITERATURE

I. Effect of temperature and humidity on oviposition.

Dandy and Elkington (9) reported that the optimum temperature for oviposition was 27.8°C and the lower temperature limit for multiplication was probably 18.3°C. Tsai and Chang (38) found the range for oviposition as 10-35°C for temperature and 60-100°/o for relative humidity. The vital optimum conditions at which the highest number of eggs were recorded varied from 24-29°C and 90-100°/o relative humidity. Lavrekhin (18) reported that the weevils showed high fertility even directly after emerging at a temperature of 25-27°C and fairly high air humidity. The number of eggs laid per day was 1.7 at 4-14 days and increased to 2.5 eggs during the first month and then diminished rapidly. Pruthi (30) found, that at temperatures between 24.4°C and 32.2°C, females did not lay eggs when kept at humidities greater than 95°/o, and at humidities less than 50°/o they did not feed and died within 30 days. Nakayama (24) reported that the number of eggs laid by females kept at 26-27°C and 80-85°/o relative humidity averaged 68.75 during the life period. Prevett (29) confirmed the findings of Nakayama (24) and those of Birch (2, 3). Oxley and Howe (26) recorded that the maximum temperature for oviposition was about 32°C. Birch (3) studied the effect of three temperatures, (23°, 25.5° and 29°C) on oviposition of small strain of _Calandra oryzae_ (L.)

(at present called <u>Sitophilus</u> <u>sasakii</u> (Tak.)) and found that the length of life and the time at which the maximum rate of egglaying was reached did not vary much with temperatures. According to this author, the total number of eggs laid at 25.5°C was greater than that at 29.1°C. The number of eggs laid in grains of 20°/o moisture content was found to be slightly greater than that laid in grains of 14°/o moisture content despite the development of mold on grain of 20°/o moisture content. The same author (2) found that the rate of oviposition of weevils fell greatly with any reduction of moisture content below 13°/o. Richards (34) conducted experiments at 17°C, 21°C and 25°C both at 80°/o and at 50°/o relative humidities. He found that at 17°, 21° and 25°C, and 80°/o R.H., 0.65, 1.16 and 4.1 eggs per female per day might be expected. In the experiments conducted at 100°/o, 90°/o, 80°/o, 70°/o, 60°/o, and 50°/o relative humidities the only reliable result was that at all three temperatures, oviposition was much reduced below 70°/o R.H. and somewhat increased above 80°/o R.H. The amount of oviposition at 17°, 21° and 25°C was in the proportions of 43:100:268. Reddy (31) conducted studies on oviposition at temperatures ranging from 13 to 35°C and relative humidities from 30°/o to 99°/o and found that at 84°/o R.H., most eggs were laid at 30°C. The number of eggs laid at temperatures above or below 30°C steadily decreased and that very few eggs were laid at 13°C and 35°C. The best range of temperature for oviposition was from 28-30°C. Regarding the relative humidity, he concluded that number of eggs per 100 kernals of wheat increased corresponding with increasing relative humidity and maximum number of eggs was laid at 99^{o}/o R.H. Relative humidity of 73^{o}/o or less was distinctly unfavourable for egg laying and no eggs were laid at 30^{o}/o R.H. He concluded that at 30^{o}C, relative humidities from 90 to 99^{o}/o were best for oviposition. Segrove (36) investigated the oviposition behaviour of the weevil in wheat at 20^{o}C and 25^{o}C and under moisture conditions equivalent to 50^{o}/o and 70^{o}/o R.H. and found that the females kept at 70^{o}/o R.H. oviposited over periods of 20 weeks at 25^{o}C and 32 weeks at 20^{o}C whereas the corresponding figures for females kept at 50^{o}/o R.H. were 12 and 14 weeks. The mean numbers of eggs laid per female over the total life period at 50^{o}/o and 70^{o}/o humidity were 44.6 and 235 respectively at 20^{o}C and 37.1 and 271 at 25^{o}C. The number of grains provided to each weevil also influenced their egglaying. He further reported that at either temperature, the lower humidity shortened the life of the insect and fecundity was of low order.

In an experiment conducted by Howe (15) at 17^{o}C, 21^{o}C and 25^{o}C, high egg output at high humidity with a sharp decrease at 60^{o}/o R.H. and below was recorded. At 21^{o}C and 50^{o}/o R.H. eggs were laid only in one grain compared with thirty one out of forty at 100^{o}/o R.H. and the daily egg rates were 0.03 and 1.48 per female respectively. Comparison of 100^{o}/o and 90^{o}/o R.H. at 25^{o}C and that of 100^{o}/o and 80^{o}/o R.H. at 21^{o}C showed that laying was better in both cases at 100^{o}/o R.H. The number of eggs per female for periods of 48 hours at 25^{o}C was 5.5 at 100^{o}/o R.H. and 5.1 at 90^{o}/o R.H.

Nishigaki (25) recorded observations on four strains of Sitophilus oryzae (L.) collected from Japan, Australia, Indonesia and Missouri and found that the velocity of development and the rate of reproduction increased in general as the water content of rice was increased from 12.2 to 16.7 percent. The rate of reproduction with increase of temperature between 25° and 30°C decreased.

