THE INFLUENCE OF TEMPERATURE, MOISTURE, AND FOOD UPON THE DEVELOPMENT AND SURVIVAL OF THE SAW-TOOTHED GRAIN BEETLE [1]

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INTRODUCTION

The saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.) (family Cucujidae), has been reported from many parts of the world as a pest of a wide variety of stored-food products. It is the grain insect most frequently sent in by Minnesota farmers for identification. Many observations in regard to its life history have been made and numerous short accounts of its distribution, habits, and biology are available in various reports. Prior to 1926 the brief biological notes of Chittenden (*6*)[2] were almost the only ones of a quantitative nature that had been published. In 1926 Back and Cotton (*3*) reported their observations made under ordinary room conditions with no attempt to control either temperature or moisture. The object of the present work was to obtain more definite information on the life history of this insect over a considerable range of controlled conditions in relation to temperature, food, and atmospheric moisture.

METHODS OF STUDYING DEVELOPMENT

Mass populations of saw-toothed grain beetle adults were reared on the moist, balanced food mixture recommended by Haydak (*8*) and held in a constant temperature chamber at 32° C. and 75 percent relative humidity. Under these conditions it was possible to obtain large numbers of the insect in a relatively short time. Several hundred beetles were collected and placed in an oviposition chamber, a pint fruit jar containing a small amount of the food mixture and several irregularly broken pieces of a large cork stopper. The cork had previously been softened and made pliable by moistening and autoclaving.

The eggs, which are normally laid in cracks and crevices of food material, are covered with an adhesive substance which causes them, when first deposited, to adhere to each other and to the food particles. Cork was found to provide a very suitable surface for the females to oviposit on and from which to retrieve the eggs. Following oviposition, the pieces of cork were removed and the adhering beetles shaken into the culture jar for future use. The eggs adhering to the cork were readily observed by means of a binocular microscope and were picked off with a fine moistened brush. They were then placed individually on the inner walls of 2-dram vials some distance above a small supply of food. Nearly half of the hatching experiments had

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[2] Italic numbers in parentheses refer to Literature Cited, p. 614.

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to be discarded because of injury to the eggs during handling. The larvae left the empty eggshells attached to the walls, where they could be seen easily, making it unnecessary to locate and disturb the minute, white, fragile larvae among the food particles.

The adult beetles are very excitable, and as handling of them was unavoidable before each oviposition period considerable time elapsed before the deposition of eggs actually occurred. Oviposition periods of 2, 4, and 6 hours were tried, but it was found necessary to extend the period to 10 hours. The beetles were placed in the oviposition chamber at midnight to facilitate the measuring of the development periods. Including the time required to retrieve them, the eggs were from 1 to 14 hours old before they were exposed to the various experimental conditions. Very few eggs were found to have been laid in the first 4 hours, however, so it is assumed that the majority of them were not over 6 to 7 hours old.

Eggs were placed singly in individual 2-dram vials which contained sufficient food and were stoppered with perforated corks covered with small pieces of silk bolting cloth. The vials containing the food had previously been conditioned at the desired temperature and humidity for at least 36 hours. Groups of 30 vials, each vial containing one egg with food, were placed in small desiccators held at constant temperature. Various known concentrations of sulfuric acid in water were used to control the atmospheric moisture within the desiccators. The acid concentrations required to give the desired atmospheric conditions were calculated from a graph taken from Wilson (*16*). The desiccators were at no time removed from the cabinets during the experimental period, and the vials were out only for a few minutes daily during the critical periods, preliminary tests indicating approximately when observations were to be made. It is believed that the atmosphere of the vials reached an equilibrium with the atmosphere in the desiccators within a reasonably short time since the desiccators were small and the vials were but a short distance above the acid solutions.

The various stages of the insect were exposed to temperatures of 15°, 20°, 25°, 30°, 35°, and 40° C. in cabinets controlled by toluene-mercury thermostats which did not vary more than $\pm 0.5°$. At least three replications were made in each category.

Two levels of atmospheric moisture or saturation deficiency were at first chosen, 5 mm. and 12.5 mm. As the work progressed it was thought desirable to provide a wider range of moisture conditions and a third level, 22.5 mm. of saturation deficiency, was added.

