The Arkansas Laboratory Strain of the Maize Weevil[1,2]

By HOBART P. BOLES[3]

The parent insects of the Arkansas laboratory strain of *Sitophilus zeamais* Motschulsky were collected by the author from a bin of corn located on a farm near Stuttgart, Ark., in 1955. The strain was retained and reared as a separate culture because the insects were darker and larger than the laboratory strain of "rice" weevils. Also, preliminary efforts to rear the strain on wheat and corn showed that wheat was a non-productive medium for the Stuttgart weevils. These differences (since shown to be non-definitive characters for separating the so-called rice weevil into separate species [Soderstrom and Wilbur 1965, 1966]) suggested further study to establish whether more than one species of rice weevil was involved as had been suggested in studies by Japanese workers (Kiritani [1965] reviews some of these studies). However, some authorities held that the differences were expressions of intraspecific variation within the species and advised that continued growth of the strain on a wheat diet would erase them.

The insects were offered to Professor D. A. Wilbur of Kansas State University in 1957, and the Department of Entomology, KSU, continued the culture on a maintenance basis until Edwin L. Soderstrom,[4] a graduate student of Professor Wilbur, undertook a study of the strain three years later as one of the primary objects in his research. This initial study of Soderstrom (1960) was the first of many studies conducted with this strain in the Stored-Grain Insects Laboratory of the Department of Entomology at Kansas State University under the direction of Prof. Wilbur and continuing under Prof. Robert Mills. In all the tests made by different researchers over a 13-year period, the descendants of the original parent insects were used. The total research is a useful profile of the Arkansas laboratory[5] strain of the maize weevil—a proven research tool. The studies also show, by inference, that the maize weevil as a species is a serious economic pest.

Identification

Most studies of the Arkansas laboratory strain of maize weevil identify it as to source, and the 1st study (Soderstrom 1960) identified it as the Arkansas rice weevil under the scientific name, *Sitophilus oryzae* (L.), in keeping with the terminology of Floyd and Newsom (1959), who presented evidence that the "large" and "small" rice weevils were distinct, reproductively isolated species. (The "large" weevils studied by Floyd and Newsom came from a southern area adjacent to the area where the Arkansas laboratory strain weevils were collected.) In 1961, Kuschel confirmed the evidence of Floyd and Newsom that there were indeed 2 separate species within the *Sitophilus* complex; however, he reduced Floyd and Newsom's name *Sitophilus oryzae* to a synonym status and restored *Sitophilus zeamais* as the proper name for the species. The common name, maize weevil, was officially adopted by the Entomological Society of America in 1968 (Blickenstaff 1968). Danon et al. (1969) reviewed the species *zeamais,* including its known world distribution.

Life History

Sharifi and Mills (1971) made daily radiographs of infested kernels to study the development of the Arkansas maize weevil from egg to adult and its behavior during development within wheat kernels. Enlarged photographic prints were prepared from these radiographs to facilitate interpretation. They found that pre-pupae, pupae, pre-emergence adults, and post-emergence kernels were easily recognizable. The mean development periods for stadia 1–4 at 27°C and 69 ± 3% RH were 3.6, 4.7, 4.8, and 5 days, respectively. The average development periods for pre-pupa, pupa, and pre-emerged adult stages were 1, 5.3, and 5.3 days. The average length of the development cycle from the start of a 3-day oviposition period to emergence of the adult was 36.3 days. In dissected kernels, the percentages of egg deposited in the endosperm, germ perimeter, and germ center of the kernels were 42, 37, and 21, respectively. Sometimes 2 maize weevils developed inside 1 kernel, but only ca. ¼ as often as for rice weevils.

Other studies showed that the development time of the Arkansas maize weevil from egg to adult can be affected by the medium on which it is grown (Table 1).

