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Biological, Ecological, and Morphological Investigations of the Rice Water Weevil, Lissorhoptrus Oryzophilus Kuschel, on Two Rice Genotypes.

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BIOLOGICAL, ECOLOGICAL, AND MORPHOLOGICAL INVESTIGATIONS OF THE RICE WATER WEEVIL, *LISSORHOPTRUS ORYZOPHILUS* KUSCHEL, ON TWO RICE GENOTYPES

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To all of the above, "Alea iacta est".

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ABSTRACT

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, is the most important insect pest of rice, *Oryza sativa* (L.), in the United States. Although this insect has been associated with *O. sativa* since the introduction of this plant species into the United States in 1685, some aspects of its biology remain obscure. Larvae of *L. oryzophilus* have four instars, based on measurements of head-capsule widths of field-collected larvae in 1981 and 1982. The head-capsule widths of each instar were: I, 0.14 to 0.18 mm; II, 0.20 to 0.26 mm; III, 0.28 to 0.38 mm; IV, 0.40 to 0.60 mm. Further studies revealed that the duration of each instar was: I, 1.20; II, 2.56; III, 7.14; and IV, 10.33 days, respectively at 27.1 ± 5.6 °C. Plant introduction PI 321264 sustained significantly ($p<0.01$) lower larval populations of *L. oryzophilus* and was significantly ($p<0.01$) less preferred for feeding than the susceptible variety Saturn.

Populations of *L. oryzophilus* larvae appear to conform to a clumped distribution pattern. Sampling plans using the equation: $\log_e T_n = (\log_e (D_o{}^2/a)/b - 2) + (b - 1/b - 2)\log_e n$, show that 15 samples of Saturn and 19 samples of PI 321264 are needed to estimate *L. oryzophilus* larval populations with a relative variance of 10%.

Scanning electron microscopy of the antenna and venter of *L. oryzophilus* revealed bifurcate sensilla trichodea, sensilla basiconica, and sensilla placodea on the antennal club. All three sensilla types were also found on the rostrum. Brush-like sensilla were found on the rostrum, legs, coxae and abdominal sternites VI and VII. All receptor types are found to be distributed similarly on both males

and females. Females possess significantly ($p<0.01$) more sensilla basiconica and longer sensilla placodea than males.

INTRODUCTION

Rice comprises the staple diet of over half the world population. About 90 percent of the world rice crop is grown in China, India, Japan, Korea, southeastern Asia, and the adjacent islands of the Pacific. Outside of Asia, Brazil and the United States produce the largest amounts of rice, yet their production is less than 5 percent of the total world production (Adair 1973, Poehlman 1979). Rice is grown from latitudes 55° north to 35° south, and from sea level to altitudes of 3000 meters (Pathak 1968). It is grown either by broadcast or drilled seeding, or by transplanting. It is grown as a rain fed, upland crop or under lowland conditions with impounded rain or irrigation water (Pathak 1975).

As many as 10,000 varieties of rice have been distinguished (Pathak 1975) The traditional tropical (indica) varieties are tall and leafy, and often lodge during the latter growth stages. Temperate (japonica) varieties are short, ca. one meter high, with stiff straw and erect leaves (Pathak 1975). In current rice breeding programs there is an increasing amount of hybridization between the tropical and temperate plant types. As a result, the distinctiveness of the two varietal types is being lost (Poehlman 1979). In the southern United States, many of the rice varieties originated from crosses between the tropical and temperate plant types (Poehlman 1979). In California, the temperate varieties are grown due to their tolerance of low temperature (Poehlman 1979).

Rice was introduced into North America as early as 1609 and became established as a crop in South Carolina about 1685 (Rutger and Brandon

1981). It is believed that Carolina rice originated from Madagascar, and was an upland type (Grist 1975). The first rice production in Louisiana was in Plaquemine Parish about 1718 (N.E. Jodon, Rice Research Station, Crowley, Louisiana, personal communication), and soon spread into Texas, Arkansas, California (Rutger and Brandon 1981), and Mississippi (Adair 1973). Small amounts of rice are also grown in Missouri, Oklahoma, South Carolina, and Tennessee (Adair 1973). Additionally, some rice has been grown in each of the states in the southeastern United States (Adair 1973).

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, is the most important pest of rice in the United States. Adult feeding damage to the foliage is generally of little importance, although Ingram (1927) reported plant death due to adult feeding in some late planted rice fields. Adults have also been reported to feed on rice panicles, consuming floral parts or the endosperm of the developing rice grain (A. A. Grigarick, University of California, Davis, personal communication). Larval feeding is considered the greatest source of damage, since larvae can prune almost all of the roots from the plant. This results in stunted seedlings and yield losses of up to 1,000 pounds per acre (Newsom and Swanson 1962). Heavy larval infestations may also reduce vigor and cause lodging during harvest (Riley 1881, Webb 1914).

Chemical control with dieldrin, aldrin, and lindane seed treatments provided about 90% *L. oryzophilus* larval control (Bowling 1957). Additional research by Rolston and Rouse (1960) and Newsom and Swanson (1962) led to the use of 0.25 lb of aldrin per cwt rice as an effective control. This practice eventually led to the development of resistant populations however, in Louisiana (Hendrick and Everett 1963), Arkansas

(Rolston et al. 1965), and Texas (Bowling 1968).

Aldrin resistance renewed interest in finding better insecticides for L. oryzophilus control. Research by Everett and Trahan (1965), Gifford and Trahan (1967), and Gifford et al. (1968, 1969, 1970) showed that a postflood broadcast application of granular carbofuran resulted in satisfactory control and increased yields. The efficacy of this compound continues at the present time and recent studies (Rahim et al. 1981) have revealed no economically important levels of carbofuran resistance.

