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THE BEAN WEEVIL AND THE SOUTHERN COWPEA WEEVIL IN CALIFORNIA
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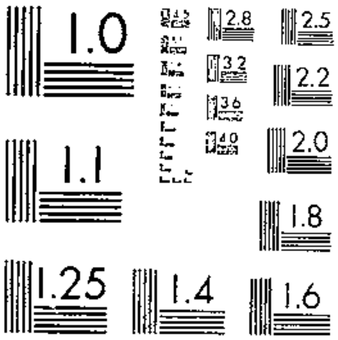


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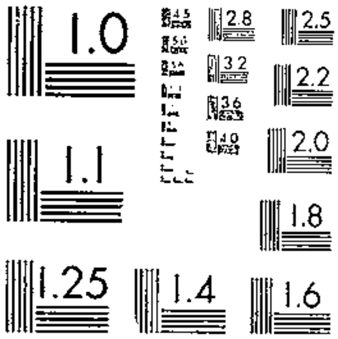


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# THE BEAN WEEVIL AND THE SOUTHERN COWPEA WEEVIL IN CALIFORNIA[1][2]

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## INTRODUCTION

Wherever common varieties of beans (*Phaseolus vulgaris* L.), lima beans (*Phaseolus lunatus macrocarpus* Benth.), and cowpeas (*Vigna sinensis* (Torner) Savi.) are grown, losses usually result from injuries to the seeds by the bean weevil (*Acanthoscelides obtectus* (Say)) and the southern cowpea weevil (*Callosobruchus maculatus* (F.)). Climatic conditions favorable to the production of beans and cowpeas are ideal for the development of these weevils, and growers (*52*)[4] and warehouse operators often unconsciously maintain conditions which aid the development and spread of the weevils. In some sections favorable for the production of beans and peas severe weevil

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[2] The investigations upon which this bulletin is based were made in the former Division of Stored Product Insect Investigations, and the manuscript was prepared and submitted by this Division.

[3] The writers hereby express their thanks to E. A. Back, under whose direction the work was carried on, for valuable assistance, and to W. R. Irving, Perez Simmons, Edgar Nelson, B. Smit, and A. H. Amis, who at different times assisted in the investigation; to Adam G. Böving, who prepared the technical descriptions of the full-grown larvae; and to other workers of the Bureau of Entomology and Plant Quarantine who have assisted in different ways. Cooperating county farm advisors, agricultural commissioners, warehouse operators, threshing crews, and farm bureau bean weevil committees have assisted in numerous ways in collecting the data, and their help in the work is appreciated.

[4] Italic numbers in parentheses refer to Literature Cited, p. 66.

injury has forced growers to discontinue their production and substitute less profitable crops.

Investigations of the bean weevil and the southern cowpea weevil were begun by the senior author in 1919, and have been carried on principally in California, where the most varied conditions prevail. Many varieties of beans and cowpeas are there grown from high elevations on mountain sides down to elevations 100 or 200 feet below sea level; from the fog belts along the seacoast to the desert valleys

FIGURE 1.—Blackeye cowpeas as a profitable intercrop between rows of Persian (English) walnut trees: *A*, In a young grove; *B*, between mature trees.

of the interior where irrigation is necessary; from frost-free areas, where winter beans are grown, to the cooler sections with short growing seasons; and they are grown in quantities ranging from a few plants in back yards to thousands of acres. In some sections they are grown as an intercrop in citrus orchards, groves of Persian (English) walnuts (fig. 1), or orchards of deciduous fruit; in other sections they are grown as the only crop, while in still others they are grown as a second crop following a crop of grain.

## HISTORY AND DISTRIBUTION

### THE BEAN WEEVIL

The specimens from which Thomas Say made the original description of *Acanthoscelides obtectus* in 1831 (*85*) were collected in Louisiana, where the insect was thought to be indigenous. For this reason it was called the American (*25*) weevil, but at present the consensus of opinion among coleopterists is that it originated in Central America or other tropical American region and was carried in commerce to Louisiana where it became established. On this point Essig (*22, p. 588*) says:

Red lima beans taken from the ancient Indian graves in the valley of Ica and the Ancón Necropolis in Peru show the work of the bean weevil. Ica records date from 1–500 A. D., whereas those of Ancón are more recent, 1000–1500. However, both antedate the arrival of the Spanish in Peru. An adult bean weevil taken from the Ancón beans does not differ in anatomical characters from the bean weevils of today.

After its description in 1831 it was next noted in Rhode Island in 1860. The first economic account of it was published in 1861 by Fitch (*26*), who discussed the injury caused by it. It was next reported from New York, and in the next few years from Pennsylvania (*72*), Illinois (*74*), New Jersey (*75*), Kansas, and Missouri (*76*). Probably the first account of its injury in France was by Girard (*31*) in 1879. In 1890 Decaux (*21*) listed it from New Caledonia, Uruguay, Argentina, Brazil, Guatemala, Chile, Greece, Russia, Spain, Mexico, France, Portugal, and Italy. In 1899 Chittenden (*16*) reported it from the Antilles, Central America, Persia, Indo-China, Madeira, Algeria, the Azores, and the Canary Islands. Fletcher (*27*) reported that the first serious outbreak in Canada occurred in Ontario in 1898. Jablonowski (*42*), in 1920, reported that it had been introduced into Hungary 40 years earlier but had been exterminated. It was again only recently introduced into Hungary from Yugoslavia. It has been intercepted in beans from Nicaragua (*90*). In the United States it has at some time or other been reported from every State. In some States it is a constant pest, and it is probably found wherever beans are grown or handled extensively.

### THE SOUTHERN COWPEA WEEVIL

The southern cowpea weevil (*Callosobruchus maculatus*) was first described by Fabricius (*23*) in 1775 as *Bruchus maculatus* from material supplied by Von Rohr, with America as its habitat. It probably actually came from the West Indies or South America where Von Rohr collected. Fabricius described it again (*24, p. 371*) in 1792 as *B. quadrimaculatus* from material collected by Dr. Pflug at St. Croix, West Indies. It has been recorded from widely separated localities, but its original home is still somewhat uncertain, though it undoubtedly originated in an Old World tropical or subtropical region along with its favorite host plant, the cowpea, which also seems to be of uncertain origin. Concerning the host plant, Wight (*97, p. 21*) says:

It may be concluded that both *Vigna unguiculata* (*V. sinensis*) and *V. catjang* (*V. cylindrica*) originally came from a region including and extending from India to Persia and the southern part of the Trans-Caspian district, and that the Persians called one or both of them by the name "lubia" and applied that name to *V. unguiculata* in northwest India after their conquest of that region. The cultivation of *V. unguiculata* extended to China at a very early date, but the distribution of at least one species with the name "lubia" had extended from the region of its origin at the beginning of the Christian Era to Arabia and Asia Minor and had reached some of the Mediterranean countries of Europe at about the same time, but did not become known in Central Europe until the middle of the sixteenth century.

Piper (*68, p. 32*), writing of the origin of the cowpea, says:

> There is scarcely room for doubt * * * that the African plant with blackish scabrous pods and scabrous leaflets found wild over a great area (southward from the Sahara Desert and extending across the continent) and occasionally cultivated is the original wild form of our cultivated cowpea.

At the present time this weevil is known to be in both the areas claimed as the original home of its host plant.

In 1897 Chittenden (*15*) recorded it from Brazil, Venezuela, the East Indies, and Sierra Leone, as well as from the United States, where it was then widely distributed. It has since been reported from the Canal Zone (*98, p. 184*), India (*43*), Jamaica, Trinidad, South Africa, Hawaii (*14*), Barbados (*5*), Germany (*41*), and other places. It probably occurs wherever cowpeas are cultivated.

It gained attention as an economic pest in 1885 when "black-eyed table beans" from Texas, exhibited at the Cotton Exposition in Georgia, were found to be heavily infested (*82*). It next attracted attention in 1893 when it practically destroyed the beans exhibited by Brazil and Venezuela at the World's Columbian Exposition in Chicago (*79*). At that time the Division of Entomology of the United States Department of Agriculture recorded it as common in the Southern States. It was probably reported from France first in 1890 (*21*).

Their ability to withstand several months of low temperature while within the bean permits bean and pea weevils to be carried in commerce to all parts of the world. Commerce insures their wide distribution and man produces ideal conditions for their multiplication, but their own power of flight, aided by the wind, secures their local dispersal to the growing crop and assures opportunity for propagation in storage.

Anything in which they are allowed to breed serves as a source of infestation from which they spread, but the planting of weevily beans does not seem to be a grave source of infestation, as has been so often reported. The sale and distribution of weevily beans and cowpeas in summer for feed for sheep, hogs, and poultry does, however, greatly aid their spread.

## SYNONYMIES

### THE BEAN WEEVIL

The bean weevil has been treated in economic and taxonomic papers under many scientific names. The following list has been furnished by J. C. Bridwell:

#### ACANTHOSCELIDES OBTECTUS (SAY)

*Bruchus obtectus* Say, 1831.
? *Bruchus leguminarius* Gyllenhal, 1833.
*Bruchus irresectus* Fahraeus, 1839.
*Bruchus pallidipes* Fahraeus, 1839.
*Bruchus subellipticus* Wollaston, 1854.
*Bruchus acanthocnemus* Jekel, 1855.

*Bruchus fabae* Fitch, 1861; Riley, 1871.
*Bruchus breweri* Crotch, 1867.
*Bruchus granarius* Packard, 1870 (not Linné, 1761, err. det.).
*Bruchus obsoletus* LeConte, 1870; Horn, 1873 (not *Bruchus obsoletus* Say, 1831, err. det.).
*Bruchus varicornis* LeConte, 1870; Motschulsky, 1874.
*Bruchus fabi* Rathvon, 1870.
*Bruchus mimosae* Gemminger and Harold, 1873 (in part, not *Bruchus mimosae* Fabricius, 1781).
? *Bruchus gilvipes* Motschulsky, 1874.
*Mylabris obsoletus* Crotch, 1874 (not *Bruchus obsoletus* Say, 1831).
*Mylabris mimosae* Reitter, 1883 (not *Bruchus mimosae* Fabricius, 1781).
*Mylabris irresecta* Baudi, 1886.
*Bruchus ? subarmatus* Janson, 1889 (not *Bruchus subarmatus* Gyllenhal, 1833).
*Laria obtecta* Bedel, 1901.
*Acanthoscelides irresectus* Schilsky, 1905.
*Acanthoscelides obtectus* Schilsky, 1906.
*Bruchidius (Acanthoscelides) obtectus* Reitter, 1912.
*Bruchus (Acanthoscelides) obsoletus* Pic, 1913 (in part).
*Bruchus pusillus seminarius* Day, 1915 (not *Bruchidius pusillus seminarius* Schilsky, 1905, err. det.).
*Mylabris obtectus* Long, 1920.

### THE SOUTHERN COWPEA WEEVIL

Several other specific names have been applied to *maculatus*, but most of the literature dealing with its biology and economic relatives treats it as *quadrimaculatus*, in *Bruchus*, *Mylabris*, *Laria*, or *Pachymerus*. The following list has been furnished by J. C. Bridwell:

CALLOSOBRUCHUS MACULATUS F.

*Bruchus maculatus* Fabricius, 1775.
*Bruchus 4-maculatus* Fabricius, 1792.
*Bruchus barbicornis* Fabricius, 1801.
*Bruchus bistriatus* Fabricius, 1801.
*Bruchus chinensis* Thunberg, 1816 (not *Curculio chinensis* Linné, 1758).
*Bruchus longicornis* Thunberg, 1816.
*Bruchus litteratus* Schoenherr, 1833.
*Mylabris quadrimaculatus* (Fabricius) Baudi, 1887.
*Laria quadrimaculata* (Fabricius) Bedel, 1901.
*Pachymerus quadrimaculatus* (Fabricius) Schilsky, 1905.

## ECONOMIC IMPORTANCE

Weevily beans and cowpeas are unfit for human food, and if badly infested are unsuitable for planting. Among the early entomologists who made reports on the economic importance of the bean weevil were Fitch in 1861 (*26*), Riley in 1870 (*74, 75*), Lintner in 1881 (*57*), and Hamilton in 1889 (*33*). In the United States the economic importance of this weevil has been noted in several State agricultural experiment station bulletins and circulars (*29, 71, 83, 86*), in agricultural journals (*17, 32, 39, 55, 58, 96*), in trade journals (*28, 47*), and in previous publications of the United States Department of Agriculture (*2, 3*).

With all the publicity, the habits of bean and cowpea weevils are still not well understood by those who grow and handle beans and cowpeas, therefore the injury is on the increase in some parts of the country and is constantly spreading to new sections.

The injury may be noted at harvest time, but it is not usually noted until after the crop has been stored in the warehouse or after it has reached its destination if shipped. One company shipped a carload of blackeye cowpeas, frequently spoken of as blackeye beans or blackeye peas, which after reaching its destination was condemned, involving a total loss of $3,000. Frequently part of a carload is found weevily and condemned, causing heavy losses. Growers often store beans or blackeye cowpeas in what appears to them to be perfect condition, only to find later that they have been partly or completely ruined. Many such lots of cowpeas, in quantities from a few sacks to as many as 4,000 90-pound bags, have come to the attention of the writers. One of these lots represented a loss of $3,600 to the grower. Lots of "blackeyes" are frequently infested with both *Acanthoscelides obtectus* and *Callosobruchus maculatus*.

The large-scale grower and the wholesale dealer often sustain heavy losses from weevils, but they usually say little for fear publicity will prevent or hinder the sale of their products. Individual and community losses frequently mount into thousands of dollars. One grower contracted to sell his crop, but on delivery it was found to be heavily infested with weevils. He finally accepted $100 for the beans which, had they been free from weevil injury, would have brought him $1,100. The next year he sold his crop to another bean buyer for $1,235, but after delivery this crop also proved to be heavily damaged by weevils. He finally received $135 for the crop. He then discontinued growing what should have been a profitable crop. Another man sold his beans on the basis of "choice recleaned" for $4,200, delivered them, and received a check for the amount. When he went later to cash the check, payment on it had been stopped because inspection showed the beans to be weevily. He settled for $1,200, thus sustaining a loss of $3,000. Another man lost $8,000 on 4,000 bags.

The operators of two warehouses handling the major portion of the beans and blackeye cowpeas in their particular sections of the San Joaquin Valley of California gave the following estimates of damage from the weevils *Acanthoscelides obtectus* and *Callosobruchus maculatus*, since these two species frequently infest the same lot. Up to November 10 one had handled 30,909 bags of about 90 pounds each. It was estimated that the price to growers had been reduced 50 cents per bag on at least half of these receipts, making a total loss to the growers of $7,727. Another warehouse handling 50,000 bags estimated that the price had been reduced 50 cents per bag on 40 percent of the sacks, entailing a loss of $10,000 to the growers. One would be led to believe, after talking with the growers, that the loss was even heavier. Two growers who produced 570 bags said that they had been docked $1 per bag because on arrival at the warehouse they had been found infested by weevils. Another said that his weevil loss amounted to $30 per acre. Most of the growers with whom the writers talked had sustained heavy price reductions and reported the same for many of their neighbors. Kieffer (*45*) says that weevils cost the bean growers in the three counties—San Joaquin, Stanislaus, and Merced—between $1,000,000 and $1,250,000 on their 1926 crop. One of the largest bean buyers in that section said that about 70 percent of the lots of beans were infested. In the writers' opinion, based on the results of examination of several hundred samples and the schedule of price reductions due to weevil attack, the warehousemen's estimates were far too low to indicate the loss to growers.

Different warehouses have different methods of arriving at the price reduction for weevil infestation indicated by inspections. The following rule is quite generally used with cowpeas or beans coming in from the field: After they are cleaned and sacked about 3 pounds are taken in a pan from several bags by means of a trier. The quantity of seeds is about the same for different varieties, but the approximate number would vary with the varieties, large varieties having a smaller number actually examined than smaller varieties. Blackeye cowpeas, which constituted the majority of the seeds handled by these warehouses, would run from 5,000 to 6,000 to the sample. The cowpeas or beans in the sample are carefully examined, and if one to three weevily seeds are found the whole lot is reduced 50 cents per 100 pounds. If four to six weevily seeds are found the lot is reduced 75 cents per 100 pounds. If more weevily seeds are found the price of the lot may be reduced $1 or more, or the lot rejected.

Cowpeas are packed 90 pounds to the bag, whereas beans contain 100 pounds per bag.

The writers' samples from this section showed that 74 percent of all lots were weevily. The price would have been reduced 50 cents per 100 pounds on 36 percent of the lots, 75 cents per 100 pounds on 15 percent, and $1 per 100 pounds on 23 percent of the lots.

From this schedule it is evident that the price reduction is not directly proportional to the number of beans visibly injured but is based on the probability of a later infestation developing and on the probability that the beans will have to be hand-picked in order to make them salable as choice beans. A visible infestation of 0.1 percent of the individual beans would cause a price reduction of from 15 to 25 percent or more, depending on the price of the beans. The same amount of weevil infestation, however, does not always cause the same price reduction, as McVey (*62*) has pointed out. He says:

> If the market is strong and the buyers are keen they will often take a grower's crop even though there may be a weevily bean or two show up in the sample. But if the market is dull and the buyer can easily get all the beans he needs to fill his order, then it's "Good Night." In case the sample shows a bad percentage of weevil the buyer will not take them even though he may be anxious for beans, except by docking the grower anywhere from 10% to 50% or even more.

The heavy loss due to weevil injury results from the inability of the shipper to detect infestations while the immature stages are hidden away inside the beans. After being in transit several weeks, or soon after arrival at their destination, the beans are found to be weevily and are rejected, causing a partial or total loss to the shipper.

The impossibility of determining definitely whether seeds are infested at time of harvest is shown in table 1. Immediately after harvest eight varieties of beans and cowpeas were carefully examined at the laboratory for weevil infestation. Each seed of every lot was examined for visible signs of weevil infestation. On first examination only 11 samples of black-eye cowpeas were found to be weevily. The other samples were put away for a few weeks and were again carefully examined. The second examination showed 118 more weevily samples. A third examination after a few weeks showed 6 more weevily lots, so that instead of there being 11 weevily samples as was shown by the first examination there were actually 135. On first examination none of the lima beans were found weevily, but there were actually 61 weevily lots.

TABLE 1.—*Successive examinations of eight varieties of seeds grown in the San Joaquin Valley, Calif., for infestations of Acanthoscelides obtectus, 1931*

| Variety | Samples examined | Samples found infested | | | |
|---|---|---|---|---|---|
| | | First examination | Second examination | Third examination | Total |
| | *Number* | *Number* | *Number* | *Number* | *Percent* |
| Blackeye cowpea (*Vigna sinensis*) | 3,053 | 11 | 118 | 6 | 4.4 |
| Lima bean (*Phaseolus lunatus macrocarpus*) | 430 | 0 | 37 | 24 | 14.0 |
| Pink bean (*P. vulgaris*) | 26 | 2 | 16 | 2 | 76.9 |
| Small red bean (*P. vulgaris*) | 2 | 1 | 0 | 0 | 50.0 |
| Small white bean (*P. vulgaris*) | 4 | 0 | 3 | 0 | 75.0 |
| Red Kidney bean (*P. vulgaris*) | 5 | 0 | 1 | 0 | 20.0 |
| Cranberry bean (*P. vulgaris*) | 2 | 0 | 1 | 0 | 50.0 |
| Bayo bean (*P. vulgaris*) | 2 | 0 | 0 | 0 | .0 |

A bean-growing community that has the reputation of producing weevily beans has a hard time selling its product, because buyers are suspicious of them and consequently discriminate against them, usually by a heavy price reduction whether the sample shows weevils or not.

If weevily beans are not too heavily infested, they can be fumigated and rerun through the cleaner to take out the lighter beans, and then be hand sorted and sold as choice beans. If they are heavily infested they are disposed of for feed for cattle, sheep, hogs, or poultry, usually at about 25 percent or less of the value of choice beans of the same variety.

## HOST PLANTS

### THE BEAN WEEVIL

The bean weevil normally confines its attack to a relatively few species of seeds in any one locality, but it prefers the different varieties of common beans, *Phaseolus vulgaris*, although it is capable of breeding in a great many kinds of seeds, as has been demonstrated experimentally.

Razzauti (*73*) says that *Acanthoscelides obtectus* adapts itself to many kinds of seeds besides beans. He reports having bred it from *Dolichos melanophthalmus* DC. (*Vigna sinensis*) and *Lupinus albus* L. and says it has even adapted itself to maize (*Zea mays* L.). Slingerland (*89*) says that the larvae entered corn (*Z. mays*) and buckwheat (*Fagopyrum esculentum* Moench). Marcucci (*64*) says that many kinds of seeds are attacked, but that those having oily content are injurious to the larvae. Daviault (*19*) reports its occurrence on *Vicia sativa* L. and *Lupinus albus*. Bridwell (*13*) reports having reared it from lima beans and tepary beans as well as from three varieties of common beans. Strong (*91*) reports it breeding in *Albizzia* seed from China.[5]

The writers have reared it from upward of 50 varieties of garden beans (*Phaseolus vulgaris* L.), and from more than 20 varieties of cowpeas (*Vigna sinensis*) and have not found a variety of either in which it would not breed freely (fig. 2). Other seeds from which the writers have reared it include eight varieties of lima beans (*P. lunatus* L. and *P. lunatus macrocarpus* Benth.), asparagus beans (*Vigna sesquipedalis*

[5] J. C. Bridwell, after reviewing the manuscript of this bulletin, expressed the opinion that the *Dolichos melanophthalmus* of Razzauti must be *Vigna sinensis* (black-eye cowpea) and that the records of *Lupinus albus* are in error, based on *Lathyrus sativus* seed being mistaken for that of *Lupinus*. He also expressed the opinion that Strong's bruchid from *Albizzia* was doubtless something else.

(L.) Fruwirth), 10 varieties of garden peas (*Pisum sativum* L.), garbanza or chickpeas (*Cicer arietinum* L.), scarlet runner (*P. coccineus* L.), tepary beans (*P. acutifolius latifolius* Freeman), rice beans (*P. calcaratus* Roxb.), moth beans (*P. aconitifolius* Jacq.) broad Windsor and small Windsor beans (*Vicia faba* L.), chickling vetch (*Lathyrus sativus* L.), *Cajanus indicus* Spreng., lentils (*Lens esculenta* Moench), cowpeas (*Vigna sinensis*), conch beans, and mung beans (*P. aureus* Roxb.). To this list more extensive observations may add more host plants covering a wider range. The writers have observed that it will bore into a great variety of seeds in which it is unable to develop. It will bore into cork or wood but soon dies.