Research Use

Species Separations and Comparisons.—Several investigators have used the Arkansas maize weevil to study structural and biological differences between species of the rice weevil complex and/or the granary weevil, *Sitophilus granarius* (L.). In his initial study, Soderstrom (1960) compared the larval instars of the Arkansas maize weevil and the granary weevil and determined the number of instars by using head capsule measurements. Subsequently, Soderstrom (1962)[6] and Soderstrom and Wilbur (1965, 1966) studied structural and behavioral variations in populations of rice weevils from Louisiana and Kansas and in the Arkansas maize weevil reared on 6 grain hosts. They demonstrated that body size is not a reliable criterion for separating the species. Minor differences were found between the 2 populations of rice weevils, but more and greater differences were found between the rice weevil and the maize weevil. They also found that the Arkansas maize weevils produced the most progeny in the shortest development time, that Kansas and Louisiana rice weevils mated readily and produced normal progeny, that attempted matings between rice weevil males and maize weevil females or rice weevil females and maize weevil males did not produce offspring, and that maize weevils ejected appreciably more frass from the kernels than did either of the rice weevil populations.

Hunkapiller and O'Donnell (1967) utilized head capsule morphology of the larvae of the Arkansas maize

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[5] Hereafter referred to as the Arkansas maize weevil, a distinct laboratory strain, strictly maintained to preserve its purity, uniqueness, and standardization as a research tool.

[6] Soderstrom, E. L. 1962. Variations of two geographical populations of lesser rice weevils, *Sitophilus oryzae* (L.) and one geographical population of rice weevil, *Sitophilus zeamais* Motschulsky. Ph.D. Dissertation, Kansas State Univ., Manhattan.

Table 1.—Development time of the Arkansas maize weevil on different media.

Medium	Oviposition period (days)	Average Development time (days)	Reference
Wheat, hard red winter:			
Ponca variety	7	40.0	Soderstrom and Wilbur (1966)
Bulgur, from hard red winter wheat, Scout variety (?)	7	37.9	Mills (1973)
Wheat, soft white spring:			
Gaines variety	7	34.4	Mills (1973)
Pearled, Gaines variety	7	33.5	Mills (1973)
Processed, lye peeled, acid neutralized, Gaines variety	7	39.5	Mills (1973)
Sorghum, variety:			
Ark-614	3	31.6	Russell and Rink (1965)
Atlas	7	38.0	Soderstrom and Wilbur (1966)
Caprock	3	33.0	Russell and Rink (1965)
Kansas sourless	7	38.0	Soderstrom and Wilbur (1966)
Martin	7	38.0	Soderstrom and Wilbur (1966)
Midland	7	37.0	Soderstrom and Wilbur (1966)
RS-610	3	30.5	Russell and Rink (1965)
Sagrain	3	31.8	Russell and Rink (1965)
Rice, Avg of 6 varieties	4	32.5	Russell (1968)

weevil for taxonomic separation from the other *Sitophilus* species.

McLaurin and Downe (1966) compared antigens of populations of adult rice weevils, Arkansas maize weevils, and granary weevils by precipitin tests and found them distinguishable serologically.

Singh and Wilbur (1966) studied the effects of temperatures of 21° and 27°C on the survival of starved Kansas and Louisiana rice weevils and Arkansas maize weevil adults of different ages, sex, and mating conditions. The populations of maize weevils lived significantly longer than either population of rice weevils, but all populations survived nearly twice as long at 21° as at 27°C. One-day-old adult maize weevils lived significantly longer than 15-day-old adults, but only minor differences in longevity were found among the populations of rice weevils. In general, both males and females lived longer when they were not allowed to mate.

Williams and Wilbur (1968) studied the respiratory environments of Arkansas maize weevils in culture jars in laboratory rearing rooms. Rearing units were open-top mason jars in which CO_2 was retained and specially designed plastic jars open at both ends in which CO_2 was dissipated. They found that CO_2 gradually built up during larval development while O_2 was gradually depleted. The greatest CO_2 accumulation occurred in the bottom of the mason rearing jars and in the middle of the plastic jars. Laboratory atmospheres contained less CO_2 and more O_2 than rearing rooms, and each had much less CO_2 and more O_2 than the culture jars. In a later study, Williams and Wilbur (1969) compared the respiratory atmospheres produced by laboratory populations of Kansas State University laboratory strains of granary and rice weevils and Arkansas maize weevils by determining the CO_2 and O_2 at 4-day intervals in culture jars containing selected infestations of each species. The populations ranged from 5 to 20% with each infestation; as they were increased from 5 to 20%, the CO_2 content increased proportionally during the period from oviposition to pupation. However, with rice weevils and maize weevils, the CO_2 increased gradually during early instars to a maximum the 22nd day. Then it decreased rapidly during pupation until the 30th day when it was only 15–25% of the maximum. Finally a buildup of CO_2 occurred again as the adults emerged. Maximum CO_2 accumulated on the 26th day with the granary weevil, which has a longer development period than the other 2 species. Larval development of the 3 species was not retarded or curtailed by the high CO_2 in the culture jars. The CO_2 concentrations during larval development were highest in cultures of Arkansas maize weevils, intermediate in cultures of granary weevils, and least in cultures of rice weevils. The O_2 decreased during larval development as the CO_2 increased, but the depletion of O_2 was not proportional to the buildup of CO_2.