Host plant resistance should prove a suitable alternative as well as an effective addition to control of L. oryzophilus with insecticides. Previous research has revealed some rice varieties that sustain less root damage and support fewer weevil larvae than susceptible lines (Grigarick et al. 1976, Gifford et al. 1974, Robinson et al. 1979, Smith and Robinson 1982). Knowledge of the biology of L. oryzophilus is necessary in order to assess accurately rice germplasm in host plant resistance studies. Two important gaps in knowledge of the biology of this insect exist; the number of larval instars and the duration of each instar. Similarly, an understanding of the spatial distribution of L. oryzophilus will also aid in the development of sampling schemes for screening rice germplasm. In addition, adult L. oryzophilus exhibit a nocturnal positive phototaxis for rice growing in thin stands (Rolston and Rouse 1964a) and information on adult sensory morphology may aid in explaining the behavior of this insect once the function of these structures are known.

The objectives of this study were to: 1) elucidate the number and duration of L. oryzophilus larval instars; 2) determine the spatial distribution and develop an accurate sampling method for *L. oryzophilus* in experimental rice plots; 3) compare the growth and development of *L. oryzophilus* on resistant and susceptible rice varieties; and 4) study the ultrastructure of sensilla of *L. oryzophilus* using scanning electron microscopy.

LITERATURE REVIEW

Taxonomy

The rice water weevil was originally described by Say in 1831 as *Bagous simplex* (Tucker 1912), but in 1876, this insect was placed in the genus *Lissorhoptrus* LeConte (Riley 1883). Early researchers referred to this species as *L. simplex*. Kuschel (1951) revised the genus, and described a new species, *L. oryzophilus*, from a specimen collected in Texas. This species was found to be predominant in the southern U. S. rice producing area (Everett 1966).

Description

The adult rice water weevil is a small, (ca. 32mm long), olive-gray to tan weevil, with a dark V-shaped area on the elytra. This V-shaped area is most distinct on females or moist specimens (Ingram 1927, Douglas and Ingram 1942, Lange and Grigarick 1959). The sexes are distinguished as follows: the abdomen of the female is more robust than that of the male. The first two ventral abdominal segments are flat to convex at the midline, and the fifth abdominal segment has a raised area which occupies more than half of the length of this segment, and is rounded posteriorly. In males, the first two abdominal sternites are broadly concave, and the raised area of the fifth segment occupies less than half of the length of the sternite, and is straight posteriorly (Everett and Newsom 1964).

The egg is white, elongate, and slightly curved. It is about 0.80 mm long and three or four times as long as broad (Ingram 1927, Webb 1914).

The larvae are white, legless grubs. The head is brown-colored, and small in relation to the rest of the body. Larvae are almost microscopic at hatch, and attain an approximate length of 8mm (Ingram 1927). Additionally, larvae possess dorsal hooks which are formed by the modification of the abdominal spiracles. These hooks are thought to facilitate the movement of the larvae through the soil, and in the acquisition of oxygen from the aerenchyma of rice roots (Isely and Schwardt 1930, Everett 1966).

Distribution

The genus Lissorhoptrus is restricted to North, Central, and South America and Cuba (Kuschel 1951, Vicente-Chandler et al. 1977). According to Blatchley and Leng (1916), the North American distribution is from New England and Canada, westward to Michigan and Iowa, and South to Texas and Florida. In the United States, L. oryzophilus normally reproduces sexually. However, in 1959, a parthenogenic strain was found in California (Lange and Grigarick 1959), and has recently been introduced into Japan (Hirao 1978).

Host Plants

Newell (1913), Webb (1914), and Isely and Schwardt (1934) have noted a number of alternate hosts which support development of L. oryzophilus. These include: Paspalum larrangoe Arech., P. plicatulum Michx. (brownseed paspalum), P. dissectum L. (mudbank paspalum), P. boscianum Flugge (bull paspalum), P. membranaceum Walt., P. urvillei Steud. (vasey grass), Cyperus flavicornis Michx., Echinochloa crusgalli var zelayensis H.B.K., E. crusgalli Beauv. (barnyard grass), Syntherisma sanguinalis (L.) Dulac, Cynodon dactylon (L.) Ktze. (bermuda grass), Axonopus compressus (Sw.) Beauv. (carpetgrass), Panicum hians Ell. (gaping panicum), P. dichotomiflorum Michx. (fall panicum), Jussioea suffruticosa L., and Eleocharis obtusa Schult. (spikerush). Douglas and Ingram (1942) also report that adult weevils have been found feeding on corn, Zea mays L., and sugarcane, Saccharum officinarum L. In California, Lange and Grigarick (1959) found that the following plants serve as hosts for the weevil: Polypogon monspeliensis (L.) Desf. (rabbitfoot grass), E. crusgalli Beauv., Agrostis avanacea Gmel. (bentgrass), Setaria geniculata (Lam.) Millsp. & Chase (knotroot bristlegrass), Eleocharis palustris R & S (spikerush), and Scirpus mucronatus Pursh. (rough-seed bulrush). Additionally, adults have been found feeding on Paspalum distichum L. (knotgrass)(Lange and Grigarick 1959).

Economic Importance

Adult L. oryzophilus strip the epidermal tissue from the leaves of the rice plant, leaving a scar. As the leaves grow or are battered by the wind, this scarred area will break through and produce a tear (Newell 1913, Ingram 1927). Douglas and Ingram (1942) reported that in some fields, adult infestation was so high, and the feeding so intense, that some plants were killed as a result of the leaf shredding. If the infestation is great enough, larvae will prune almost all of the roots from the plant, causing seedling stunt that results in rough rice yield loss of up to 1,000 pounds per acre (Newsom and Swanson 1962). Other researchers (Tucker 1912, Bowling 1957, Rolston and Rouse 1960, Newsom and Swanson 1962, Grigarick 1963) have reported yield losses ranging from 1-75%. Heavy larval infestations also result in the reduction of plant vigor, and cause lodging during harvest (Pathak 1968).

