THE DEVELOPMENT AND HABITS OF THE GRANARY WEEVIL, *Sitophilus granarius* (L.), WITHIN THE KERNEL OF WHEAT

by

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INTRODUCTION

There are many species of insects but relatively few can survive on grain in storage, and only four species develop inside the kernels on the endosperm. One of these four insects, the granary weevil, Sitophilus granarius (Linn.) (Plate I) was selected for observation of its development and habits within kernels of wheat. The granary weevil is one of the most destructive stored grain insects. It prefers the temperate climate and therefore has been found more in the northern states than in the southern states. This weevil has lost its power of flight and either walks or depends upon man for its transportation from one place to another.

The adult granary weevil is brownish to blackish in color, and has a maximum length about three-sixteenths of an inch. Its head has elongated into a long slender snout with mouthparts located at the tip. The pronotum is marked with larger oval punctures as compared with the smaller, round, densely pitted pronotum of the rice weevil. The adult granary weevil may live from seven to eight months and usually takes more than four weeks to complete its life cycle.

The granary weevil has been studied as an adult, but little information is known about its development inside the grain. Such information was obtained by sacrificing the insect and the kernel.

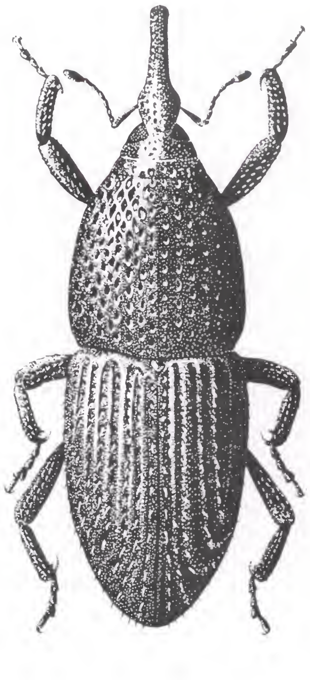
The object of this study was to obtain full information about the immature granary weevil using the new X-ray techniques thereby observing their undisturbed development and habits inside kernels of wheat. The study began on September 3, 1960 when 200 adult granary weevils were placed in a prepared grain sample to obtain internal larval infestations for radiographing.

EXPLANATION OF PLATE I

Granary weevil, Sitophilus granarius (Linn.)

(From N. C. Agric. Expt. Sta. Bul. 389, May 1954)

PLATE I



REVIEW OF LITERATURE

Origin

The granary weevil is thought to have been present in the tombs of Asia. Many writers have referred to this insect through the years. Carolus Linnaeus (1758) first described the weevil as *Curculio granarius*. In 1790 Oliver published a report that has been the basis of many later articles. Clairville and Schellenberg (1798) determined *Calandra* to be the genus for the grain weevils. However, Pierce (1919) pointed out that the correct generic name should be *Sitophilus*.

Stages

The granary weevil is destructive to the grain in both adult and larval stages. Gavit (1849) observed that the life cycle lasted from 40 to 45 days and that some adults lived more than 1½ years. Back and Cotton (1922) found that the weevils lived approximately 10 months during which time the female laid between 200 and 300 eggs. Taschenberg (1865) observed a granary weevil which laid 150 eggs.

According to Strachov-Koltchin (1915) the egg developing period ranged from five days at 75°F. to 15 days at 62°F. Back and Cotton (1922) observing individual eggs determined that the incubation period was four days at a mean temperature of 81.5°F. and 15 days at a mean temperature of 61.0°F. Nakayama (1926) noted that the egg stage in Japan varied from 12 days in April to five days in August.

The larval period varied from 21½ days to 84 days depending on the temperature according to Strachov-Koltchin (1915). The larvae develop in all the common grains, acorns, chestnuts, and even sunflower seeds. Nakayama (1926) pointed out that the prepupal form lasts from one to two days which agreed with Back and Cotton's findings in 1922. The time between the pupal stage and the emerged adult varied from five days to 15 days according to Back and Cotton (1922).

Detection

Chemical. Detection of insect infestation by chemical methods is widely used today. In 1948, J. C. Frankenfeld developed the acid fuchsin staining procedure which stains the egg plugs a dark red. Goossens (1949) used the gentian violet stain to color the egg plugs purple. Milner et al. (1950a) soaked the kernels in a berberine sulfate solution and then examined them with ultraviolet light to detect the fluorescing egg plugs. Apt (1950) hydrolyzed the kernels with sodium hydroxide which exposed larvae inside the kernels. Harris et al. (1952) developed the cracking-flotation method to detect insect infestation.

X-ray. X-rays are a form of radiant energy similar to the visible light rays. They have an extremely short wave length of 1/10,000 the length of a visible light wave. The application of X-rays in the detection of insects has been rather recent. In 1926 Yuasa indicated that insects could be identified in plant quarantine work by utilization of X-rays. Fenton and Waite (1930) profited by the X-ray method to detect pink bollworms in cottonseeds. Shevchenho (1937) X-rayed 33 species of plants that were injured by 20 different pests. He pointed out that this method of detection was very useful. Schevchenho also observed that the X-ray dosage absorbed by the seeds during the process of radiation had no harmful effects on their viability. Milner et al. (1950b) applied X-rays to stored grain. In 1953 the Food and Drug Administration evaluated the procedures used in X-raying wheat and corn. Hampe (1958) presented the various factors that affect the development of a radiograph. Harris (1960) noted that dead larvae can occasionally be seen, but dead pupae and adults are not visible when reading the radiograph. Portable gamma radiation from Cobalt-60 has become popular because of its low cost as indicated by Collins (1961). This material has a half-life of 5.3 years. No electrical supply would be necessary and the X-ray techniques may be employed for detection of insects on growing plants as well as harvested kernels.

MATERIALS AND METHODS

Insects

The granary weevils used in this study were reared from parental stock obtained by mixing adults from cultures of the United States Department of Agriculture, Stored Products Insect Section at Manhattan, Kansas and cultures from Kansas State University. At various times adult weevils collected from elevators were added.

Wheat

A Hard Red Winter wheat of the Ponca variety, used in this study, was obtained from a combine in Riley County, Kansas.

The wheat was stored in a large walk-in type cooler with a temperature of 20^{o}F. to 40^{o}F. which was below the desirable temperature for insect development.

As the wheat was removed from the cooler, it was cleaned by pouring the grain slowly from one container to another in front of a fan. This method was adequate for the small amounts of wheat used in these studies.

The moisture content is one of the important factors in nearly all laboratory studies involving the use of grain. The moisture content was determined by a Model S. Steinlite Moisture Tester. The proper moisture adjustment was calculated by using the procedure outlined by R. T. Cotton. The wheat was placed in containers, tempered, tightly sealed, and rolled two hours a day for one week on a barrel roller. Prior to adjustment the moisture content of the wheat was approximately 10 percent. A moisture content of 13 percent was used throughout this study.