Because of this ability of the larvae to enter numerous kinds of seeds, the writers undertook to determine whether or not they would exercise a choice as to the species and varieties attacked. On June 14, 1922, 5 seeds each of 39 species and varieties were placed in a quart

FIGURE 2.—Beans (*Phaseolus vulgaris* and *P. lunatus*) and cowpeas (*Vigna sinensis*) that have been attacked by the bean weevil (*Acanthoscelides obtectus*).

mason jar together with 50 adult weevils. On the 3 following days identical lots of seeds and 50 weevils were placed in like jars. The beans were all dry and had been kept in the laboratory under identical conditions and therefore apparently contained approximately the same percentage of moisture. After many eggs had been deposited in each jar the weevils were removed, and the eggs were left to hatch undisturbed in order that the young larvae might have an opportunity to choose the species and varieties they would enter. The seeds in each jar were kept together until "eye spots" began to show in some of them. The seeds of each variety from all 4 jars were then placed in separate vials, making a total of 20 seeds in each of the 39 vials. These were watched for the emergence of the weevils, and the date of emergence as well as the number of weevils emerging was recorded. During the period from July 29 to September 2, 214 weevils emerged from 100 seeds, or from 12.8 percent of the seeds. All the seeds were then dissected and all dead weevils contained therein were recorded.

Table 2 shows the different species and varieties used, the number of adult weevils that emerged from each species and variety as well as the number of larvae, pupae, or adults that died in the seeds, and the number and percentage of infested seeds. Some of the seeds not attacked in this experiment are known to be badly damaged at times in storage. This can be explained by the fact that in the warehouse the insect does not have a chance to choose but is compelled to develop on the seeds present.

TABLE 2.—*Preference shown by larvae of Acanthoscelides obtectus for different species and varieties of seeds, 20 seeds of each variety having been exposed*

| Species and variety | Weevils emerged | Larvae dead within seeds | Seeds infested | |
|---|---|---|---|---|
| | *Number* | *Number* | *Number* | *Percent* |
| *Phaseolus vulgaris:* | | | | |
| Superior Kentucky Wonder | 21 | 4 | 5 | 25 |
| Dutch Case-knife | 7 | 1 | 2 | 10 |
| White Wonder | 4 | 0 | 2 | 10 |
| Lazy Wife | 2 | 1 | 3 | 15 |
| Navy | 0 | 0 | 0 | 0 |
| Extra Early Refugee | 22 | 1 | 5 | 25 |
| Stringless Green Pod | 19 | 2 | 7 | 35 |
| Black Wax | 7 | 3 | 6 | 30 |
| Early Mohawk | 27 | 0 | 7 | 35 |
| Pinto | 2 | 1 | 2 | 10 |
| Refugee Wax | 9 | 0 | 2 | 10 |
| Baldwin Wonder Wax | 3 | 0 | 2 | 10 |
| Eastern Cornfield | 11 | 8 | 16 | 80 |
| Small Red | 1 | 0 | 2 | 10 |
| Kentucky Wonder Wax | 4 | 5 | 2 | 10 |
| Red Kidney | 9 | 1 | 5 | 25 |
| Italy's Favorite | 10 | 0 | 4 | 20 |
| Cranberry | 11 | 0 | 4 | 20 |
| Bayo | 0 | 0 | 0 | 0 |
| Long Yellow Six Weeks | 20 | 0 | 7 | 35 |
| Canadian Wonder | 7 | 1 | 5 | 25 |
| Pink | 2 | 0 | 2 | 10 |
| *Phaseolus acutifolius latifolius:* Tepary | 0 | 0 | 0 | 0 |
| *Phaseolus lunatus:* Bush lima | 2 | 6 | 2 | 10 |
| *Canavali ensiformis* (L.) DC.: Jack bean | 0 | 0 | 0 | 0 |
| *Stizolobium deeringianum* Bort: Velvetbean | 0 | 0 | 0 | 0 |
| *Ricinus communis* L.: Castorbean | 0 | 0 | 0 | 0 |
| *Vigna sinensis:* | | | | |
| Blackeye | 4 | 0 | 1 | 20 |
| Holstein | 0 | 0 | 0 | 0 |
| Red Ripper | 3 | 0 | 3 | 15 |
| *Lens esculenta:* Lentil | 0 | 0 | 0 | 0 |
| *Pisum sativum:* | | | | |
| Little Gem | 0 | 0 | 0 | 0 |
| Admiral | 0 | 0 | 0 | 0 |
| Yorkshire Hero | 0 | 0 | 0 | 0 |
| Dwarf Sugar | 0 | 0 | 0 | 0 |
| *Cicer arietinum:* Garbanzo | 0 | 0 | 0 | 0 |
| *Vicia faba:* | | | | |
| Broad Windsor | 1 | 1 | 1 | 5 |
| Small Windsor | 0 | 0 | 0 | 0 |
| *Soja max* (L.) Piper: Mammoth Yellow | 0 | 0 | 0 | 0 |
| Total or average | 211 | 35 | 100 | 12.8 |

In table 2 the first 22 varieties are all common garden beans. Of these, 20 were infested and produced 95 percent of the emerged adults, and weevils emerged from every variety entered. It seems that the larvae prefer varieties of *Phaseolus vulgaris* to other bean and pea seeds. It also seems that they exercise a choice even among varieties of *P. vulgaris*, as 80 percent of the Eastern Cornfield were infested, and over 13 percent of all the weevils emerged from the Early Mohawk whereas the Navy and Bayo were uninfested. Both the Navy and Bayo are frequently found infested in commerce. The 17 kinds of seeds other than *P. vulgaris*, although several of them are known to be severely attacked in storage, produced less than 5 percent of the emerged weevils.

Under usual conditions the larvae do not have an opportunity to choose between varieties but must choose merely between seeds of the same variety. That the larvae exercise a choice among beans of the same variety is evident from the examination of any lot of heavily infested beans. This choice is shown by the number of emergence holes found per bean. When a few beans remained uninfested in a jar of heavily infested beans the writers marked these beans and put them with others of the same variety that were to be exposed. These marked beans again remained uninfested, but when such beans were put in a container alone they were attacked. Some beans will have only 1 emergence hole while others in the same container may have as many as 33 holes per bean. The writers have taken 42 larvae and pupae from 1 lima bean. Figure 3 shows the frequency of any certain number of emergence holes from 1 to 20 in a lot of 361 Red Kidney beans. Figure 4 shows the heavy infestation that may develop in the lima bean.

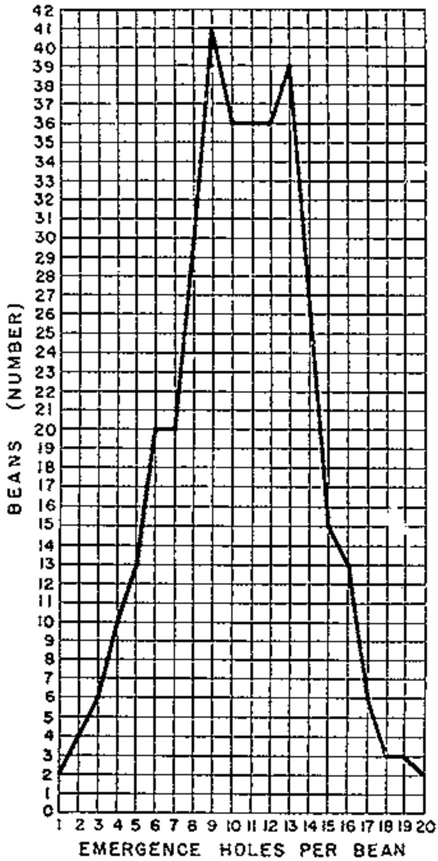


FIGURE 3.—Choice of beans made by larvae of *Acanthoscelides obtectus* as indicated by the number of emergence holes in each of 361 infested Red Kidney beans.

In some kinds of seeds practically every larva becomes an adult weevil under favorable conditions, but in other seeds, notably the Windsor bean (*Vicia faba*), lima bean, and soybean, only a very small percentage of the young larvae reach maturity. In some lots of these and other seeds all the young larvae die before reaching the second instar; in other lots of the same variety part of the young larvae die, others succumb in more advanced stages, and only a very small percentage emerge as adults. This indicates that some seeds are always unsuitable for food and that others are unsuitable under some conditions but under other conditions some weevils are able to develop in them, the number becoming less with each successive instar, and a large percentage of those that become adults being


FIGURE 4.—Lima beans infested with *Acanthoscelides obtectus*: *A*, Interior of a weevily lima bean; *B*, seed coats removed to show larval burrows and pupal cell.

moribund and soon dying without producing eggs. Similar adults sometimes develop in an overcrowded seed from larvae that have eaten all available food before becoming fully developed.

Larvae of *Acanthoscelides obtectus* covered with bean flour made from their favorite host, *Phaseolus vulgaris*, failed to develop normally. They had to be watched daily, as they would work to the top of the bean flour and had to be covered frequently. Fewer and fewer of them reached each succeeding instar. The larvae were unable to obtain sufficient food for proper development because of the lack of the normal support of the firm walls of the larval burrow. Whether this is the case within certain seeds or whether the food obtained is unsuitable is not certain, but with some seeds it is quite evident that the seed is chemically unsuitable. In this connection Bridwell (*13*) says:

> It is not improbable that the inability of Bruchids to breed in legumes otherwise similar in composition to their host seeds may be due to the diversity of their proteids.

Marcucci (*64*) says that seeds having oily contents are injurious to the larvae. He does not explain the nature of the injury. In the case of seeds in which most of the larvae die after the first molt the senior author (*49, p. 73*) has expressed the opinion that the larvae die because of their inability to obtain sufficient food rather than because of receiving unsuitable food. Very little has yet been learned that will explain why a bruchid is able to breed in one seed and not in another. In seeds, such as soybeans, having an oily content the larvae either die or develop slowly, the adults that emerge being reduced in vigor and vitality and producing only a few eggs, so the infestation soon dies out. On the other hand, weevils developing in certain varieties of lima beans seem to be vigorous, but they require a greatly prolonged period for development, and the emerged adults are very small, sometimes being less than half as large as those from other beans.

## THE SOUTHERN COWPEA WEEVIL

Although the southern cowpea weevil usually confines its attacks to a relatively few varieties of seeds in any one locality, it has been found to be capable of breeding in a great many kinds of seeds.

Speaking of this insect, Pettit (*66, p. 100*) says, "It will also feed on table bean on occasion," and later (*67, p. 38*) he says:

> It also works in the common bean and, like the common bean weevil, it works indefinitely in the stored seeds until nothing of value is left. * * * Like the bean weevil, this creature starts work in the field, coming into the granary with the harvested beans, or it may gain access after the beans have been stored away.

Back and Duckett (*4*) say: "Peas and beans of many varieties are attacked." Skaife (*87*) reported that they—

> oviposit freely on peas and beans, but I have not succeeded in rearing any in these seeds. The eggs hatch normally and the young larvae burrow into the seeds but they all die without attaining any size.

Bridwell (*15*), working in Hawaii, says:

> I have bred it experimentally from *Phaseolus lunatus*, *P. articulatus*, *P. aureus*, *P. acutifolius*, *Vigna chinensis*, *Vigna lutea*, *Cajanus indicus*, *Dolichos lablab*, *D. sudanensis*, *Glycine hispida*, *Cicer arietinum*, *Vicia faba*, and *Pisum sativum*.

Paddock and Reinhard (*65, p. 14*) say, "The cowpea weevil has not been observed to feed upon any plant except the cowpea * * * it is doubtful if any other plants can be added to the cowpea as a food for this insect." Speaking of its adaptive capacity (*65, p. 51*) they say:

> There is very little flexibility in the habits of this insect to adapt itself to a strange environment. This is particularly true with respect to its food plant. Changing the food from one variety of cowpea to another did not apparently affect the weevil, but when a nearly related food plant, such as certain varieties of beans, navy, and lima, were repeatedly tried, the weevil could not complete its life cycle. In all experiments egg deposition took place readily enough * * *. The eggs hatched in a large percentage of cases, but the larvae could not subsist in the substituted food, and all were dead within three days after hatching. In the field the cowpea weevil has not been collected consistently on any plant except cowpeas.

The writers have bred it repeatedly in more than 20 varieties of cowpeas (*Vigna sinensis*) (fig. 5, *C*), 9 varieties of soybeans (*Soja max*), 10 varieties of garden peas (*Pisum sativum*), yard long or asparagus beans (*Vigna sesquipedalis*), *Cajanus indicus*, lentils (*Lens esculenta*), garbanzos or chickpeas (*Cicer arietinum*), *Lathyrus sativus*, *L. clymenum* L., 2 different strains of bitter vetch (*Vicia ervilia* Willd.), broad beans and small Windsor beans (*Vicia faba*), buff catjang, 3 varieties of adsuki beans (*Phaseolus angularis* Willd.), mung beans (*P. aureus*), urd beans (*P. mungo* L.), moth beans (*P. aconitifolius*), 2 varieties of hyacinth beans (*Dolichos lablab* L.), and conch beans. To these lists more extensive observations may add more host plants covering a wider range.

The following is a list of seeds from which the writers have not been able to breed *Callosobruchus maculatus*, although eggs have been deposited more or less freely on each variety: Red Valentine, Brown Kentucky Wonder, Lady Washington, Prolific Black Wax, Improved Golden Wax, Pinto, Colorado Pinto, Hanson Yellow, Bates, California Pink, Dwarf Spanish, Nicaragua, Black Valentine, Burpee Stringless Green Pod, Baldwin Wonder Wax, Eastern Cornfield, Long Yellow Six Weeks, Mexican Red, Kentucky Wonder Wax, Superior Kentucky Wonder, White Kentucky Wonder, Lazy Wife, Cranberry, Dutch Case Knife, Early Mohawk, Improved Early Mohawk, Italy's Favorite, Bayo, Red Kidney, Black Wax, Navy, Navy Bluepod, Large White, Creaseback, Reuter Longfellow, Wonderful Kidney Wax, Refugee Green Pod, Ventura Wonder Wax, Full Measure, and nine other varieties of *Phaseolus vulgaris*, the common names of which are not known to the writers, rice bean (*P. calcaratus*), tepary (*P. acutifolius latifolius*), Scarlet Runner (*P. coccineus*), Large White lima, Giant Pod lima, Fordhook lima, Field lima, King of Garden lima (*P. lunatus macrocarpus*), Henderson Bush lima, Hopi lima (*P. lunatus*), velvetbean, Chinese White velvetbean, Early Bird velvetbean (*Stizolobium deeringianum*), Mexican Tree bean, castor-bean (*Ricinus communis*), woollypod vetch (*Vicia dasycarpa* Ten.), monantha vetch (*V. monantha* Retz.), purple vetch (*V. atropurpurea* Desf.), hairy vetch (*V. villosa* Roth), common vetch (*V. sativa*), narrowleaf vetch (*V. angustifolia* (L.) Reichard), Hungarian vetch (*V. pannonica* Crantz.), Tangier pea (*Lathyrus tingitanus* L.), Hickory King corn, Bloody Butcher corn, several kinds of Indian corn (*Zea mays*), White kafir, Honey Drip sorghum, spelt, Burbank Superior wheat, Kanred wheat, Turkey wheat, California Red oats, common buckwheat, Japanese buckwheat, Egyptian cotton.

In every variety of the above seeds, except the Egyptian cotton, the young larvae have bored through the seed coat, but in no case did the small larvae develop to any appreciable extent before dying.

A striking feature of the food habits of *Callosobruchus maculatus* is its ability to breed in some species of *Phaseolus* and not in others, especially those species that include common garden and field beans, the limas, the runners, and the teparies. The fact that *C. maculatus*

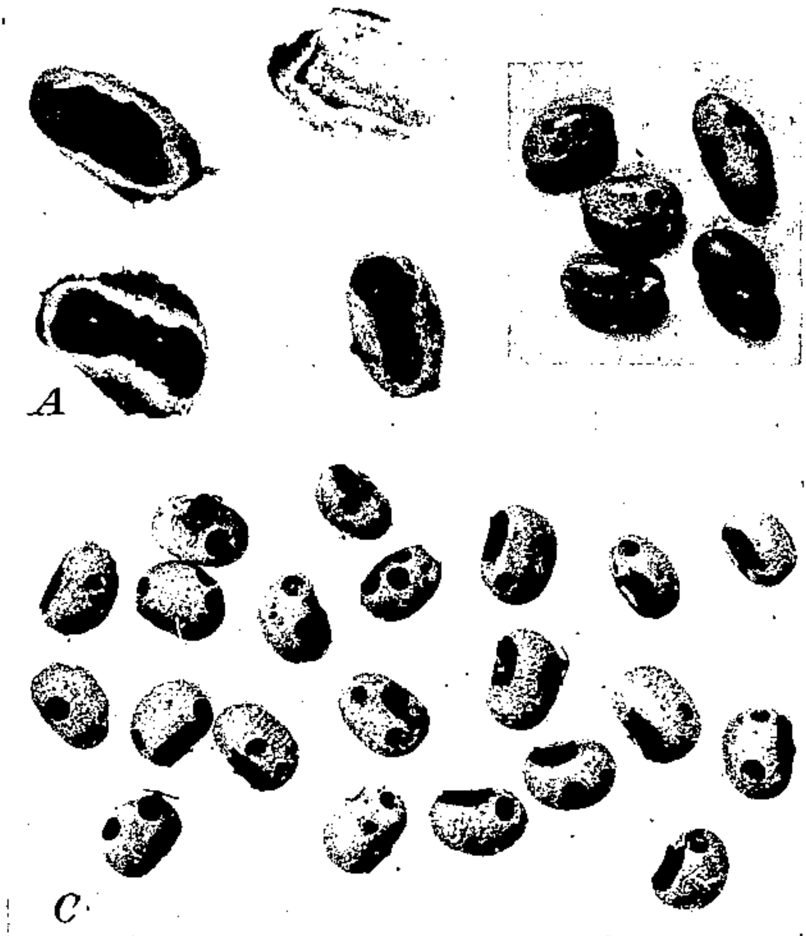

FIGURE 5.—Weevil infestations in beans and peas: *A*, Pupal cells removed from a bean; sometimes a bean is so heavily infested that only frass and cells remain beneath the seed coat; *B*, beans showing windows where weevils are ready to emerge; *C*, blackeye cowpeas infested with *Callosobruchus maculatus*.

oviposits freely on all of those species and varieties and is frequently found among them has probably given rise to the erroneous belief that it breeds in them.

In some seeds, under favorable conditions, practically every larva becomes an adult weevil; but in other seeds, notably those of the Windsor (*Vicia faba*) and soybean, only a very small percentage of the young larvae reach maturity. As observed with *Acanthoscelides* *obtectus*, in some lots of these and other seeds all of the young larvae of *Callosobruchus maculatus* die before reaching the second instar; in other lots of the same variety only part of the larvae die young, while others die in more advanced stages, and only a very small percentage emerge as adults. In other varieties the young larvae always die before reaching the second instar. As with *A. obtectus* this indicates that some seeds are unsuitable for food and other seeds are unsuitable under some conditions but under other conditions can be used for food.

Larvae of *Callosobruchus maculatus* covered with bean flour made from their favorite host, *Vigna sinensis*, failed to develop normally. The same difficulties were encountered as with larvae of *Acanthoscel-*

FIGURE 6.—Eggs of *Acanthoscelides obtectus* on a bean in an open pod.

*ides obtectus* developing in flour made from *Phaseolus vulgaris*. Oily seeds were also unsuited to *C. maculatus*, the few emerged adults being less vigorous and producing very few eggs.

## LIFE HISTORIES AND DESCRIPTIONS

### THE BEAN WEEVIL

#### THE EGG

##### Description

The eggs of *Acanthoscelides obtectus* are smooth, translucent whitish, ellipsoidal, with ends rounded, one broader than the other. In length they are from 0.546 to 0.798 mm and in diameter from 0.189 to 0.357 mm (fig. 6).

Although the eggs are frequently found in clusters of from 3 to 30 or more they have very little cementing fluid about them, so they are not flattened against the seed and easily become separated from one another and from the surface to which they were attached. In this respect they differ from the eggs of all other economically important bruchids.

As the eggs are variable in size, different measurements have been recorded by the various workers. Garman (*30, p. 312*) gives the length as 0.64 mm and the diamter as 0.25 mm, and Kannan (*44, p. 7*) the length as 0.65 to 0.70 mm and the width as 0.26 mm. Manter (*63*) gives the length as 0.84 mm and the width as 0.30 mm, and says they are so light that it would take 40,000 to weigh a gram. The eggs laid by the same weevil not only vary in size from day to day, but eggs laid the same day show quite a range. Eggs laid on the last day of oviposition are usually smaller than those laid earlier. During November and December 1924, 231 eggs were measured. They ranged from 0.546 to 0.798 mm in length and from 0.189 to 0.357 mm in width. In April 1925, 248 eggs laid by 27 weevils over a 3-day period were found to range from 0.588 to 0.798 mm in length and from 0.210 to 0.336 mm in diameter.

### Incubation Period

Slingerland (*88*) reported the egg stage of *Acanthoscelides obtectus* as from 12 to 20 days at Ithaca, N. Y., and Manter (*63*) gave it as from 7 to 17 days. The writers find that the duration of the egg stage is from 3 days under the most favorable conditions to 27 days or longer in winter. Table 3 gives typical incubation periods at different times of the year. The percentage of hatch in winter is always very low.

Table 3.—*Duration of the egg stage and the time from hatching of eggs to emergence of adults of Acanthoscelides obtectus at different times of the year at Alhambra, Calif., 1924*

| Date eggs laid | Date eggs hatched | Incubation period | Date adults emerged | Period from hatching to emergence of adults |
|---|---|---|---|---|
| | | *Days* | | *Days* |
| Jan. 1 | Jan. 28 | 27 | May 5–20 | 98 to 113 |
| Feb. 5 | Feb. 27 | 22 | May 15–28 | 78 to 91 |
| Mar. 8 | Mar. 30 | 22 | May 20–June 8 | 51 to 70 |
| Apr. 11 | Apr. 28 | 17 | June 6–21 | 30 to 54 |
| May 1 | May 13 | 12 | June 28 | 46 |
| June 26 | July 5 | 9 | July 31–Aug. 6 | 26 to 32 |
| July 11 | July 21 | 10 | Aug. 9–18 | 19 to 28 |
| Aug. 3 | Aug. 6 | 3 | Aug. 28–31 | 22 to 25 |
| Dec. 25 | Jan. 18 | 24 | May 17–22 | 120 to 125 |

## THE LARVA

### First Instar Larva of Acanthoscelides Obtectus

Riley (*78*) and Riley and Howard (*81*) first pointed out the structural peculiarities of the first-instar larvae of *A. obtectus* in 1892, when they described the toothed prothoracic plates, but it remained for Kannan (*44*) to show the function of these plates.

The following description of the first-instar larva is from Kannan (*44, pp. 7–8*) and a reproduction of his drawing of the larva is shown in figure 7.