II. Effect of temperature and humidity on the mortality of rice weevil.

Dandy and Elkington (9) reported that survival of adult weevils when placed at a temperature of 0.5-2.2°C for 11 days was 3 percent and such surviving weevils showed very feeble signs of life.

Bodenheimer (6) found that least mortality of the weevil was at 12-16°C. Tsai and Chang (38) concluded that the maximum longevity occurred below 16°C and at 85-100°/o R.H. Mathlein (20) found that adult weevils kept without food at temperature of 25°, 20° and 12-14°C and relative humidities of 38-40°/o, 35-40°/o, and 45°/o respectively, survived upto 5,8 and 22 days. When the humidity was increased to 75-80°/o, 80-100°/o and 70-80°/o at the same temperatures, the period of survival rose to 20, 45 and 95 days respectively. Complete mortality of all stages was obtained by exposure to temperatures of 55°, 48-50°C, and 45°C for 30, 45 and 210 minutes respectively. At 4.5°C, the adults survived for 80 days. Harris (13) recorded that in an experiment, 52°/o of 250 adults kept at a temperature just below freezing point survived for two days and 2°/o for five days. All stages were killed in a few minutes at 51.6°C.

Birch (4) reported that a temperature of 35°C was injurious to adult weevils and none survived for any length of time at 38-40°C although a temperature more than 45°C was necessary for their rapid destruction. The resistance of adult weevils to starvation at different temperatures and relative humidities was investigated by Howe (16) and he found that at 20°C and R.H. 31°/o or below, complete mortality of the weevil was obtained within ten days. The number of days required at 54°/o, 77°/o, and 80°/o R.H. was 13,33 and 35 respectively. At 25°C and R.H. 49°/o or below, complete mortality was obtained within ten days whereas this period increased to 16 and 28 days for 66°/o and 83°/o relative humidity respectively.

Lefevre (19) found that weevils when kept without food at 18-24°C and R.H. 44-45°/o survived for a maximum of 19 days and no cannibalism occurred.

Reddy (32) exposed weevils to temperatures ranging from 20° to 35°C and relative humidities of 30°/o and 73°/o and also to relative humidities of 52°/o and 94°/o at 35°C, some in each series being provided with rice or wheat of various moisture contents as food and others without food. He found that at 30°/o R.H., the period of survival was longest at 20°C and decreased steadily as the temperature rose. At 32°C or more, food appeared to have little effect. In the absence of food, mortality was complete in 186 hours at 20°C and in 66 hours at 35°C. At 35°C and 52°/o R.H., the mortality of males and females was complete in 248 hours and 296 hours respectively in the presence of rice and 162 and 222 hours in its absence. At $84^{\circ}/o$ R.H. only $14^{\circ}/o$ and $8^{\circ}/o$ respectively of the males and females died in 296 hours in the presence of rice whereas all were dead in 248 and 296 hours where no food was provided. According to Solomon and Adamson (37), Ushatinskaya found that the adult weevils could survive even at $-15^{\circ}C$ for 15 hours. Bhambani (5) reported that mortality of weevils was increased as the humidity was decreased and the longevity of the weevil was increased when humidity increased.

MATERIALS AND METHODS

The original stock of *Sitophilus oryzae* (L.) was obtained from warehouses in Beirut. From this stock, which consisted of fifty adult weevils, stock cultures were set up in glass jars of 2 lbs. capacity and maintained on wheat of the "Florence Aurore" variety. The moisture content of this wheat was 13.1°/o. The weevils used for infecting the stock cultures were allowed to remain in contact with the wheat for a period of 25 days and thereafter removed by sieving. The cultures were kept continuously at 25°C in an incubator and the weevils reared at this temperature were used in the subsequent experiments. Thus all the insects used throughout the course of the present investigations were the progeny of those insects which had been bred at a constant temperature. This eliminated all possible chances of error due to any difference or variation in the behaviour of insects otherwise possible for their having been reared at different temperatures. When the adult weevils started emerging from the grains, they were removed daily from the stock by sieving and transferred to other glass jars containing the same quality of food. They were labelled and placed in the incubator at 25°C. Thus it was possible to obtain and maintain groups of weevils of known age.

I. Oviposition experiments.

The effect of combination of two temperatures, 25°C and 30°C and four relative humidities, 52°/o, 75°/o, 90°/o and 100°/o was studied on the oviposition of the weevil. Two incubators were run at 25°C and 30°C and to obtain the four relative humidities the following saturated salt solutions were used (7)

Relative Humidity	Salt
52°/o	$Mg\ (NO_3)_2.6H_2O$
75°/o	$NaCl$
90°/o	$BaCl_2$
100°/o	Distilled water.