Insect Rearing Room and Cultures

Rearing Room. The stored grain insect rearing room is adjacent to the photographic and radiographic room. This reduced the time to a minimum of handling the plate containing the infested wheat kernels to be radiographed. The insects were kept in this room except as the radiographs were being prepared.

Temperature Control Apparatus. The temperature in the rearing room was maintained at 80°F. $\pm 2^{\circ}$ by means of an electric heater, wired through two thermostats for protection against a defective thermostat that may cause excessive heating. Above this electric heater a 14-inch electric fan was mounted to circulate the heated air to all parts of the room. A large 4' x 4' water radiator was used to cool the room. Water would circulate through this radiator and a 14-inch fan was mounted behind to circulate the cool air.

Humidity Control Apparatus. An attempt was made to maintain the relative humidity at 70% ± 2 percent by the use of a Walton Electric Humidifier. This humidifier was placed on top of the water cooling equipment and the fan from the cooler would circulate the moist air throughout the room.

Parent Stock Cultures. All cultures were reared in one-quart wide mouth mason jars with a fine wire screen of 48 mesh per inch cut to fit inside the ring. Beneath this wire was placed a filter paper to prevent the escape or entrance of very small insects. Approximately three inches of wheat containing 13 percent moisture was introduced into each correctly labeled jar. These jars were then placed in the rearing room for seven days after which the jars were removed from the rearing room and the adults screened by the use of a converted rotomatic sifter. Jars without the parent insects were returned to the rearing room and left undisturbed until the progeny emerged.

Special Equipment

Moisture Tester. Moisture determinations were made using a Model S. Steinlite Moisture Tester that had been checked periodically by the air oven method.

Oven. A laboratory oven manufactured by the Precision Scientific Company was used to dry all the screens and glassware. This oven also was used to determine the moisture content of the grain by the air oven method.

Freezer. A chest type deep-freeze was used to kill the weevils upon completion of the experiment and to assure that all wheat used in the experiments was free of live insects.

Aspirator. An electrically operated aspirator was adapted for handling the adults and for holding the kernels so that the egg plugs could be detected during the microscopic examinations. The delicate dissected larvae were handled with a specially designed aspirator (Kirkpatrick, 1962).

Microscopic Equipment. A laboratory type, broadfield, Bausch and Lomb sliding nosepiece microscope was placed on a stand to observe the radiograph by transmitted light from a mirror beneath the stage.

X-ray Apparatus. Radiographs were made with a General Electric Grain Inspection Unit (Plate II). In applying the X-ray apparatus for wheat, 20 kilovolts and 5 milliamperes gave the best images. This low energy resulted in less penetrating power from the long X-rays and produced a greater contrast in the film from a small amount of absorption by the plastic screen and kernels of wheat. The main parts of the X-ray unit are the X-ray tube, a high voltage transformer, an automatic transformer, a rectifier, and a power supply for the X-ray filament.

Radiographs. The radiographs, which provided a photographic record of the infested wheat, were made on Type M Industrial Film, exposed for $2\frac{1}{2}$ minutes. Normally the exposure takes $1\frac{1}{2}$ minutes for wheat but an additional one minute was required to compensate for the plastic frame and the glue used to hold the kernels in place.

As in regular photographic techniques, changes take place in the film emulsion upon exposure to X-rays. Exposed areas turn dark when acted upon by the developing fluid. As the temperature increases, the time in the developing fluid decreases. The recommended time and temperature is 5 minutes at $68^{\circ}F$.

For the clearest image the kernels should be as close as possible to the film. The best images result when the film is in contact with the

EXPLANATION OF PLATE II

General Electric Grain Inspection Unit.

PLATE II

kernels. The X-ray film had an emulsion on both surfaces; these layers absorb additional rays which would be lost if emulsion were only on one side.

After development in the General Electric Supermix Developer, the film was dipped in clear water and placed in a General Electric Supermix Fixer. This fixer has a hardener added to help protect the film from scratches. The fixing bath process, requiring five to ten minutes, dissolved away the undarkened portion of the sensitive salts. Then the film was rinsed in running water for 30 minutes, and was placed on a rack to dry.

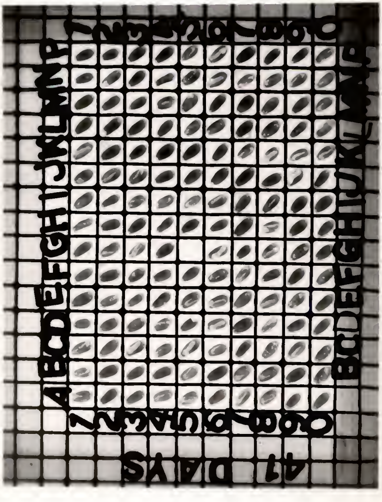
Photographs. In this study the radiograph was used as a photographic negative. The radiograph was placed in an enlarger that used light to expose a sheet of photographic paper. This paper was developed in Dectol Solution, fixed in acid fixer, washed in water and dried by the ferrotype process to give a glossy finish to the print. The black areas on the radiograph became white on the print; that is, the colored areas are reversed. The radiographs were enlarged from one-fourth inch (Plate III) to one inch prints (Plate IV, V, and VI).

Radiographic Plate. This consisted of a sheet of plastic 1/32 inch in thickness and $4\frac{1}{4}$ x $5\frac{1}{4}$ inches in size. Above this plastic was placed galvanized "hail screen" (commonly called rodent proof wire) that contained square openings of $\frac{1}{4}$ inch in size. This wire was taped to the plastic with masking tape. The masking tape was strong enough in bonding power to hold the wire to the plastic throughout the experiment even with many handlings. Numbers were then placed along both sides from 1 to 0 and letters from A to P, omitting O as this letter was the same as the number 0. This gave each kernel a specific identification (Plate III).

EXPLANATION OF PLATE III

A contact print of the radiograph of wheat infested by granary weevils taken on the forty-first day of this study. The numbers and letters give each opening, kernel, or insect its own identification.

PLATE III

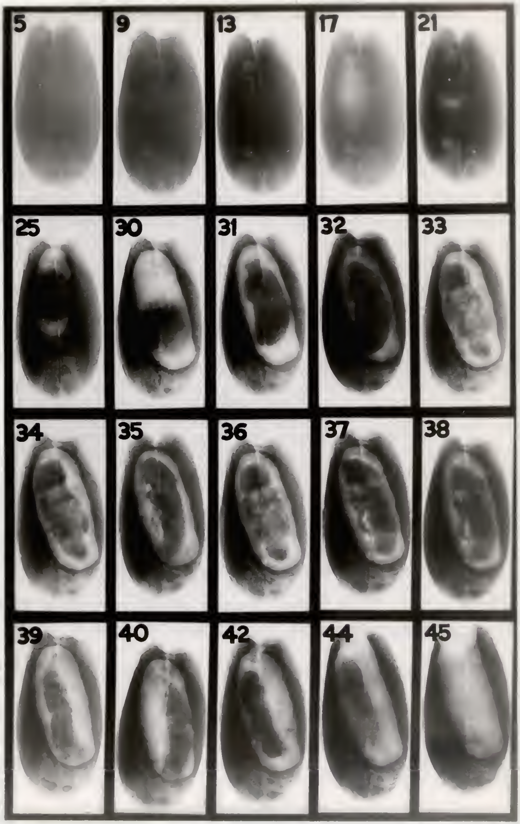


EXPLANATION OF PLATE IV

LIFE HISTORY OF THE GRANARY WEEVIL. Enlarged photographic prints of radiographs of a granary weevil living inside of a wheat kernel of 13 percent moisture. The radiographs were made daily from oviposition through emergence and show an egg, four larval instars, prepupa, pupa, and pre-emerged adult. The numbers refer to days following exposure of kernels to ovipositing females.