Three rather different types of food commonly infested by the saw-toothed grain beetle were used, namely, rolled oats, English walnuts, and raisins. A sufficient quantity of each for the entire experiment was obtained at the beginning of the study. Each vial contained enough of the food material to more than support the insect, but not enough for the larva to burrow into and become covered. The larva, therefore, was more or less exposed to the atmosphere at all times. Raisins, because of their hygroscopic nature, did not lend themselves to some of the conditions of the experiment. The young larvae frequently became enmeshed in the sticky syrup produced by the raisins and in such cases there was a high mortality.

Two measures of moisture were utilized in this work, saturation deficit and relative humidity. The first is a measure of the evaporative power of the atmosphere and, being uniform at different temperatures, may be applied to the study of the direct effect of atmospheric moisture upon insect growth. At a 5-mm. saturation deficiency, for example, the rate of evaporation is theoretically constant at the temperatures 35° 30°, 25°, and 20° C.

Atmospheric moisture, on the other hand, is absorbed by food materials in proportion to the relative humidity of the air. The relative humidities corresponding to a 5-mm. saturation deficiency at 35°, 30°, 25°, and 20° C. are 88, 84, 79, and 72 percent respectively. In preliminary tests rolled oats exposed in desiccators at these temperatures and humidities for 4 days and then dried at 105° for 24 hours showed a moisture content on a dry-weight basis of about 21.6, 22.8, 18.8, and 15.9 percent respectively. In the analyses of Atwater and Bryant (*1*) soft-shelled walnuts averaged 2.5 percent moisture. Finely divided soft-shelled walnuts exposed to relative humidities of 46.7 and 88.0 percent at 35° for 5 days and then dried over sulfuric acid for 10 days gave approximate moisture-content values of 1.7 and 6.6 percent. Walnuts appear to be less hygroscopic than rolled oats owing possibly, to their high oil content and to their reduced surface.

If moisture were held constant in terms of relative humidity, regardless of temperature, the food moisture content would be constant, but the rate of evaporation from the surface of the insect would then be variable because of the differences in saturation deficiency. By holding one value constant the other will be variable. It is realized, therefore, that in studying the effects of temperature alone, the moisture relationships are not entirely in agreement. Although the rates of evaporation are constant, the moisture content of the food material differs slightly at each temperature, and the changes in the rate of development cannot be said to be due entirely to the effects of temperature. The larvae in a condition of higher relative humidity, because of a higher percentage of water in the food, will be able to replace water loss with greater ease than those at a lower relative humidity. Much greater effects, in general, can be attributed to temperature, and it is believed that errors due to the variation in food moisture content are not very great. On walnuts, the moisture content of which is little affected by wide variations in humidity, the error is probably much reduced.

In these experiments the walnuts were divided to permit accessibility of the food to the newly hatched larvae. Schwardt (*14*) observed that finely divided foods of high oil content were detrimental to larval development. He stated that when the larvae crawl upon or through divided oily food they are brushed on all sides and become coated with a thin film of oil. If the food particles are larger the larvae can pass through the interstices and only touch the food with their tarsi and part of the ventral surface of the abdomen. In this study it was found that ground walnuts were fatal to the larvae whereas chopped walnuts had no detrimental effects.

In the statistical procedure the following formula of Fisher (*7*) was used:

$$S.\ E. = \frac{\sqrt{\dfrac{S(x^2) - S(x)\bar{x}}{N-1}}}{\sqrt{N}}.$$

The formula for determining the error of the difference between two means is as follows:

$$\frac{(\bar{x}_1-\bar{x}_2)}{\sqrt{S.\,E._1{}^2+S.\,E._2{}^2}},$$

when $\bar{x}$ is the mean, and S. E. is the standard error of the mean.

RESULTS OF DEVELOPMENT STUDIES

EGG

The eggs are usually laid in groups of 3 or 4 in the cork supplied for oviposition. Frequently, however, as many as 20 to 30 were found in a cluster.