Chemical Control

Newell (1913) suggested lead arsenate for the control of *L. oryzophilus*. Whitehead (1954) found that broadcasting organochlorine materials onto the soil before flooding the fields was effective. Bowling (1957) obtained 90% larval control with seed treatments of aldrin, dieldrin, and lindane, but these failed to increase yields. Bowling (1959), Rolston and Rouse (1960), and Newsom and Swanson (1962) found that the use of 0.25 pounds of aldrin per cwt seed was the most effective and economical means for *L. oryzophilus* control. Seed treatment with aldrin was short-lived, however, as resistant weevil strains were found in Louisiana (Everett et al. 1964), Arkansas (Rolston et al. 1965), and Texas (Bowling 1968). This development renewed interest in finding better chemical control measures.

Numerous workers (Bowling 1967a, Everett and Showers 1964a, b, Gifford and Trahan 1967, Gifford et al. 1972, Grigarick and Beards 1965) found that those chemicals which provided satisfactory control were phytotoxic to the seeds or seedlings, or interacted with propanil, an herbicide commonly used on rice, and damaged the seedlings. Other workers (Everett and Trahan 1965, Gifford and Trahan 1967, Gifford et al. 1968, 1969, 1970) showed that granular insecticide applications broadcast post-flood controlled *L. oryzophilus* larvae and increased yields in replicated small plot and aerial treated outfield trials. These studies have led to the practical use of granulated carbofuran for weevil control. Further studies by Gifford et al. (1972, 1975a) demonstrated that a pirimiphos-ethyl seed treatment also gave good control, and showed no seedling phytotoxicity. Recent work at the Louisiana State University Rice Research Station has shown that several new compounds offer an effective means of control of *L. oryzophilus* adults and larvae (Robinson et al. 1980, Smith 1981).

Cultural Control

Webb (1914), Isely and Schwardt (1934), and Douglas and Ingram (1942) found that draining rice fields caused a considerable reduction in the damage caused by *L. oryzophilus*. This procedure is prohibitive because of restricted water supply, loss of fertilizers, and ineffectiveness of killing the larvae if the rice is reflooded prematurely. Additionally, in Louisiana, in dry years when much of the fresh water is pumped from canals and wells, salt water may enter from the Gulf of Mexico, and an excess of salt may be pumped into the fields causing injury to the rice. Rolston and Rouse (1964b) found that soil type, seeding method, and treated seed storage intervals exerted little *L. oryzophilus* control, but presence of aquatic grass and rice seeding rate did influence larval population levels. Control decreased as the ratio of aquatic grasses to rice plants increased. Apparently, adults and larvae became established on the grasses, and then migrated to the rice seedlings.

Biological Control

Bunyarat et al. (1977) reported that an undescribed mermithid nematode found almost exclusively in females, parasitized *L. oryzophilus* in Arkansas. Peak abundance occurred in late June and a small second peak occurred in early August. The nematode is thought to be a new genus, closely resembling the genus *Skrjabinomermis*. Tucker (1912) and Ingram (1927) reported that ten species of birds were known to ingest *L. oryzophilus* adults, and noted finding adult weevils (up to 7/web) entangled in the webs of spiders. Puissegur (1976) dissected 291 *Hyla cinera* Daudin and *H. squirella* Bosc. individuals, and found that 9.3% contained *L. oryzophilus* adults. Concomitantly, 4.0% of 25 *Rana pipiens* Schreber individuals dissected contained *L. oryzophilus* adults. In field cage studies, Puissegur (1976) also found that the tettigoniid grasshoppers *Conocephalus fasciatus fasciatus* (De Geer), *Neoconocephalus triops* (L.), and *Orchelimum agile* (De Geer), consumed *L. oryzophilus* adults. Additionally, he reported that significantly lower *L. oryzophilus* larval populations were found in field test cages containing naiads of the libellulid dragonfly, *Pantala flavescens* (F.), than in control cages.

Host Plant Resistance

Recently, host plant resistance has begun to be studied as a method to manage *L. oryzophilus*. In Louisiana, Oliver and Gifford (1972) found two selections (WC 7072 and CI 9810) that in three years of screening had infestations that were 45-75% and 42-87% as great, respectively, as the susceptible check variety, Saturn. Gifford et al. (1974) identified one Japanese rice variety, PI 224842 (Mogami mochi) and two U. S. varieties, CI 9903 [(Bluebonnet x Belle Patna) (Dawn 71 x Beaumont 305)] and CI 8900 (R3 111), with larval infestations that were 20%, 40%, and 56% less, respectively, than Saturn. Gifford and Trahan (1976) found three plant introductions (PI 162162, PI 162254, and PI 224927) that exhibited *L. oryzophilus* tolerance. Grigarick et al. (1976) identified seven rice genotypes in California with resistance to *L. oryzophilus*. Robinson et al. (1981) screened 2,800 rice genotypes in 1979, 1980, and 1981, and found six with moderate levels of resistance. Low levels of resistance have also been identified in five varieties of Philippine origin (Smith and Robinson 1982). Bowling (1973) has devised a method for screening rice germplasm in the laboratory.

Behavior and Biology

The life cycle of *L. oryzophilus* requires approximately 40 days for completion under field conditions. Factors such as temperature, food supply, and soil moisture influence this period. Adult weevils begin overwintering as early as July in spanish moss, rice stubble, and perennial bunch grasses in and around rice fields (Tucker 1912, Webb 1914, Isely and Schwardt 1934, Gifford and Trahan 1969a). Nilakhe (1977) examined 636 overwintering females and found only 13.7% mated. Thus, because the gonads are undeveloped, overwintering weevils are considered to be in a state of diapause (Nilakhe 1977). Adult emergence may begin in late March, but migration into the rice field occurs in early April and continues until late May. Flight does not occur during daylight hours, but adults in flight are trapped by both incandescent and fluorescent light at night. Isely and Schwardt (1934) noticed that large field to field migrations occurred at night. Muda et al. (1981) studied the flight muscles of hibernating adults and found that they are reduced in size during the winter, regenerate just before the exodus from overwintering sites, and then degenerate with the onset of feeding and oviposition.