DAYS	DESCRIPTION
5, 9	One egg has been deposited in the upper left at the brush end of the kernel. A second egg can be seen faintly at the lower left in the germ end of the kernel.
13	The egg in the upper left has hatched and the 1st instar larva is moving towards the germ end of the kernel. The egg in the lower left of the kernel did not hatch and is drying up.
17	The larva has tunneled to the center of the left side of the crease and is moving back towards the egg site. Last day of 2nd instar.
21	The 3rd instar larva is enlarging the tunnel under the crease.
25	The tunnel has been widened from the brush end to the germ end, prior to molting to a 4th instar larva.
30	The 4th instar larva has completed the tunnel and has packed the excess frass in the germ end as indicated by the material beneath the dark line around the cavity. This dark margin around the cavity represents an attempt to make a pupal chamber prior to transformation to the prepupa. From its indefinite outline, the larva appears to be changing to prepupa.
31, 32	The prepupa has an elongated body without appendages but with a definite head capsule.
31-38	The pupa is recognized by the head with a snout, the thorax with wing pads and legs, and a definite abdomen. The pupa has rotated within the pupal chamber.
39-42	An adult has developed from the pupa. Movement of the legs, snout, and rotation of the body can be seen in this series.
44	The adult is cutting a hole at the brush end of the kernel in preparation for emergence from the kernel.
45	The adult has left the kernel. The radiograph exposes the full extent of the internal damage to the kernel.

PLATE IV

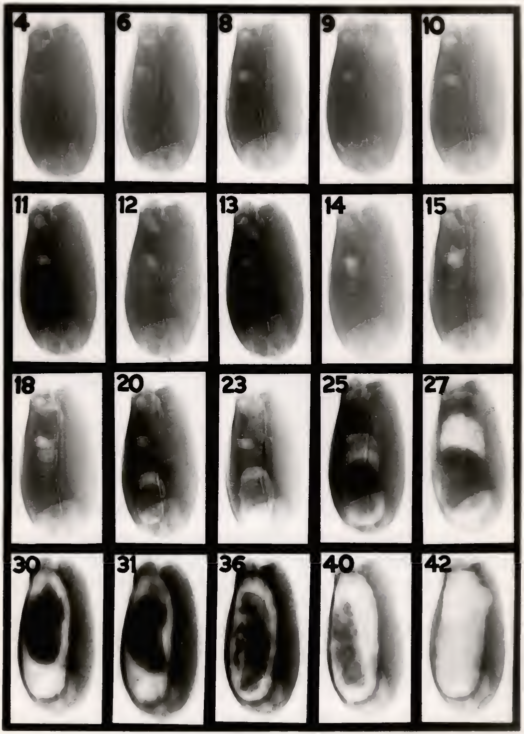


EXPLANATION OF PLATE V

ANTAGONISTIC BEHAVIOR OF GRANARY WEEVIL LARVAE. Enlarged photographic prints of radiographs showing developmental stages of granary weevils living inside a wheat kernel of 13 percent moisture. The prints show the behavior of two 1st instar larvae from hatching to combat and the further development of the surviving larva. The numbers refer to days after exposure of kernels to ovipositing females.

DAYS	DESCRIPTION
4-9	Eggs have been deposited in the upper left portion of the brush end of the kernel and at left upper center below the first egg.
10, 11	The two eggs hatched about the same time into 1st instar larvae. Each larva began to tunnel towards the center of the kernel.
12	The lower 1st instar larva has tunneled to the center of the kernel and has started towards the germ end. The upper larva has nearly reached the tunnel of the lower larva.
13	The upper larva is continuing its downward movement. The lower larva has changed direction and is moving towards the upper larva.
14	Combat has occurred during which one larva was killed. The survivor is moving to the brush end of the kernel. This larva has molted to a 2nd instar.
15	The 2nd instar larva is enlarging its tunnel towards the brush end between the crease and the outer surface.
18	The 2nd instar larva is moving back towards the brush end of the kernel after having completed a tunnel to the center of the kernel.
20, 23	The 3rd instar larva is enlarging its tunnel at the germ end.
25	The 3rd instar larva is molting to become a 4th instar larva.
27	The 4th instar larva is enlarging its cavity to form a pupal chamber at the germ end.
30, 31	The prepupa has developed a thoracic and abdominal region and shows a characteristic head capsule.
36	The pupa shows a characteristic head, thorax with appendages, and abdomen.
40	An adult has developed from the pupa. Its snout, legs, and body movement are apparent. While this adult remains within the kernel it is known as a pre-emerged adult.
42	The kernel shows the extent of feeding by the insect prior to emergence.

PLATE V

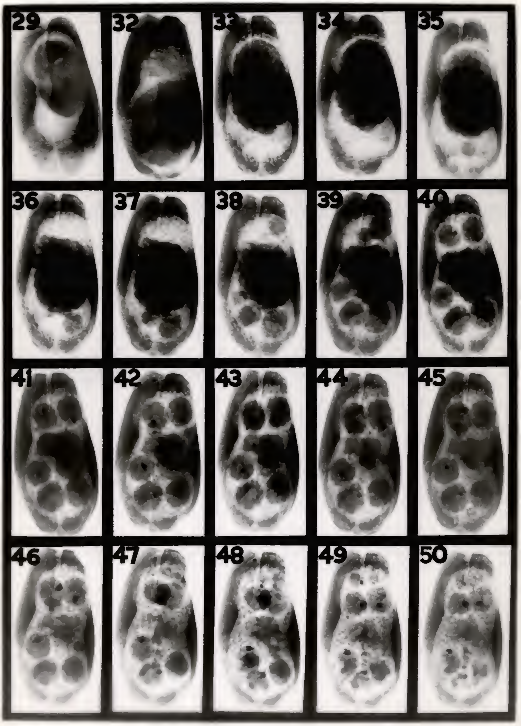


EXPLANATION OF PLATE VI

DESTRUCTION OF A GRANARY WEEVIL LARVA BY THE PREDACEOUS MITE, PYEMOTES (PEDICULOIDES) VENTRICOSUS (Newport). Enlarged photographic prints of radiographs taken between the 29th and the 50th day of the development and destruction of a larva in a wheat kernel of 13 percent moisture. The number on each picture refers to days after exposure of kernels to ovipositing females.