* * * The young larva is only 0.52 to 0.56 mm. long which is nearly one-tenth shorter than the egg. The greatest breadth is only about 0.21 mm. * * * The

larva is cylindrical, the posterior end being narrower than the anterior end. There is a series of subdorsal hairs each with a smaller hair at the root and a similar row of bristles occurs below the spiracles, of which there are nine pairs. Above the first abdominal spiracle is a well developed conical spine. On the pronotum immediately behind the head is the H-shaped prothoracic plate. There are four or five feebly curved teeth on the upper extremities of the plate and they are ranged more in a straight line than in a curve. At the level of the cross piece there are two teeth one on each side. These are larger and conical. The two limbs of the H are not jointed together but the teeth just described come so close together that the whole structure has the shape of the letter H. * * *

The head is small and black in contrast to the pale colour of the body. The epicranium and the clypeus are not firmly fused but a thin pale line indicates their limits showing the suture to be feeble. There are two eye-spots fairly conspicuous. The labrum is triangular. The mandibles are broad, equilateral, and capacious, each with a double hinge. * * * The maxillae are much reduced and bristly. There are two large segments. The one above is surrounded by a whorl of bristles and shows inside a minute stump. This stump is divided into two parts, the distal segment being terminated by bristles. The labium is absent, the part from which it normally arises being slightly triangular with sloping edges to allow, apparently, for the passage of the borings.

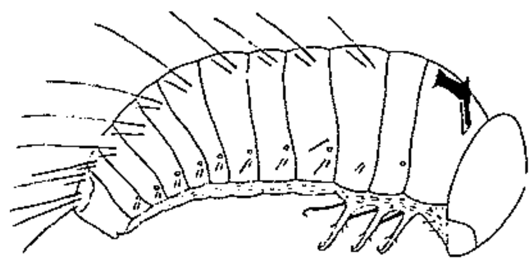

FIGURE 7.—First-instar larva of *Acanthoscelides obtectus*, showing prothoracic plates. (Kannan (*44*).)

There are three pairs of legs, each pair shorter than the succeeding one. There are but two divisions in each leg. The first one has at its distal end two spines and the second joint is paddle-shaped at the extremity. „The terminal flattening is a very unusual feature for an insect leg. Inward, near the origin of each leg, is a long bristle about the length of the bristles of the body but much more curved at the tip. The whole of the ventral surface is covered over with minute bristles, all turned backwards. Dorsally on the penultimate segment is a thick chitinous plate with a few bristles on it.

### LARVAL ADAPTATIONS

In 1892, Riley and Howard (*80*) writing of *Acanthoscelides obtectus* (*B. fabae*) larvae described structural peculiarities; the prothoracic plate bearing two pairs of projecting spurs, the hinder pair having each a serrate edge of four teeth, and the anal plate also bearing four horny, pointed tubercles all of which, they said "are evidently of advantage in aiding the young creature in the work it has to do," that is, in boring into and becoming established within the bean. That the young larvae had difficulty in entering and usually entered only at the point of contact between two beans or a bean and the container or at the point of a rupture in the seed coat has been noted by Lintner (*59, p. 271*), Manter (*63*), Bridwell (*13*) and others (fig. 8.) Kannan (*44*) has shown that with *A. obtectus* the legs, a well-developed anal sphincter, and the prothoracic plate all combine with the arched dorsum in securing a foothold and maintaining a leverage between the seed that is being entered and some other bean or other object with which it is in contact.

Without such a leverage the larva would be unable to make an entrance. This accounts for the fact that several larvae frequently enter a bean at the same point whereas their larval burrows begin to diverge just within the bean, as indicated in figure 9.

Kannan's description of the excavating (*44, pp. 15–16*) is as follows:

> * * * The upper limbs of the plate are, of course, fixed against the adjacent seed or pod, the lower limbs on the surface near the point of excavation. The plate may be placed not only directly in front of the larval head but also to either the right or the left at about the same distance in each case. It is the limitation imposed by the plate that explains the circular character of the hole. In working on the hind edge of the hole the head is bent by the plate being fixed further forwards. The operations deeper into the seed obviously cannot be followed. It is possible, however, that the two lower teeth come into use when they are fixed against the rim of the hole as the larva works near the centre of the pit. Then also the V-shaped neck unfolds. * * * The expansion of the V-shaped infolding will have the effect of bringing the mandibles within reach of the hind wall of the pit without a ventral infolding which is inevitable if the neck was as long below as above. When the excavation has come deep enough, the body wall will come into contact all around and further progress is easy with the aid of peristaltic movement. The difficulty of initial purchase ceases at this point.

FIGURE 8.—Lima beans having a broken seed coat are more easily entered by the newly hatched larvae of *Acanthoscelides obtectus* and are usually more heavily infested than those with an unbroken seed coat.

A mass of powder or borings make the point of entrance plainly visible if the seed has not been disturbed. When the larvae find themselves in a bean pod they frequently bore out of the pod instead of into the bean.

### Larval Development

The writers' observations correspond to those of Marcucci (*64*), who says that *Acanthoscelides obtectus* molts three times and then makes a cell in which it molts the fourth time and becomes a pupa.

The average width of the head before the first molt is 0.15 mm, between the first and second molts 0.225 mm, between the second and third molts 0.381 mm, between third and fourth molts 0.456 mm, and between the fourth molt and the prepupal stage 0.487 mm. Molting is very irregular, even in the same variety of beans under identical conditions.

### Duration of the Larval Stage

The duration of the larval stage of *Acanthoscelides obtectus* varies not only with temperature and humidity but also with the seeds in which the weevils are breeding. This accounts for the different lengths of time given by different writers, such as 24 to 42 days (*88*)

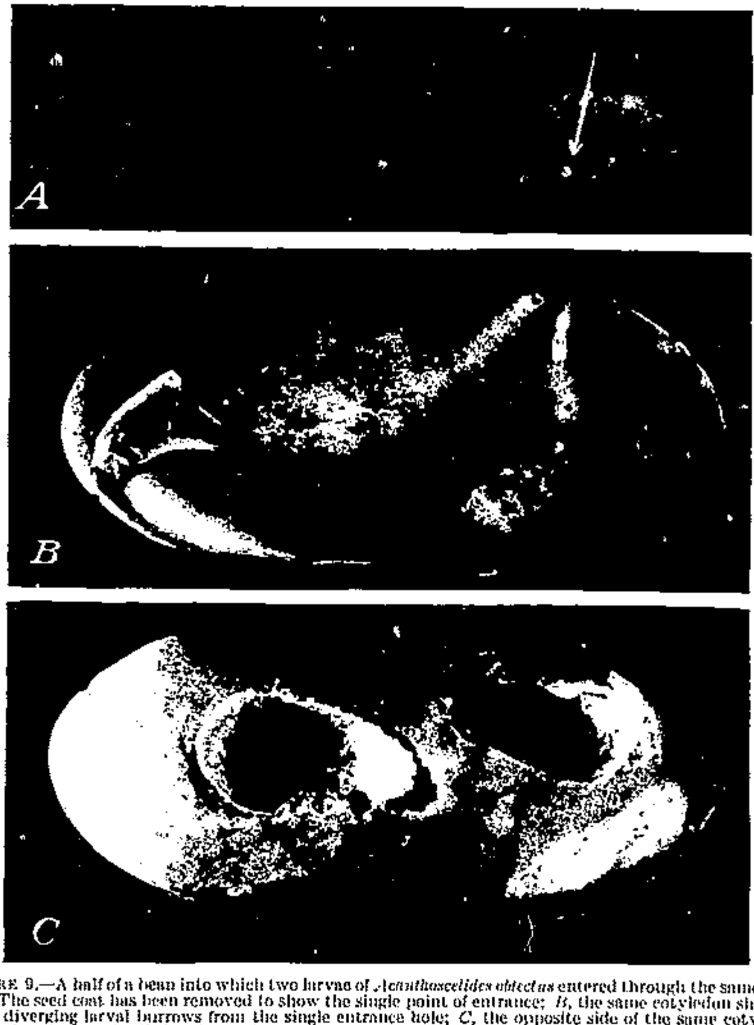


Figure 9.—A half of a bean into which two larvae of *Acanthoscelides obtectus* entered through the same hole: *A*, The seed coat has been removed to show the single point of entrance; *B*, the same cotyledon showing the diverging larval burrows from the single entrance hole; *C*, the opposite side of the same cotyledon showing the pupal cells just beneath the seed coat.

and 27 to 54 days (*63*) for the larval stage, and 21 days for the complete cycle (*15*). The writers find that the larval stage may be completed in 12 days or that it may continue for 6 months or longer. During warm weather in California it usually lasts from 17 to 25 days. During winter the mortality is high.

The moisture content of the beans undoubtedly has an important influence not only on the length of time required by the young larvae to bore into the seed but also on the rate of growth after they are within the seed.

The range of time for the molts of larvae in dry beans held in an incubator at 80° F. during the period of larval development was found to be as follows: First molt, 3 to 9 days after hatching; second, 11 to 15 days after hatching; third, 18 to 22 days after hatching; fourth, 24 to 27 days after hatching.

Under more favorable conditions (higher temperature with more moisture in the beans) the complete life cycle can be passed in 21 days or less, whereas under less favorable conditions it requires several months; so it will be seen that the length of time required for the development of each larval instar must vary considerably.

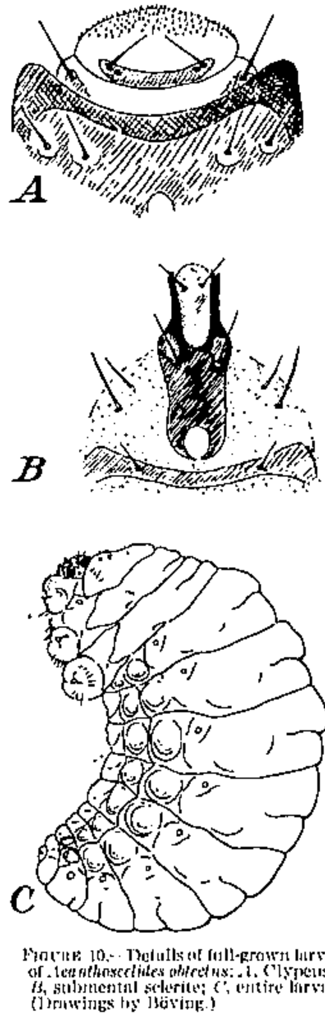

FIGURE 10.—Details of full-grown larva of *Acanthoscelides obtectus*: *A*, Clypeus; *B*, submental sclerite; *C*, entire larva. (Drawings by Böving.)

### Description of the Full-Grown Larva of Acanthoscelides obtectus

The following description of the full-grown larva has been prepared by Adam G. Böving:

> Full-grown larva (figs. 10 and 11) about 4 mm long; in size, general aspect of body, and anatomical details similar to *Callosobruchus maculatus*, particularly in having only one ocellus on each side, a maxillary palpus of one joint, in lacking completely a labial palpus, and in possessing small, circular, annuliform spiracles. It can, however, be separated from *maculatus* by the following combination of characters:
>
> Clypeus (fig. 10, *A*) without median large plate and only a slight chitinization at basis of lateral setae. Labrum beset in front of its plate with numerous very short and fine setulae. Submental sclerite (fig. 10, *B*) weak and not covering that part of the subfacial region in which two pairs of anterior and lateral setae are located. Labial plate laterally concave in outline and posteriorly provided with a single, median, light, round spot; anterior pair of light spots at basis of arms indistinct or lacking. Prothoracic tergal shields lacking or almost so. Finally, the papillary rudiment of the terminal part of the leg is still smaller than in *maculatus* and consists of only two indistinct joints.

Daviault (*20*) gives very excellent descriptions, not only of the larval instars but also of the pupae and adults.

### Prepupal Activity

As the larvae become fully grown they eat their way out to the seed coat and prepare pupal cells in which they transform to adults. The prepupal condition may last from a few hours in warm weather to several days at a low temperature. The larvae appear to rotate within the cells so as to rest upon their backs thus giving more freedom for the body and leg movements which accompany molting.

### THE PUPA

The pupa of *Acanthoscelides obtectus* is white, smooth, oval and closely resembles that of *Callosobruchus maculatus*.

The duration of the pupal stage, like that of the other stages of this weevil, varies greatly according to temperature. A few degrees difference in mean temperature makes a very noticeable difference in

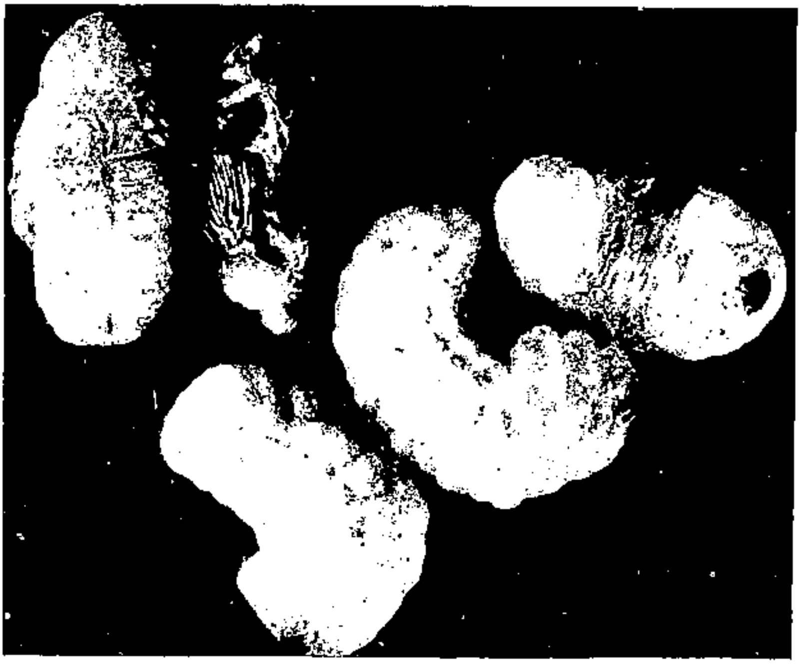

FIGURE 11.—Full-grown larvae and pupae of *Acanthoscelides obtectus* removed from a bean seed.

the duration of this stage. It has been reported to be from 11 to 18 days (*88*) and from 8 to 20 days (*63*), but the writers' observations indicate that it may extend longer than 25 days.

### DESCRIPTION OF ADULT OF ACANTHOSCELIDES OBTECTUS

Say's original description of *Acanthoscelides obtectus* (*85, vol. 1, p. 259*) is as follows:

*B. obtectus.*—Dusky; base and tip of the antennae, feet and abdomen obscure rufous.

Inhabits Louisiana.

Body above blackish; with prostrate, somewhat dense, dull yellowish hairs; antennae gradually thicker to the tip, basal half and terminal joint dull rufous, second joint nearly as long as the third: thorax with numerous, distinct punctures; elytra immaculate, the striae distinct; apical margin obsoletely rufous; beneath black, with prostrate hair; feet dull rufous; posterior thighs somewhat dilated, beneath blackish with a tooth near the tip and about two small ones nearer the tip; abdomen dull rufous, immaculate.

Length less than three-twentieths of an inch.

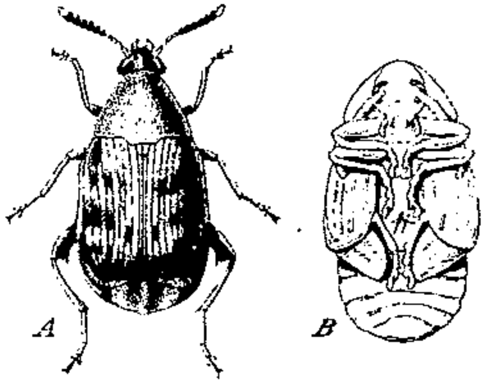


FIGURE 12.—*Acanthoscelides obtectus*, adult (*A*) and pupa (*B*) × 12.

The sexes are almost identical in color, shape, and size, but the gravid female is perhaps a little the larger on the average. The writers have found that they range from 2 to 3.8 mm in length (fig. 12).

## THE SOUTHERN COWPEA WEEVIL

### THE EGG

#### Description

The egg is glossy, oval, broader at one end than at the other. One side is glued to the seed, this side being flattened and the opposite convex. The eggs range in length from 0.409 to 0.756 mm, and in width from 0.294 to 0.462 mm. The viscid appearance of the freshly laid egg gradually changes as the embryo develops. After the larva enters the seed the eggshell remains attached and appears dirty white.

Although the measurements of the eggs as given by different writers vary considerably, it is quite evident that there is some mistake about the measurements 1.98 to 2.64 mm, length, and 1.34 to 1.80 mm, width, as given by Paddock and Reinhard (*65, p. 15*). Garman (*30, p. 314*) gives the length as 0.615 mm and the diameter 0.371 mm. Kannan (*44, p. 23*) gives the length as 0.68 mm and the width as 0.36 mm, and Brauer (*7, p. 287*) gives the length as 0.71 mm.

The writers have measured eggs at different seasons of the year and find that the same variation in size occurs at all times. During November, December, and January 1922 and 1923, the writers measured all the eggs laid daily by 10 pairs of weevils. A total of 713 eggs were measured. Of these the extreme range in length was 0.409 to 0.756 mm and in width from 0.294 to 0.462 mm. Some weevils consistently laid larger eggs than others. The ratio of length to width was quite different with eggs from different weevils. The eggs laid toward the latter end of the oviposition period were smaller than the eggs laid earlier. There seems to be a correlation between the size of the eggs from any given female and their viability. Larson and Simmons (*53*) showed that the first eggs laid by a weevil produced slightly less vigorous larvae than those laid later and that the eggs laid at the latter end of the egg-laying period showed the least vitality of all. Measurements of the eggs show that the first eggs are hardly as large as those laid later and those laid toward the latter end of the series are smaller than those laid during the middle part of the egg-laying period.

### Incubation Period

The duration of the egg stage is from 3 days under the most favorable conditions to 37 days or longer in winter. Table 4 shows the duration of the egg stage at different times of the year. The percentage of eggs that hatch in winter is always very low.

Table 4.—*Duration of the egg stage and the time from egg stage to emergence of adults of Callosobruchus maculatus at different times of the year at Alhambra, Calif., 1926 and 1927*

| Date eggs laid | Date eggs hatched | Incubation period | Date adults emerged | Period from hatching to emergence of adults | Date eggs laid | Date eggs hatched | Incubation period | Date adults emerged | Period from hatching to emergence of adults |
|---|---|---|---|---|---|---|---|---|---|
| | | *Days* | | *Days* | | | *Days* | | *Days* |
| Jan. 9 | Feb. 5 | 27 | May 30 | 114 | June 7 | June 16 | 9 | July 21 | 35 |
| Mar. 26 | Apr. 20 | 25 | June 9 | 50 | Aug. 11 | Aug. 20 | 9 | Sept. 23 | 34 |
| Mar. 26 | do | 25 | June 22 | 63 | Dec. 2 | Dec. 28 | 26 | Apr. 11 | 104 |
| Apr. 12 | Apr. 28 | 16 | June 11 | 44 | Dec. 17 | Jan. 13 | 27 | May 15 | 122 |
| Do. | do. | 16 | June 18 | 51 | June 21 | June 26 | 5 | July 22 | 26 |
| May 16 | May 27 | 11 | June 30 | 34 | June 22 | June 28 | 6 | July 30 | 32 |
| Do. | do. | 11 | July 3 | 37 | Aug. 10 | Aug. 13 | 3 | Sept. 17 | 35 |

Paddock and Reinhard (*65, p. 21*) writing of *Callosobruchus maculatus*, say, "The shortest period observed, 4 days, occurred frequently during the warmer portions of 1916. In fact, every period during June, July, and August, 1916, was four days." In their table (*65, p. 19*) they record two different dates in September in which only 3 days had been required. The longest time recorded by them is 37 days in the middle of winter with 25.5 as the average and 11 the shortest at that time. Slingerland (*89*), writing of the same insect, recorded 50 days as the length of time required for eggs to hatch on green pea pods. The writers are inclined, however, to think that the eggs he recorded on the green pea pods and the ones that hatched 50 days later were not the same eggs.

## THE LARVA

The larva of *Callosobruchus maculatus* molts three times and then makes a cell in which it molts the fourth time and becomes a pupa. The first-instar larvae are quite different from those of the later stages.

### The First-Instar Larva of Callosobruchus maculatus

Kannan (*44, p. 23*), after describing the first-instar larvae of a number of other species, says of those of *Callosobruchus maculatus:*

> The larvae are short and thick-set, with the anterior region more enlarged than the posterior. The legs are no longer long, slender and spatulate, but short and stout, about half the usual length. The two joints are subequal. The curved bristles near the legs are present as also the ventral spines.

The prothoracic plate is extremely variable, no two appearing quite alike. It is fairly broad and has about five teeth on each of the upper limbs, variable in number and size, and two on each side on the lower row equally variable. There are two stiff bristles midway between the upper and lower rows but shifted more toward the inner margin (fig. 13).

Although the larvae of *Callosobruchus maculatus* and *Acanthoscelides obtectus* are very similar after the first molt, Slingerland (*89, p. 448*) says:

Larvae in all stages after the first may be easily separated from those of *obtectus*, however, by a glance at the cephalic margin of the front of the head. The front is of a dark brown color for a considerable distance caudad * * *.

LARVAL ADAPTATIONS

In discussing the special adaptations of *Callosobruchus maculatus*, Kannan (*44, p. 23*) says:

The method of penetration of the larva is more easily watched on account of the transparency of the egg-shell. The prothoracic shield may be seen to be fixed in different situations against the egg-shell in front of the larva to its left or right. The lower limbs may be seen fixed to the rim of the hole.

In greater detail he (*44, p. 2*) describes the process by which the larva of *Bruchus chinensis* enters the seed. *B. chinensis* is typical of the insects of this group which cement their eggs firmly to the seed or pod as does *Callosobruchus maculatus*.

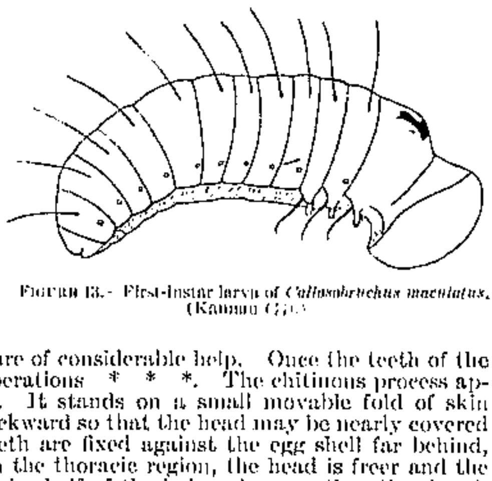

FIGURE 13.—First-instar larva of *Callosobruchus maculatus*. (Kannan (*44*).)

* * * Before making the excavation the H-shaped chitinous plate is brought at a convenient angle and fixed against the egg shell in which process the re-curved teeth of the upper limbs of the H are of considerable help. Once the teeth of the plate are fixed, the larva begins operations * * *. The chitinous process apparently serves a two-fold object. It stands on a small movable fold of skin which can be moved forward or backward so that the head may be nearly covered or completely free. When the teeth are fixed against the egg shell far behind, i. e., near its greatest convexity in the thoracic region, the head is freer and the mandibles are engaged in the anterior half of the hole; when, on the other hand, the posterior half of the hole has to be made, the chitinous structure is adjusted further forwards. In either case, the angle at which the chitinous process is fixed against the egg shell, appears to determine the inclination of the head and consequently the part of the hole that the larva works on at a particular moment.