The weevils were sexed after four days of their emergence by making a close examination of the dorsal side of the rostrum which in case of a female has a lesser number of punctures as compared to that in the male (34). Each pair of weevils was put into a glass tube measuring 3"x1" and containing 20 grains of "Florence Aurore" wheat previously acclimatized to the respective humidity at which the tube was to be kept. It was done before the start of the oviposition experiment by keeping the small jars containing wheat, for a period of 7 days, in the desiccators having saturated solutions for the respective humidities. There were six replications for each humidity. As preliminary observations had revealed that there could be chances of death of the weevil at 52.0°/o R.H. a few additional tubes were maintained at this humidity with a view to replace the dead weevil if any, during the course of the experiment. The tubes closed with fine nylon cloth and rubber band were then stacked in the four respective desiccators. The weevils were supplied with twenty new acclimatized grains at the end of each week in new tubes of the same size and the old tubes along with the grains were removed and placed in desiccators with $75^{o}/o$ R.H. kept at $25^{o}C$. Such tubes were left there with the object of allowing the weevils to emerge from the used wheat.

The adults, emerged upto and including the 32nd day from the date of starting the experiment; were counted and then the grains put in $50^{o}/o$ alcohol for 24 hours to study the number of larvae contained in them by slicing the grain with a razor blade. The performance of each female was studied over a period of four weeks and the number of eggs oviposited per female was calculated by adding the emerged adults and the larvae found in grains.

This experiment was laid out according to the splitplot design by keeping weeks as main plots, temperature as sub-plots and relative humidities as sub-sub-plots. The data obtained were analyzed by the standard analysis of variance methods.

The moisture content of wheat was determined by keeping four glass tubes of the same size as used for oviposition studies, filled with wheat in each of the four respective desiccators for a period of 7 days and then removing them and finding the moisture content with the help of the universal moisture tester.

There are some other techniques of detecting eggs by the use of flourescent stains (21) and X-ray (22) but these could not be used because of their complicated nature which hardly fitted into an effort to seek a simple technique.

II. Studies on the mortality of adult weevil.

The effect of combination of six temperatures, 5°C, 20°C, 25°C, 35°C and 40°C and six relative humidities, namely 0°/o, 33°/o, 52°/o, 75°/o, 90°/o and 100°/o was studied on the mortality of the adult weevil. The 0°/o and 33°/o relative humidities were obtained by using anyhydrous phosphorus pentoxide (P_2O_5) and a saturated solution of magnesium chloride ($MgCl_2.6H_2O$) respectively. The rest of the four relative humidities were maintained as given under I above. Insects of one month's age, reared according to the method outlined on page 10 were used in all these experiments. Glass tubes measuring 3"x1" and each containing 15 wheat grains of "Florence Aurore" variety, were used. Ten adult weevils were put in every tube and the same was kept closed with fine nylon cloth held in place with a rubber band. The treatments were replicated four times and the four tubes each were placed in desiccators with different controlled humidities.

Two other experiments of exactly the same nature were set up with the only difference that in one set of experiments rice was substituted for wheat and in the other no food of any kind was provided to the adult weevils. Thus, there were 12 glass tubes in each desiccator. Observations were recorded after every 24 hours upto a period of ten days or till such time that complete mortality was achieved, whichever was earlier. Any individual weevil which did not show any sign of life was taken out of the tube and examined carefully to be sure of its death. The tardiness of movements of the appendages of the weevil was not taken as a sure sign of death. An insect was, however, considered dead if it did not respond by reflex movement to a slight pressure with a soft brush (14). The weevils found dead were removed daily from the tubes.

This experiment was laid out according to the randomized block design. Appropriate methods were used for the analysis of data.

RESULTS AND DISCUSSION

I. Effect of temperature and relative humidity on oviposition.

A. Results: The results obtained are summarized in Tables I and 2.

Table 1 - Analysis of variance for oviposition.

Source	D.F.	M.S.
Replication	5	12.4
Weeks	3	31.9
Error (a)	15	15.0
Temperature	1	5.0
Weeks X Temperatures	3	4.5
Error (b)	20	7.42
Humidity	3	1641.8 **
Humidities X Weeks	9	11.4
Humidity X Temperature	3	7.1
Error (c)	129	11.86

Table 1 shows that there is no significant difference in oviposition due to weeks and almost equal number of eggs were deposited per week upto the first four weeks of the start of oviposition. Similarly no significant difference exists in the number of eggs laid at 25° and 30°C. There are, however, highly significant

** denote F value significant at 1°/o level.

differences in oviposition due to changes in relative humidity. These differences are shown in Table 2.

Table 2 - Average number of eggs laid per female of <u>Sitophilus oryzae</u> (L.) at different combinations of temperature and relative humidity over a period of four weeks.