DAYS	DESCRIPTION
29	Normal 4th instar larva occupying the center of the kernel.
32	First faint indication of mite attacking the larva.
33-36	Mites are beginning to damage the larva which appears to be dead on the 36th day.
37-50	Mite progeny develop rapidly and the destruction of the larva is completed by the 41st day. A maximum of six mites are apparent in the larval tunnel from about the 39th day until the 45th day when their numbers and size begin to drop.

PLATE VI



Next, the kernels of wheat that contained an egg plug, as had previously been determined using a microscope, were glued to the plastic in an orderly manner, making sure the kernels did not touch the wire as this would create a problem in the reproduction of the radiograph. Various types of glue were tried for fastening the kernels in place. It was found that Elmer's Glue-All, manufactured by the Borden Company, absorbed less of the long X-rays and did not form shadows on the radiograph. If the glue was thick around the kernel, a shadow appeared as in 7-L (Plate III). This shadow was apparent outside the kernel as well as under the kernel. The germ end of the kernel was placed in the lower right hand side of the square with the crease side glued down facing the plastic to give more surface area to hold the kernels. Thus the insects were required to emerge from the upper surface.

The photographic plates or holders were kept in the rearing room and removed daily for a brief time to be X-rayed. The kernels were radiographed daily at 11:00 a.m. from the third day through the 50th day when the radiographing was concluded since the majority of the insects had completed their development. From the 30th to 50th day the plate was kept in a wide mouth gallon jar to retain the insects as they emerged.

LIFE HISTORY AND HABITS OF THE GRANARY WEEVIL

Egg Stage

After the female had eaten a hole into a kernel, her ovipositor was inserted into the hole and an oval milky-colored egg deposited. A milky or light brown gelatenous substance was then secreted over the egg forming a protective egg plug.

It was necessary to enlarge the radiographs from ¼ inch to one inch squares to observe the different behavioral and structural characteristics of the insects in detail. Eggs in kernel 4-A on the fifth and ninth day after oviposition are shown in Plate IV. Two eggs were deposited in the left side of the kernel; the egg in the upper left hatched while that in the lower left dried up.

Many eggs in the kernels failed to develop or the larvae failed to mature. There appeared to be 265 eggs in the 150 kernels of wheat examined. It was not always possible to distinguish all the eggs on a radiograph not only because of their small size but because of blemishes on the kernel and because of the angle at which the eggs were X-rayed.

Of the 265 eggs deposited in the 150 kernels, 122 eggs or 46 percent hatched and 58 eggs or 22 percent completed their development. Approximately 39 percent of the infested kernels yielded adults. Only one granary weevil developed in a kernel of wheat.

Table 1. Number of kernels with one or more granary weevil eggs per kernel.

Kernels	Eggs
69	1
55	2
19	3
6	4
1	5

The number of eggs that hatched and the number of insects that completed their life cycle is indicated in Table 2.

Two insects that hatched in 4 days are shown as kernel numbers 6-G and 4-M in Plate VII. These insects completed their life cycle on the 39th day and 49th day respectively. The insect in kernel 5-P took 14 days which was the longest time in the egg stage. This insect completed its life cycle in 45 days. Apparently the length of the egg stage is not the only determinant of the length of the life cycle.

Table 2 showed that a few eggs hatched between four and six days; a peak of hatching occurred on the seventh day, followed by a gradual decrease to the 11th day. One egg in kernel 5-P hatched on the 14th day. This is shown graphically in Plate VIII, Fig. 1.

The width of the eggs determined by measurements of the radiographs is recorded in Plate IX, Fig. 1. The measurements were rounded to the nearest 0.125 mm. Fig. 1 indicated that all the eggs measured at least 0.375 mm. Forty-one of the eggs measured 0.5 mm. on the radiograph. These eggs were larger than those measured by Nakayama (1926) in Japan.

Some eggs were deposited outside the kernels. This occurred when the female was unable to locate a suitable place to oviposit or when oviposition was interrupted by sudden alarm, or other disturbances (Nakayama, 1926).

First Instar

The granary weevil after completing its embryonic development emerged as a legless, milky-white, semi-circular shaped larva. It had well developed, hardened mandibles and was ready to eat the food present.

Table 2. Number of eggs, instars, prepupa, pupa, pre-emerged adult, and emerged adults of the granary weevil in days from the first day of exposure of the wheat to the adults for oviposition.

Stadia:	Days																							
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Egg	0	2	2	1	21	18	10	8	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1st instar	0	2	4	5	25	43	52	54	31	28	21	11	5	4	1	0	0	0	0	0	0	0	0	0
2nd instar	0	0	0	1	1	1	2	8	32	37	43	43	46	36	28	16	11	6	2	1	1	0	0	0
3rd instar	0	0	0	0	0	0	0	0	0	0	1	9	12	22	31	41	43	42	47	38	29	22	14	6
4th instar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	5	6	9	18	29	36	42	43
Prepupa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7
Pupa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Pre-emerged adult	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Emerged adult	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

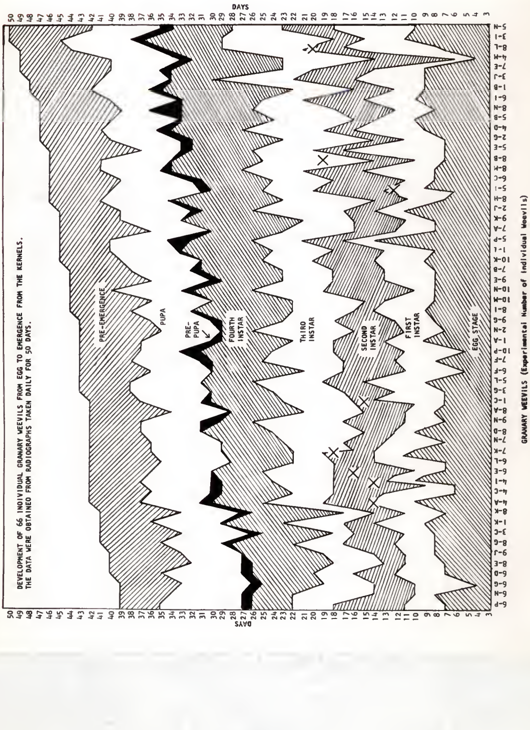
Stadia:	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Egg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1st instar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2nd instar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3rd instar	4	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4th instar	40	42	31	28	21	15	9	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prepupa	6	3	11	15	12	11	10	8	7	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Pupa	8	10	15	25	31	35	33	40	38	32	27	23	17	9	4	2	2	1	0	0	0	0	0	0
Pre-emerged adult	0	0	0	0	0	1	5	7	12	22	30	35	37	43	44	35	27	23	18	12	7	5	2	0
Emerged adult	0	0	0	0	0	0	0	0	0	0	0	0	3	3	4	11	8	5	6	6	5	2	3	2

EXPLANATION OF PLATE VII

Development of 66 individual granary weevils from egg to emergence from the wheat kernels. The data were obtained from radiographs taken daily for 50 days.