To understand clearly why the larva does not bend its head downward, as one might expect it to do in these circumstances, it has to be remembered that its body is very short and thick. It seems certain, therefore, that any active bending of the body would have to take place in the middle, so as to form a semi-circular shape, which in fact the larva does take in the later stages of the growth. In these earliest stages, while the larva is still restricted to the narrow confines of the egg shell, there is no room for such a bending process. Moreover, as the legs are atrophied, they cannot function in gripping the surface of the seed. The posterior end of the egg is also narrow and is fully occupied by the abdomen of the larva.

The procedure which the larva follows is therefore very different from what one might expect. The forces exerted in the process of boring seem to be of two kinds. Firstly, the chitinous process being fixed against the egg shell in the region of its greatest convexity, forms a firm base for the action of the mandibular muscles. Secondly, there is a thrust forward from the abdominal end which, as already stated, is closely applied to the egg shell. This forward movement is, by reason of the attachment of the H-shaped process to the egg shell, converted into a vertical force thrusting the mandible against the surface of the seed * * *.

The tension on the egg shell exerted by the larva soon reveals itself in minute folds rediating from the anterior and posterior extremities of the egg shell. There are shallow grooves produced by the teeth of the chitinous process as they are moved forward or backward during the course of larval adjustments. The force so exerted may be so great as to rupture the egg shell. This break usually occurs in the region of the greatest convexity of the egg and through it meal from the excavation may also be seen to come out.

The fact that the young larva ordinarily cannot enter the seed from the egg unless it is firmly attached points to a reason why larvae from eggs laid on the seeds of Egyptian cotton did not enter the seed. The eggs instead of being firmly attached to the seed were attached to the fibers which would allow movement and prevent the larva from being able to bore out of the egg shell. This may account for the habit of the adult of selecting firm, whole seeds for oviposition rather than seeds on which the seed coat is broken.

## Larval Development

The moisture content of the seeds undoubtedly has an important influence not only on the length of time required by the young larvae to bore into the seed but also on the rate of growth after they are within the seed.

In measurements made of larvae reared in dry blackeye cowpeas the average width of the head was found to be 0.24 mm following the first molt, 0.33 mm after the second, and 0.48 mm after the third molt.

The molts occurred as follows: First molt, 10 to 15 days after hatching; second molt, 18 to 25 days after hatching; third molt, 24 to 27 days after hatching; fourth molt, 32 or more days after hatching.

Since this weevil may complete its life cycle in as short a period as 14 days or may extend it to 9 months, depending on the temperature and moisture conditions, so the length of each larval instar may differ from those recorded above.

## Duration of the Larval Stage

The duration of the larval stage varies not only with temperature and humidity but also with the hosts in which they are developing. It has been observed to range from 9 days (*65, p. 28*) or less (*11*) to 8 months (*53*). A larva was dissected from a blackeye cowpea 235 days after the egg had been laid on September 26. During warm weather in California the larval stage lasts from 17 to 22 days. During winter the mortality is high.

## Description of the Full-Grown Larva of Callosobruchus maculatus

The following description of the full-grown larva of *Callosobruchus maculatus* has been prepared by Adam G. Böving:

Full-grown larva (fig. 14) about 4 mm long, thick, curved, and white; almost naked and with rudimentary legs.

Head elongate, oval and usually deeply retracted; only the exposed parts of the head capsule colored, the remainder whitish; head connected with body by a cervical collar which is particularly broad dorsally, and because of this membrane the head may be almost completely protruded from the prothorax when necessary.

Epistomal margin of frons (*epi*) strongly chitinized and behind it anterior part of frons also chitinized, but much lighter and thinner; anteriorly on each side of frons are two setae of moderate length, and paramedianly a round, almost white spot is often observed. One small ocellus. Antenna short, two-jointed, terminally beset with many tactile papillae. Clypeus (*c*) transverse, almost completely covered with a chitinous plate that carries a long seta at each end. Labrum transverse, with anterior margin convex, about as long as clypeus but somewhat narrower; like the clypeus it has a chitinous plate with a long seta at each end, and more inwardly, some distance from the seta, is a small sensory point; in front of the plate the labrum is densely beset with setae of rather equal size, and most of them are as long as one-third of the middle length of the labrum.

Mandible robust, subtriangular, about as wide as long, without teeth or grinding surface, distally with a rounded, sharp edge, and facing the buccal cavity somewhat gouged on inner side.

Maxillary palpus consisting of a single, rather short, conical joint; palpiger broad, jointlike, and carrying a small, projecting digitiform mala, which terminally is armed with a comblike organ formed by five long, flat setae placed closely together.

Subcranial area undivided and formed by a fusion of the mental, submental, and labial areas; labial palpi lacking. Posteriorly a fairly well developed but thinly chitinized submental sclerite (*sm*) located some distance away from the labial plate, not surrounding it. Labial plate (*lp*) yellowish, anteriorly roundly incised between a pair of strongly chitinized darker arms; externally, at basis of each arm, a clear, white, round spot indicating the place where in other larvae a labial palpus is located; laterally the labial plate convex and posteriorly rather indistinctly outlined, without a median incision or a median single round white spot. Ligula (*li*) greatly reduced but carrying two long setae.

Prothorax provided with a pair of thin, light-yellow tergal shields with from four to five round whitish marks. Mesothorax and metathorax identically built, metathorax slightly the larger; both with two rather flat and short tergal pleats.

Each of first seven abdominal segments with two large swollen tergal pleats, a large hemiglobularly bulging epipleural lobe, and a smaller but similar hypopleural lobe; eighth abdominal segment smaller than seventh and its tergal pleats rather indistinct; ninth abdominal segment short and button-shaped; tenth small and mammiliate.

Legs represented by three pairs of protuberant pedal lobes (coxae?), arranged in two posteriorly diverging series, each lobe carrying on the top a papillary rudiment of the three terminal leg joints; no claws.

Spiracles small, ring-shaped, and only slightly chitinized, one mesothoracic and eight abdominal pairs of spiracles present, all of about equal size, the mesothoracic placed in the skin between the prothoracic and mesothoracic epipleural areas, all the abdominal spiracles located in lower part of terga and above epipleural lobes; eighth abdominal spiracle near end of body.

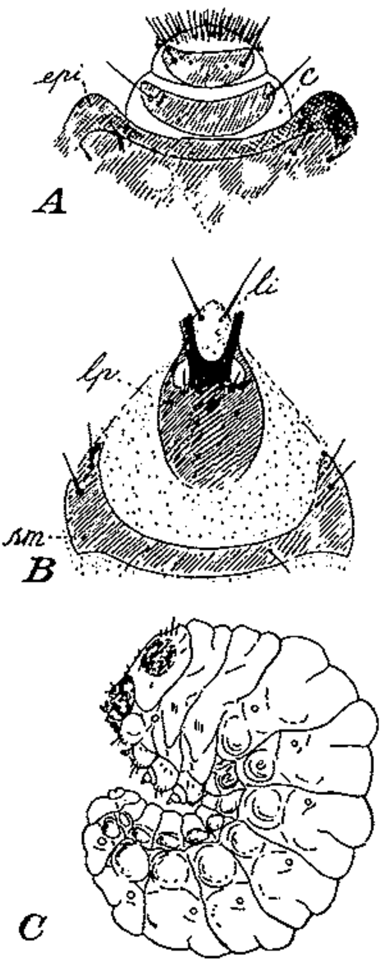


FIGURE 14.—Mature larva of *Callosobruchus maculatus*: *A*, Clypeus; *B*, submental sclerite; *C*, entire larva. (Drawing by Böving.)

### Prepupal Activity

When the larvae become full grown they go through the same movements as were described for the larvae of the bean weevil.

## THE PUPA

The pupa of *Callosobruchus maculatus* is stout, compact, white, free from bristles or hairs.

Ventral view: Outline oval, tapering to a blunt point distally, broadly rounded anteriorly. Head distinct, bent closely upon thorax; mouth parts immediately between coxae of first pair of legs; mandibles distinct; palpi free, segments distinct, reaching second pair of legs. Eyes prominent; antennae strongly curved, passing behind first and second pairs of legs, lying flat upon the elytra, segmentation quite distinct, almost three-fourths as long as elytra; longitudinal ridges of elytra very distinct. First and second pairs of legs equal in length, folded horizontally over elytra; tarsi parallel with body, segmentation distinct; last pair of legs covered by wings, except tarsi, which reach almost to the base of the last abdominal segment.

Lateral view: Head deflexed, prothorax depressed anteriorly, spiracles inconspicuous; first and second pairs of legs cover basal portion of elytra beneath the antennae; antennae curved ventrally behind the legs to about last one-fourth of elytra; wings prominent, curved ventrally behind second pair of legs and cover all but tarsi of last pair of legs; abdominal segments distinct, spiracles inconspicuous.

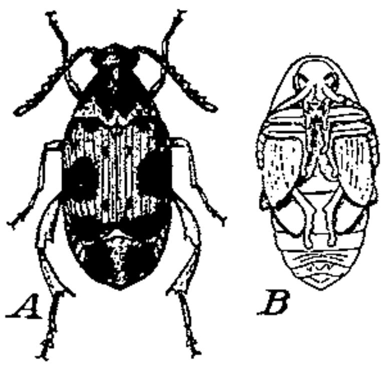

FIGURE 15.—*Callosobruchus maculatus*, or southern cowpea weevil, adult (*A*) and pupa (*B*). × 10.

Dorsal view: Head concealed by prothorax; thoracic segments distinct, prothorax more or less triangular in outline, much wider posteriorly, terminating in sharp points above base of wings, median line conspicuous, abdominal segments nearly equal in size.

Length 3.2 to 5 mm (fig. 15).

The duration of the pupal stage, like that of the other stages of this weevil, varies greatly according to the temperature. A few degrees' difference in mean temperature makes a very noticeable difference in the duration of this stage. The writers have not noted as short, or as long, durations of this stage as are recorded by Paddock and Reinhard (*65, p. 37*), who record extremes of 3 and 53 days. They show not only that the mean temperature may have a positive effect on the length of the pupal stage but that the average length of the stage may be influenced by a severe low temperature or by a few days of warm weather. Larson and Simmons (*53*) noted that the duration of all later stages may be influenced by a period of cold or warm weather during the first few days after the eggs have been laid.

## DESCRIPTION OF THE ADULT OF CALLOSOBRUCHUS MACULATUS

Because Horn's description (*40*) of *Callosobruchus maculatus* (*Bruchus quadrimaculatus*) is more in detail than the original description by Fabricius (*23*), the former is here given as follows (*40, p. 318*):

Elongate oval, moderately shining. Beneath equally clothed with whitish pubescence. Elytra ferruginous or pale brown with large lateral spot and apex broadly black. Head dark brown or black, densely punctured, front sub-carinate. Antennae as long as head and thorax, serrate in both sexes, four basal joints pale rufous, outer joints dark and nearly black. Thorax trapezoidal, broader at base than long, sides distinctly arcuate, base trisinuate, basal lobe emarginate and clothed with whitish hairs; color variable from ferruginous to black, coarsely punctured, sub-granulate and feebly shining, sparsely clothed with cinereous hair. Scutellum with median impressed line and clothed with whitish hair. Elytra broader at base than thorax and longer than wide, sides feebly arcuate, humeri moderately prominent; striate, striae punctured, intervals flat, densely punctulate; color ferruginous with large lateral spot and apex black, clothed with whitish and cinereous pubescence. Pygidium nearly black with median line of whitish pubescence. Body beneath piceous densely punctulate and sparsely but evenly clothed with cinereous hairs; abdomen pale brown. Anterior and middle legs pale rufous, hind legs pale brown. Hind femora armed with an acute tooth on the inner side and a broad triangular tooth on the outer side. Length .12—.18 inch; 3—4.5 mm.

The writers find that the adults range in length from 2 to 5 mm. The males are more reddish and are smaller than the females, but a large male may be larger than a small female. Breitenbecher (*9, 10*) has shown that the colors vary greatly and that the order of dominance is red, black, white, and tan. He (*12*) has also recorded an apterous mutation of this species.

## EMERGENCE OF THE ADULTS OF BOTH SPECIES

The method of emergence of both species is practically the same in every respect. After casting the pupal skin the beetles require some time, ranging from less than 1 day to several days, according to the temperature, to complete their development before they are ready to emerge from the seed. They lie quietly for some time after they are apparently fully developed. This is shown by the fact that merely moving the beans will cause the weevils to become active and emerge. Emergence is accomplished by the adult cutting a tiny groove in the seed coat along the edge of the larval burrow. In some instances the groove apparently is cut all the way around the disk and at other times only part way around. After the groove has been made, pressure is applied to the disk over the burrow by the head and front feet. After the beetle has its head out of the burrow it sometimes waves its antennae before completing the emergence. Sometimes the disk of the seed coat is pushed completely away from the seed by the head of the beetle, but at other times it is merely pushed out like a trap door to permit emergence, after which it swings back and closes the burrow so completely that close scrutiny is necessary to detect it. The same thing may be noted when the beetles cut through paper bags in which they have emerged (fig. 16).

Paper bags are cut through only by adults cutting their way out from seeds in contact with the paper where they have the necessary support and conditions similar to those of beans in a pod. The writers have not observed cotton bags being perforated except where the fabric is loosely woven; then the weevils work out between the threads but do not cut them.

The exit holes left in the beans by *Acanthoscelides obtectus* and *Callosobruchus maculatus* are exactly circular and may be of the same size. Those made by a large female *maculatus* are larger than those made by *obtectus*. The exit hole may be on any part of the seed, but the angle of the burrow to the surface of the seed aids in determining which species has emerged. The burrow left by *obtectus* often lies just beneath the seed coat and almost parallel to it, whereas that left by *maculatus* is usually at an angle of 45° or more and sometimes extends directly through to the seed coat on the opposite side.

*Callosobruchus maculatus* frequently emerges from the end of blackeye cowpeas. In this case the larvae seem to have eaten into the central cavity within the seed and to have been unable to obtain food except at the end where the cavity is small enough for its sides to serve as a brace for their bodies.

At the time of emergence the beetles are larger and the color markings are more distinct than they are at any later time. As the beetles get older their abdomens become much smaller and shorter. In certain grain weevils this decrease in size is due to the absorption of the

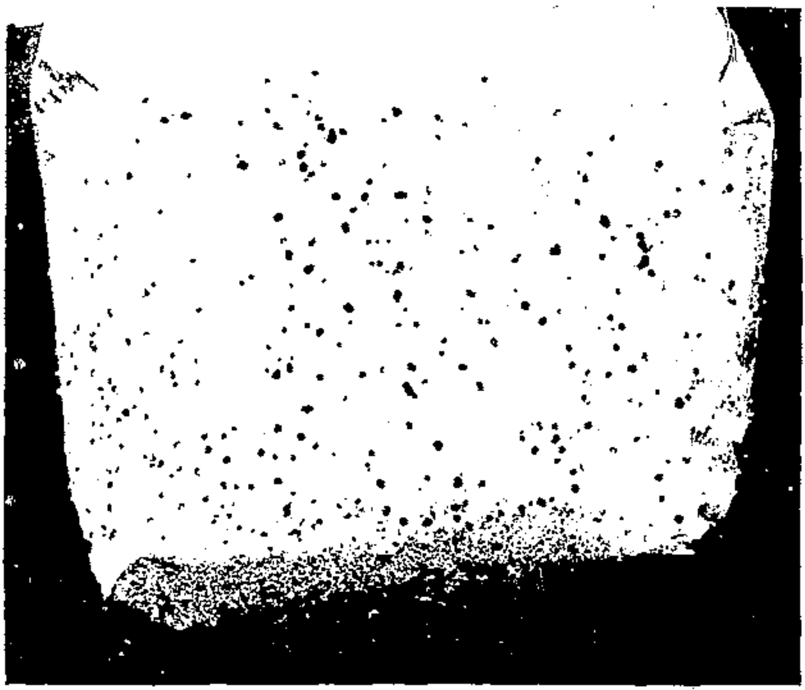

FIGURE 16.—Paper bag showing holes cut by weevils emerging from beans.

fatty bodies (*98*), and it is probably due to the same cause in the case of bean weevils.

Although Prichard and Breitenbecher (*70*) showed that theoretically there should be equal numbers of males and females of *Callosobruchus maculatus*, the writers have observed that there is a preponderance of males. With favorable food in which to develop, from 52 to 59 percent of the beetles usually are males. In less favorable food, the percentage of males has been observed to be even higher.

## ACTIVITIES OF THE ADULTS

The activity of the beetles of both sexes and both species is greatly modified by temperature. Even in the summer they become sluggish during a cool night but resume activity the next day after it has become warm again, and during the hot part of the day they are exceedingly active and restless, the males running about incessantly and making numerous short flights, and the females seeming to be continually searching for suitable places for oviposition.

## FEEDING BY THE ADULTS

The feeding habits of the adults seem to have received very little attention. In the literature on bean weevils the statement is frequently made that some of the weevils emerge in the fall and others in the spring and lay their eggs on the pods, or that they live on the young bean plants until they lay their eggs. The life history of this insect, as it has been discussed by numerous writers, deals with the number of eggs laid and the length of time required for the development of the different stages. Where the length of life of the adult is given it is usually the life of an insect that has been caged on a bean plant or of one that has been confined on dried beans. Such life histories may be accurate for insects so treated and still not reflect the lives of weevils at liberty in the warehouse or in the field. The feeding habits of the adults and the time and rate of dispersal from infested seeds have usually been overlooked. These greatly influence the length of life of the weevils and the number of progeny produced. They may be the determining factors in the degree of infestation in a crop.

When studying the habits of both *Acanthoscelides obtectus* and *Callosobruchus maculatus*, especially in connection with oviposition, the writers have frequently caged weevils on different varieties of growing beans where it was possible to observe their feeding habits on the plants. For this work three types of cages were used, (1) a muslin-cloth-covered cage 6 by 8 by 6 feet high with a door in the end to permit entry; (2) screen-wire-covered cages 3 by 2 by 2 feet 5 inches high, with a door in the side; and (3) cages 18 by 18 by 18 inches, covered with screen wire on the top and three sides and having window glass in the fourth side. In these cages it has been possible to study the habits of the weevils under conditions similar to those in the field.

These weevils, according to Zacher (*98*), are provided with a sufficient quantity of reserve substance in the form of fatty bodies to carry them over from the pupal stage to sexual maturity of the adult without other nourishment. Speaking of *Acanthoscelides obtectus*, Slingerland (*88*) said that they soon die on dry beans but live in a cage on the growing plant for a month or more feeding on the parenchyma of the leaves, but when questioned he said he had not seen them feeding on the leaves in the field. Later he said (*89, p. [445]*), "The beetles fed upon the surfaces of the leaves until the pods were nearly full grown but still green." Hawley (*35*), writing about this weevil, says:

> In an effort to determine the summer habits of the weevils that emerge from infested seed when it is planted, the writer, on June 18, 1918, placed weevils, and beans containing larvae and pupae of the insect, in a field cage in which small bean plants were growing. On July 2 it was noted that the parent beetles had eaten small pieces from the leaves of the plants.

Hawley did not say that he or any one else saw the weevils eat the pieces from the leaves. The writers have watched for but have failed to note similar injury to the bean plant, the only injury noted being the oviposition scars made by the mouth parts of the female in the sides of the growing pod and the oviposition scars made in the suture of the more developed pods.

On caged plants, these weevils remain almost motionless for hours at a time. The base of the petiole and, less frequently, other parts of the leaf and the stem are selected as resting places. Sometimes the weevils appear to be searching the blossoms, but careful watching has failed to show that they obtained food from them. They do not go from flower to flower as nectar-seeking insects do but appear to obtain some nourishment from the small particles of dew and honeydew on the plants. The habits of the caged weevils appear to be identical with those free in the field, as far as the writers have observed.

In most of the cage experiments the exact length of life of the adult was not recorded, but in 1923 it was recorded in five cage tests in which the weevils lived from 7 to 18 days with an average of 15 days, a length of time quite closely corresponding to that of the weevils that received no food in confinement, as recorded in table 5. Under certain climatic conditions weevils live longer than this in cages just as weevils sometimes live longer when confined on dry beans than is recorded in the table.

The general assumption is that adults of *Callosobruchus maculatus* require no food, and that as soon as the reserve food material stored up by the larva is exhausted the adult dies. This is borne out by the fact that weevils of both sexes are smaller toward the end of life than at the time of emergence, the female shrinking to about one-fourth her former size. In warm weather this reserve food material is used up more rapidly than in cool weather; therefore the weevil lives longer in cool or mild weather than in hot weather, although it does not produce more eggs during the long period of life than during the shorter period at the higher temperature.

The few known statements regarding the feeding habits of *Callosobruchus maculatus* are not altogether in accord with one another. Speaking of *Bruchus chinensis*, which he says is typical of the other bruchids, Kannan (*43*) says: "The adults appear to take no food during their life." Wade (*95*) says:

> Weevils were bred in successive generations * * *, the adults taking neither food nor drink throughout their existence without apparent injury to them or effect upon their activities. Under these conditions adult females were kept alive for as many as 40 days. * * * That the adults will drink was demonstrated on several occasions when water was given to them, of which they partook greedily. So far as could be learned, access to water did not stimulate their activities or prolong their life. That they feed cannot be stated definitely; none were ever observed to do so, although it is quite possible that they may feed some on the green pods and foliage of the host plant.

Sanborn (*83, p. 12*) says: "The adults are not as ravenous as the young or larvae."

Ashmead (*1*) and Cushman (*18*) report *Callosobruchus maculatus* visiting the blossoms and nectaries of cotton plants. Paddock and Reinhard (*65, p. 38*) say:

> The cowpea weevil has not been observed to feed on any solid food in the adult stage, and the cowpea is injured only by the feeding larva. Observations show that the adult weevil never attacks cowpeas directly, except when emerging it sometimes gnaws its way through the thin shell covering the exit of the larval burrow. Frequently the adults reenter the larval burrows in the peas and die, giving rise to an erroneous popular opinion that they feed upon the peas. In the field the adults feed almost exclusively upon nectar secreted by the nectaries located at the base of the green pods. A few adults have been collected from the blossoms of cowpeas. None were observed to visit blossoms of other plants with any regularity. The adults are egregious in feeding. Invariably single individuals were found feeding; occasionally two or three were observed at the base of the

same pod, but they never fed in larger numbers. The weevils, while feeding, are very active and seek shelter very quickly upon the slightest disturbance.

The writers have observed that when this weevil is disturbed in the field it sometimes flies away, but more often it drops into the foliage of the plant.

### MATING AND PREOVIPOSITION

Both species of weevils mate frequently. Under storage conditions this may occur any time from a few hours to a few days after emergence. In warm weather mating of *Callosobruchus maculatus* takes place almost immediately after emergence, and eggs may be laid within a few minutes or hours. Even with favorable temperatures, mating of *Acanthoscelides obtectus* does not always take place during the first 2 days following emergence. The weevils usually mate, however, before the females fly away in search of new material on which to oviposit. Competition among the males is very keen. After mating has ceased, however, the female is left alone for several hours and an ovipositing female is not disturbed by the male. When weevils are confined in a bell jar under a partial vacuum their impulse for mating is greatly increased.