Bang and Tugwell (1976) and Sooksai and Tugwell (1978) demonstrated that young plants are preferred, and that preference decreases as plants increase in age from about 2 to 7 weeks. Bang and Tugwell (1976) also reported that increased levels of nitrogen fertilizer increase the level of feeding.

Oviposition begins as soon as the rice fields are flooded. The majority of the eggs are deposited in the submerged leaf sheaths of seedling rice (Everett 1965, Grigarick and Beards 1965, Everett and Trahan 1967) and a few on the roots (Webb 1914, Isely and Schwardt 1930, Douglas and Ingram 1942, Grigarick and Beards 1965). Maximum oviposition occurs 7 to 14 days after flood (Everett 1966). This agrees with the results of Bang and Tugwell (1976), who reported that plants 30-40 days of age were preferred for oviposition. Larval survival was highest on plants of this age. The egg stadium lasts four to nine days, depending upon temperature (Raksarart and Tugwell 1975). After eclosion, first instar larvae feed in the leaf sheath while moving down the plant to the roots. After a short period of time, the larvae cut an exit hole and move by gravity through the water to the soil, where they feed on the roots (Bowling 1972). Feeding increases in each successive stadium, and the larvae attain a maximum length of 8mm in approximately 21 days (Everett 1966).

Pupation takes place in oval mud cells lined with a water-tight material and attached to the plant roots. Adult eclosion occurs several days later (Everett 1966, Gifford et al. 1973). Under optimal conditions, four generations of *L. oryzophilus* can occur in south Louisiana; however, Gifford et al. (1973) indicate that two and perhaps a partial third generation occur more frequently. There are two generations per year in California (Everett 1966), and Isely and Schwardt (1934) found one generation per year in Arkansas. Successive generations occur within the same field only when there is no seedling rice in the vicinity (Gifford et al. 1973).

CHAPTER I

NUMBER OF INSTARS OF THE RICE WATER WEEVIL, *LISSORHOPTRUS ORYZOPHILUS* (COLEOPTERA: CURCULIONIDAE)

This Chapter is published in

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ABSTRACT

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, was determined to have four instars, based on measurements of head-capsule widths of field-collected larvae. The head-capsule widths of each instar were: 1st, 0.14 to 0.18 mm; 2nd, 0.20 to 0.26 mm; 3rd, 0.28 to 0.38 mm; and 4th, 0.40 to 0.60 mm. The existence of four instars is substantiated by Dyar's "Rule" and linear regression analysis.

INTRODUCTION

The rice water weevil (RWW), Lissorhoptrus oryzophilus Kuschel, is the major insect pest of rice in the southern United States and California (Riley 1881, Webb 1914, Bowling 1961, Newsom and Swanson 1962).

Parts of the insect's life history were described by Newell (1913) and Webb (1914), but neither mentioned the number of instars or head-capsule widths. Isely and Schwardt (1934) reported three instars and the corresponding head-capsule widths. Grigarick and Beards (1965) reported four instars, but gave no head-capsule widths. Bowling (1972), finding some larvae with widths smaller than those reported by Isely and Schwardt (1934), concluded that the RWW has four instars.

Part of the difficulty in enumerating the number of instars is due to the small size of the larvae (ca. 8 mm maximum for last instars). Therefore, we sought to establish both the number of larval instars, and corresponding head-capsule measurements, once and for all.

Materials and Methods

Larvae were collected from flooded plots of the rice varieties 'Saturn' and PI 321264 at Crowley, La., from 26 June to 22 September 1981. Collections, made at 3 to 4 day intervals, consisted of soil-root core samples (one plant per core) 10.0 cm deep by 9.2 cm in diameter. Samples in plastic bags (one core per bag) were taken to the laboratory and elutriated through 35-mesh wire buckets, or 35-mesh U. S. Standard soil sieves. Buckets/sieves were then placed in plastic dishpans containing a saturated solution of NaCl. Samples were agitated briskly, and larvae floating to the top were collected. The bottoms of the buckets/sieves were also examined for larvae which failed to float. All larvae were preserved in 80-100% EtOH.

Results and Discussion

Four larval instars were indicated by frequency distributions of the measurements of head-capsule widths (Table 1, Fig. 1). Isely and Schwardt (1934) reported head-capsule widths for three instars of *L. oryzophilus*: 1st, 0.20 to to 0.22 mm; 2nd, 0.33 to 0.35 mm; 3rd, 0.44 to 0.45 mm. Bowling (1972) found widths of 0.14 to 0.18 mm. and concluded that the RWW had four instars. Our results show that Isely and Schwardt (1934) missed the 1st instar, and they substantiate Bowling's conclusion (1972).

Our calculations of Dyar's constant (1890)(Table 1) indicate that no instar was omitted. Gaines and Campbell (1935) pointed out that a perfect geometrical progression of head-capsule widths can be represented by a straight line. If the logarithm of the widths is plotted against the number of instars, the resulting line is expressed by the following equation:

$$\ln Y = a + bX$$

where: Y = head-capsule width; X = instar for which the head-capsule width is required; and b = slope of the line.

A plot of this equation for *L. oryzophilus* larvae (Fig. 2) reveals that the calculated regression line is highly significant ($p<0.01$; $r^2 = 0.999$). Since such a close fit could not have been obtained if an instar had been overlooked, it can be concluded that *L. oryzophilus* has four instars.

Table 1. Head capsule widths (mm) and ratios between instars for larvae of _L_. _oryzophilus_ Kuschel, Crowley, La., 1981.