From inspection of the data in table 1, it is seen that atmospheric moisture has little or no effect on the rate of development of the egg. The length of the egg stage varies considerably with the temperature. Eggs failed to develop at 15° or at 40° C. At 20° somewhat more than 12 days were required for them to hatch, while the greatest rate of development occurred at 35° when only a little over 4 and a fraction days were necessary. Although separate series of data are given for each of the three foods, all are computed on a similar basis and a comparison of the results will give an idea of the reliability of the differences caused by temperature changes.

TABLE 1.—*The development of the saw-toothed grain beetle under various conditions of temperature, moisture, and food*

Food and temperature (° C.)	Saturation deficit	Relative humidity	Egg		Larva			Pupa		Total		
			N	$\bar{x}$	*N*	$\bar{x}$	Standard error	*N*	$\bar{x}$	*N*	$\bar{x}$	Standard error
Rolled oats:	*Millimeters*	*Percent*		*Days*		*Days*			*Days*		*Days*	
20°	5.0	71.6	19	12.79	19	39.74	0.66	18	16.33	18	69.06	0.90
	12.5	28.7	36	11.58	36	44.64	.85	14	17.43	14	73.64	1.02
25°	5.0	78.8	45	6.29	45	15.51	.27	45	8.53	45	30.31	.23
	12.5	47.3	32	6.75	32	17.66	.48	31	8.13	31	32.23	.43
	22.5	5.2	44	6.84	44	23.61	.37	40	8.55	40	39.15	.43
30°	5.0	84.3	36	4.89	36	10.28	.19	36	5.50	36	20.67	.17
	12.5	60.7	36	4.99	36	12.28	.31	36	5.51	35	22.80	.30
	22.5	29.2	36	5.00	36	15.72	.25	34	5.74	34	26.41	.27
35°	5.0	88.1	43	4.16	43	9.37	.14	43	4.47	43	18.00	.14
	12.5	70.4	33	4.30	33	10.85	.45	33	4.67	33	19.82	.44
	22.5	46.7	45	4.31	45	14.84	.25	45	4.71	45	23.87	.30
English walnuts:												
20°	5.0	71.6	31	12.61	31	44.26	.74	17	15.12	17	70.59	1.00
	12.5	28.7	19	12.32	19	52.47	.86	3	16.00	3	77.67	1.78
25°	5.0	78.8	44	6.52	44	18.32	.29	40	7.83	40	32.73	.33
	12.5	47.3	31	6.65	31	21.74	.52	25	8.32	25	36.52	.66
	22.5	5.2	50	6.70	50	33.08	.77	31	9.29	31	48.55	1.25
30°	5.0	84.3	29	5.03	29	13.59	.36	28	5.68	28	24.11	.43
	12.5	60.7	31	5.03	31	15.74	.31	28	5.93	28	26.54	.37
	22.5	29.2	50	4.98	50	21.20	.46	30	5.47	30	30.97	.52
35°	5.0	88.1	37	4.00	37	15.30	.29	22	4.45	22	23.68	.45
	12.5	70.4	32	4.09	32	16.09	.47	14	4.79	14	25.14	.71
	22.5	46.7	29	4.24	29	21.76	.96	14	4.57	14	29.57	.89
Raisins:												
20°	5.0	71.6	3	12.00	3	51.00	-------	3	17.67	3	80.67	-------
25°	5.0	78.8	10	6.20	10	30.10	-------	5	8.20	5	40.80	-------
	12.5	47.3	10	6.20	10	32.50	-------	10	8.40	10	47.20	-------
30°	5.0	84.3	4	4.00	4	21.50	-------	1	6.00	1	36.00	-------
	12.5	60.7	8	4.00	8	27.50	-------	8	5.63	8	36.63	-------

LARVA

Since the eggs failed to hatch at 15° C., some were hatched at 20°, the next higher point in the temperature series, and the newly hatched larvae were placed on rolled oats at a saturation deficiency of 5 mm. and a temperature of 15°. The larvae failed to develop. Under the same food and atmospheric moisture conditions at 20°, larvae developed in an average of 39.74 days as compared with 15.51 days at 25°. On rolled oats the optimum temperature for development is about 35° where 9.37 days are required for the larval stage, while at 30° the developmental time is 10.28 days. With walnuts as food, and under the same moisture conditions, the developmental optimum appears nearer to 30°, where 13.59 days are required as compared with 15.30 days at 35° C.