	Temperature 25°C				Temperature 30°C			
	Relative Humidity Percent				Relative Humidity Percent			
Period	H1	H2	H3	H4	H1	H2	H3	H4
	52	75	90	100	52	75	90	100
1st Week	2.5	10.0	11.3	14.3	1.7	12.5	12.3	15.8
2nd Week	3.0	11.7	13.3	14.5	2.1	12.3	15.1	13.7
3rd Week	2.7	12.8	13.0	14.7	2.0	11.3	13.1	14.8
4th Week	2.3	12.1	15.1	17.3	2.1	12.3	17.1	17.1

C.D. at 1°/o level = 1.78

C.D. at 5°/o level = 1.38

	H1	H2	H3	H4	
At 1°/o level					
	2.31	11.89	<u>16.27</u>	<u>17.9</u>	*
At 5°/o level	2.31	11.89	16.27	17.9	

______ * denotes treatment means that did not differ significantly at 1°/o level.

It is seen from Table 2 that at 5°/o level the effect of all the relative humidities is significantly different from each other. At 1 percent level, H1 and H2 are significantly different from H3 and H4 and also from each other but there is no significant difference between H3 and H4.

The relationship between the relative humidity, the moisture content of grain and oviposition is shown in Table 3.

Table 3 - Effect of relative humidity on moisture content of wheat and oviposition by *Sitophilus oryzae* (L.)

R. H. Percent.	Percent moisture contents of grain on 7th day of placing grain at various humidities.		Average number of eggs laid (Average of four weeks.)
	25°	$30^{\circ}C$	
52	11.8	11.7	2.31
75	14.3	14.2	11.89
90	16.2	16.0	16.27
100	17.2	18.2	17.9

Table 3 indicates that there is a direct relationship between the relative humidity and moisture content of wheat grain which further influences the oviposition, but practically no differences exist in the moisture content of grain at 25°C and 30°C under the same relative humidity conditions.

B. Discussion:

In determining the influence of temperature, a change from 25°C to 30°C with a fixed humidity neither altered the rate of oviposition nor the total egg production. These results agree with those obtained by some of the previous workers and differ with others. Segrove (36) found no significant difference in the total number of eggs laid by a female at 20°C and 25°C under 50°/o and 70°/o R.H. conditions though the rate of oviposition at 25°C was higher than that recorded at 20°C. Birch (3) states that there was no significant difference in the rate of oviposition at 25.5° and 29.1°C. Richards (34) and Howe (15) have reported an increase in the number of eggs with the corresponding increase in temperature from 17°C to 21°C and 25°C. Reddy (31) states that at temperature above or below 30°C, the number of eggs laid steadily decreased. Nishigaki (25) recorded a decrease in oviposition as the temperature increased from 25°C to 30°C.

These facts reveal that there is no general agreement regarding the effect of temperature on oviposition. No satisfactory explanation of these differences can be given. Perhaps the difference may be due to the variations in behavior and response of weevils to temperature due to the different genetic make up of the stocks used by various workers.

Regarding the effect of relative humidity, the number of eggs laid per 20 grains of wheat over a period of one week increased correspondingly with an increase of relative humidity; the maximum number of

17.9 eggs being laid at a relative humidity of 100°/o and followed in descending order by 16.27, 11.89 and 2.31 at 90, 75 and 52°/o R.H. respectively. These results are at variance with those of Tsai and Chang (38) who reported that the range of R.H. for oviposition was 60 to 100 percent but in the present investigations egg laying was observed at a relative humidity of 52°/o. Pruthi (30) has stated that the oviposition stops when the R.H. goes beyond 95°/o but in the present studies, the highest number of eggs was recorded at 100°/o R.H. The results achieved are, however, in conformity with those of Howe (15), Reddy (31), Richards (34) and Segrove (36) who reported a corresponding increase in oviposition with an increase in relative humidity.

The rate of oviposition in relation to the age of the weevils has also been studied by a few previous workers. Levrekhin (18) reports that rate of egg laying between the age of 4-14 days was 1.7 per day but increased to 2.5 during the first month and diminished afterwards. According to Birch (3) no significant difference occurred in the rate of oviposition excepting the last four weeks of life. Segrove (36) states that the peak period of egg laying is reached when the weevil attains the age of 4-6 weeks and falls thereafter. In the present studies, no significant difference in egg laying was recorded over the period of four weeks and these results are in agreement with those of Birch (3).

As regards the moisture content of grain, Dandy and Elkington (9), state that the rate of oviposition of the weevil depends on the hardness of the grain and this would seem to gain support from the results of Sandner (35) who records that a very small number of eggs were laid by the rice weevil on rice and oats as compared with rye, wheat and barley. Birch (2) obtained a far higher number of eggs in wheat of 14 percent moisture as compared to that on 12 percent moisture contents. Prevett (29) suggests that this effect of moisture is in relation to the hardness of the grain.

The results obtained in the present study are in conformity with those of Reddy (31) and Richards (34) who obtained a similar trend with the increase of moisture content of grain. Some differences however, exist in the moisture content of wheat grain determined at various relative humidities by the previous workers and that obtained during the present studies. These differences occur due to different strains of wheat used by different investigators and also due to differences in techniques. It is for this reason that varying figures of moisture content considered suitable for oviposition and development of rice weevil have been quoted in literature from time to time (2, 3, 10, 13, 20, 23, 31). Hence the lowest figure for moisture content of grain considered essential for oviposition of the rice weevil cannot be fixed and there is likelihood of variation in the results obtained by various workers.