Instar	n	$\bar{X}$ ± SD	Size range	Coefficient of variation (%)	Inter-instar ratio (Dyar's constant)
I	252	0.16 ± 0.2	0.14–0.18	5.31	
II	672	0.22 ± 0.02	0.20–0.26	6.99	1.38
III	1,009	0.32 ± 0.02	0.28–0.38	6.45	1.45
IV	1,761	0.45 ± 0.06	0.40–0.60	12.66	1.41

Figure 1. Frequency distribution of larval head-capsule widths of the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel.

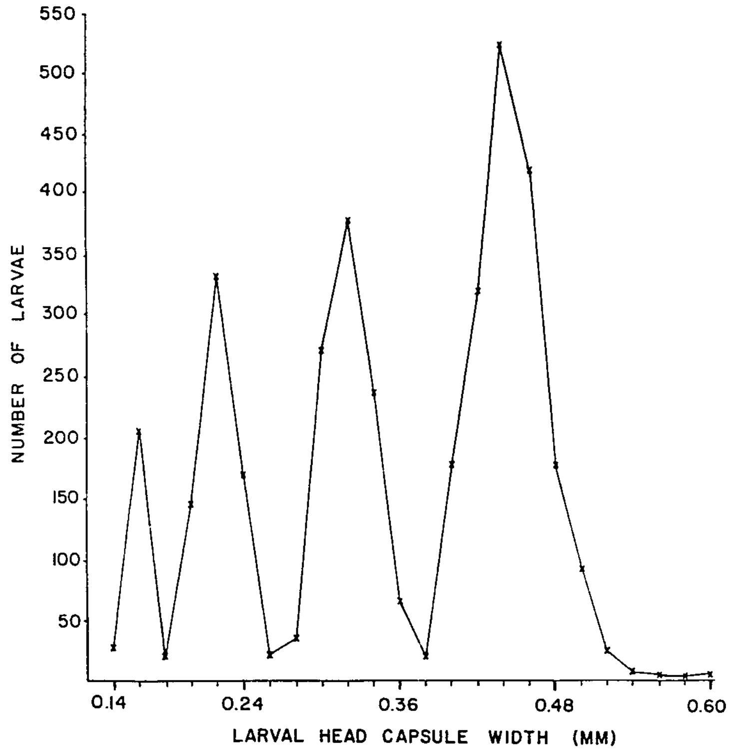
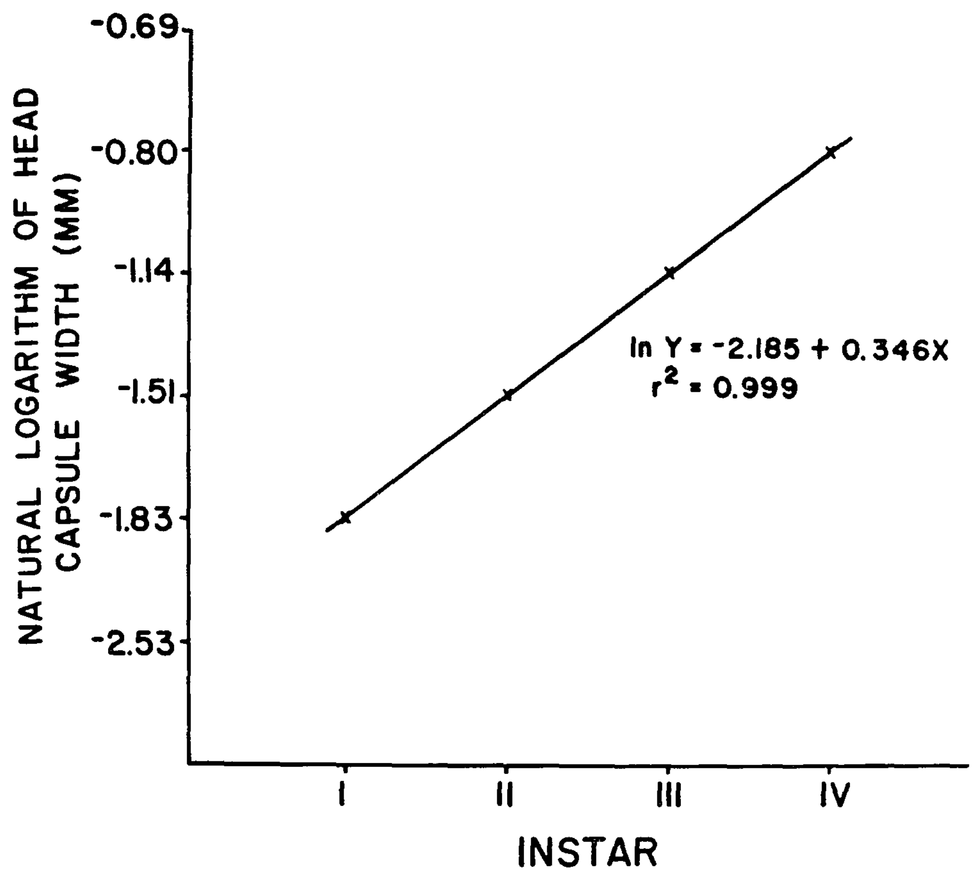

550
500
450
400
350
300
250
200
150
100
50
NUMBER OF LARVAE
0.14
0.24
0.36
0.48
0.60
LARVAL HEAD CAPSULE WIDTH (MM)

Figure 2. Semilog plot of the mean larval head-capsule width of the four instars using the regression line, ln Y=-2.815 + 0.346X.


NATURAL LOGARITHM OF HEAD CAPSULE WIDTH (MM)
-0.69
-0.80
-1.14
-1.51
-1.83
-2.53
ln Y = -2.185 + 0.346X
r² = 0.999
I
II
III
IV
INSTAR

As the biology of L. oryzophilus is incompletely known, our findings are important for the construction of its life table. In addition, to assess different rice varieties for L. oryzophilus resistance, a knowledge of the number of instars is crucial.