In general the data show significant differences in the rate of larval development at the three moisture levels within each temperature. Larval development tends to be more rapid at a higher humidity. The differences in developmental time between the moisture levels are greatest at 20° C. on both rolled oats and walnuts, because of the longer periods involved; in other words, differences in the developmental period decrease with an increase in temperature. Between 12.5 mm. and 22.5 mm. of saturation deficiency the data differ more because of the greater spread in atmospheric moisture conditions. Because of insufficient numbers, the raisin data are not statistically treated. From inspection, however, they appear to show the same trend as the other foods.

On the basis of the rate of development, rolled oats is superior to either walnuts or raisins as food for the saw-toothed grain beetle. The raisin data are admittedly lacking in sufficient replications and are presented only as an indication of the value of raisins as food for this insect. Comparing the rates of development at 25° C. and 5-mm. saturation deficiency, the larvae completed development in 15.51 days on rolled oats, 18.32 days on walnuts, and 30.1 days on raisins.

PUPA

The rate of development of the pupa varies with the temperature, the maximum being 16 to 17 days at 20° C. and the minimum about 4.5 days at 35°. From inspection of the data, the atmospheric moisture or type of food shows little or no effect on the rate of development, although here, as in the egg stage, any actual differences would be slight and would be obscured by the short developmental period and the relatively long intervals between observations. The data, however, are mostly rather uniform within each temperature regardless of humidity, and the values in each class on the different foods approach each other.

TOTAL DEVELOPMENTAL PERIOD

Since food and atmospheric moisture conditions have little or no measurable effect on the rate of development of the egg and pupa, the rate of development under the various conditions for the entire period from egg to adult is similar to that of the larva. On rolled oats at a 5-mm. saturation deficiency, the insect completes its development in the shortest time of 18.0 days at 35° C., while the longest mean period occurs at 20° where 69.06 days are required. With walnuts as food the data for total development at 30° are not significantly different from those at 35°. The optimum condition lies somewhere between these temperatures. The shortest mean period on walnuts at a

5-mm. saturation deficiency is 23.68 days at 35°, while the maximum, which occurs at 20°, is 70.59 days. On raisins the developmental periods appear from the few available data to be somewhat longer. At 30° and at the high humidity, one complete life cycle requires about 36.0 days, while at 20° the complete developmental time is 80.67 days.

The longest total period of individual development recorded in these experiments was 84 days on raisins at 20° C. and a 5-mm. saturation deficit. Under the same conditions, but on rolled oats instead of raisins, the longest period was 78 days, the shortest 64 days. The comparable data for 35° with rolled oats as the food are 20 and 17 days, respectively.

DISCUSSION

Chapman and Baird (*5*) determined the duration of the developmental stages of *Tribolium confusum* Duval at several temperatures

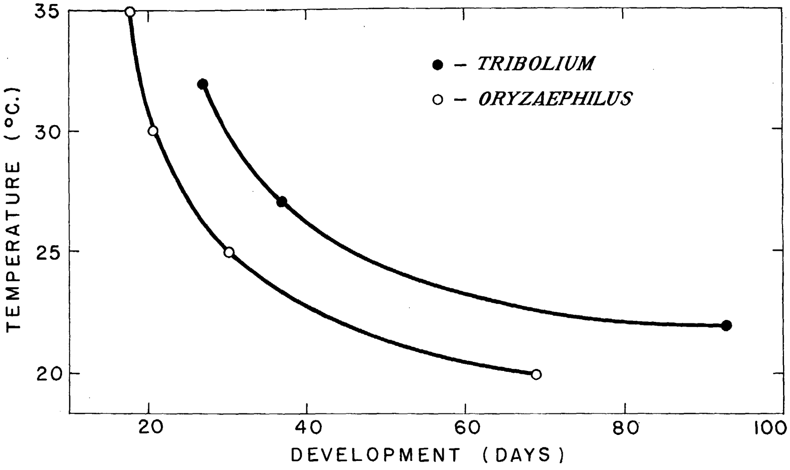

FIGURE 1.—Comparison of the total developmental periods at different temperatures for *Oryzaephilus surinamensis* fed on rolled oats at 5 mm. saturation deficiency and *Tribolium confusum* fed on whole-wheat flour at 75 percent relative humidity.