Paddock and Reinhard (*65, p. 52*) noted a pair of *Callosobruchus maculatus* in copulation 1 minute after they had emerged. They (*65, p. 51*) say:

> Copulation is generally of short duration, rarely comprising more than three or four minutes. * * * ten pairs of weevils were timed while copulating. The average time was three minutes and twenty seconds. * * * Without exception the female makes the initial attempt at release. * * *.

They also say that the same female has been observed to copulate as many as three times. The writers have observed the same female in copulation as many as 7 times and the same male as many as 23 times. They have noted that the male sometimes makes the initital effort at release. Frequent observations indicate that duration of copulation is shortest while the male is young and vigorous. The writers have observed old males in copula with dead females. One newly emerged male of *C. maculatus* was kept under observation and allowed to mate only with virgin females. The male was kept alone except while under observation as noted. He lived 13 days and mated with 23 females. The duration of copulation was from 5 to 34 minutes. Fourteen of the females produced fertile eggs. Four were fertilized the same day. The male copulated six times in 1 day.

At favorable summer temperatures oviposition by *Callosobruchus maculatus* usually begins during the first 24 hours after emergence. The writers have frequently noted oviposition within 2 hours after emergence. One was observed to lay its first egg 46 minutes after mating while another was observed to lay its first egg 31 minutes after mating and the second egg 3 minutes later. Both eggs hatched and produced vigorous adults. The egg laid 31 minutes after mating produced a female which emerged on the thirtieth day after the egg was laid. Under similar favorable conditions oviposition by *Acanthoscelides obtectus* may begin the first day but usually not until the second or third day after emergence. Table 5 gives the typical preoviposition periods for the two species throughout a year. The preoviposition period is longer in cool or cold weather. Drink as well as liquid food lengthens the preoviposition period. When no food is obtained the eggs develop rapidly and are laid early in the life of the adult; but when food is obtained egg development is retarded, giving the weevil an opportunity to make a more extended search for material on which to oviposit, which is necessary in the field, especially before the crop is well ripened.

TABLE 5.—*Length of preoviposition period at different times of the year, length of oviposition period, number of eggs laid, and length of life of adults of Acanthoscelides obtectus and Callosobruchus maculatus, Alhambra, Calif., 1922–25*

ACANTHOSCELIDES OBTECTUS

| Adult emerged | First egg laid | Length of preoviposition period | Last egg laid | Length of oviposition period | Total eggs laid | Date adult died | Length of life of adult |
|---|---|---|---|---|---|---|---|
| *1922* | *1922* | *Days* | *1923* | *Days* | *Number* | *1923* | *Days* |
| Dec. 10 | Dec. 18 | 8 | Jan. 2 | 16 | 27 | Jan. 28 | 49 |
| | *1923* | | | | | | |
| Dec. 23 | Jan. 1 | 9 | Feb. 8 | 39 | 8 | Feb. 9 | 48 |
| *1923* | | | | | | | |
| Jan. 16 | Feb. 1 | 16 | Feb. 10 | 10 | 15 | Feb. 28 | 43 |
| Mar. 20 | Apr. 15 | 26 | Apr. 25 | 11 | 26 | May 1 | 42 |
| Mar. 25 | Apr. 10 | 16 | Apr. 19 | 10 | 38 | Apr. 30 | 36 |
| Apr. 3 | Apr. 11 | 8 | Apr. 28 | 18 | 39 | May 2 | 29 |
| May 2 | May 15 | 13 | June 5 | 22 | 70 | June 11 | 40 |
| May 13 | May 14 | 1 | May 29 | 16 | 66 | May 30 | 17 |
| May 31 | June 16 | 16 | July 1 | 16 | 13 | June 25 | 25 |
| June 22 | June 23 | 1 | July 5 | 13 | 68 | July 5 | 13 |
| July 29 | July 30 | 1 | Aug. 3 | 5 | 52 | Aug. 11 | 13 |
| Do | July 31 | 2 | Aug. 11 | 12 | 82 | Aug. 11 | 13 |
| Aug. 9 | Aug. 10 | 1 | Aug. 16 | 7 | 93 | Aug. 23 | 14 |
| Aug. 28 | Aug. 29 | 1 | Sept. 5 | 8 | 82 | Sept. 12 | 15 |
| Sept. 4 | Sept. 6 | 2 | Sept. 12 | 7 | 73 | Sept. 25 | 21 |

CALLOSOBRUCHUS MACULATUS

| Adult emerged | First egg laid | Length of preoviposition period | Last egg laid | Length of oviposition period | Total eggs laid | Date adult died | Length of life of adult |
|---|---|---|---|---|---|---|---|
| *1924* | *1924* | | *1924* | | | *1924* | |
| Jan. 5 | Jan. 15 | 10 | Jan. 22 | 8 | 15 | Jan. 21 | 16 |
| Do | Jan. 6 | 1 | Feb. 10 | 36 | 72 | Feb. 12 | 38 |
| Jan. 15 | Jan. 16 | 1 | Feb. 18 | 34 | 32 | Feb. 21 | 37 |
| Jan. 23 | Jan. 26 | 3 | Feb. 16 | 22 | 39 | Feb. 26 | 34 |
| Feb. 9 | Feb. 13 | 4 | Mar. 5 | 22 | 18 | Mar. 8 | 28 |
| Mar. 28 | Apr. 7 | 10 | May 2 | 26 | 8 | May 4 | 37 |
| Apr. 11 | Apr. 16 | 5 | Apr. 30 | 15 | 75 | May 8 | 27 |
| May 9 | May 10 | 1 | May 25 | 16 | 77 | May 26 | 17 |
| June 26 | June 28 | 2 | July 5 | 8 | 93 | July 6 | 10 |
| July 12 | July 13 | 1 | July 28 | 16 | 133 | July 28 | 16 |
| July 16 | July 17 | 1 | July 24 | 8 | 85 | do | 12 |
| Do | do | 1 | July 27 | 11 | 95 | Aug. 1 | 16 |
| Do | do | 1 | July 25 | 9 | 85 | July 26 | 10 |
| Do | do | 1 | July 24 | 8 | 102 | do | 10 |
| Do | do | 1 | July 26 | 10 | 100 | Aug. 1 | 16 |
| Do | do | 1 | do | 10 | 110 | July 28 | 12 |
| Do | do | 1 | July 24 | 8 | 87 | July 27 | 11 |
| Do | do | 1 | July 25 | 9 | 88 | July 26 | 10 |
| Do | do | 1 | July 26 | 10 | 88 | do | 10 |
| Do | do | 1 | July 24 | 8 | 84 | July 29 | 13 |
| Do | do | 1 | do | 8 | 90 | do | 13 |
| Do | do | 1 | July 25 | 9 | 96 | do | 13 |
| Do | July 18 | 2 | July 26 | 9 | 95 | do | 13 |
| Aug. 5 | Aug. 6 | 1 | Aug. 14 | 9 | 123 | Aug. 15 | 10 |
| Sept. 17 | Sept. 21 | 4 | Oct. 2 | 12 | 95 | Oct. 7 | 20 |
| Oct. 11 | Oct. 16 | 5 | Nov. 7 | 23 | 112 | Nov. 11 | 31 |
| | | | *1925* | | | *1925* | |
| Dec. 20 | Dec. 21 | 1 | Jan. 11 | 22 | 26 | Jan. 22 | 33 |
| Dec. 21 | Dec. 22 | 1 | Jan. 8 | 18 | 64 | Jan. 11 | 21 |
| Do | do | 1 | Jan. 16 | 25 | 86 | Jan. 18 | 28 |
| Dec. 22 | Dec. 27 | 5 | Jan. 15 | 20 | 48 | Jan. 21 | 30 |
| Do | Dec. 23 | 1 | Jan. 13 | 22 | 10 | Jan. 22 | 31 |
| Do | Dec. 24 | 2 | Jan. 12 | 20 | 64 | Jan. 20 | 29 |
| Do | Dec. 25 | 3 | Jan. 13 | 20 | 61 | Jan. 19 | 28 |
| Dec. 23 | do | 2 | do | 20 | 42 | Jan. 17 | 25 |
| Do | do | 2 | Jan. 9 | 16 | 48 | Jan. 18 | 26 |
| Dec. 24 | do | 1 | Jan. 4 | 11 | 33 | Jan. 7 | 14 |
| Do | do | 1 | Jan. 20 | 27 | 80 | Jan. 30 | 37 |
| Do | Dec. 26 | 2 | Jan. 5 | 11 | 30 | Jan. 8 | 15 |
| Dec. 26 | Dec. 27 | 1 | Jan. 10 | 14 | 55 | Jan. 23 | 28 |
| Dec. 29 | Dec. 30 | 1 | Jan. 10 | 12 | 20 | Jan. 11 | 13 |

## HOW WEEVILS FIND BEANS ON WHICH TO OVIPOSIT

In trying to solve the problem of how weevils find beans on which to oviposit, the writers have concluded that sight is of minor importance and that the insects are guided to the seeds mainly by smell. Although weevils will sometimes alight on glass jars in which beans are stored they have no trouble in locating seeds in small paper or cotton sacks, even when such sacks of beans have been hidden away in drawers and almost completely covered with other materials. The weevils enter the drawers at the edges where these do not fit snugly, and then go to the beans in the sacks. It is altogether probable that the ripening pods and seeds in the field emit an odor that attracts the weevils and that a similar odor is given off by dried seeds in storage. Vasiliev (*94*) is of the opinion that females of *Acanthoscelides obtectus* are attracted to more or less ripe pods by the peculiar and rather strong smell of these pods.

## OVIPOSITION IN THE FIELD

### THE BEAN WEEVIL

In the field the females of *Acanthoscelides obtectus* search out over-ripened pods split open along the suture (fig. 17), crawl into them, and lay eggs. If a pod is not opened sufficiently for entrance, the weevil inserts its ovipositor and lays its eggs within the pod. When such pods cannot be found, more immature pods are accepted, and after long and careful examination the female selects a spot near the middle on the side of the pod between two growing beans and makes an opening. The hole is excavated slowly with the mandibles, and apparently none of the solid portion of the green pod is eaten, although probably some of the juice is swallowed. As the excavation progresses the weevil frequently turns around, inserts its ovipositor, and probes. When more mature pods are available the suture is always chosen and a small hole is made through which the eggs are laid. The weevil takes a position at right angles to the suture (fig. 18, *A*) and bites and pries with its mouth parts at the same point until it makes a suitable opening. This often requires several hours' work. During the process it frequently turns around and tries to insert its ovipositor, which it also uses as a feeler to determine the size and depth of the opening. It sometimes stops to rest and may crawl about the pod for a minute or more, but it usually returns directly to the point at which it was working, without stopping to feel or hunt for its location. Slingerland (*89*) says that several beetles would work on the same slit, one driving the other away and continuing the work itself, but the writers have never observed such an occurrence. Sometimes a pod is abandoned after considerable work has been done. After a satisfactory opening or slit in the suture has been made the weevil takes a position at right angles to the suture with the head away from it (fig. 18, *B*), then forces its long semichitinous, telescopic ovipositor into the slit and begins oviposition. With the aid of a good reading glass, the ovipositor can be seen to expand and contract as the eggs pass downward in rapid succession. After several eggs have been laid the ovipositor is withdrawn, and the eggs appear to be pushed down through the slit by the mouth parts of the insect. The ovipositor is again inserted and more eggs are laid. From 10 to 35 eggs are commonly laid in one place by a young, vigorous female, but as the weevil gets older it lays fewer eggs. The writers have noted 66 eggs beneath one oviposition slit, but in storage they have never known a weevil to lay more than 59 eggs in 1 day; one weevil, however, laid 16 eggs 1 day and 59 the next.

Riley and Howard (*80*) report the emergence of 91 beetles from one pod collected "when mature and yellow." They also found 82 weevil eggs in a hole made by a caterpillar.

FIGURE 17.—Overripened bean pods make ideal place for oviposition by weevils.

Harris (*34*), writing of an infestation of *Acanthoscelides obtectus* says that with Golden Wax and Burpee Stringless beans there is a direct relation between the size of the mature pods and the probability of infestation; that is, the pods having a large number of seeds are more likely to be infested than smaller pods having fewer seeds. There was no relation between the location of the bean in the pod and the probability of infestation. The writers think that the correlation between the size of the matured pod and the infestation is dependent upon a factor which Harris failed to note and that is the time of ripening of the pod with reference to the other pods on the same vine. The early ripening pods (*46*) are selected by the weevils for oviposition. The early pods are frequently the largest on the vine and are almost always larger than the late-maturing pods. A small well-ripened or overripe pod on one vine is more likely to be selected for oviposition than a large green pod on the next vine.

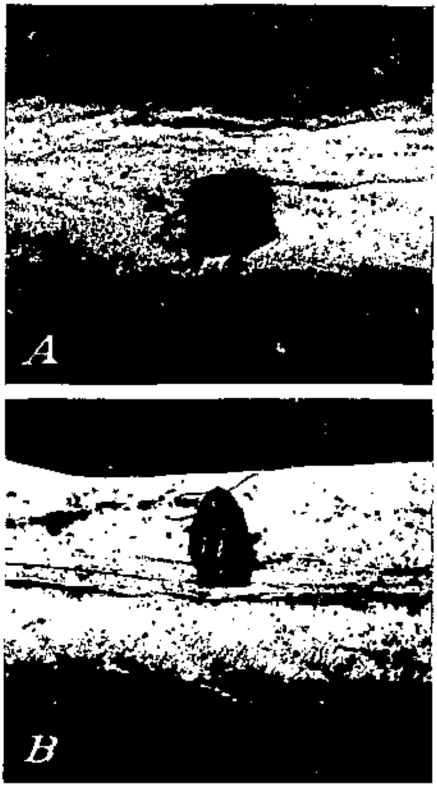

FIGURE 18.—Oviposition by *Acanthoscelides obtectus*: *A*, Weevil chewing a hole at the suture of a bean pod; *B*, position when inserting the ovipositor.

### THE SOUTHERN COWPEA WEEVIL

In the field the adults of *Callosobruchus maculatus* also search out the overripened pods that split along the suture. On the exposed portion of the seeds in such pods the females glue their eggs (fig. 19). They prefer exposed beans on which to oviposit, but when such beans cannot be found they deposit their eggs on the outside of the pods (fig. 20). They have been observed to oviposit on pods of blackeye cowpeas which were not more than half grown, showing a preference for those just beginning to turn yellow. Seldom are more than three eggs found on one pod unless there are only a limited number of pods close to a source from which weevils are emerging.

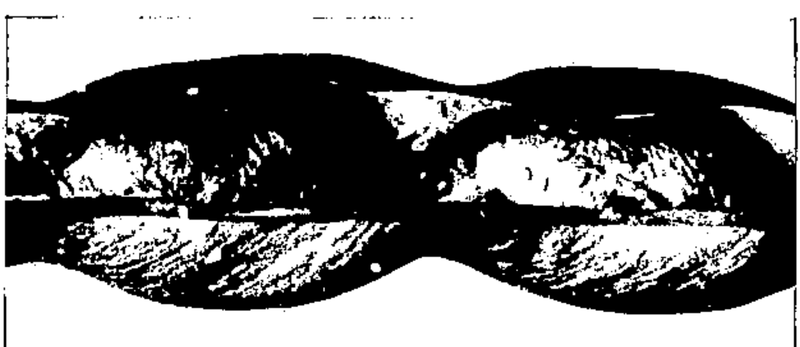

FIGURE 19.—Cowpeas in open pod bearing numerous eggs of *Callosobruchus maculatus*. This is an extreme case.

FIGURE 21.—Eggs of *Callosobruchus maculatus* on the exterior of a pod of cowpeas. The small white spots represent eggshells, which remain firmly attached even after the adults have emerged; the dark spots represent exit holes.

## OVIPOSITION IN STORAGE

### THE BEAN WEEVIL

In stored beans *Acanthoscelides obtectus* generally chooses a space between two or more beans and oviposits in the narrow portion of the space and usually toward the upper part of the container, but never on the upper surface of the top layer of beans unless these are in contact with the container. With some varieties of beans and perhaps with most varieties the weevil searches for beans having a cracked seed coat and oviposits beneath the seed coat of the bean. This habit is quite

FIGURE 21.—Eggs of *Acanthoscelides obtectus* on stored beans.

the reverse of that of *Callosobruchus maculatus*, which avoids seeds having broken or loose seed coats. The eggs of *A. obtectus* are only lightly attached and are easily brushed off (fig. 21).

That the rate of oviposition and the number of eggs laid by *Acanthoscelides obtectus* in confinement are influenced by different foods is indicated in table 6. This table shows that one weevil during its life laid 209 eggs—the greatest number recorded. Without water the number laid daily varied greatly. The maximum number of eggs laid was smaller and the oviposition period shorter in the case of those receiving no food than with those given water.

TABLE 6.—*Oviposition record of females of Acanthoscelides obtectus given different foods, Alhambra, Calif.*

| Food supplied | Temperature | | | Females | Eggs deposited | | | Oviposition period | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | | Maximum | Minimum | Average | Maximum | Minimum | Average |
| *1923* | *° F.* | *° F.* | *° F.* | *Number* | *Number* | *Number* | *Number* | *Days* | *Days* | *Days* |
| Water | 95 | 61 | 75.5 | 10 | 158 | 6 | 60.4 | 16 | 3 | 11.7 |
| Honey | 96 | 61 | 76.8 | 13 | 170 | 50 | 97.5 | 36 | 6 | 18.8 |
| Sugar water | 97 | 53 | 74.5 | 17 | 178 | 73 | 116.2 | 60 | 3 | 31.8 |
| Nothing | 95 | 61 | 75.6 | 13 | 82 | 12 | 55.1 | 10 | 3 | 8.7 |
| *1924* | | | | | | | | | | |
| Water | 90 | 55 | 72.7 | 25 | 209 | 0 | 61.0 | 29 | 0 | 12.12 |
| Nothing | 100 | 55 | 73.2 | 25 | 101 | 0 | 36.0 | 17 | 0 | 6.12 |



During the oviposition period the females are active, continually crawling about among the seeds, stopping only momentarily to examine the surface of a seed or to massage their abdomens. Brauer (*8*) says that the massaging with the metathorasic legs aids in the removal of the eggs. The egg emerges with the micropylar or small pointed end first, and when this comes into contact with the surface of the seed it is held fast by the cementing substance exuded at the same time. With the normal female there is sufficient cementing fluid with the egg to allow it to lie full length in contact with the seed and be firmly attached the entire length; but as the female becomes moribund, it appears that less cementing fluid is generated, and this hardens more quickly so that the egg is attached to the seed only at the micropylar end and can easily be brushed off. Such eggs fail to hatch. When an egg is laid, the weevil may crawl directly away, or she may merely move away from the egg and stop long enough to massage her body with her legs and antennae before moving on. The activity of the females insures the distribution of the eggs over the surface of many seeds (fig. 22). The eggs may be deposited on the upper, lower, or side surfaces. Apparently the weevil oviposits from any position and never turns around to examine the newly laid egg. No matter how the eggs are laid the young larvae always develop with their heads in the big end of the eggs.

That this weevil is quite discriminating in its choice of seeds for oviposition has been shown by Larson (*49, p. 74*), who says:

> It oviposits freely on some varieties even in which there is a total mortality of the young larval stage but it shows a marked hesitancy in ovipositing on other varieties in which the young larvae cannot survive. Again oviposition occurs freely on some seeds in which the mortality of all larval stages is high but from which some individuals emerge as adults. While it oviposits freely on certain varieties which are favorable for all stages of development it almost refuses to oviposit on other varieties which seem to be equally favorable for larval development. * * * This indicates that there are certain seeds which are favored for oviposition and certain ones which are avoided. The fact that the weevils consistently avoid ovipositing on certain varieties of seeds even after having bred therein for several generations indicates that there is no inherited predilection for that host. Continued breeding in a host does not appear to intensify the preference for that host.

There seems to be a predilection for seeds having smooth, well-filled coats. The weevil also oviposits rather freely on painted penholders, lead pencils, varnished handles, and doorframes that have been stained and varnished, but refuses to oviposit on rough or unpolished wood (fig. 23).

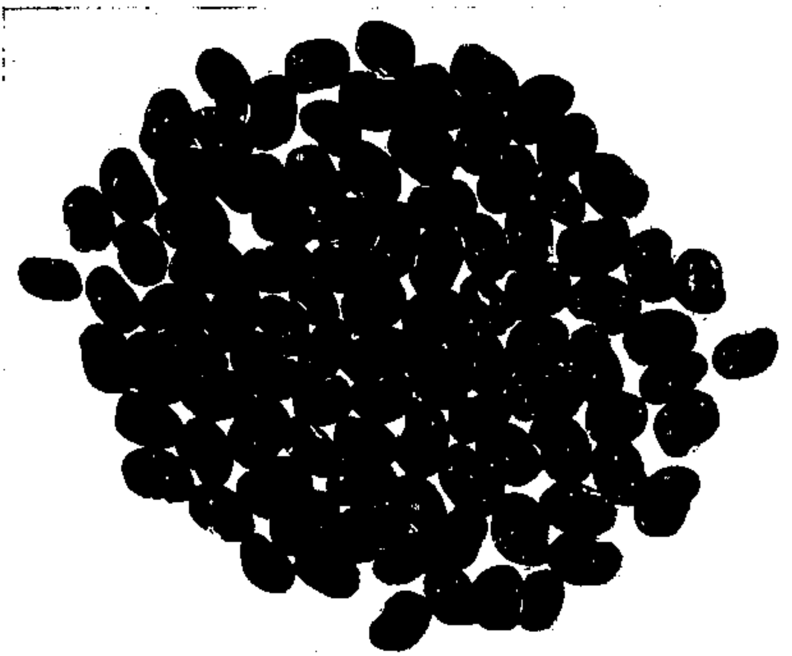

FIGURE 22.—Eggs of *Callosobruchus maculatus* well distributed over early red cowpeas.

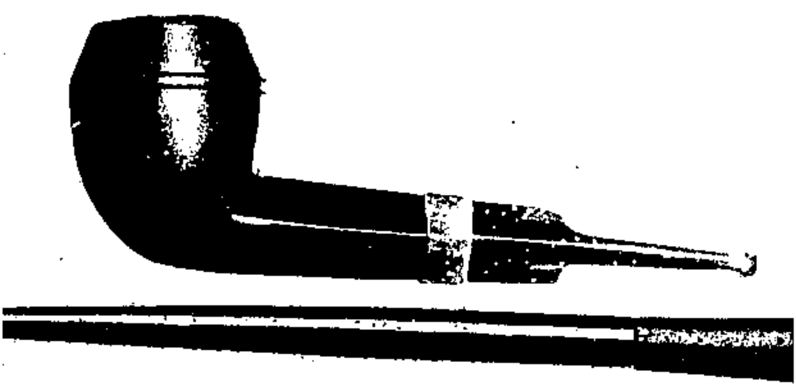

FIGURE 23.—A pipe and penholder on which eggs of *Callosobruchus maculatus* have been laid. Note that the cork tip of the penholder has been avoided by the weevil.