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CHAPTER II

POPULATION DYNAMICS, SPATIAL DISTRIBUTION, AND SAMPLING OF THE RICE WATER WEEVIL ON RESISTANT AND SUSCEPTIBLE RICE VARIETIES

This chapter is written in the style of

Environmental Entomology

ABSTRACT

The rice water weevil (RWW), *Lissorhoptrus oryzophilus* Kuschel, was studied on the rice plant introduction PI 321264 (moderately RWW resistant) and the variety Saturn (RWW susceptible) in 1981 and 1982. PI 321264 sustained significantly ($p<0.01$) lower larval populations and was significantly ($p<0.01$) less preferred for feeding and oviposition than Saturn. Manly's instar duration technique revealed that the length of each larval instar was 1.20 (I), 2.56 (II), 7.14 (III), and 10.33 (IV) days, respectively. Taylor's power equation, and Iwao's distribution function strongly indicate a clumped distribution pattern for immature RWW on each variety for both years. The equation: $\log_e T_n = \log_e(D_o^2/a/b - 2) + (b - 1/b - 2)\log_e n$, indicated that 15 samples of Saturn and 19 samples of PI 321264 are needed to estimate RWW larval populations with a relative variance of 10%.

INTRODUCTION

The rice water weevil (RWW), Lissorhoptrus oryzophilus Kuschel, is the most destructive insect pest of rice in the southern United States. Adult feeding is considered unimportant, but larval root feeding is economically significant and results in stunted seedlings, lodging during harvest, and yield losses of up to 1,000 pounds of rough rice per acre (Newsom and Swanson 1962). The seasonal history of RWW in a given field begins with the flooding of rice fields. At this time, the field is invaded by swarms of weevils (Isely and Schwardt 1934). Adults feed on the upper surface of the foliage, leaving narrow, longitudinal scars. The eggs are deposited under the epidermis of the leaf sheath below the surface of the water (Grigarick and Beards 1965) and larvae hatch within 4 to 9 days (Raksarart and Tugwell 1975). First instar larvae mine the leaf sheaths while migrating towards the roots where they feed and develop into adults. The four larval instars (Cave and Smith 1983) require about 21 days for development (Everett 1966). Weevils normally reproduce sexually, but a parthenogenic biotype exists in California, (Grigarick and Beards 1965) and Japan (Hirao 1978).

Although rice has been grown in the United States since about 1685, host plant resistance research did not begin until the early 1970's. Initial research in Louisiana (Gifford and Trahan 1975b) demonstrated tolerance to RWW larval feeding in five genotypes. Robinson et al. (1981) evaluated 2500 plant introductions for resistance to RWW root feeding, and found seven lines which gave between 22-34% control. Smith and Robinson (1982) evaluated 106 rice cultivars grown in the United States, and found five Philippine-derived cultivars which had significantly ($p<0.05$) lower RWW infestations than the susceptible check variety Saturn. Even though a considerable amount of RWW resistance research has been conducted, no comparative life history studies on resistant and susceptible varieties exist. Similarly, the duration of each RWW larval instar is also unknown. Limited information exists concerning the spatial distribution of RWW in rice, a prerequisite for developing accurate RWW sampling procedures for screening germplasm. The objectives of this study were to compare the population dynamics and spatial distribution of RWW on a resistant and a susceptible rice variety, to determine RWW larval instar duration, and to determine the optimum sample size for use in screening rice germplasm for RWW resistance.

MATERIALS AND METHODS

Sample Collection. The rice plant introduction PI 321264 (moderately RWW resistant) (Robinson et al. 1981) and variety Saturn (RWW susceptible) were hand planted (18 May, 1981; 20 May, 1982) at the LSU Rice Research Station, Crowley, Louisiana. Plots consisted of three rows of plants 3.9 m long separated by 0.5 m, with 7 m alleys between each plot. The plots were flushed on 20 May 1981 and 21 May 1982. Permanent flood was established on 19 June, 1981 and 18 June, 1982. The herbicides Propanil (3',4'-Dichloropropionanilide) and Bolero (S-(4-Chlorophenyl)methyl diethylcarbamothioate) (2.6 + 2.6 kgs ai/ha were applied for weed control on 12 June, 1981 and 14 June, 1982. Plots were fertilized with 100-60-60 lb/A (N-P_2O_5-K_2O) on 19 June, 1981 and 18 June, 1982. Plants within each plot were thinned to one plant per 0.15 x 0.46 m on 16 June in both years (this equals one plant/0.1 m^2, as compared with the commercial situation of three to four plants/0.1 m^2). Each variety was replicated 15 times in 1981 and 10 times in 1982. Plots were arranged in the field in a completely random design in both years.

In both years RWW eggs, larvae, and pupae were sampled every 3-4 days (from 26 June until 22 September, 1981, and from 1 July until 26 August, 1982). Root core samples (15/variety/date in 1981) consisting of a single plant, its roots and surrounding soil, were collected with a 9.1 cm diam x 10.0 cm deep metal sampler, and held individually in plastic bags until they were processed. In 1982, 10 samples/variety/date were collected based on preliminary sampling results. Each sample was elutriated (1981), or placed in a metal funnel fitted on the bottom with a piece of hardware cloth, washed with water at 80 psi (1982) and immatures were collected in a 35-mesh wire bucket. Buckets were then placed in plastic dishpans containing a saturated NaCl solution, and agitated briskly. For use in sample size determinations, floating larvae, categorized as small, medium, or large, and pupae were collected with forceps and preserved in 80% EtOH. Bottoms and sides of buckets were also examined for pupae and larvae which failed to float. For use in plant resistance studies, larvae were further classifed as to instar by measurement of head-capsule widths.