and 75 percent relative humidity. In figure 1 are shown these data in comparison with the present determinations for *Oryzaephilus*. The data, although not exactly comparable, are nearly so. In the second species the data plotted are those at 5 mm. saturation deficiency, but the latter is close enough to 75 percent relative humidity that not over 1½ days correction would be necessary for developmental periods of 70 days or more. Furthermore, *Oryzaephilus* was reared on rolled oats whereas *Tribolium* had whole-wheat flour as food. These foods, however, are not widely different. The comparison of the two species with respect to the time required for development from egg to adult shows *Oryzaephilus* to be considerably faster than *Tribolium confusum* in its development. At 30° C. the difference amounts to about 8 days; at 22°, to about 52 days. Therefore the development of *Tribolium confusum* under somewhat comparable conditions may take over twice the time required by *Oryzaephilus*.

Holdaway (*9*) studied the development of *Tribolium confusum* at several relative humidities and a single temperature (27° C.) in connection with population studies. He found a 24.4-percent increase in the total developmental period when the relative humidity was reduced from 75 to 25 percent. In the present studies with *Oryzaephilus* at 25° a comparable lengthening of the period was found amounting to a 25.9-percent increase when the saturation deficit was increased from 5.0 to 22.5 mm. pressure (a drop from 78.8 to 5.2 percent relative humidity).

The fact that stored-product insects are able to develop in very dry food is well known. Certain insects can gain water from an atmosphere which is nearly saturated, the water entering through channels other than the mouth. Babcock (*2*) pointed out that through oxidation of food material a considerable quantity of water is produced which many animals use to carry away nitrogenous wastes in solution. Insects living on dry foodstuffs, however, excrete solid uric acid and are able to retain the water of metabolism which would otherwise be used in excretion.

The water content of their food has been shown to influence the proportion of water in insects. Insects that feed on food of high moisture content contain a much higher percentage of water than those that live on dry materials. Living on dry food, the insects themselves contain a higher percentage of water than there is in the food. Schultz (*13*) has shown that larvae of *Tenebrio molitor* L. fed on bran pass feces of which 80 percent is undigested food but lower in moisture than the original bran. Buxton (*4*) explained this as the result of wasteful eating as well as the formation of water of metabolism. When food is eaten wastefully the small amount of free water contained in it is probably extracted by mechanisms in the rectum, which results in dry excreta. Schwardt (*14*) observed the saw-toothed grain beetle develop in food containing practically no free water.

According to Buxton (*4*) starved larvae of *Tenebrio molitor* lose weight when exposed to a humidity of 80 percent or lower, but if kept at 90 percent and temperatures of 23° or 30° C. they gain weight. He stated that the phenomenon is not similar to the hygroscopy of hair and other dead materials, but that it is due to biological activity. Water from the liquid in the tracheoles is thought to be continuously secreted into the insect body, thereby increasing the concentration of the tracheole liquid and causing atmospheric moisture to be absorbed by it.

Stored-product insects are able to conserve moisture in various ways, thus protecting themselves against desiccation. Mellanby (*10*) stated that practically all the water that evaporates from an insect is lost through the spiracles. When the spiracles are closed the air within the tracheae becomes saturated and in most cases remains so when the spiracles are opened. Otherwise, when the air becomes very dry, the air of the tracheae becomes dry, the tissues being unable to supply water fast enough. One of the best methods that insects possess for protecting themselves against loss of water, then, is their ability to close the spiracles. Certain factors, however, such as an increase in temperature, may accelerate metabolic activity and increase the rate of respiration, causing the spiracles to be opened more often and increasing the rate of water loss.