II. Effect of different temperatures and relative humidities on the mortality of rice weevils.

A. Results.

1. Effect of temperature and relative humidity where wheat was used as food.

The results of the effect of temperature and relative humidity on the mortality of weevils where wheat served as food are shown in Table 4. The table shows separately the effect of temperature and relative humidity and that of interactions between the two factors on the mortality of weevils.

i. Effect of temperature. It is found that the mortality of the weevils after a period of ten days was only 10°/o at 5°C and it differed significantly from those obtained at the remaining five temperatures. As the temperature increased, the mortality increased till it reached 100°/o at 40°C.

At 35°C, the mortality obtained was 63°/o and it differed significantly both at 1°/o and 5°/o level from that obtained at 40°C and also from the rest of the four levels of temperature. There were, however, no significant differences in the mortality of weevils at 30°C, 25°C and 20°C.

ii. Effect of relative humidity. The effect of relative humidity is almost quite opposite to that of temperature. It was found that the highest mortality of 88°/o was obtained at the lowest relative humidity of 0°/o and it continued to decrease with an increase in relative

Table 4 - Mortality percentage of weevils at different temperatures and relative humidities

Type of Food - Wheat

Temperature only

Temperature		Mortality
T_1	5°C	10°/o
T_2	20°C	31.6°/o
T_3	25°C	31.6°/o
T_4	30°C	45.4°/o
T_5	35°C	63.0°/o
T_6	40°C	100.0°/o

C.D. at 1°/o level = 18.8

C.D. at 5°/o level = 14.2

	T_6	T_5	T_4	T_3	T_2	T_1
At 1°/o level	100	63	45.4	31.6	31.6	10
At 5°/o level	100	63	45.4	31.6	31.6	10

Humidity only

R. Humidity		Mortality
H_1	0°/o	88.0°/o
H_2	33°/o	83.3°/o
H_3	52°/o	46.6°/o
H_4	75°/o	20.8°/o
H_5	90°/o	21.6°/o
H_6	100°/o	21.3°/o

C.D. = same as under temperature

	H_1	H_2	H_3	H_4	H_5	H_6
At 1°/o level	88	83.3	46.6	20.8	21.6	21.3
At 5°/o level						

_______ denote treatment means that did not differ significantly at 1°/o and 5°/o levels.

Table 4 - Continued

Interaction (Temperature X Relative Humidity)

	T_1	T_2	T_3	T_4	T_5	T_6
H_1	27.5	100	100	100	100	100
H_2	20.0	90	90	100	100	100
H_3	10.0	0	0	72.5	97.5	100
H_4	0	0	0	0	25.0	100
H_5	0	0	0	0	30.0	100
H_6	2.5	0	0	0	25.0	100

C.D. at 1°/o level = 14.65

C.D. at 5°/o level = 11.08

Analysis of Variance

Source	D.F.	M.S.
Replications	3	0.9
Temperature	5	235.4 **
R. Humidity	5	239.2 **
Temp. X R. Humidity	25	24.98**
Error	105	0.65

** denote F value significant at 1°/o level.

Table 4 - Continued

Interaction (Temperature X Relative Humidity)

	T_1	T_2	T_3	T_4	T_5	T_6
H_1	27.5	100	100	100	100	100
H_2	20.0	90	90	100	100	100
H_3	10.0	0	0	72.5	97.5	100
H_4	0	0	0	0	25.0	100
H_5	0	0	0	0	30.0	100
H_6	2.5	0	0	0	25.0	100

C.D. at 1°/o level = 14.65

C.D. at 5°/o level = 11.08

Analysis of Variance

Source	D.F.	M.S.
Replications	3	0.9
Temperature	5	235.4 **
R. Humidity	5	239.2 **
Temp. X R. Humidity	25	24.98**
Error	105	0.65

** denote F value significant at 1°/o level.

humidity till it varied from 20.8°/o to 21.3°/o at 75°/o to 100°/o R.H. No significant difference existed between 0°/o and 33°/o R.H. but both these differed significantly from the remaining four treatments. Similarly no significant differences were found at 75°/o, 90°/o and 100°/o R.H. though they differed significantly from 52°/o R.H.

ii. Interaction (Temperature X Relative Humidity).

Regarding the combined effect of temperature and relative humidity it was found that a temperature of 40°C in combination with any of the experimental relative humidities gave complete mortality of the pest.

At 35°C, complete mortality was obtained with 0°/o and 33°/o R.H. but it fell down to 97.5°/o, 25°/o, 30°/o, and 25°/o at 52°/o, 75°/o, 90°/o and 100°/o R.H. respectively. At 30°C, the mortality was complete with 0°/o and 33°/o R.H. and decreased to 72.5°/o at 52°/o R.H. No mortality occured at 75°/o R.H. and above in combination with this temperature.

Temperatures 20°C and 25°C proved effective only with 0°/o and 33°/o R.H. and gave 100°/o and 90°/o mortality respectively.

At 5°C, only 27.5°/o and 20°/o of the weevils died in combination with 0°/o and 33°/o R.H. respectively and the figures for other relative humidities were even much lower. These results show that the combination of 0°/o R.H. with 5°C did not give even 50°/o mortality.