As a Tool to Study Grain Resistance.—Corn.—Surprisingly, the Arkansas maize weevil has been seldom used by workers with corn. However, Diaz (1967)[7] used it in his preliminary studies of the resistance of representative races of corn from the Latin America Germ Plasm Seed Bank to infestation by the maize weevil. He found that some of the most resistant races of corn came from lowland tropical regions, regions probably favorable for the development of natural resistance because of the abundance of rice weevils.

Rice.—Rosetto (1966)[8] found that varieties of rough rice varied in their resistance to attack by Arkansas maize weevils. Russell (1968) also studied the resistance of rice varieties to attack by rice and maize weevils and demonstrated differences in resistance of 6 American varieties. Rough rice samples (200 kernels) of each variety were exposed for 4 days to 150 weevils of both sexes selected at random. Oviposition by Arkansas maize weevils ranged from 2 to 44 eggs and by rice weevils from 2 to 25. Adult emergence (from 3000 grains) ranged from 30 to 572 for maize weevils and from 51

[7] Diaz, G. C. 1967. Some relationships of representative races of corn from the Latin America Germ Plasm Seed Bank to intensity of infestation by the rice weevil, *Sitophilus zeamais* Motschulsky. (Coleoptera-Curculionidae). Ph.D. Dissertation. Kansas State Univ., Manhattan. 84 pp.

[8] Rosetto, Carlos Jorge. 1966. Resistance of varieties of rough rice (passy) to *Sitophilus zeamais* Mot. (Coleoptera:Curculionidae). Unpublished m.s., Kansas State Univ., Manhattan.

to 516 for rice weevils. Maize weevils required an average 32.5 days for emergence, and the insects emerged over a span of 19 days. Rice weevils required an average 41.4 days for emergence, and they emerged over a span of 28 days.

Sorghum.—Russell and Rink (1965) used the Arkansas maize weevils to investigate the effects of several sorghum varieties on development of the insect. They concluded that the effects of sorghum varieties on the number of 1st-generation progeny and the length of the development period of these offspring are controlled in large part by the relative hardness of the sorghums. The development period ranged from 31.8 days on the softest sorghums to 33 days on the hardest sorghums.

Rogers and Mills (1974) screened 1511 cultivars of sorghum from the international Germ Plasm Seed Bank, Chapingo, Mexico, for resistance to 2 strains of maize weevils, the rice weevil, and the granary weevil. The preliminary screening was done with the Mexican strain of maize weevils, another standard strain frequently used by researchers (Singh and McCain 1962, Diaz 1967, VanDerShaaf et al. 1969, Schoonhoven et al. 1973a,b). From this screening, 497 cultivars were selected for a secondary screening in which each was tested with the consistently more productive Arkansas maize weevil (so as to increase the level of insect infestations). The more resistant cultivars had glumes tightly surrounding the seed, but sorghums possessing this characteristic are rarely grown for grain.

Hunkapiller (1970),[9] in a search for resistance to the Arkansas maize weevil, the lesser grain borer, *Rizopertha dominica* (F.), and the Angoumois grain moth, *Sitotroga cerealella* (Olivier) among 269 cultivars of sorghum, found further evidence that sorghum varieties varied in their resistance to maize weevils. Lange and Mills (1972) also studied resistance of sorghum varieties to attack by the Arkansas maize weevil and found that the ability of the weevil to infest grain was affected by the medium in which it had been reared. Neither rate of oviposition nor quantity of grain had any appreciable effect on the comparative resistance of the sorghum varieties. Lange (1973)[10] later presented a more detailed study of the resistance of sorghums to the Arkansas maize weevil. Also, additional sorghum varieties were tested by Rout et al. (1973). They reported that differences in RH (43, 58, and 71%) did not affect the resistance ranking of 5 selected sorghum varieties, but when the varieties were stored up to 300 days at 27°C and 68% RH, they became more resistant to attack by the Arkansas maize weevil during longer storage periods.