That the sense of touch is very highly developed in the adult weevils is indicated by the fact that broken seeds of all varieties are avoided almost entirely. Cowpeas or other seeds having seed coats that have become loosened are always passed over if other seeds are available. The Holstein cowpea seems to be a direct cross between a black smooth-skinned cowpea and a white rough-skinned variety. It is variable in color markings as well as in the texture of the seed coat, there being all gradations from white with a few black spots to black with a small white area, and from smooth to quite wrinkled. Some of these seeds have coats that are partly smooth and partly rough. On such seeds the choice of the weevil is frequently quite noticeable, eggs being laid on the smooth areas and not on the rough.

Other factors besides smoothness of seed coat seem to govern oviposition on seeds. Thus the tepary bean is avoided. Its surface seems as favorable for oviposition as others selected, but the seed coat will begin to wrinkle as soon as it is moistened, and *Callosobruchus maculatus* seems aware of this, though there is no indication of it in the dry seed. Larson (*49, p. 75*) goes on to say:

> If the sense of touch is responsible for the selection of seeds for oviposition as it appears to be, the next question is, where this highly developed sense organ is located. Is it the antennae or the mouthparts or the feet and legs, or is it the ovipositor? The writer after studying the oviposition of numerous weevils is inclined to think that all of these parts of the weevil function in this respect. The weevil will walk over some seeds without showing any reaction while it will carefully feel others with its antennae, its mouthparts and finally extrude its ovipositor several times before selecting a location for the egg. On other seeds it will oviposit without giving any apparent concern to the location. In some cases the feet and legs appear to determine the desirability or undesirability of the seeds.

A year's record of the daily oviposition of 345 laying females of seven generations was made in connection with the maximum, mean, and minimum daily temperatures. The records from these insects would probably correspond closely to that of insects in warehouses of corresponding temperatures and indicate that the weevils were influenced more by the minimum temperature than by the mean or maximum. This was directly reflected in the rate of oviposition, the total number of eggs laid, and the length of life of the adult. Table 10 shows parts of this record taken in summer and in winter. It shows that at the higher temperatures the maximum oviposition period lasted only 13 days, whereas at the lower temperatures egg deposition extended as long as 36 days. The greater number of eggs per day and per weevil, however, were laid at the higher temperatures.

Results obtained from a series of 183 females of *Callosobruchus maculatus* that began oviposition April 11, 1922, show that they laid 3,593 eggs, or an average of 19.63, the first day. The total and average numbers of eggs laid daily decreased with greater regularity than did the number of surviving weevils. Only 5 of the 183 females oviposited 20 days, and only 1 oviposited longer—22 days. These 183 weevils laid 19,119 eggs, or an average of 104.48 each. This is considerably above the averages, 73, 70, 75, 82, as given by Paddock and Reinhard (*65*), Brauer (*7*), Larson and Simmons (*53*), and others. This goes to substantiate the findings of Breitenbecher (*9*), who says that certain strains produce more progeny than others. He says the black strain is most prolific. The writers have also noted a great difference in the number of eggs produced by weevils obtained from different stocks or strains under apparently identical conditions, and have recorded as many as 196 eggs from one female.

The rate of oviposition as well as the total number of eggs that hatched and the time they were laid with reference to the age of the female is shown in table 9, which gives the number of eggs laid daily by 100 pairs which were divided into four groups of 25 each, three groups being given different foods and one group fed nothing. The effects of the food have been discussed elsewhere in this bulletin.

### STIMULUS TO OVIPOSITION

The writers have frequently found that the presence of bean or cowpeas acts as a stimulus to oviposition. When pairs of weevils were placed in vials without seeds and others in vials with seeds, mating occurred in both sets of vials, but in those without beans practically no eggs were deposited, whereas many were deposited in the vials with seeds. Weevils that do not have seeds on which to oviposit do not live so long as those with the seeds. Beans and cowpeas in storage furnish a stimulus to oviposition as do the maturing pods in the field. Young vines apparently do not furnish this stimulus, as weevils caged on such vines have invariably died without being observed to oviposit.

In storage, oviposition proceeds as readily in the dark as in the light if the temperatures are equal. Weevils have been put on similar seeds in similar vials, some of which were wrapped in cloth or paper and put inside of a mailing tube so that no light could penetrate to the seeds. The vials were then put in a closed container with an electric light. Oviposition occurred as freely on the seeds in the dark as on those in the light. The same thing has been noted within vials placed in a photographic darkroom and those in a light room adjoining it. This would be expected from the weevils' habit of ovipositing on beans in the interior of sacks or bins where little light penetrates or in the darkness of metal containers.

## EFFECT OF FOOD ON OVIPOSITION AND LENGTH OF LIFE

Although the writers have been unable to determine that the adult weevils eat solid food material from any part of the bean plant or seed, they have demonstrated by experiments that liquid foods have a direct influence not only on the length of adult life and on the number of eggs laid but also on the rate of oviposition.

Under warehouse conditions weevils cannot obtain food or drink, but during the growing season those that escape to the field may obtain liquid food or at least water from the dew. The liquid food observed consists of nectar from the blossoms and honeydew from the leaves and bracts and other parts of the plant. Probably most of the sustenance obtained in the field is only water. Observations indicate that in southern California, where the relative humidity is very low during summer, very little if any moisture is obtainable because the weevils remain inactive in the morning until after it warms up and the dew is gone. The writers' observations indicate that in the bean-growing districts of California the chances for increased length of life of adults in the field as a result of food and drink are minimized by the heat of the sun and low humidity during the day as well as by the hazards of capture by predacious insects and spiders.

## FEEDING EXPERIMENTS WITH THE BEAN WEEVIL

Two series of feeding experiments with *Acanthoscelides obtectus* were carried on during 1923. The weevils used in the one series began emerging July 29 and were put by twos into glass vials each containing five red kidney beans. The vials were 3 inches by ⅞ inch in size and were provided with cork stoppers. The first 18 vials were supposed to contain pairs. These were enclosed with seeds the same day they emerged, but, as it was practically impossible to determine the sexes without injuring the weevils, it was decided to observe them 1 day before beginning to feed them. On July 30 14 pairs had mated and eggs were laid. The eggs were counted, and the weevils were placed in new vials and were fed. The other weevils of this series were taken from the same source as the first lot, the last ones having emerged July 30, and two weevils were placed in each vial with no effort to determine the sexes. The vials of the entire lot were numbered consecutively from 1 to 100. Nos. 1, 5, 9, etc., were given a drop of water; nos. 2, 6, 10, etc., were given a drop of honey; nos. 3, 7, 11, etc., were given a drop of saturated sugar-water solution; while nos. 4, 8, 12, etc., were left in the vials with only the dry beans. The vials were examined daily, the eggs were removed and counted, and food and water were replenished as often as was necessary.

Table 7, summarizing the feeding experiment, shows that 16, 14, 17, and 13 females in the four respective groups deposited 1,402, 1,287, 1,956, and 717 eggs, or an average of 87.6, 91.9, 115.1, and 55.2 eggs for each laying female that had had access to water, honey, sugar water, and nothing, respectively. The maximum number of eggs laid by one weevil was approximately twice as great in each of the fed groups as in the unfed group. The average length of life was 17.25, 39.3, 66.7, and 16.0 days, while the maximum number of days lived was 28, 100, 176, and 23, respectively. The weevils had all developed to maturity in the same container and after separation were kept in similar containers side by side, so there was no apparent difference in temperature or other condition except the food and drink that helped to make the remarkable difference in the number of eggs laid and the length of life.

Table 7 also shows that eggs were laid by individual weevils during periods as long as 25, 37, 62, and 17 days, respectively, from the groups receiving water, honey, sugar water, and nothing; but for the same groups the maximum numbers of days on which viable eggs were laid were only 16, 29, 58, and 13 days, respectively. The weevils that received the food not only lived longer than those that received no food but they laid more eggs over a much greater period of time. The weevils having access to honey laid viable eggs on more than twice as many days as did those without food, whereas those receiving sugar water laid viable eggs over a period more than four times as long.

The time required for emergence of the resultant brood was very nearly uniform for each feeding group, the first emergence in each being noted on September 11. Although most of the weevils in each lot emerged in approximately the same length of time there were individual variations, although these were no greater between groups than between the individuals in one group. One hundred and four weevils emerged from the water-fed group and required a minimum of 39 days and a maximum of 77 for development; 95 emerged from the honey-fed group and required a minimum of 40 days and a maximum of 62; 92 emerged from the sugar-water group and required a minimum of 39 days and a maximum of 56; and 54 from the group fed nothing needed only 36 days as a minimum and 55 as a maximum. This variation in the length of time required for development of weevils from the same parents and even in the same beans seems to be one of nature's provisions for insuring the perpetuation of the species.

The second series of feeding experiments carried on during 1923 was with 100 unmated weevils that emerged from July 31 to August 16. The unmated weevils were used to ascertain whether they, like *Callosobruchus maculatus* (*50*), would live longer than the mated weevils, how many infertile eggs the individual would lay, and the number of days after emergence during which eggs would be deposited. It was thought that these weevils were isolated before mating had occurred, but seven weevils laid viable eggs. The habit of crawling back into the beans makes it possible that these seven beetles had mated previously, but parthenogenesis is not absolutely excluded.

Table 8 shows the length of life, the number of eggs laid, the number of days after emergence during which viable eggs were laid, and the total oviposition period of each weevil, with the same foods as had been given the mated weevils.

TABLE 7.—*Summary of feeding experiment with 100 supposed pairs*[1] *of Acanthoscelides obtectus when not fed and when fed different foods, Alhambra, Calif., 1923*

| | Water | | | | Honey | | | | | Sugar water | | | | | Nothing | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pair no. | Length of life | Eggs laid | Period of oviposition of viable eggs | Total oviposition period | Pair no. | Length of life | Eggs laid | Period of oviposition of viable eggs | Total oviposition period | Pair no. | Length of life | Eggs laid | Period of oviposition of viable eggs | Total oviposition period | Pair no. | Length of life | Eggs laid | Period of oviposition of viable eggs | Total oviposition period |
| | *Days* | *Number* | *Days* | *Days* | | *Days* | *Number* | *Days* | *Days* | | *Days* | *Number* | *Days* | *Days* | | *Days* | *Number* | *Days* | *Days* |
| 1 | 11-15 | 101 | 9 | 9 | 2 | 62-73 | 83 | 27 | 27 | 3 | 73-73 | 111 | 16 | 16 | 4 | 12-13 | 52 | 5 | 5 |
| 5 | 15-20 | 60 | 16 | 16 | 6 | 39-46 | 126 | 13 | 15 | 7 | [2] 3-113 | 73 | 3 | 3 | 8 | 12-15 | 52 | 2 | 2 |
| 9 | [2] 3-15 | 64 | 3 | 3 | 10 | 37-44 | 138 | 22 | 22 | 11 | 62-62 | 137 | 25 | 25 | 12 | 8-13 | 66 | 8 | 8 |
| 13 | [2] 3-16 | 83 | 3 | 3 | 14 | 34-40 | 81 | 29 | 29 | 15 | 81-111 | 0 | ----- | ----- | 16 | 16-18 | 12 | 8 | 17 |
| 17 | 18-20 | 53 | 15 | 15 | 18 | 73-73 | 0 | ----- | ----- | 19 | 34-78 | 138 | 58 | 62 | 20 | 20-23 | 0 | ----- | ----- |
| 21 | 18-18 | 110 | 15 | 15 | 22 | 24-91 | 0 | ----- | ----- | 23 | 52-57 | 98 | 12 | 12 | 24 | 17-19 | 30 | (3) | 16 |
| 25 | 14-19 | 0 | ----- | ----- | 26 | 16-16 | 92 | 10 | 12 | 27 | 37-89 | 110 | 24 | 31 | 28 | 17-18 | 79 | 13 | 13 |
| 29 | 19-19 | 0 | ----- | ----- | 30 | 19-53 | 77 | 12 | 12 | 31 | 26-43 | 0 | ----- | ----- | 32 | 17-23 | 48 | 8 | 8 |
| 33 | 15-26 | 0 | ----- | ----- | 34 | 38-45 | 0 | ----- | ----- | 35 | 24-38 | 0 | ----- | ----- | 36 | 12-18 | 0 | ----- | ----- |
| 37 | 12-18 | 43 | 14 | 24 | 38 | 17-66 | 70 | 7 | 7 | 39 | 45-93 | 0 | ----- | ----- | 40 | 16-18 | 78 | 11 | 11 |
| 41 | 13-16 | 114 | 14 | 14 | 42 | 38-43 | 0 | ----- | ----- | 43 | 57-61 | 104 | 25 | 25 | 44 | 18-19 | 0 | ----- | ----- |
| 45 | 14-14 | 0 | ----- | ----- | 46 | 21-52 | 0 | ----- | ----- | 47 | 7-115 | 73 | 7 | 7 | 48 | 15-16 | 82 | 11 | 13 |
| 49 | 17-17 | 86 | 12 | 12 | 50 | 16-19 | 88 | 12 | 12 | 51 | 37-45 | 0 | ----- | ----- | 52 | 15-17 | 0 | ----- | ----- |
| 53 | 9-13 | 100 | 10 | 10 | 54 | 17-43 | 111 | 10 | 10 | 55 | 39-91 | 118 | 43 | 43 | 56 | 14-15 | 64 | 7 | 7 |
| 57 | 14-16 | 113 | 12 | 14 | 58 | 22-63 | 0 | ----- | ----- | 59 | 43-176 | 98 | 14 | 14 | 60 | 17-18 | 0 | ----- | ----- |
| 61 | 17-28 | 6 | ----- | 25 | 62 | 31-52 | 0 | ----- | ----- | 63 | 14-84 | 117 | 26 | 36 | 64 | 11-18 | 36 | 4 | 4 |
| 65 | 17-19 | 0 | ----- | ----- | 66 | 24-52 | 0 | ----- | ----- | 67 | 59-63 | 0 | ----- | ----- | 68 | [2] 3-14 | 64 | 8 | 8 |
| 69 | 19-19 | 0 | ----- | ----- | 70 | 17-36 | 20 | 4 | 4 | 71 | 68-89 | 0 | ----- | ----- | 72 | 15-16 | 0 | ----- | ----- |
| 73 | 19-24 | 0 | ----- | ----- | 74 | 19-21 | 104 | 14 | 16 | 75 | 82-107 | 107 | 19 | 19 | 76 | 14-16 | 54 | 7 | 14 |
| 77 | 15-16 | 158 | 12 | 14 | 78 | 4-59 | 77 | 5 | 28 | 79 | 44-75 | 168 | 38 | 44 | 80 | 12-15 | 0 | ----- | ----- |
| 81 | 17-25 | 116 | 14 | 14 | 82 | [2] 1-39 | 50 | 1 | 22 | 83 | 61-93 | 101 | 53 | 53 | 84 | 15-18 | 0 | ----- | ----- |
| 85 | 17-17 | 0 | ----- | ----- | 86 | 36-37 | 0 | ----- | ----- | 87 | 45-61 | 0 | ----- | ----- | 88 | 14-17 | 0 | ----- | ----- |
| 89 | 17-19 | 106 | 15 | 15 | 90 | 22-22 | 0 | ----- | ----- | 91 | 52-80 | 132 | 37 | 37 | 92 | 14-15 | 0 | ----- | ----- |
| 93 | 14-15 | 89 | 15 | 15 | 94 | 43-100 | 0 | ----- | ----- | 95 | 43-84 | 136 | 38 | 38 | 96 | 16-21 | 0 | ----- | ----- |
| 97 | 19-24 | 0 | ----- | ----- | 98 | 30-43 | 170 | 26 | 37 | 99 | 66-107 | 135 | 39 | 61 | 100 | 17-17 | 0 | ----- | ----- |
| Total | 360-468 | 1,402 | 179 | 218 | | 699-1,228 | 1,287 | 192 | 253 | | 1,151-2,118 | 1,956 | 477 | 526 | | 354-430 | 717 | 92 | 126 |
| Average [4] | 17.25 | 87.6 | 11.9 | 13.6 | | 39.3 | 91.9 | 14 | 18 | | 66.7 | 115.1 | 28.1 | 30.9 | | 16.0 | 55.2 | 7.6 | 9.7 |
| Maximum | 28 | 158 | 16 | 25 | | 100 | 170 | 29 | 37 | | 176 | 168 | 58 | 62 | | 23 | 82 | 13 | 17 |

[1] It is difficult to distinguish between the sexes of *A. obtectus;* 2 beetles were used in each test which were thought to be male and female, but this may not always have been true. Hence the sex has not been indicated.

[2] Weevil escaped, not included in total or average.

[3] This weevil laid no viable eggs and this record is not included in the average.

[4] Average number of eggs and average oviposition periods are based upon number of laying females.

TABLE 8.—*Summary of feeding experiment with unmated individuals of Acanthoscelides obtectus when not fed and when fed on different foods, the weevils having emerged July 31 to Aug. 16, 1923, Alhambra, Calif.*

| Water | | | | | Honey | | | | | Sugar water | | | | | Nothing | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Weevil no. | Length of life | Eggs laid | Period of oviposition of viable eggs | Total oviposition period | Weevil no. | Length of life | Eggs laid | Period of oviposition of viable eggs | Total oviposition period | Weevil no. | Length of life | Eggs laid | Period of oviposition of viable eggs | Total oviposition period | Weevil no. | Length of life | Eggs laid | Period of oviposition of viable eggs | Total oviposition period |
| | *Days* | *Number* | *Days* | *Days* | | *Days* | *Number* | *Days* | *Days* | | *Days* | *Number* | *Days* | *Days* | | *Days* | *Number* | *Days* | *Days* |
| 1 | 23 | 54 | 0 | 20 | 2 | 62 | | | | 3 | 90 | | | | 4 | 17 | 10 | 0 | 16 |
| 5 | 20 | | | | 6 | 23 | 9 | 0 | 16 | 7 | 81 | | | | 8 | 21 | | | |
| 9 | 17 | | | | 10 | 37 | 45 | 0 | 29 | 11 | 51 | 34 | 0 | 37 | 12 | 20 | | | |
| 13 | 20 | 65 | 16 | 16 | 14 | 24 | 18 | 0 | 16 | 15 | 81 | | | | 16 | 24 | 14 | 0 | 18 |
| 17 | 20 | | | | 18 | 54 | 40 | 0 | 35 | 19 | 60 | | | | 20 | 15 | | | |
| 21 | 15 | | | | 22 | 88 | | | | 23 | 42 | 24 | 0 | 40 | 24 | 15 | | | |
| 25 | 25 | | | | 26 | 48 | 75 | 0 | 24 | 27 | 78 | 21 | 0 | 26 | 28 | 17 | 50 | 0 | 13 |
| 29 | 17 | | | | 30 | 17 | | | | 31 | 164 | | | | 32 | 14 | | | |
| 33 | 14 | | | | 34 | 43 | 23 | 0 | 33 | 35 | 177 | | | | 36 | 17 | | | |
| 37 | 17 | 12 | 0 | 11 | 38 | 48 | 63 | 0 | 17 | 39 | 103 | | | | 40 | 26 | 21 | 0 | 22 |
| 41 | 20 | | | | 42 | 48 | | | | 43 | 76 | 29 | 0 | 36 | 44 | 17 | | | |
| 45 | 20 | | | | 46 | 42 | | | | 47 | 68 | | | | 48 | 25 | | | |
| 49 | 19 | | | | 50 | 33 | 30 | 0 | 16 | 51 | 71 | | | | 52 | 19 | 3 | 0 | 12 |
| 53 | 15 | | | | 54 | 27 | | | | 55 | 73 | | | | 56 | 16 | 79 | 15 | 15 |
| 57 | 19 | 8 | 0 | 6 | 58 | 48 | | | | 59 | 50 | 18 | 0 | 22 | 60 | 15 | | | |
| 61 | 19 | | | | 62 | 34 | 34 | 0 | 21 | 63 | 82 | 44 | 0 | 20 | 64 | 19 | | | |
| 65 | 17 | | | | 66 | 96 | | | | 67 | 75 | | | | 68 | 13 | | | |
| 69 | 28 | | | | 70 | 50 | | | | 71 | 130 | 92 | 19 | 34 | 72 | 16 | 8 | 0 | 12 |
| 73 | 21 | | | | 74 | 35 | 30 | 0 | 29 | 75 | 73 | 83 | 0 | 33 | 76 | 16 | | | |
| 77 | 29 | 8 | 16 | 16 | 78 | 35 | 31 | 0 | 35 | 79 | 69 | 32 | 0 | 33 | 80 | 14 | | | |
| 81 | 15 | 6 | 0 | 5 | 82 | 62 | | | | 83 | 35 | | | | 84 | 14 | 1 | 0 | 10 |
| 85 | 22 | 1 | 0 | 8 | 86 | 59 | | | | 87 | 77 | | | | 88 | 14 | | | |
| 89 | 21 | 15 | 0 | 8 | 90 | 38 | | | | 91 | 74 | 17 | 0 | 31 | 92 | 23 | 22 | 0 | 8 |
| 93 | 9 | | | | 94 | 64 | | | | 95 | 73 | | | | 96 | 8 | | | |
| 97 | 19 | 21 | 12 | 12 | 98 | 19 | 7 | 4 | 4 | 99 | 35 | 41 | 26 | 26 | 100 | 7 | | | |
| Total | 481 | 190 | | | | 1,134 | 305 | | | | 1,988 | 435 | | | | 422 | 208 | | |
| Average | 19.2 | | | | | 45.3 | | | | | 79.5 | | | | | 16.9 | | | |
| Maximum | 29 | 65 | | | | 96 | 75 | | | | 177 | 92 | | | | 26 | 79 | | |

Table 8 shows that of the group fed water, 9 beetles laid a total of 190 eggs, some eggs being deposited 20 days after the weevil emerged. Three weevils of this group laid viable eggs, some as long as 16 days after emergence. Of the honey-fed group, 12 weevils laid 405 eggs over a period of 35 days; only 1 laid viable eggs. Eleven of those having sugar water laid 435 eggs over a period of 40 days; 2 laid viable eggs for 19 and 26 days, respectively. Of those receiving no food, 9 laid 208 eggs over a period of 22 days; 1 laid viable eggs for 15 days. In the first, third, and fourth groups the weevil that laid the most eggs in each group laid fertile eggs. In these cases it is believed that mating stimulated egg production. Frequently in other experiments a female apparently through laying would produce additional eggs after another mating. For an insect that mates frequently, as this one does, 26 days is a long time to produce viable eggs after mating. This is important in connection with field infestations where relatively few insects have dispersed, making it difficult if not impossible for them to mate again after leaving the original source of infestation.

From tables 7 and 8 it will be seen that weevils receiving no food, those which were kept most nearly as they live in the warehouse, lived the shortest time and produced the smallest number of eggs. Those having access to water lived a little longer, while those having honey and sugar water each in turn lived longer still and produced more eggs. This would indicate that there may be quite a difference in both the length of life and the number of eggs laid by the weevils in storage and those in the field. This weevil lives and reproduces normally in warehouses without access to food or drink, but suitable liquid food prolongs the life of both sexes. Weevils without food or drink lay more eggs at the beginning of their oviposition period, whereas those having access to food or drink lay fewer eggs in the beginning of the oviposition period and greater numbers later, continue to oviposit longer, and lay a greater number of eggs.