X refers to antagonistic behavior of the granary weevil larvae for a particular day.

PLATE VII


DEVELOPMENT OF 66 INDIVIDUAL GRANARY WEEVILS FROM EGG TO EMERGENCE FROM THE KERNELS.
THE DATA WERE OBTAINED FROM RADIOGRAPHS TAKEN DAILY FOR 50 DAYS.
DAYS
PRE-EMERGENCE
PUPA
PRE-PUPA
FOURTH INSTAR
THIRD INSTAR
SECOND INSTAR
FIRST INSTAR
EGG STAGE
GRANARY WEEVILS (Experimental Number of Individual Weevils)

EXPLANATION OF PLATE VIII

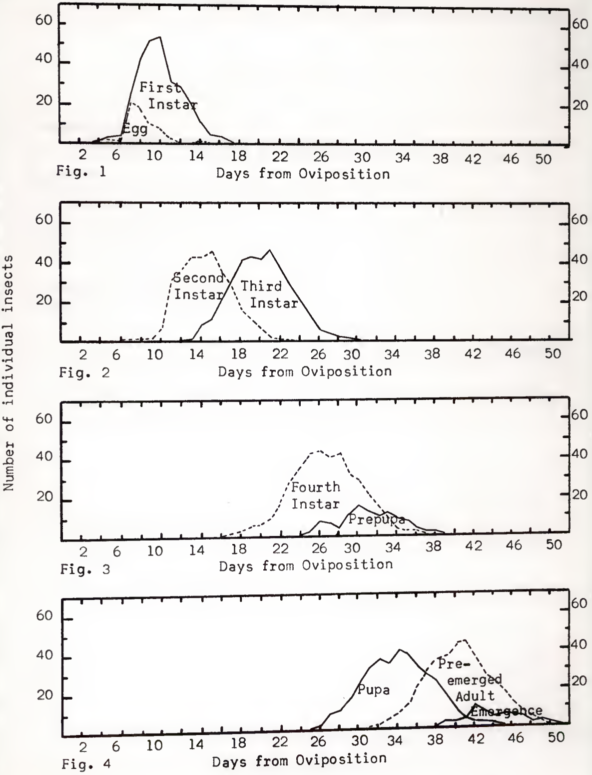
Fig. 1. Number of eggs and first instar granary weevils recorded by days from oviposition.

Fig. 2. Number of second and third instar granary weevils recorded by days from oviposition.

Fig. 3. Number of fourth instar larvae and prepupae of granary weevils recorded by days from oviposition.

Fig. 4. Number of pupae, pre-emerged and emerged adults recorded by days from oviposition.

PLATE VIII


Number of individual insects
60
40
20
First Instar
Egg
2 6 10 14 18 22 26 30 34 38 42 46 50
Fig. 1
Days from Oviposition
Second Instar
Third Instar
Fig. 2
Days from Oviposition
Fourth Instar
Prepupa
Fig. 3
Days from Oviposition
Pupa
Pre-emerged Adult
Emergence
Fig. 4
Days from Oviposition

EXPLANATION OF PLATE IX

Fig. 1. Number of insects found with their width of tunnels in wheat measured on radiographs of 58 granary weevil eggs and larval instars.

Fig. 2. Width of tunnels in wheat measured on radiographs of 58 granary weevil eggs and larval instars.

PLATE IX

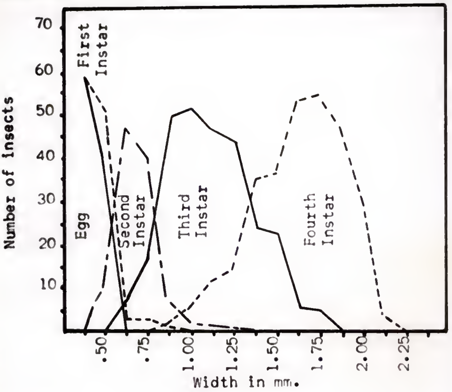
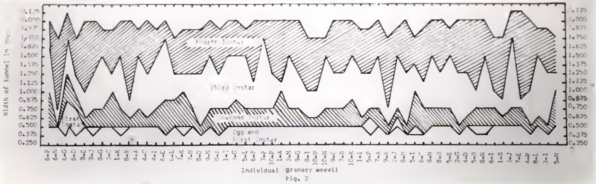


Fig. 1.



Individual granary weevil
Fig. 2

The larva could be distinguished on the radiograph from the egg by the hollow egg cavity which was darker in color than the surrounding endosperm. After hatching, the larva tunneled from the egg cavity towards the center of the kernel where it turned at right angles and continued lengthwise of the kernel. The larva was usually the same color as the endosperm but it could be distinguished from the endosperm by a surrounding tunnel which produced a darker ring-like effect around the larva.

The width of each insect's tunnel was measured daily and recorded in millimeters. Length was not measured because of the constant turning, contraction, expansion and reversing of positions by the larvae within the tunnels. Most first instar larval tunnels and egg cavities measured the same diameter as shown on the 10th day (Plate V and IX). Change in instars was determined by a marked increase in the tunnel diameter as shown by daily measurements. When there was no increase in tunnel diameter, a molt was thought to have taken place (Fig. 1).

A few first instar larvae hatched from the egg between four and six days, but molting increased on the tenth day. All first instar larvae had molted by the 18th day (Table 2 and Plate VIII, Fig. 1).

The peak of egg hatching occurred on the 8th day, while the peak of the first instar larvae occurred on the third day of the stadium (Plate X, Fig. 1). Eight first instar larvae enlarged their tunnels only 0.125 mm. in width, but larva 6-D enlarged its tunnel 0.375 mm. and larva 6-G increased its tunnel 0.5 mm. (Plate IX, Fig. 2).

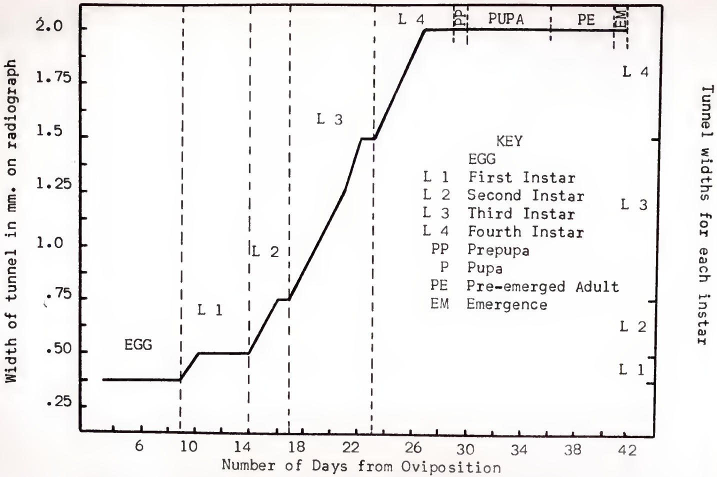


Fig. 1. Development of granary weevil (No. 1-K) from oviposition to emergence showing developmental stages.