2. Effect of temperature and relative humidity where rice was used as food.

An examination of Table 5, where rice was used as food reveals that in general the results show the similar trend as found in wheat, though there are some differences in the percentage mortalities obtained at different temperatures and relative humidities in this case as compared to those in the previous one.

i. Effect of temperature. The lowest mortality namely 18.3°/o was obtained at 5°C and the highest viz. 100°/o at 40°C. The other figures for mortality are 57°/o, 40.4°/o, 33°/o and 31.6°/o at 35°C, 30°C, 25°C and 20°C respectively. The results obtained at 40°C and 35°C are significantly different at 5°/o level from the remaining four temperatures and also from each other.

There is no significant difference in the effect of 30°, 25° and 20°C and also of 25°, 20° and 5°C on the mortality of weevil. T_4 (30°C) differs significantly from T_1 (5°C) in its effect.

ii. Effect of relative humidity. The highest mortality of 91.6°/o was obtained at 0°/o R.H. followed by 88.3°/o mortality at 33°/o R.H. and these results differed significantly from those obtained at the remaining four relative humidities but not from each other. There was abrupt fall at 52°/o R.H. when mortality obtained was only 37.5°/o. The range of mortality varied from 19.1°/o to 24.5°/o between 75 to 100°/o R.H. and there were no significant differences in these treatments though they differed significantly from 52°/o R.H.

Table 5 - Mortality percentage of weevils at different temperatures and relative humidities

Type of Food - Rice

Temperature only

Temperature		Mortality
T_1	5°C	18.3°/o
T_2	20°C	31.6°/o
T_3	25°C	33.0°/o
T_4	30°C	40.4°/o
T_5	35°C	57.5°/o
T_6	40°C	100°/o

C.D. at 1°/o level = 21.1

C.D. at 5°/o level = 16.0

	T_6	T_5	T_4	T_3	T_2	T_1
At 1°/o level	100	57	40.4	33.0	31.6	18.3
At 5°/o level	100	57	40.4	33.0	31.6	18.3

Humidity only

Humidity		Mortality
H_1	0°/o	91.6°/o
H_2	33°/o	88.3°/o
H_3	52°/o	37.5°/o
H_4	75°/o	19.1°/o
H_5	90°/o	19.5°/o
H6	100°/o	24.5°/o

C.D. = As under temperature

	H_1	H_2	H_3	H_4	H_5	H_6
At 1°/o level	91.6	88.3	37.5	24.5	19.5	19.1
At 5°/o level	91.6	88.3	37.5	24.5	19.5	19.1

______ denotes treatment means that did not differ significantly at 1°/o and 5°/o levels.

Table 5 - Continued

Interaction (Temperature X Relative Humidity)

	T_1	T_2	T_3	T_4	T_5	T_6
H_1	50	100	100	100	100	100
H_2	42.5	90	97.5	100	100	100
H_3	7.5	0	0	42.5	75.0	100
H_4	5.0	0	0	0	10	100
H_5	0	0	0	0	17.5	100
H_6	5.0	0	0	0	42.5	100

C.D. at $1^{o}/o$ level = 13.2

C.D. at $5^{o}/o$ level = 9.9

Analysis of Variance

Source	D.F.	M.S.
Replication	3	0.70
Temperature	5	279.48**
Relative Humidity	5	202.46**
Temperature X R. Humidity	25	19.70**
Error	105	0.85

** denote F value significant at $1^{o}/o$ level.

iii. Interaction. Regarding the interaction of temperature and relative humidity it was found that 100°/o mortality of the pest was obtained at 40°C with any of the six relative humidities.

At 35°C, complete mortality was obtained with 0°/o and 33°/o R.H. followed by 75°/o, 10°/o, 17.5°/o and 42.5°/o mortality at 52°/o, 75°/o, 90°/o and 100°/o R.H. respectively.

All the weevils died at 30°C in combination with 0°/o and 33°/o R.H. and only 42.5°/o were found dead at 52°/o R.H. There was no mortality at the higher relative humidities. At 20°C and 25°C, complete mortality was obtained at 0°/o R.H. but only 90°/o and 97.5°/o respectively at 33°/o R.H. Higher relative humidities at the two temperatures remained totally ineffective.

The only temperature where no combination of R.H. proved 100°/o effective was 5°C and the maximum mortality of 50°/o was obtained in combination with 0°/o R.H.

3. Effect of temperature and relative humidity where no food was provided to weevils.

The data are presented in Table 6.

i. Effect of temperature only. The results of the effect of temperature show that 100°/o mortality of the pest was obtained at 40°, 35° and 30 and this differed significantly from 61.6°/o, 50.8°/o and 13°/o mortality achieved at 25°, 20° and 5°C respectively. Furthermore, T_3 (25°C) and T_2 (20°C) differed significantly from T_1 (5°C) but not from each other.

Table 6 - Mortality percentage of weevils at different temperatures and relative humidities where no food was provided.