## FEEDING EXPERIMENTS WITH THE SOUTHERN COWPEA WEEVIL

In a series of carefully conducted experiments the writers (*50*) showed that weevils of *Callosobruchus maculatus* in their normal surroundings in the warehouse live a shorter time without food than when they have access to water, sweetened or unsweetened. The difference in the average length of life of the weevils receiving no food and those receiving water ranged from less than 3 days with the lone males to 11 days with the lone females. Access to water lengthened the lives of the pairs about 10 days. Sugar water lengthened their lives from 13 to 27 days as averaged for different groups of weevils. Access to water increased the average number of eggs laid by about 30 percent, and access to sugar water increased the number of eggs about 50 percent. Plain water or sweetened water reduced the number of eggs laid during the first few days of oviposition, but lengthened the time over which eggs were laid. Viable eggs were laid over twice as great a period of time by weevils receiving sugar water as by those without food. These weevils do not consume solid food of any kind.

Table 9 gives a summary of the effects of feeding honey and sugar water and of supplying water on the oviposition and viability of the eggs of *Callosobruchus maculatus*, compared with data from weevils that were kept without food or drink.

TABLE 9.—*Summary of the oviposition of 100 pairs of Callosobruchus maculatus when not fed and when fed different foods, and the number of eggs that hatched, there being 25 females in each group, Alhambra, Calif., 1923*

| Day after emergence of female | Water | | Honey | | Sugar water | | Nothing | |
|---|---|---|---|---|---|---|---|---|
| | Total eggs laid | Viable eggs laid | Total eggs laid | Viable eggs laid | Total eggs laid | Viable eggs laid | Total eggs laid | Viable eggs laid |
| | *Number* | *Number* | *Number* | *Number* | *Number* | *Number* | *Number* | *Number* |
| First | 386 | 325 | 379 | 305 | 313 | 261 | 417 | 327 |
| Second | 330 | 263 | 335 | 275 | 311 | 256 | 310 | 257 |
| Third | 215 | 198 | 239 | 201 | 224 | 172 | 225 | 161 |
| Fourth | 195 | 159 | 179 | 135 | 200 | 118 | 183 | 130 |
| Fifth | 158 | 133 | 149 | 106 | 153 | 115 | 119 | 119 |
| Sixth | 163 | 136 | 156 | 101 | 161 | 132 | 117 | 113 |
| Seventh | 180 | 137 | 165 | 110 | 143 | 121 | 132 | 106 |
| Eighth | 108 | 86 | 144 | 91 | 112 | 87 | 112 | 56 |
| Ninth | 131 | 87 | 132 | 88 | 126 | 97 | 85 | 57 |
| Tenth | 117 | 84 | 114 | 66 | 118 | 89 | 91 | 61 |
| Eleventh | 114 | 86 | 113 | 72 | 116 | 83 | 89 | 58 |
| Twelfth | 111 | 82 | 103 | 65 | 116 | 87 | 63 | 35 |
| Thirteenth | 114 | 73 | 106 | 72 | 120 | 91 | 66 | 47 |
| Fourteenth | 109 | 77 | 101 | 71 | 122 | 88 | 49 | 25 |
| Fifteenth | 119 | 67 | 107 | 60 | 125 | 93 | 47 | 27 |
| Sixteenth | 84 | 31 | 102 | 63 | 137 | 95 | 22 | 11 |
| Seventeenth | 77 | 21 | 61 | 29 | 102 | 59 | 12 | 1 |
| Eighteenth | 47 | 10 | 63 | 31 | 96 | 52 | 6 | 1 |
| Nineteenth | 32 | 7 | 48 | 19 | 79 | 15 | 4 | 0 |
| Twentieth | 21 | 1 | 46 | 23 | 70 | 31 | 0 | |
| Twenty-first | 5 | 0 | 41 | 18 | 58 | 31 | 2 | 0 |
| Twenty-second | 5 | 0 | 28 | 11 | 44 | 20 | 2 | 0 |
| Twenty-third | 2 | 0 | 17 | 3 | 45 | 21 | 0 | |
| Twenty-fourth | 0 | | 17 | 9 | 22 | 9 | 0 | |
| Twenty-fifth | 2 | 0 | 11 | 4 | 33 | 12 | 0 | |
| Twenty-sixth | 1 | 0 | 8 | 2 | 24 | 6 | 0 | |
| Twenty-seventh | 1 | 0 | 8 | 1 | 19 | 1 | 0 | |
| Twenty-eighth | 3 | 0 | 6 | 0 | 16 | 3 | | |
| Twenty-ninth | 1 | 0 | 3 | 0 | 12 | 2 | | |
| Thirtieth | 1 | 0 | 5 | 0 | 12 | 0 | | |
| Thirty-first | 2 | 0 | 1 | 0 | 10 | 0 | | |
| Thirty-second | 1 | 0 | 0 | | 3 | 2 | | |
| Thirty-third | 0 | | 5 | 0 | 30 | 5 | | |
| Thirty-fourth | 0 | | 0 | | 9 | 0 | | |
| Thirty-fifth | 1 | 0 | 0 | | 1 | 2 | | |
| Thirty-sixth | 0 | | 1 | 0 | 6 | 0 | | |
| Thirty-seventh | 1 | 0 | 0 | | 2 | 0 | | |
| Thirty-eighth | 0 | | 0 | | 2 | 0 | | |
| Thirty-ninth | 2 | 0 | 0 | | 0 | | | |
| Fortieth | 0 | | 1 | 0 | 0 | | | |
| Forty-first | 0 | | 0 | | 0 | | | |
| Forty-second | 0 | | 0 | | 2 | 1 | | |
| Forty-third | 0 | | 0 | | 1 | 0 | | |
| Forty-fourth | 0 | | 0 | | 0 | | | |
| Fifty-first | 0 | | | | 0 | | | |
| Fifty-fourth | | | | | 0[1] | | | |
| Total | 2,872 | 2,060 | 2,997 | 2,031 | 3,301 | 2,325 | 2,213 | 1,631 |

[1] Last 0 indicates when last female died.

## EFFECT OF TEMPERATURE AND HUMIDITY ON THE LIFE CYCLE

The length of the life cycle of both weevils varies with temperature, humidity, and the seed in which they are developing. Repeated experiments by the writers also showed that much more time was required for development at any temperature if the weevils were confined in an airtight container such as a glass vial having a paraffined cork stopper. In Alhambra, during the summer, *Callosobruchus maculatus* will produce a new generation in from 27 to 42 days. Eggs laid the same day by one weevil do not develop at the same rate. The difference in rate of development is greatest during cool weather. *C. maculatus* began emerging in December from eggs laid in September (*53*) while full-grown larvae from the same lot of eggs were dissected from the black eye cowpeas the next June. A comparable development in the case of *Acanthoscelides obtectus* is shown in figure 24.

Breitenbecher (*11*) has shown that *Callosobruchus maculatus* responds very readily to a modified environment. He found that at a constant temperature of 100° F. the entire life cycle may be passed in 19 days and at 90° in 20 days. He further found that certain chemicals when placed in the breeding chamber had a marked effect on the development of the weevils. Thus dilute sulphuric acid hastened development by furnishing an optimum humidity in the breeding chamber. When a sulphuric acid-and-water solution just concentrated enough to turn litmus was used, the developmental period from egg to adult was reduced to 14 days. This was the minimum period observed by him. A dilute solution of sodium hydroxide had the effect of prolonging the developmental period to 36 days, while a more concentrated solution prolonged the period to 42 days. Exposing the weevils to the fumes of alcohol resulted in their death.

FIGURE 24. Three stages (one larva, two pupae, and two adults) of *Acanthoscelides obtectus* developed from eggs laid in a bean the same day.

Seeds in which development by *Callosobruchus maculatus* is slow also produce smaller adult weevils than those in which development is more rapid under similar conditions of temperature and humidity. Larvae within seeds in tightly corked vials without a proper supply of air become undersized adults after an extended period of development.

Larson and Simmons (*53*) report the emergence of weevils of this same species 217 and 212 days after the eggs had been laid on September 27 and 28, 1919, respectively. That this may not be the extreme duration of the life cycle was shown when they dissected from the beans living adults of both sexes 223 and 224 days after the eggs had been laid on September 24 and 25. A living pupa was dissected out 226 days after the egg was laid on September 24, and a living, fully grown larva was dissected out 235 days after the egg had been laid September 26. The eggs from which these weevils developed were laid at the beginning of a cold, stormy period, and were kept in individual containers.

When developing in lima beans the time required by *Acanthoscelides obtectus* is longer than is required in garden beans or cowpeas. The complete life cycle may be passed in 30 days or less in California or may require several months. Table 3 records one instance when the incubation period of the egg was only 3 days and from hatching to emergence 22 days, a developmental period of 25 days in August. The same table shows an incubation period of 27 days and a developmental period of 140 days. In the summer it usually requires 33 to 45 days. Chittenden (*15*) reported a complete life cycle passed in 21 days. Larvae within seeds in tightly corked vials without a proper supply of air become undersized adults after an extended period of development.

Lipman (*60*), referring to *Acanthoscelides obtectus,* says that a decrease in atmospheric moisture lengthens the life cycle, shortens the life of the adult, and prevents the young larvae from entering the beans. He also says (*61, p. 37*) that an atmospheric moisture of 26 percent or less will prevent reproduction. This is corroborated by Headlee (*36, 37, 38*). The writers find that with *Callosobruchus maculatus* a decrease in atmospheric moisture also lengthens the life cycle and shortens the life of the adult. Low humidity is less injurious to young larvae of *C. maculatus* than to those of *A. obtectus* because the latter are directly exposed to desiccation while seeking for a suitable place to bore into beans, but the former are at all times protected by the chorion or the seed. After the larva is well within the seed the lack of moisture is not felt so keenly.

The effect of temperature on *Callosobruchus maculatus,* as it is indicated by the number of eggs laid, and the period of oviposition, is given in table 10, which covers these phases of the insect's activity during summer and winter. In this table it will be seen that the number of eggs ranged from 0 to 115. More eggs were laid during warm weather than during cold weather, but the weevil lived a shorter time.

Brauer (*6*), who conducted experiments on the length of life of adults of *Callosobruchus maculatus* at different temperatures, found that at 15° C. (59° F.) the average length of life was 26 days with 30 as the maximum. At 27° C. (80.6° F.) the average was 10 days; at 34° C. (93.2° F.) the average length of life was 7 days, and all were dead in 8 days. At 37° C. (98.6° F.) and at 38° C. (100.4° F.) the length of life was 7 to 5 days, while at 44° C. (111.2° F.) it was only 1 or 2 days. From the oviposition records he concludes that 98.6° F. is their optimum temperature. Breitenbecher (*11*) found that 100° is optimum for genetic research. However, the writers' observations indicate that the weevils live longer and produce more eggs if there is a daily variation in temperature such as normally occurs between day and night.

TABLE 10.—*Summary of oviposition records of 47 females of Callosobruchus maculatus in summer and in winter, Alhambra, Calif., 1923–24*

| Months | Temperature | | | Females | Eggs deposited | | | Oviposition period | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | | Maximum | Minimum | Average | Maximum | Minimum | Average |
| | *° F.* | *° F.* | *° F.* | *Number* | *Number* | *Number* | *Number* | *Days* | *Days* | *Days* |
| July | 99 | 46 | 73 | 28 | 115 | 0 | 83.6 | 13 | 0 | 8.25 |
| December, January, February | 81 | 40 | 60.6 | 19 | 88 | 12 | 46.4 | 35 | 8 | 19.8 |

That weevils do not live the same length of time or lay the same number of eggs at different times of the year has already been pointed out. That such differences occur with whole broods of weevils is emphasized by table 11 which gives a summary of seven broods during 1919 and 1920. In these seven broods complete records were made from 345 laying females. The table shows that the average number of eggs laid each laying day by each female of the different broods ranged from 2.79 in winter to 12.23 in summer, and the average number of laying days per female ranged from 5.07 in summer to 11.45 in winter. The average number of eggs per female ranged from 32 to 82, the maximum laid by one weevil in one day from 17 to 50, and the greatest total number laid by one weevil from 90 to 132. The smallest average number of eggs per female per laying day, the smallest average number per female, the smallest maximum number laid by one weevil in one day, the smallest maximum number laid by a weevil of any brood, as well as the greatest average number of laying days were all recorded for the one winter brood. Although the table does not show it, there were also more nonlaying days per female in this brood, making the average length of life greater for this than for any other brood. The percentage of the eggs that produced adults ranged from 5 with this winter generation to 55 with a summer generation.

TABLE 11.—*Summary of the oviposition of a series of 7 consecutive generations of Callosobruchus maculatus, Alhambra, Calif., 1919–20*

| Brood no. | Dates oviposition began | Average eggs per female each laying day | Average laying days per female | Average eggs per female | Laying females | Total laying days | Total eggs | Maximum eggs in 1 day by 1 female | Maximum total eggs by 1 female |
|---|---|---|---|---|---|---|---|---|---|
| | *1919* | *Number* | *Number* | *Number* | *Number* | *Number* | *Number* | *Number* | *Number* |
| 1 | July 7 | 10.61 | 6.97 | 73 | 82 | 572 | 6,069 | 37 | 117 |
| 2 | Aug. 17 | 10.41 | 5.48 | 57 | 48 | 263 | 2,742 | 39 | 101 |
| 3 | Sept. 18 | 7.84 | 10.47 | 82 | 61 | 639 | 5,004 | 29 | 115 |
| 4 | Dec. 12 | 2.79 | 11.45 | 32 | 68 | 779 | 2,198 | 17 | 90 |
| | *1920* | | | | | | | | |
| 5 | May 18 | 8.51 | 8.78 | 75 | 23 | 202 | 1,723 | 37 | 110 |
| 6 | July 6 | 12.23 | 5.07 | 62 | 42 | 213 | 2,618 | 50 | 132 |
| 7 | Aug. 18 | 7.73 | 10.48 | 81 | 21 | 220 | 1,701 | 37 | 104 |
| Total or average | | 7.63 | 8.37 | 63.9 | 345 | 2,888 | 22,055 | | |

## NUMBER OF GENERATIONS

Riley (*77*), in 1882, was the first to report continuous breeding in stored beans with successive generations of *Acanthoscelides obtectus*. Lhoste (*56*), in France, has reported four generations a year for this insect. Marcucci (*64*), in Italy, reports six generations as follows: Adults emerging about the last of April lay eggs which produce the first generation in about 45 days. Toward the end of July adults of the second generation are ovipositing. The third generation, which develops very rapidly, is the one that attacks mature beans still on the vines. At the end of August the first larvae of the fourth generation may be observed. This generation develops more slowly, so late pupae are present in the middle of October. The fifth generation appears from late in November until January, and the sixth about the last of April. The writers find that the generations in California correspond quite closely to those given above, excepting that there is a variation due to changes in climatic conditions from year to year. Some years only five generations occur.

Speaking of *Callosobruchus maculatus*, Wade (*95*) and Sanborn (*84*) say that it has seven generations with the eighth partly developed in Oklahoma. Wade (*95, pp. 7–8*) gives the generations as follows:

May 3, 1918, adults were placed with cowpeas and allowed to oviposit.
June 7, adults of first generation emerging.
July 11, adults of second generation emerging.
August 15, adults of third generation emerging.
September 19, adults of fourth generation emerging.
October 24, adults of the fifth generation emerging.
January 15, 1919, adults of sixth generation emerging.
March 16, adults of seventh generation emerging.
May 25, adults of eighth generation emerging.

In California the writers have observed six generations of *Callosobruchus maculatus* in some years and seven in others. Six generations were observed during a year (1919–20) as follows from eggs deposited June 7:

July 7, adults of the first generation ovipositing.
August 11, adults of the second generation ovipositing.
September 18, adults of the third generation ovipositing.
December 21, adults of the fourth generation ovipositing.
May 18, adults of the fifth generation ovipositing.
July 6, adults of the sixth generation ovipositing.

The emergence of a brood of weevils of *Acanthoscelides obtectus* or *Callosobruchus maculatus*, all the progeny produced by one pair or by one generation, varies so much in time that the earliest emerging individuals may produce another generation some of which will emerge before the more slowly developing individuals of the first have come out. This variation in rate of development under quite similar conditions seems to help assure the propagation of the species. If all emerged together they would be less likely to find food for the next generation than if their emergence extended over several weeks. This gives the species an advantage when the early-emerging weevils are not able to find seeds suitable for oviposition.

## SEASONAL ABUNDANCE

There is a decided seasonal variation in the number of weevils found in any infested locality. In warehouses the adult weevils make their appearance during and immediately following the first prolonged warm weather late in the winter or early in the spring. If not checked they become abundant in June or early in the summer and continue so as long as breeding is not limited by lack of food. Seasonal abundance is determined in part by climate and in part by the amount of food available for the larvae.

Tschermak (*92*) reported that a small number of *Acanthoscelides obtectus* were noted in Vienna in 1918. There were more in 1919, and there was a serious infestation in 1920. Popenoe (*69*) reported that this weevil seemed to be local in its attacks. These observations very well describe the seasonal abundance of this weevil. It becomes established in one locality and spreads therefrom, becoming a greater pest each year unless steps are taken to prevent its development and spread. For this reason the production of its favorite host crop has been discontinued over great areas.

## SPREAD OF INFESTATIONS

The influence of seasonal variation in temperature and humidity on the length of the life cycle is of minor importance as compared to its effect on the dispersal of the adults, the rate of oviposition, the viability of the eggs, and the mortality of the weevils in all stages. A temperature sufficiently low to retard development of the weevils within the seeds is also low enough to prevent the flight of adults or to restrict it to a short time during the warmest part of the day. Such low temperature causes the weevils to lay very few eggs, many of which fail to hatch, and produces a high mortality in every stage. Larson and Simmons (*54*) showed that adults of *Acanthoscelides obtectus* that emerged after long periods of cold storage failed to produce eggs. Also in this connection, the observations of Marcucci (*64*) that many adults and larvae of *A. obtectus* die owing to low temperature, and only a few of the first-emerging adults lay eggs, many of which do not hatch, correspond to those of the writers.

### SOURCES OF INFESTATION

The conditions found in Merced County in 1926 show very well how the beans become infested in the fields. Practically worthless lots of beans in storage on the farms were primary sources of infestation from which weevils flew to nearby bean fields. That year many of the early beans dropped, leaving a very light crop which ripened some 2 weeks earlier than usual. Just then a second crop set on the same vines, and the early beans were left until the later crop was harvested, leaving ample time for one generation of weevils to develop in them and infest the late-set crop. Unused early snap beans were also left to ripen on the vines (fig. 25). These early-maturing beans, infested from the primary sources, became important secondary sources of infestation so as to render it difficult to locate the primary sources. As a result of the neglect of these almost worthless sources of early infestation, most of the beans of a large section in Merced and Stanislaus Counties became weevily in the field.

In public warehouses the principal sources of infestation are lots of unfumigated beans thought to be in perfect condition, lots of beans known to be weevily for which there is no sale, rain-damaged beans, bean screenings, and spilt beans. Beans in the cracks of the floor and in the bean cleaners may also become important sources of infestation.

On the farm the main sources of infestation are left-over seed beans, or a few pounds of beans left in the bean planter, and beans that remain in the bean straw, together with small lots of beans kept or purchased for home use. Beans left in the threshing machines seldom become heavily infested, but they serve as a means by which a few weevils can carry over from one generation to another until they can find maturing beans. The bean- and pea-straw stacks (*52*) may become important centers of infestation, because many beans and peas are left in the straw to serve as a breeding place for weevils, sometimes for 2 or 3 years (fig. 26). Infestations occur because the farmers and the warehouse men do not realize the importance of small sources of infestation.

Small lots of beans may produce a great number of weevils. One such lot of 419 Improved Golden wax beans, left-over seed, was found in August of the first year to contain 4,230 emergence holes, 19 in 1 bean, and only 7 beans were sound. Another such lot left in a cigar box in a garage until after harvest time in the fall consisted of about

FIGURE 25.—Early snap beans left in the garden often serve as breeding places for weevils which infest the next crop.

one-third of a 15-cent package of brown Kentucky Wonder (155 beans) and 95 Scarlet Runner beans (fig. 27). The Kentucky Wonder beans had 1,546 emergence holes and the Scarlet Runners 2,006 holes, or 3,552 in all, and there were still living weevils contained in them. Thirty-three weevils had emerged from each of three of the Scarlet Runner beans. Such small lots of beans, and sometimes larger lots, are put away in the spring and forgotten until weevils are noticed. A nickel's worth of beans saved may cause many dollars worth of damage to a growing crop.

FIGURE 26.—Stack of cowpea straw in which weevils bred for 2 years. It was kept for bedding for horses, but proved expensive bedding as it caused heavy infestations in nearby fields with resulting heavy losses.

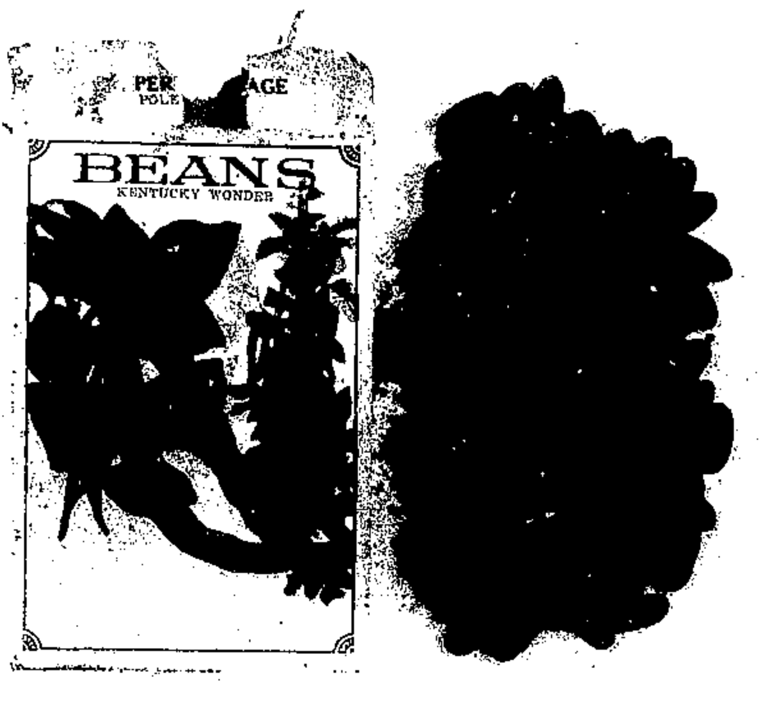


FIGURE 27.—Left-over seed packets of beans such as frequently become infested with weevils and constitute important sources of infestation for the growing crop.