Second Instar

After completing their first molt (Fig. 1), the second instar larvae widened their tunnels to the opposite end of the kernels. Second instar larvae were distinguished from first instar larvae by an increase in size (Plate IX, Fig. 2) and by their tunneling pattern. The first instar usually tunneled to the center of the kernel towards the crease, while the second instar increased its penetration of the kernel to the opposite end.

Eighty-one percent of the second instar larval tunnels measured 0.625 mm. or more on the radiograph. An average second instar tunnel diameter was 1.8 times greater than the average head capsule measurements as reported by Kunike (1936), Nakayama (1926), Richards (1947), and Soderstrom (1960) in granary weevil studies (Table 5). Eighteen second instar larvae increased their tunnels only 0.125 mm. in width on the radiograph while the remainder increased their tunnels to a greater extent.

The second instar stadia lasted from six to 23 days with a peak of 15 days. This is shown in Table 2, and Plate VII, and graphically illustrated in Plate VIII, Fig. 2.

Third Instar

After the second molt a greater increase in size took place. The larvae enlarged their tunnel as they made several trips through the kernel. The number of trips daily through the kernel was not determined.

There was a different feeding pattern towards the last of the third instar. The larvae enlarged one end of their tunnel, then moved to the other end of the kernel where they behaved in the same manner. The third molt occurred between 13 and 29 days following oviposition (Table 4). During the molting period, usually one day, the larval tunnel was not enlarged. One of the interesting exceptions was in kernel 6-N. This larva did not increase in size until the third instar (Plate IX, Fig. 2), then it increased its tunnel 0.25 mm. in diameter. But after molting to a fourth instar it increased its tunnel diameter from 0.75 to 1.75 mm. in four days. There was a wide variation in the diameter of the tunnels during the third instar. They ranged from 0.625 to 1.75 mm. with 77.6% of the larval tunnels measuring 1.125 mm. (Table 5).

The third stadium (Table 3) ranged from two to 11 days before molting. This is shown in Plate X, Fig. 2 and Plate VII. Twenty-one days after oviposition more third instar larvae were found than at any other time.

Fourth Instar

After molting the larvae continued a feeding pattern started in the latter part of the third instar. They moved rapidly from one end of the kernel to the other. The enlarging of the ends and central area of the tunnel cavity continued from 17 days through 36 days. Forty-three of the insects were found in the fourth instar 26 days following oviposition (Table 4, Plate VIII, Fig. 3). The enlarging of the tunnel width by fourth instar larvae ranged from 0.750 to 2.125 mm.

At the close of the fourth instar the prepupal chambers were measured and recorded as follows:

Table 3. Length of stadia in days for various stages of the granary weevil.

Stage	Number of Days														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Egg stage	0	0	0	2	2	3	16	<u>18</u>	11	7	3	0	0	1	0
1st instar	0	1	<u>18</u>	17	10	6	6	2	1	1	0	0	0	0	0
2nd instar	0	6	10	12	<u>15</u>	11	4	2	2	0	0	0	0	0	0
3rd instar	0	1	3	7	12	<u>13</u>	7	7	6	1	2	0	0	0	0
4th instar	0	0	0	3	8	<u>14</u>	13	6	7	1	2	1	0	0	0
Prepupa	23	<u>29</u>	3	1	0	0	0	0	0	0	0	0	0	0	0
Pupa	0	0	0	2	2	23	<u>24</u>	4	2	0	0	0	0	0	0
Pre-emerged adult	0	0	0	2	<u>18</u>	16	9	8	4	0	0	0	0	0	0

Table 4. Range in days from exposure of the kernels of wheat to the ovipositing females of the granary weevil for each developmental unit beginning with the egg and continuing until the adults emerged from the kernel. The number of days for each stadium including maximum, mode and minimum for all developmental units.

	Days from oviposition			Days in stadia		
	Minimum	Mode	Maximum	Minimum	Mode	Maximum
Egg stage	1	7	14	4	8	14
1st instar	4	10	17	2	3	10
2nd instar	6	15	23	2	5	9
3rd instar	13	21	29	2	6	11
4th instar	17	26	36	4	6	12
Prepupa	25	30	38	1	2	4
Pupa	26	34	44	4	7	9
Pre-emerged adult	32	41	49	4	5	9
Emergence	39	42	50			

Table 5. Head capsule measurements of granary weevil larvae in wheat determined by previous workers, compared with tunnel diameter for eggs and each larval stadium.

Number of insects for each tunnel width for eggs and each larval stadium						Tunnel diameter	Head capsule measurements				
Egg	1st instar	2nd instar	3rd instar	4th instar	Prepupa	Cross Section of tunnel Width in mm. Radiograph	Kunike (1936)	Nakayama (1926)	Richards (1947)	Soderstrom (1960)	Average
0	0	0	0	3	3	2.125					
0	0	0	0	30	28	2.000					
0	0	0	0	47	16	1.875					
0	0	0	0	58	11	1.750	.64	.61	.68	.68	.65
0	0	0	5	53	0	1.625					
0	0	0	22	36	0	1.500					
0	0	0	23	35	0	1.375					
0	0	1	43	14	0	1.250					
0	0	1	46	11	0	1.125	.46	.52	.51	.51	.50
0	0	6	45	7	0	1.000					
0	1	10	44	3	0	0.875					
0	2	39	15	2	0	0.750					
0	4	47	7	0	0	0.625	.32	.37	.35	.35	.35
34	16	8	0	0	0	0.500	.23	.25	.24	.25	.25
39	11	8	0	0	0	0.375					
0	0	0	0	0	0	0.250					

EXPLANATION OF PLATE X

Length of Stadia in Days 66 Granary Weevils

Fig. 1. This chart gives the number of individual granary weevils and the number of days spent as egg and 1st instar.

Fig. 2. This chart gives the number of individual granary weevils and the number of days spent as 2nd and 3rd instar.

Fig. 3. This chart gives the number of individual granary weevils and the number of days spent as 4th instar and the prepupa.

Fig. 4. This chart gives the number of individual granary weevils and the number of days spent as pupa and pre-emerged adult.