Temperature only

Temperature		Mortality
T_1	5°C	13.0°/o
T_2	20°C	50.8°/o
T_3	25°C	61.6°/o
T_4	30°C	100°/o
T_5	35°C	100°/o
T_6	40°C	100°/o

C.D. at 1°/o level = 20.2

C.D. at 5°/o level = 15.32

	T_6	T_5	T_4	T_3	T_2	T_1
At 1°/o level	100	100	100	61.6	50.8	13.0
At 5% level	100	100	100	61.6	50.8	13.0

Humidity only

R. Humidity		Mortality
H_1	0°/o	90.8°/o
H_2	33°/o	85.8°/o
H_3	52°/o	74.8°/o
H_4	75°/o	65.8°/o
H_5	90°/o	54.5°/o
H_6	100°/o	53.7°/o

C.D. = As under temperature

	H_1	H_2	H_3	H_4	H_5	H_6
At 1°/o level	90.8	85.8	74.8	65.8	54.5	53.7
At 5% level	90.8	85.8	74.8	65.8	54.5	53.7

——— denotes treatment means that did not differ significantly at 1°/o and 5°/o levels.

Table 6 - Continued

Interaction (Temperature X Relative Humidity)

	T_1	T_2	T_3	T_4	T_5	T_6
H_1	45	100	100	100	100	100
H_2	45	100	100	100	100	100
H_3	12.5	70	65	100	100	100
H_4	0	12.5	15	100	100	100
H_5	0	7.5	15	100	100	100
H_6	5	15	75	100	100	100

C.D. at 1°/o level = 12.7

C.D. at 5°/o level = 9.6

Analysis of Variance

Source	D.F.	M.S.
Replications	3	0.633
Temperatures	5	306.7**
R. Humidity	5	58.56**
Temperature X R. Humidity	25	182.84**
Error	105	0.75

** denote F value significant at 1°/o level.

<u>ii. Effect of relative humidity.</u> The general effect of relative humidity is almost the same as was obtained in the two previous cases. A mortality of 90.8°/o and 85.8°/o was obtained at 0°/o and 33°/o R.H. and differed significantly from the rest of the treatments at the 5°/o level. The effect of 75°/o and 52°/o R.H. differed significantly from that of 90°/o and 100°/o R.H. but not from each other. Similarly there was no significant difference in the results obtained at 75°/o, 90°/o and 100°/o R.H.

<u>iii. Interaction</u>. The interaction of temperature and R.H. indicates that the temperatures 30°, 35° and 40°C in combination with any of the six relative humidities gave complete mortality of the pest.

At 20° and 25°C, 100°/o mortality was obtained only with 0°/o and 33°/o R.H. and it varied from 7.5°/o to 70°/o between 52°/o to 90°/o R.H. The figure for mortality at 25°C and 100°/o R.H. was 75°/o.

The highest mortality obtained at 5°C was in combination with 0°/o and 33°/o R.H. and this in both cases came to 45°/o only. The other relative humidities in combination with this temperature remained ineffective.

B. Discussion:

The results obtained under the three experimental conditions (wheat, rice and no food) with the same set of temperatures and relative humidities, reveal that both these factors show the same general trend regarding the mortality of the pest. The effect of temperature is direct and any increase in it beyond a certain level brings a significant increase in the mortality of the weevil. On the other hand, relative humidity affects the rate of mortality of the rice weevil inversely and any appreciable decrease beyond a critical point increases the mortality of the pest. It is further seen from the results obtained that the change of food from wheat to rice did not make any appreciable difference in the mortality of the weevil but the absence of food certainly increased the mortality at or above 30°C. At the temperatures 20° and 25°C, the absence of food affected the mortality only to a limited extent.

At 5°C, the mortality obtained was almost the same under all the treatments of temperature and relative humidity irrespective of the presence or absence of food, probably because at 5°C the temperature is below the threshold of feeding. These results in general, are in agreement with those of Birch (4), Bhambani (5), Mathlein (20), Reddy (32) and Tsai and Chang (38).

C. <u>Time required for complete mortality of weevils at effective combinations of temperature and relative humidity</u>.

The time taken by different combinations of temperature and R.H. to obtain 100°/o mortality of the weevil is given in Table 7.

The table shows that at 40°C and 0°/o R.H. complete mortality of the pest was obtained after 24 hours and this period increased to 48 hours with 33°/o and 52°/o R.H.; 72 hours with 75°/o R.H. and 96

Table 7 - Time required in hours to obtain 100°/o mortality of the pest at the effective combinations of temperatures and relative humidities

Temp.	Nature of Food	Relative Humidity (Percent) 0	33	52	75	90	100
		Time in hours for 100°/o mortality.					
40°C	Wheat	24	48	48	72	96	96
	Rice	24	48	48	72	96	96
	No Food	24	48	48	48	48	48
35°C	Wheat	48	96				
	Rice	48	96				
	No Food	48	96	144	144	144	144
30°C	Wheat	72	216				
	Rice	72	240				
	No Food	48	96	120	192	192	192
25°C	Wheat	96					
	Rice	96					
	No Food	72	144	144			
20°C	Wheat	96					
	Rice	96					
	No Food	72					
5°C	Wheat						
	Rice						
	No Food						

hours with 90°/o and 100°/o R.H. There was no difference in time due to a change of food, from wheat to rice, but where no food was provided all the weevils died within 48 hours.