In both years, rice plants were returned to the laboratory where length of adult feeding scars on the distal 5 cm of leaf was determined. In 1982, height and number of tillers were also measured in the laboratory. Concomitantly, the volume of excised roots was also determined by displacement. Roots were oven-dried at 30°C for 24 h and weighed. Stems of plants were stained for RWW eggs and counted using the method of Gifford and Trahan (1969b).

Statistical and Mathematical Analyses. Egg, larval and pupal counts were not normally distributed, so were transformed for analysis of variance using the slope, b, from Taylor's power equation (1961) and the z transformation, $z = x^p$ of Healy and Taylor (1962); where z is the transformed value, x is the original value, and $p = 1 - b/2$. Untransformed root volumes and weights were analyzed by analysis of variance. Single classification ANOVA was used to separate mean larval numbers by variety and date, and mean lengths of feeding scars by variety and date. Duration of each instar was determined using the insect stage-frequency method of Manly (1976).

Spatial Distribution and Optimum Sample Size. Spatial distribution patterns of RWW immatures were determined by Taylor's power law (Taylor 1961), and Iwao's mean crowding-mean density regression (Iwao 1968). Sample sizes were calculated based on Green's (1970) equation: $\log_e T_n = (\log_e(D_o^2/a)/b-2) + (b-1/b-2)\log_e n$; where T_n is the cumulative total for each sample; D_o is the fixed level of precision; a and b are the intercept and regression coefficient, respectively, from Taylor's power equation; and n is the sample size.

RESULTS AND DISCUSSION

Host Plant Resistance. In both 1981 and 1982, a greater amount of feeding occurred on Saturn than on PI 321264 (Fig. 1). A combined ANOVA for both years of the study showed that the two lines were significantly ($p<0.01$) different on 10 of 17 dates. In 1981, there was little difference in egg counts between PI 321264 and Saturn, but in 1982 females significantly ($p<0.05$) lower egg counts were found on PI 321264 (Table 1). However, since so few eggs were collected in 1982, this difference may not be real. The reason for the low egg recovery in 1982

Figure 1. Adult *Lissorhoptrus oryzophilus* feeding on PI321264 (resistant) and Saturn (susceptible) rice. Crowley, Louisiana. 1981-1982.

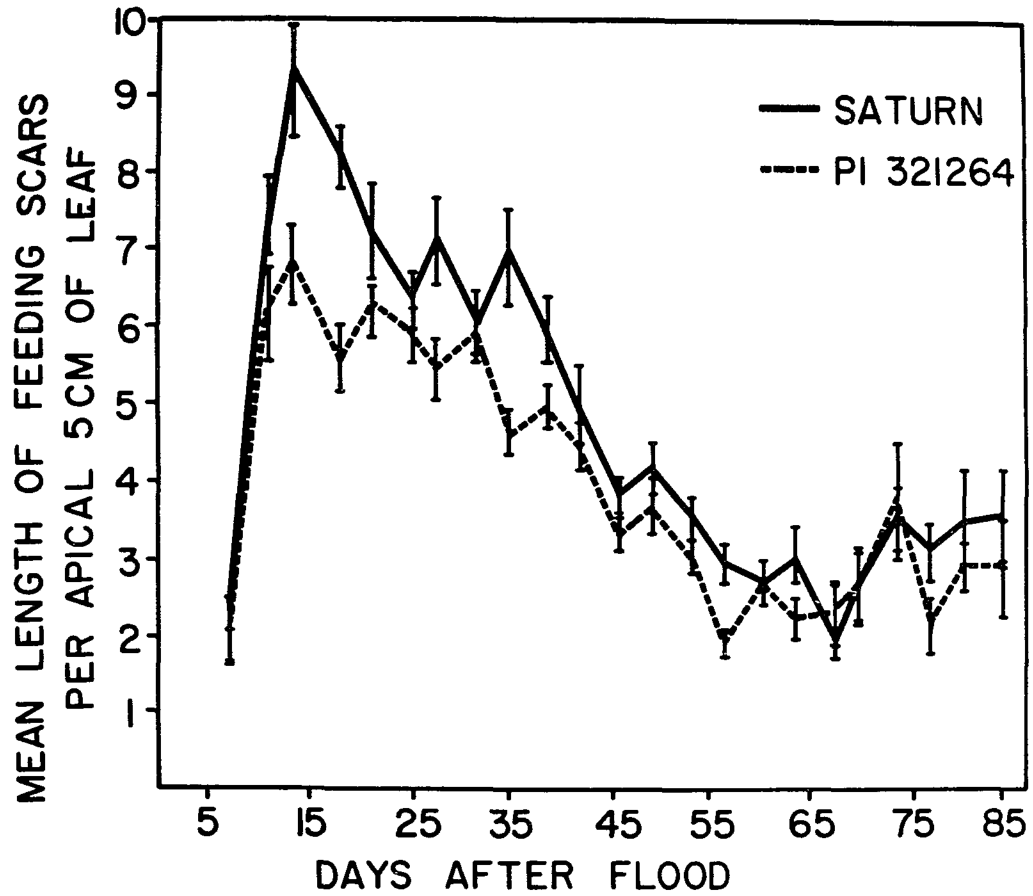

MEAN LENGTH OF FEEDING SCARS
PER APICAL 5 CM OF LEAF
DAYS AFTER FLOOD
SATURN
PI 321264

Table 1. *L. oryzophilus* populations on Saturn and PI 321264 rice. 1981-1982. Crowley, Louisiana.