PLATE X

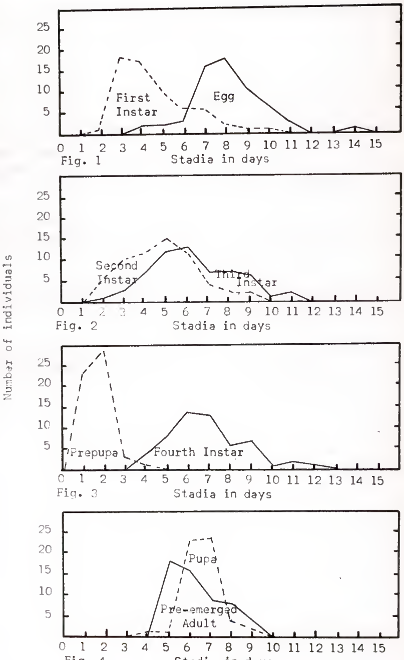


Fig. 1
Fig. 2
Fig. 3
Fig. 4

Diameter of pupal chamber	Number of fourth instar larvae
mm.	
1.750	11
1.875	16
2.000	28
2.125	3

As the larvae completed their excavations for pupal chambers, they began to secrete a fluid which was applied to the walls of the tunneled area. This is shown in the prints by a dark ring around the walls of the pupal chamber (Plate IV, 30-45 days, and Plate V, 27-42 days). In Plate VI the larva was almost ready to secrete this fluid when it was attacked by mites.

The average head capsule measurement of Kunike (1936), Nakayama (1926), Richards (1947), and Soderstrom (1960) (Table 5) was 2.25 times smaller than the average third instar tunnel diameter. The average head capsule measurement of the fourth instar was 2.7 times smaller than the average tunnel width.

The three insects that increased their tunnel diameter the least during the fourth instar took five and six days to enlarge their tunnel 0.25 mm. in width (6-E, 7-F, 10-N, Plate VII and Plate IX, Fig. 2). The fourth stadium ranged from four days to 12 days with the mode occurring on the sixth day. Fourth instar larvae were found between 17 and 36 days after oviposition (Tables 2 and 3, Plate X, Fig. 3).

Prepupa

The prepupal condition lasted from less than one day to four days (Plate VII). During its development the prepupa appeared on the radiograph to be transparent and indefinite. When the prepupa was taken from the kernel, the body fluid could be seen through the exoskeleton (Plate IV, 30 day). This indefinite form soon changed to a characteristic prepupal form (Plate IV, 31-32 days; and Plate V, 30 and 31 days). While a prepupa, no evidence of movement could be seen on the radiograph. According to Nakayama (1926), at the close of the prepupal condition a portion of the thorax and legs become remarkably large. Then a crack in the exoskeleton appeared longitudinally between the head and thorax through which the pupa escapes leaving the larval exoskeleton behind.

The prepupa occurred between the 25th and the 38th days after oviposition. Twenty-nine prepupae were observed on the 30th day (Plate VIII, Fig. 3, and Plate X, Fig. 3).

Pupa

After the last molt the definite pupal form, with three divisions of the body and external appendages, was observed (Plate III, Plate IV, 33-38 days; and Plate V, 36th day). The pupae rotated within their pupal cavities. The pupal period extended from the 26th day to the 44th day following oviposition with most insects being in the pupa stage on the 34th day. The pupal stage is similar to the fourth instar and the egg stage in that four days was the shortest time in which the insect remained a pupa. There were two insects that remained in their pupal stage for nine days.

Pre-emerged Adult

The first signs of movement in the pre-emerged adult is in the head capsule. The snout moved up and away from the body before the legs became extended from their flexed position (Plate IV, 39th to 42nd day; and Plate V, 40th day). The new adult had to prepare an emergence hole through the kernel. An emergence hole may be seen in the brush end of the kernel as illustrated in Plate IV, 44th to 45th day; and Plate V, 40th day.

There were two adults that remained inside the kernel four days while four adults remained nine days. Eighteen of the adults took five days to emerge from the kernels (Plate VII and Plate X, Fig. 4).

The first pre-emerged adult showed signs of head movement on the 32nd day. The majority of these adults moved their head and legs on the 41st day after oviposition. The granary weevil appeared to emerge through that part of the kernel with the least amount of endosperm to penetrate. Some of the radiographs indicated that they would begin to cut an emergence hole, then stop and begin another emergence hole at another area that was not as thick.

Emerged Adult

The adults left the kernels 39 to 50 days after oviposition. Most of them emerged 42 days after oviposition.

In some species of insects one sex may emerge before the opposite sex. In the granary weevil the emerged adults were sexed by two methods, the sculpturing of the snout (Reddy, 1951) and the raised or depressed area on the sternum (Sevintuna and Musgrave, 1960). The following results show little difference between the sex of the emerged adults as shown below:

Day	Males	Females	Day	Males	Females
39	2	1	45	4	2
40	1	2	46	3	3
41	0	4	47	3	2
42	6	5	48	2	0
43	4	4	49	2	1
44	4	1	50	1	1

Areas on the Kernel for Oviposition and Emergence

The kernels of wheat were divided into six areas (Plate XI) from which to record the oviposition and emergence sites of 58 kernels containing granary weevils. From Table 6 it is evident that 86 percent of the adults emerged at the brush end of the kernel; 12 percent emerged at the germ end of the kernel; and two percent at the center sections. Thirty-one percent of the adults emerged at their oviposition site.

Table 6. Emergence sites of granary weevil in relation to oviposition sites when the kernel was divided into six areas.

Eggs deposited in section	Adults emerged		
	Brush	Center	Germ
A Brush upper left	14	0	2
B Brush upper right	9	0	1
C Center left	3	0	0
D Center right	3	1	0
E Germ lower left	5	0	4
F Germ lower right	8	0	0
Total %	86	2	12

EXPLANATION OF PLATE XI

A - F Eggs were deposited in the shaded area; adults emerged at the round dots.

G Emergence sites of those insects that survived conflict within the kernels.

PLATE XI

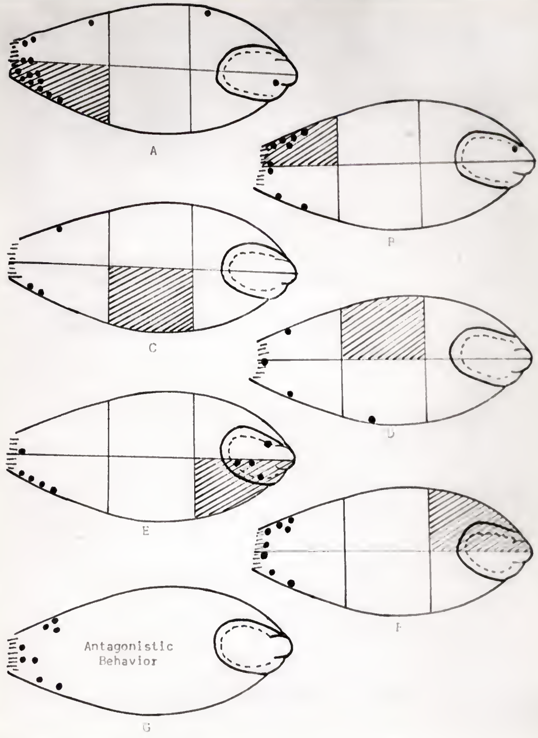


Table 7. Number of days from egg to emergence for 58 individual granary weevils grouped according to the section in which egg was deposited.