A temperature of 35°C in combination with 0°/o and 33°/o R.H. caused 100°/o mortality of the pest after 48 and 96 hours respectively irrespective of the presence or absence of food. With the increase in R.H. complete mortality was obtained only in the absence of food and it took 144 hours at 52°/o R.H. and above.

At 30°C and 0°/o R.H. it took 72 hours each with wheat and rice to obtain 100°/o mortality and this period increased to 216 hours, 240 hours and 96 hours at 33°/o R.H. in case of wheat, rice and no food respectively. At higher humidities, complete mortality was obtained only in the absence of food in 120 hours at 52°/o R.H. and in 192 hours at the rest of the relative humidities.

At 25° and 20°C and 0°/o R.H. complete mortality was obtained after 96 hours in both wheat and rice and in 72 hours in the absence of food.

All the weevils died after 144 hours at 25°C in combination with 33°/o and 52°/o R.H. in the absence of food. Apart from the aforementioned combinations of temperature and relative humidity, no other combination gave 100°/o mortality within the period of 10 days.

The results show the same trend as found by Reddy (32).

SUMMARY AND CONCLUSIONS

The present investigations were undertaken to study the effect of temperature and relative humidity on the oviposition and mortality of the rice weevil, Sitophilus oryzae (L.) The weevils were bred at 25°C in an incubator on the wheat variety "Florence Aurore" and the progeny was used in all the subsequent experiments. Studies carried out on the oviposition of the weevil on wheat over a period of four weeks at 25° and 30°C and 52°/o, 75°/o, 90°/o and 100°/o R.H. revealed that no significant differences existed in the number of eggs laid at 25° and 30°C. There were, however, significant differences in oviposition due to changes in relative humidity. It was further found that a direct relationship existed between the relative humidity and the moisture content of wheat grain and this influenced the oviposition. At 25°C, the moisture content of wheat grains when kept for 7 days at 52°/o, 75°/o, 90°/o and 100°/o R.H. reached 11.8, 14.3, 16.2 and 17.2°/o respectively and the corresponding number of eggs laid over a period of one week was 2.1, 11.89, 16.27 and 17.9. Thus an increase in R.H. was found to bring an increase in moisture content of grain and this favoured the oviposition.

Studies made on the rate of oviposition in relation to the age of the weevil did not show any significant difference during the first four weeks of the start of oviposition.

It can be concluded from these findings that the chances of breeding of <u>Sitophilus oryzae</u> (L.) are small at places where relative humidity does not increase beyond 52°/o during the storage period.

Regarding the effect of temperature and relative humidity it was found that at 40°C, complete mortality of the weevil was obtained within 96 hours under all experimental conditions.

A temperature of 35°C in combination with 0°/o and 33°/o R.H. caused 100°/o mortality after 48 and 96 hours respectively irrespective of the presence or absence of food. At higher humidities, complete mortality was obtained only in the absence of food in 144 hours. The mortality was, however, 97.5°/o and 75°/o at 52°/o R.H. after 240 hours in case of wheat and rice respectively.

At 30°C and 0°/o R.H. it took 72 hours each with wheat and rice and 48 hours without food to obtain 100°/o mortality and the corresponding period at 33°/o R.H. was 216, 240 and 96 hours. At higher humidities complete mortality was obtained only in the absence of food in 120 hours at 52°/o R.H. and in 192 hours at humidities higher than this. The mortality was 72.5°/o and 42.5°/o at 52°/o R.H. in case of wheat and rice respectively after 240 hours.

Temperature 25° and 20°C, each in combination with 0°/o R.H. gave complete mortality after 96 hours both in wheat and rice and in 72 hours in the absence of food. It took 144 hours at 25°C in combination with 33°/o and 52°/o R.H. in the absence of food, to obtain 100°/o mortality and 240 hours to get 90°/o and 97.5°/o mortality at 33°/o R.H. with wheat and rice respectively.

At 20°C and 33°/o R.H. only 90°/o of the weevil died after 240 hours.

The relative humidity of 52°/o in combination with 20° and 25°C gave 70°/o and 65°/o mortality in the absence of food. The mortality was 75°/o at 25°C and 100°/o R.H.

No other combination gave even 50°/o mortality within 240 hours. The following conclusions can be drawn from these studies.

Temperature 40°C is effective for the control of the weevil and this can be made use of in tropical and subtropical countries where sunheating of grain can be practised for effective control of the pest.

The heating of stores to 40°C for 3-4 days with the help of pipes can also be utilized for the control of this weevil.

The power of the insect to survive is higher at 5°C with all combinations of relative humidity than at higher temperatures.

At higher relative humidity, the weevil stands better chances of survival than at the lower humidity.

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