The effect of atmospheric moisture on a stored-product insect, therefore, is in proportion to the rate at which moisture is being withdrawn from the insect and to the ease with which that moisture can be replaced. The longer time required for development on walnuts than on oats is probably due in considerable part to the lower hygroscopicity of the food.

LETHAL EFFECTS OF HIGH AND LOW TEMPERATURES

The lethal effects of high and low temperatures on insects are known to vary with the species, the developmental stage, and the other environmental factors, such as moisture. Data have been presented in the preceding paragraphs showing that the egg and larva of the saw-toothed grain beetle are incapable of developing at 40° and 15° C. To obtain further information on the reactions of this insect to lethal temperatures, its longevity was determined near both the upper and the lower limits of development. Only healthy adult insects, of which the sex and age were disregarded, were used in these experiments, since it was not feasible at the time to add greatly to the experimental work by determining the effects on all stages.

Oosthuizen (*12*), working with all stages of the confused flour beetle, *Tribolium confusum*, found some variation in the heat resistance of different stages at different temperatures. He showed that at 44° C. 50 percent of the adult beetles were killed in 7.4 hours and that changes in the atmospheric moisture conditions had no effect at this temperature. At 46° only 64 minutes were required to kill 50 percent of the adults, but at this temperature moisture conditions affected the results, the beetles dying much sooner at 100 percent relative humidity and somewhat sooner at 0 and 30 percent than at 75 percent.

Temperatures between 44° and 46° C. are critical, and very slight changes in the intensity of heat between these points produce profound effects. The writers operated the same apparatus used by Oosthuizen, but it is felt that somewhat greater accuracy in measurement and control of the bath temperatures was attained. The temperatures recorded by Oosthuizen as 44° and 46° are actually slightly lower, although certainly not over 0.7° lower, and probably about half that much.

Adult beetles were exposed in a water bath arrangement and with a technique essentially the same as that described by Oosthuizen. Cages made of a fine-mesh wire screen were used instead of glass and bolting cloth. Thermometers were not placed in the cages as it was found that the desired temperature could be obtained there by maintaining the outside water bath temperature 0.7° C. higher. This difference was due to loss of heat from the exposed portions of each glass exposure chamber at the water surface. Temperatures were measured with a sensitive thermometer graduated in tenths of a degree centigrade. Cage temperatures did not vary more than $\pm 0.1°$. The exposure chambers were conditioned for at least 4 hours prior to each experiment. As active saw-toothed grain beetles cannot live long without food, a small amount of food was provided in each cage. Exposed beetles were allowed 2 days for recovery before the percentage of mortality was determined. Each point plotted in figure 2 represents in excess of 150 individuals.

Tattersfield and Morris (*15*) have shown that mortality data can best be compared at the point at which 50 percent of the individuals survive. The writers' data for adults of *Tribolium confusum* show somewhat lower values than those of Oosthuizen. At 44° C. and 30 percent relative humidity, 50 percent of the beetles were killed in a little over 4 hours while at 46° and 50 percent relative humidity about 40 minutes were required, as compared with 7.4 hours and 60 to 75 minutes respectively as found by Oosthuizen. These differences show how important a fraction of a degree may be in shifting the time required to kill a group of insects.

The exposure periods necessary to kill 50 percent of the adults of the saw-toothed grain beetle decrease rapidly with slight increases in heat intensity between the temperatures tested. At 42° C. 50-percent mortality occurs in about 34 hours while at 44°, only 2° higher,