Section A		Section B		Section C		Section D		Section E		Section F		Conflicts	
Insect	Day	Insect	Day	Insect	Day	Insect	Day	Insect	Day	Insect	Day	Insect	Day
6-D	40	6-P	39	9-J	40	6-G	39	6-L	42	6-N	39	4-A	42
8-G	41	3-C	40	7-N	42	9-G	43	8-D	42	8-E	41	6-E	42
4-C	42	8-K	41	3-J	48	8-I	44	7-F	43	1-K	41	7-K	42
9-N	42	4-I	42			8-H	46	10-P	43	8-A	42	1-C	42
2-N	43	3-G	43					10-M	44	5-L	43	1-A	44
10-N	44	6-F	43					5-P	45	7-B	44	5-I	46
1-I	45	9-E	44					6-C	46	2-G	47	8-B	46
7-A	45	10-K	45					8-N	47	3-I	50	8-L	49
9-K	45	5-B	47					8-M	46				
2-J	45	6-I	47										
5-E	46												
4-D	47												
1-B	48												
7-E	49												
4-M	49												
5-N	50												

Conflict Within the Kernel

When more than one larva was present in a kernel, combat to occupy the kernel resulted (Plates V and VII). Usually this conflict occurred during the second stadium but in kernel 5-I, a first instar larva destroyed another first instar larva. In kernel 8-B, conflict between the larvae did not take place until the third instar. In some manner insects detect the presence of other insects within the same kernel. Two kernels showed insects tunneling close to each other in opposite directions. The larger larva reversed its direction and removed the endosperm until their tunnels opened together. One larva always destroyed the other larva and sometimes both larvae were destroyed. In no case did more than one granary weevil complete their life cycle within a kernel of wheat.

The writer has observed that two second instar larvae outside the kernel exhibited antagonistic behavior. These actions were not observed until two larvae were in a tunnel of an open kernel. As their bodies touched, their mandibles tried to break the other's exoskeleton. After the exoskeleton was wounded, the insect's blood came out slowly. This excited the larva and it placed its head in the injured area with the mandibles working rapidly until the injured larva had lost all its body fluid. The injured larva tried to protect itself until it was unable to do so.

SUMMARY

This investigation was undertaken to determine the actions of granary weevil during their development within kernels of wheat.

Granary weevils were chosen because of their great importance as grain infesting insects and because little information was available about their habits within the kernel.

The insects were reared in Ponca wheat tempered to 13% moisture. Infested kernels were fastened to a radiographic plate which was kept in the rearing room at approximately 70 percent relative humidity and at 80°F. The insects were removed from the rearing room long enough to prepare a radiograph of the plate with the kernels of wheat. Each day a radiograph was prepared using TYPE M film and a General Electric Grain Inspection Unit. At the end of 30 days the grid was placed in a wide mouthed glass jar to catch the adults as they emerged. Radiographing continued daily from the third day after the parents were placed with whole kernels of wheat through 50 days.

Prints from the radiographs were enlarged from $\frac{1}{4}$ inch squares to 1 inch squares and mounted on large cards in consecutive order.

Then the prints and the radiographs were analyzed. The larvae increased their tunnel widths daily but the tunnel lengths varied from day to day. Tunnel width measurements were plotted for each individual to give the daily change in tunnel diameter. From this information each individual's stadia could be determined and followed through its life within the kernel of wheat.

Many previous observations were verified and new information was found that could not have been obtained when the larvae and kernels were sacrificed as was necessary before the X-ray technique had been developed. This ability to observe the behavior and development of undisturbed larvae inside the kernel was an advanced step in the study of the granary weevil.

Some of the important observations on larval development were as follows: time required to complete each developmental stage; determination of instars by measuring the diameter of the tunnel; characteristics observed for the other stages of development. Only one larva developed within the kernel regardless of the number of eggs oviposited. Ovipositional site of the egg did not influence the emergence site. This study gave the first consecutive pictures of mites destroying an insect.

Data from previous workers were verified as to the time spent in each developmental stage.

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THE DEVELOPMENT AND HABITS OF THE GRANARY WEEVIL, *Sitophilus granarius* (L.), WITHIN THE KERNEL OF WHEAT

by

ROBERT LOYCE KIRKPATRICK

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1962

Radiographs were made daily from egg to emerged adult of 150 kernels of wheat infested by the granary weevil, Sitophilus granarius (L.). From these radiographs enlarged prints were developed and mounted consecutively to study the development and habits of the insects within the kernels. Measurements in width of the tunnel cavities were used as the basis for determining the different instars.

The eggs hatched between four and 14 days after the adult granary weevils were placed with the kernels of wheat for oviposition. Width of the eggs measured between 0.375 and 0.5 mm. on the radiographs.

The first instars were distinguished from the eggs on the radiograph by their hollow egg cavities being darker in color than the rest of the endosperm. After hatching, the larvae tunneled from the egg cavity towards the center of the kernel. The tunnel of the first instar usually remained approximately the same width as the egg cavity.

The second instar larvae were distinguished from the first instar larvae by an increase in tunnel size and by tunneling pattern. The first instar usually tunneled to the center of the kernel towards the crease, while the second instar increased its penetration of the kernel to the opposite end.

The third instar enlarged its tunnel as it made several trips through the kernel. There was a different feeding pattern towards the last of the third instar. The larva enlarged one end of the tunnel then moved to the other end of the kernel, where it enlarged the tunnel in the same manner as at the previous end.

The fourth instar enlarged its tunnel and then prepared a pupal chamber. While completing this chamber, the larva secreted a fluid around the inside of the chamber walls.

The prepupa is a modification of the fourth instar prior to pupation. The prepupal period lasts from one to four days. At the beginning of this prepupal condition the body becomes transparent and viewed from the radiograph is indefinite in outline. When taken from the kernel, the prepupa was a transparent larva whose body fluid could be seen through the exoskeleton. This indefinite form changed promptly to the characteristic prepupa. While in this condition there was no movement indicated on the radiograph.

The pupal stage is more definite in form with head, thorax and abdomen and visible external appendages. The pupa moved in a rotation movement within the pupal cavity, not end to end as in the larval stage.

The movement of the head and the legs of the pre-emerged adult was detected on the radiographs.

Emergence took place from 39 days through 50 days at 80°F. and 70 percent relative humidity. Of the total of 265 eggs deposited in the 150 kernels used in this study, 122 eggs, or 46 percent, hatched and 58, or 22 percent, completed their development. Only one granary weevil has developed in a kernel of wheat.

Antagonistic actions occurred when more than one larva was present in a single kernel.

Eighty-six percent of the adults emerged at the brush end of the kernel.