An interesting lot was a sample that showed 34 weevil holes, several beans having windows from which the weevils had not emerged, numerous adult living weevils, and a great number of eggs, at time of delivery to the warehouse. A visit to the grower of this lot of beans revealed the following: The grower knew his beans were very weevily, had grown only 3 acres of beans and those on land on which beans had never grown before, had no bean straw, and no other beans were grown within 2 miles of his place. But when questioned further he remembered that he had a small quantity (about 2 pounds) of seed left after planting. Upon examination of these beans, which had been left in a bucket and hung under a shed, they were found to be very heavily infested. These few seeds had served as a breeding place for one or more generations of weevils which had infested his growing crop. Before the writers' visit this grower had thought that bean weevils lived either in the ground or on weeds.

Such lots of beans furnish the chief source of infestation to growing crops.

### RATE AND TIME OF DISPERSAL OF WEEVILS

A knowledge of the rate and time of the dispersal of weevils from sources of infestation is important to warehousemen as well as to bean growers. Weevils emerging during cold weather must find beans upon which to oviposit or else die without reproducing. If very few emerge in winter and many during the ripening season, the few emerging in winter can oviposit on the beans from which they emerged, whereas the many emerging late in the summer can infest all nearby growing bean crops.

The writers (*51*) made an experiment using Red Kidney beans which they infested with *Acanthoscelides obtectus* and blackeye cowpeas which they infested with *Callosobruchus maculatus*, to learn the rate and amount of emergence of weevils in storage, the time of their dispersal in search of new beans, and the duration of infestations on farms in southern California.

On May 16, 1923, 50 adults of *Acanthoscelides obtectus* were placed in an ordinary bean sack containing 87 pounds of choice recleaned Red Kidney beans. The bag was placed on a table inside of an insect cage 8 by 6 feet and 6 feet high with a narrow door in one end. The top was covered with muslin. An 18-inch strip of 16-mesh wire screen was placed around the entire upper part of the cage, another 18-inch strip around the entire lower part, and a 38-inch strip of muslin placed around the middle of the cage, allowing an inch to lap over the upper and lower wire strips, completed the covering. The screen wire and cloth were fastened securely with cleats at the edges. The door was covered with screen wire. This cage was intended to furnish conditions similar to those in many outbuildings and sheds in which left-over bags of beans are stored in California. The outdoor temperature was recorded in a screened insectary adjoining the cage on the south side. During the summer a piece of composition wallboard was laid over the sack, but later a window sash with glass was put over it to keep off the rain.

On July 13, 1923, 25 pairs of *Callosobruchus maculatus* were placed in another bean sack containing 69 pounds of choice recleaned blackeye cowpeas. This bag was placed on the same table in the cage with the bag of Red Kidney beans.

Throughout the experiment the weevils were counted as they were caught and were recorded daily for the most part. The date of capture indicates the time of dispersal from the sacks, not the actual date of emergence.

### Results of Experiment with the Bean Weevil

On July 13, 1923, the first insects of brood 1 of *Acanthoscelides obtectus*, 42 weevils, were caught in the cage. Practically 2 months of summer weather had elapsed between the introduction of the weevils and the appearance of the first brood in the cage, fully 2 weeks longer than a normal complete cycle beginning late in May. Of the 402 adults recorded from this brood, 179 were caught during the 5-day period July 13 to 17. During the next succeeding 5-day periods 119, 83, and 18 were caught, 1 was caught on August 2 and 1 on August 9.

The small number of weevils recorded in this brood and the time required for their development were surprising when compared with the usual results from the study of pairs in vials. The difference in time and number of progeny seems due to the fact that the beans used were old and very dry. As Lipman (*60*) and Headlee (*37*) have shown, the first-stage larvae find difficulty in surviving in very dry beans and their developmental period is lengthened therein. Later broods profited by moisture absorbed in the beans, which softened them and hastened the development of the weevils. Just why moisture is absorbed by bruchid-infested seeds is not understood unless it may be that penetration of the seed coats permits the cotyledons to absorb moisture. Possibly some substance introduced into the seeds by the larvae stimulates this absorption, or it may be due to the small amount of water produced by the metabolism of the larva.

The adults may have remained within the bag several days before making their way out into the cage. Probably many of the first brood remained in the bag, for until the beans were heavily infested they furnished a suitable breeding place, and the weevils did not need to search for other seeds.

The second brood was first noted about the cage on August 14, 8 weevils being recorded; 13 and 20 were recorded during the next 2 days, respectively. During the next three 5-day periods the numbers caught were 247, 116, and 1,282, respectively. Later periods showed a decided decrease in the number of weevils found, until only 26 weevils were caught from September 15 to September 20 and only 15 during the next 4 days. This brood required only 1 month for the development of the first adults; 3,501 adults were recorded from this brood.

Apparently the third brood of *Acanthoscelides obtectus* began its flight on September 25, about 6 weeks later than the second brood, and 13 adults were recorded. On succeeding 5-day periods 797, 4,274, 1,723, 4,242, 2,053, 1,269, 5,910, and 247 weevils were recorded. At the time the flight of this brood was at its peak a cold, stormy period occurred followed by warmer weather. This is directly reflected by the catch of weevils. Other periods of low temperature were reflected by the catch of weevils during the latter part of October and twice in December.

The fourth brood began its flight on November 5, or 6 weeks later than the third. The flight of this brood, like that of the third, shows a direct relationship between the prevailing temperature and the number of weevils caught.

Overlapping generations prevented a complete break in the catch of insects both at the beginning and at the latter end of this and later brood flights. The emergence of later broods is closely correlated with the temperature, but because of the great number of weevils developing within the beans and the heat thus generated, the fourth brood was able to a great extent to overcome the unfavorable low temperature prevailing outside of the bag. Larson and Simmons (*54*) showed that weevils of *Callosobruchus maculatus* in a bag were capable of raising the temperature in the bag 35° F. above the surrounding temperature. The flight of the adults, however, was more directly correlated with the outside temperature, the weevils leaving the bag only during the warm part of the day, and the greatest numbers leaving during the warmest days. During 5-day periods beginning November 8, the following numbers of adults were captured: 947, 1,708, 3,442, 8,390, 5,361, 5,284, 1,493, 1,014, 4,179, and 575, making a total of 32,393 for the brood.

The fifth brood apparently required about 50 days for development, as the flight began about December 27. Owing to the smaller number of weevils developing they and the next brood were unable to keep an optimum temperature within the bag and were therefore retarded in their development to such an extent that it is impossible to determine when this brood ended and another began. The scarcity of suitable food caused the brood to die out completely, and the last weevil of probably the seventh brood was caught on July 5, 1924. Although the beans were observed during the rest of the summer no more living weevils were found.

A total of 68,819 weevils were caught and recorded. Many were captured on the outside of the cage after they had gone through the 16-mesh screen wire. While the weevils were emerging in such great numbers it was impossible to determine the exact ratio of males and females, but the impression was that a great majority of those caught about the cage were females. Apparently the males remained among the beans in the bag, and the females, after mating, flew out in search of other beans.

At the end of the experiment 1,460 cc of dead weevils and 14½ ounces of frass were sifted from the beans in the bag and the orignal 87 pounds of beans had been reduced to 66 pounds, the loss in weight being 21 pounds, or 24.1 percent. The loss in weight due to the weevil infestation, however, will be shown to be even greater than that because many emerged weevils crawled back into the emergence holes and died, and others died within the beans in various stages. Their combined weights would materially reduce the remaining 66 pounds.

A fair estimate, based on counts of emergence holes, and weevils that had returned to the holes, checked by the numbers actually recovered in flight, would show that about 250,000 weevils had matured from the original infestation of 50.

A newly harvested Red Kidney bean will supply food for 10 to 20 or more weevils within the bean at one time, but when successive generations are forced to develop in the same beans many of the young larvae bore into the holes previously occupied and die for lack of food. Consequently fewer weevils are able to breed in the same bean if the larvae enter at different times.

Although the weevils breeding in the beans were able to keep the temperature in the bag much above that of the surrounding atmosphere, dispersal was directly correlated with the outside temperature. Emergence may have been checked a little by low temperature, but the flight of the insects away from the bag of beans occurred only during the warm part of the day and was much more pronounced during the later days of a warm spell than during the early part of the same warm period. Toward evening the weevils in the cage would seek shelter about the sack. On cold days practically no weevils left the sack.

RESULTS OF EXPERIMENT WITH THE SOUTHERN COWPEA WEEVIL

Daily examination indicated that the original 25 pairs of weevils of *Callosobruchus maculatus* put into the cowpeas on July 13, 1923, showed little inclination to search for a new supply of food in which to breed. Only five specimens, three males and two females, were found on the walls of the cage. The last living adult of the original 25 pairs was noted on July 27.

Adults of the first brood were noted first on August 9, when one weevil was found on the wall of the cage. The peak of emergence of this brood occurred between August 20 and 25. During this time approximately 1,600 weevils were caught in the cage. Practically all of the weevils of this brood remained inside of the cage because the majority of them were too large to go through the interstices of the 16-mesh screen. Apparently a large part of the females of the first brood laid eggs before leaving the infested bag of seeds in search of new material.

The daily catch of weevils became smaller and smaller until, on September 5, only 15 were taken. After that date the numbers again began to increase, indicating that a second brood was emerging. The flight peak of the second brood was reached between September 18 and October 2. During this period 54,138 weevils were recorded; 1,528, being small enough to go through the screen wire, were caught on the outside of the cage. Eggs distributed on ripening pods in the garden nearby indicated that a large number of weevils had escaped.

The third brood of weevils appeared to reach its maximum during the latter part of October. The weevils of this brood were noticeably smaller than those of the earlier broods, consequently a larger percentage of them escaped through the screen wire of the cage.

After the third brood there was such an overlapping of broods that it was impossible to say to what brood the emerging weevils belonged, but emergence continued all winter, the last weevil being caught on March 14, 1924. The 69 pounds of blackeye cowpeas produced 368,000 adult weevils (fig. 28) which reduced the weight of the cowpeas 62 percent.

## OPPORTUNITY FOR DISPERSAL

The length of life of the adult weevils after emergence varies considerably. This variation is correlated principally with temperature and humidity (p. 49), but under similar conditions some weevils live much longer than others. Manter (*63*) says adults of *Acanthoscelides obtectus* live 10 to 12 days. Marcucci (*64*) says they live 10 days in hot months, 20 days in cooler months, and may live 2 or 3 months during the winter. Without liquid food, the writers have never found them living longer than 81 days, but with food one weevil lived 141 days and another 176 days.

The length of life of the adult *Callosobruchus maculatus* after emergence is given by various authors as from 5 to 19 days. The writers have found that under different climatic conditions it lives from 1 to 50 days without food and as much as 88 days with food.

Because of the danger of injury to maturing bean crops the writers have thought it unwise to liberate marked weevils in the field in order to try to determine their length of life or the distance they would fly. Opportunities have occurred, however, for making observations along these lines. About the 1st of August 1924, while bean fields in Chino, Calif., were being inspected (*52*), a heavy infestation of *Acanthoscelides obtectus* was found in the early-planted part of an isolated bean field

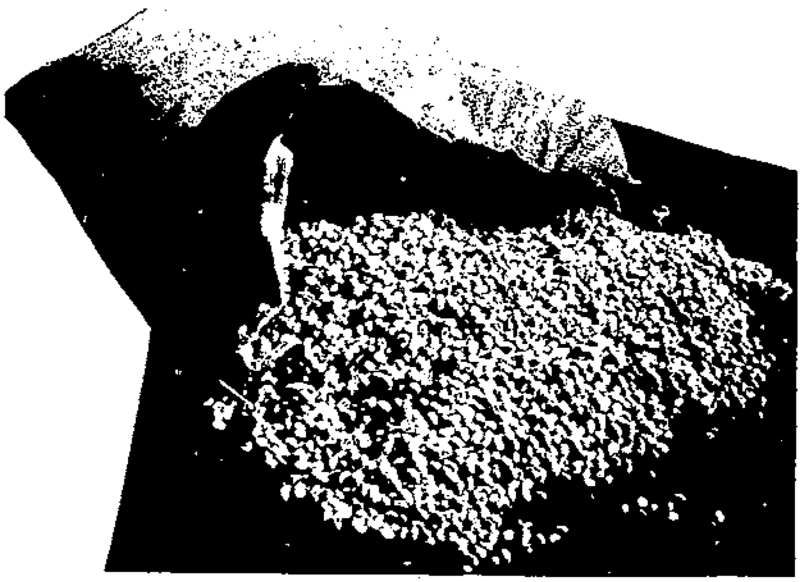

FIGURE 28.—A 60-pound bag of blackeye cowpeas that supported an infestation that increased from 50 to 368,000 weevils between July and the following March.

in which beans had been planted on successive dates for several weeks. After inspecting the 16 nearest surrounding farms the only source of infestation was found to be beans in a pile of bean straw in a barn on the farm where the beans were growing. This straw was fumigated on August 20. At that time weevils were very abundant in the field. A few minutes' search would be sufficient to find several weevils ovipositing, excavating holes in which to oviposit, or at rest on the bean plants. Thirteen days later, on September 2, long and careful search was required before a single weevil was found. This weevil, which was preparing an opening in the pod in which to oviposit, contained only four eggs. Earlier examinations had shown that weevils preparing to oviposit contained from 10 to 25 or more eggs. Repeated observations had shown that only small numbers of eggs are usually laid toward the end of the weevil's life. This seems to indicate that the one weevil found in the field 13 days after the fumigation of the source of infestation was well toward the end of its life. Under laboratory conditions at that time of year weevils sometimes lived 15 to 19 days. Since the weevils habitually remain on suitable bean plants, the extreme scarcity of weevils in the field seems to indicate that most of them had died in the 13 days after the source of infestation had been removed, and this conclusion was supported by the results of inspections of the late beans when compared with those of the early beans from the same field (*52*).

In the laboratory plot in Alhambra, several miles from bean fields, observations were made as described in an earlier paper (*48*) in an effort to determine whether or not weevils liberated at planting time or earlier would live long enough to infest the growing crop. Different plantings of beans, weevily and clean, volunteer beans, and weevily beans left standing all winter furnished a wonderful opportunity for the spread of weevils into the new crop, if it were possible for such a thing to occur in this manner. The weevily beans that had been standing all winter were plowed under on April 10, but weevily beans were planted at intervals as late as May 25. The growing beans were carefully watched for the presence of weevils or weevil injury. Some beans were ripe by the middle of July, but no weevil work had been observed, and later observations bore out the fact that no weevil injury had occurred.

Bean samples were collected at harvest time for several years. After these samples had been examined, inspectons were made of the farms that produced weevily beans as well as farms near them. It was found that sources of infestation such as lots of weevily beans about the outbuildings, or weevily beans in bean-straw stacks had been kept until late in the summer within flying distance of the maturing beans. In no case were the writers able to find that the crop was weevily as a result of weevils which had escaped from a source of infestation that had been eliminated more than a month before the earliest beans were ready to harvest. Frequently it was found that the source of infestation had been eliminated about the time the earliest beans were ripening. More often the source remained until the inspection after harvest. This indicates that neither *Acanthoscelides obtectus* nor *Callosobruchus maculatus* live long in the field. These inspections also showed that most of the infested fields were less than one-fourth of a mile from the source of infestation and that very few were more than 1 mile from the source of infestation.

## CORRELATION OF MARKET CONDITIONS AND INFESTATION

In different localities weevil infestation has been much worse in some years than during the years preceding or succeeding. The writers were the first to note a correlation between poor market conditions and heavy weevil infestations. The years 1918 and 1926 are examples of such years in portions of California.

During 1917, influenced by war-time conditions, an exceptionally large acreage of beans was planted, and a good crop was harvested; but the high prices prevailing and favorable shipping conditions led to the importation of foreign-grown beans sufficient to supply American needs, leaving large quantities of native-grown beans unmarketed to be held over in warehouses and on ranches. These beans in storage in 1918 became weevily and caused extensive infestation of the crops growing nearby and of the new beans coming in.

In 1926 certain bean-growing sections of California experienced heavy infestations, perhaps the heaviest ever known, directly correlated with preceding market conditions. During the fall of 1925 the market opened at 6¼ cents per pound for blackeye cowpeas, the principal crop, and rose to 6½ cents, then fell rapidly to 4 cents. At 4 cents there was very little buying. As a result of this market condition some farmers having only small lots of beans stored them at home to avoid warehouse charges and held them over, frequently for a total loss. When weevils are known to occur in a locality it is never safe to hold over lots of beans without fumigating them and examining them often for reinfestations. In Merced County the writers made examinations of the 1926 crops as they were delivered to the warehouses, and the farms were visited on which the more heavily infested lots were grown. On 15 of those farms, widely scattered throughout the bean-growing section, infested beans in storage were found in lots ranging from 56 sacks down to 1 quart, representing a total of about 178 sacks of 90 pounds each, all heavily infested with weevils; and these were located because of the infestation found in the new crop. Some of these were infested with *Callosobruchus maculatus* as well as *Acanthoscelides obtectus*, as both species frequently infest the same lot of beans. Two lots, containing 25 and 30 sacks, were distributed unfumigated to poultrymen, a few bags in a place, and so, instead of the original 15 sources of infestation, these were now 30 or more. Each bag could have liberated several hundred thousand weevils.

## CONTROL OF THE WEEVILS

There are two distinct problems in the control of the bean weevil and the southern cowpea weevil, one in the warehouse where no food for the adult is available and another in the field where there is food in the form of water and honeydew.

The previous discussion indicates that control in the field is accomplished by the elimination on the farms, early in the growing season, of all dried beans, cowpeas, and bean straw that serve as breeding places during the summer or crop-growing season. Infestations in the beans and cowpeas may be eliminated by proper fumigation of the seeds, feeding them to livestock, or destroying them. In the case of straw the only practical way to eliminate the weevils is by using it for feed, plowing it under for fertilizer, or burning it. This clean-up of breeding places must be done thoroughly and efficiently by everyone in a bean-growing community if satisfactory results are to be obtained. If done in a careless manner without complete cooperation from all, a few sources may be neglected, and enough weevils may escape to infest an entire bean-growing district. Fields near warehouses can be protected only by the elimination of infestations from the stored seeds.

Control in the warehouse depends on careful and frequent examination of all beans stored therein, with efficient fumigation when necessary. The floors and cleaning machinery must be kept free of beans, and general sanitary methods must be observed.

## SUMMARY

*Acanthoscelides obtectus* (Say), the common bean weevil, and *Callosobruchus maculatus* (F.), the southern cowpea weevil, have become widely distributed where beans or cowpeas are grown. They breed in many kinds of leguminous seeds, the development from first-stage larvae to adults taking place entirely within the seeds.

Weevily beans and cowpeas are unfit for human food, and if badly infested they are unsuitable for planting. Such seed may be used for food for cattle, hogs, sheep, and poultry, being worth about one-fourth as much as they would be if they were not weevily. In some bean-growing districts these weevils have caused such heavy losses that the growing of beans has had to be abandoned.

The adults are small active beetles that oviposit in or on maturing pods in the field, and on or among dry seeds in storage. They live from a few days to a month or more, depending on the temperature and food supply. Although they drink water and liquid food from the leaves and other parts of the plant, this is not necessary for the production of viable eggs. Food and drink increase the length of life and the number of eggs laid. *Acanthoscelides obtectus* fed sugar water lived an average of 66.7 days, whereas those without food lived an average of 16 days. The maximum number of days of life was 176 for a fed weevil and 23 for one without food or drink. Weevils having access to sweetened water laid an average of 115 eggs; those without food or water an average of 55.2 eggs.

*Callosobruchus maculatus* with access to unsweetened water lived on an average about 10 days longer and laid about 30 percent more eggs than those not fed. Sugar water increased the length of life 13 to 27 days for different groups of weevils and increased the number of eggs about 50 percent. Weevil problems in storage and in the field are quite different, because in storage there is no possibility of the weevil obtaining food or drink, but in the field it is able to get moisture from the leaves and food from the honeydew or secretions about the growing plants. In winter *Acanthoscelides obtectus* may live 49 days and *C. maculatus* as long as 38 days. The females usually live a day or so longer than the males. The preoviposition period is from 1 day in summer to 26 or more days in winter for *A. obtectus* and from less than an hour to 10 days for *C. maculatus*. These weevils attain their wide distribution by commerce and their local dispersal by flight.

In the field *Acanthoscelides obtectus* finds or makes a suitable opening in the pod and inserts its ovipositor and lays its eggs, several in a cluster. *Callosobruchus maculatus* lays its eggs singly on the outside of the pod or on exposed seeds. When laid they are surrounded with a cementing fluid which, when dry, fastens them firmly in place. Overripe bean pods which split open along the sutures form ideal places for oviposition. If such openings are not available the female *A. obtectus* uses its mouth parts to gouge out an opening through which it oviposits. The eggs are safely hidden from view inside of the pod. In stored beans *A. obtectus* lays its eggs in clusters loosely among the beans or under the partly loosened seed coat of some of the beans, whereas *C. maculatus* fastens its eggs securely to the seeds. As many as 209 eggs have been recorded from one female *A. obtectus* and a maximum of 196 eggs from one female *C. maculatus*. The oviposition period for *A. obtectus* ranges from a minimum of 5 days in summer to a maximum of 39 days in winter.

In warm weather the eggs hatch in from 3 to 9 days. A longer time is required in cool or cold weather. The writers have recorded incubation periods ranging from 3 days in August to 27 days in December and January.

The first-instar larva is provided with a prothoracic plate which aids it in making its entrance into the seed. The young larva of *Acanthoscelides obtectus*, among stored beans, braces against an adjacent bean or the wall of the container while it bores into another bean. The young larva of *Callosobruchus maculatus* uses the upper part of the eggshell to brace against while it bores through the pod and into the seed or directly into the seed. When within the bean the walls of the larval burrow support the larva of either species while it gnaws, the larva making a larger cell as it grows.

Four larval skins are molted between the egg and the pupal stages. The adult, before emerging, cuts a groove in the seed coat around the edge of the cell and pushes the seed coat out.

The writers have found six generations of *Acanthoscelides obtectus* to be the rule in California, with occasionally only five. *Callosobruchus maculatus* has six generations and sometimes seven in California.

If not checked by control measures the weevils become abundant in June, and the large populations continue during warm weather as long as there is a sufficient food supply.

In a bag containing 87 pounds of red kidney beans the writers placed 50 adults of *Acanthoscelides obtectus* on May 16, 1923. By July 5 of the next year they had increased to about 250,000. In a parallel experiment 50 adults of *Callosobruchus maculatus* multiplied to 368,000 in a 69-pound sack of cowpeas between July and the following March.

Field infestations result ordinarily from weevils from infested stored beans rather than from planted weevily beans. Often serious field infestations result from small left-over lots of seed. Weevils liberated at planting time search for stored seeds, and in these they produce generations that in turn infest the maturing crop.

It has been noted that heavy infestations frequently follow a year with a surplus of beans or cowpeas held over because of poor market conditions.

Control in the field is accomplished by eliminating all lots of beans or cowpeas held over after planting time, and by burning the old vines or feeding them to livestock or turning them under; in the warehouse, by fumigation and by keeping the premises clean.

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