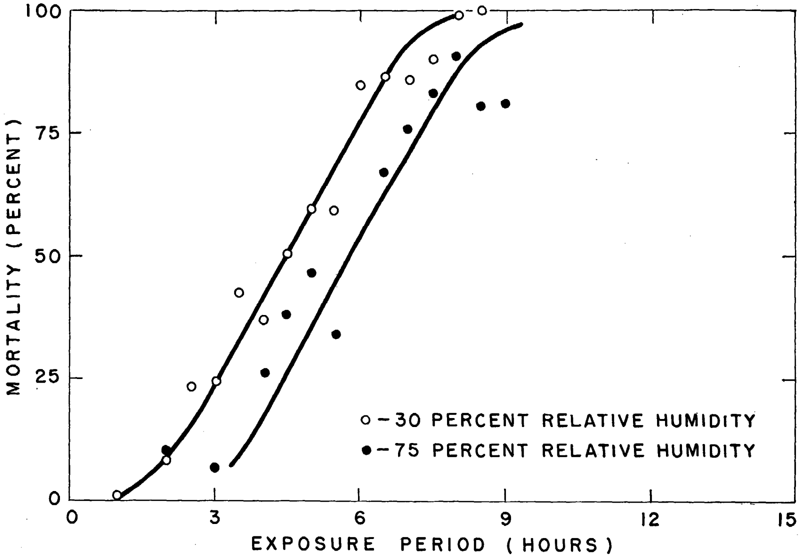

FIGURE 2.—Mortality of the saw-toothed grain beetle exposed for different lengths of time at 44° C. and relative humidities of 30 and 75 percent.

50 percent of the beetles are killed in approximately 4.5 hours at 30 percent relative humidity, and 5.7 hours at 75 percent relative humidity (fig. 2).

In general the saw-toothed grain beetle and the confused flour beetle are about equally resistant to high temperature. The chief difference between these species appears to lie in the higher sensitivity of *Oryzaephilus* to desiccation. At 44° C. this species is definitely more easily killed at 30 percent relative humidity then at 75 percent. At the same temperature and humidities, *Tribolium confusum* is unaffected by the moisture differences. It appears likely that this fact is correlated with the greater susceptibility of *Oryzaephilus* to desiccation at ordinary temperatures.

Nagel and Shepard (*11*) studied the effects of low temperatures on all stages of *Tribolium confusum*. The exposure periods necessary to obtain a 50-percent mortality of the adults at 7°, −6°, −12°, and −18° C. were 336, 8.4, 0.23, and 0.15 hours respectively.

Adult saw-toothed grain beetles were exposed in small fine-mesh wire screen cages, each cage containing approximately 50 beetles and a small quantity of food material. The cages were placed in dry desiccators in refrigerated cabinets at the desired temperatures. No attempt was made to control the atmospheric moisture conditions, but the temperatures were maintained to within ±1.0° C. Two days were allowed for the insects to recover before mortality was determined. Exposures were made at two temperatures, 10° and 2°. The exposure periods to obtain 50-percent mortality were 30 days and 105 hours respectively. It is impossible from these determinations to say whether *Oryzaephilus* differs significantly from *T. confusum* in resistance to low temperature.

SUMMARY

A study was made of the development of all stages of the saw-toothed grain beetle (*Oryzaephilus surinamensis* L.) under various conditions of temperature, atmospheric moisture, and food. Rearings were made or attempted at temperatures of 15°, 20°, 25°, 30, 35°, and 40° C., at saturation deficiencies of 5, 12.5, and 22.5 mm., and with rolled oats, English walnuts, and raisins as food.

At 5 mm. saturation deficit and on rolled oats as food, the total life cycle from egg to adult requires 69.06 days at 20° C., 30.31 days at 25°, 20.67 days at 30°, and 18 days at 35°. With rolled oats as food, the developmental optimum appears at 35° C. while with walnuts, the developmental optimum occurs between 30° and 35°. Eggs larvae failed to develop at 15° and 40°. In general, development is more rapid at the higher humidities. The egg and pupal stages appear to be little affected by atmospheric moisture conditions. On the basis of the rate of development, rolled oats are superior to either walnuts or raisins as a food for the saw-toothed grain beetle.

Adults of the saw-toothed grain beetle and the confused flour beetle were exposed to high temperatures. At 44° C. and 30-percent relative humidity, 50 percent of the flour beetles were killed in a little over 4 hours while at 46° and 50-percent relative humidity about 40 minutes were required. At 42°, 50 percent of the adult saw-toothed grain beetles were killed in 34 hours while at 44° the exposure periods were approximately 4.5 and 5.7 hours at 30- and 75-percent relative humidities respectively.

Adult saw-toothed grain beetles exposed at 10° and 2° C. gave 50-percent mortality values at 30 days and 105 hours respectively.

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