Soybeans.—Partida (1973) evaluated the susceptibility of soybeans, soybean flour, and soybean oil meal to several stored-products insects including the Arkansas maize weevils. He found that none of the materials would support a population of maize weevils.

Wheat, Whole and Processed—Robinson and Mills (1971) studied the susceptibility of bulgur and wheat to Arkansas maize weevils at RH's of 43, 58, and 71%. (Bulgur is a gelatinized wheat product that has been a mainstay in the diets of people in the Middle East countries for several hundred years.) Male and female adult weevils were introduced into 6 bulgur and 6 wheat media (different particle sizes) and allowed to oviposit for 7 days. The Arkansas maize weevil produced more adult progeny in whole kernels of bulgur and of wheat and in the larger sized particles. However, fewer maize weevils developed with smaller particles and lower humidity, and their developmental periods were longer. Males and females collected from bulgur and wheat media of the same particle size tended to weigh the same, but the smaller the particle size, the less the insect weight.

Mills (1973) studied the development of Arkansas maize weevils in WURLD wheats, a parboiled, lye-peeled product, and in untreated white wheat, a pearled white wheat, and a hard red winter wheat bulgur. He found the order of suitability of the materials for multiplication of the weevils was pearled, untreated bulgur, and WURLD wheat.

Discussion

The Arkansas maize weevil is one of a large reservoir of experimental strains of stored-product insect species available to researchers. Many of these strains are unique in that they were initiated as research tools before the widespread use of modern insecticides and thus are the only stored-product insects known to be free, or relatively free, from exposure to insecticide. Their existance in a usable state is a tribute to the foresight and diligence of the researchers who maintain them. Some strains have been handed down through several individuals and even several institutions but are still available in much the same condition as when they were first colonized.

Sitophilus zeamais as a species has biological characteristics that enhance its potential as a dangerous pest of stored grains. Danon et al. (1969) stated that the maize weevil will soon join the granary weevil and the rice weevil as Yugoslavio's major pests of stored cereals. Also, they feel it has considerably greater potential for multiplication in corn than the rice weevil while "also being much more resistant to cold." (This latter point would not be true for North America.) To support their concern, they cited Fritzsche and Sedlag (1968)[11] who consider it a more dangerous pest of German grains than the rice weevil.

The history of the Arkansas strain of maize weevil through many years of laboratory rearing would, by inference, support these statements concerning its potential. The strain still retains its vigor and has apparently been managed to avoid the loss of sterility that often occurs when stocks are bred continuously at optimum temperatures. It has been consistently more productive than some other strains of maize weevils; it produces, compared with laboratory rice weevil strains, more progeny in the sortest development time; it lives significantly longer than rice weevils; it produces higher CO_2 concentrations and greater amounts of frass during larval development than rice weevils, indication of greater larval activity; it adapts well to different rearing media; and it consistently gives reliable results in tests where it is used. Thus it is a strain that after 19 years of laboratory rearing still elicits the comparative description of "a more virulent strain" (Rogers and Mills 1974).

[9] Hunkapiller, P. D. 1970. A search for resistance to the maize weevil, the lesser grain borer, and the Angoumois grain moth among 269 cultivars of sorghum. Ph.D. Dissertation, Kansas State Univ., Manhattan. 129 pp.

[10] Lange, S. K. 1973. Laboratory studies of varietal sorghum grain resistance to the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera:Curculionidae). Ph.D. Dissertation, Kansas State Univ., Manhattan. 127 pp.

[11] Fritsche, Geiller and Sedlag. 1968. Angewandte Entomologie. Jena. Article not seen.

Additional studies are encouraged with this species and other stored-product insect species having long histories of laboratory rearing. Information from comparative studies with these species and with indigenous natural species may give insight into the biological variations that have developed under the pressure of modern insecticides and grain management practices as well as to the mechanisms producing these biological variations.

The retention and distribution of stored-product insect strains having a uniqueness conferred by genetic factors, extensive research use, or long-time successful rearing under insecticide-free conditions should be a major aim of all research rearing programs.

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