		$\bar{x}$ number of individuals/plant						
			Larvae					Total
Year	Variety	Eggs	I	II	III	IV	Pupae	Immatures
1981	Saturn	10.9	0.4	1.2	2.1	5.6	2.4	11.2
	PI 321264	11.4	0.3	0.8*	1.3*	3.9*	2.0*	8.3*
	% Reduction		13.9	36.1	36.5	29.1	18.0	25.7
1982	Saturn	1.6	0.7	2.6	4.4	8.1	2.1	17.9
	PI 321264	0.4*	0.4*	1.6*	3.4*	6.5*	1.3*	13.2*
	% Reduction	76.0	39.4	39.2	20.9	19.8	40.3	25.9
	$\bar{x}$ % Reduction	5.6	30.4	38.2	25.9	23.6	28.4	25.8

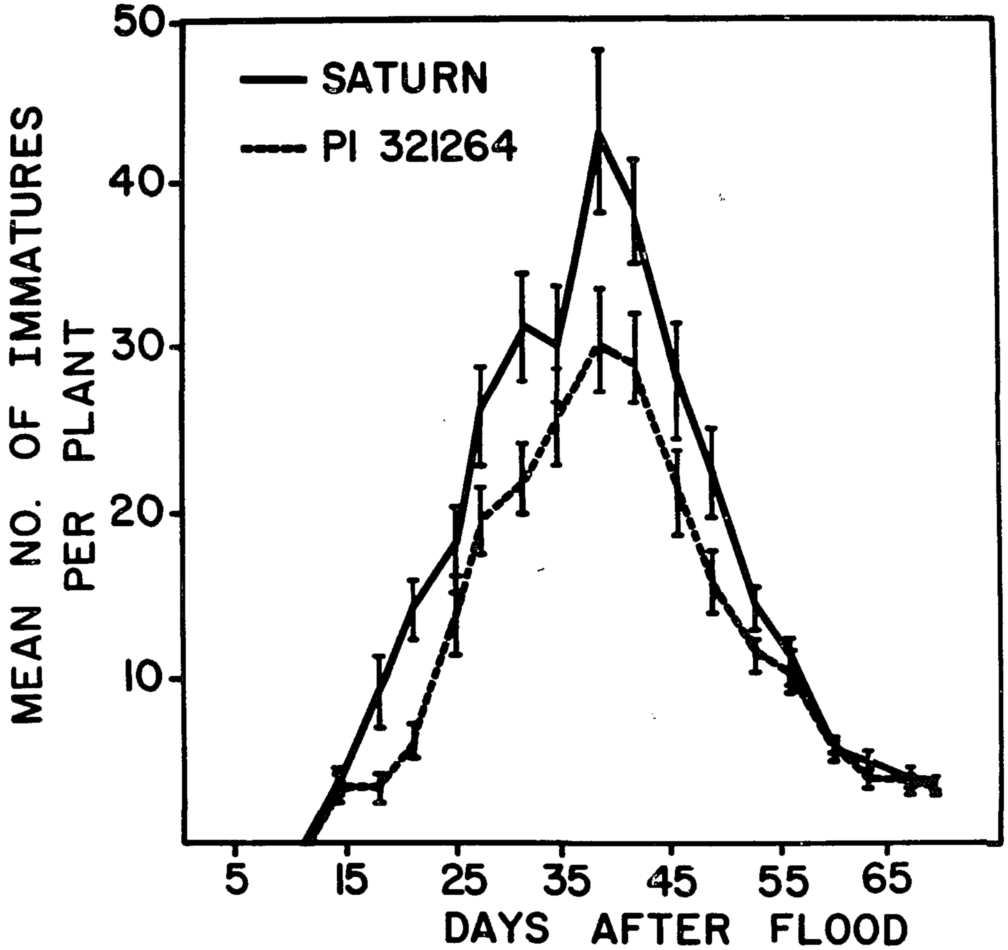
* Means in each column within each year differ significantly ($p < 0.05$) as determined by ANOVA.

is unexplained, since the same staining and counting technique was employed in both years. In 1981, approximately the same number of eggs and first instar larvae were recovered on both varieties, but the number of second, third, and fourth instar larvae, and pupae collected was significantly ($p<0.05$) lower on PI 321264. In 1982, Saturn sustained significantly ($p<0.05$) higher populations of all four instars than PI 321264 (Table 1). The differences in numbers developing on the two varieties reached a maximum in the fourth instar and declined in the pupal stage (Table 1). The mean number of immatures collected from the two varieties was significantly ($p<0.01$) different on nine of 17 sample dates (Fig. 2). There were no differences between varieties for either dry weight, numbers of tillers, or root volume.

The overall population dynamics of RWW on PI 321264 and Saturn was similar within a given year. Peak density of each instar occurred on the same dates, or within a few days of each other. The first and final dates of detection of the various instars were similar. In 1981, the RWW oviposition period peaked approximately two weeks after sampling was initiated, and no larvae were collected until one and one-half weeks after sampling was begun. In 1982, peak egg density occurred three weeks later on both varieties than in 1981; instars I and II peaked two weeks earlier than in 1981; instar III occurred one day later than in 1981; while instar IV and pupae peaked one week earlier than in 1981 (Appendices I, II).

These differences may be due to temperature, as the mean temperatures varied from 1.8 to 2.7°C on the dates of peak density over both years. Precipitation may account for some of the variability in oviposition. In 1982, a bimodal oviposition peak occurred, with a

Figure 2. *Lissorhoptrus oryzophilus* Kuschel populations on resistant (PI321264) and susceptible (Saturn) rice varieties. Crowley, Louisiana. 1981-1982.



SATURN
PI 321264
MEAN NO. OF IMMATURES PER PLANT
50
40
30
20
10
5
15
25
35
45
55
65
DAYS AFTER FLOOD

period of one week between the end of the first mode and the beginning of the second. The reasons for this are unknown.

Stage Duration. The combined duration of all four instars range from 16 to 26 days (Table 2), supporting data of Everett (1966) which indicated that 14 to 21 days are required for the larval period. First instar larvae are sheath-miners, and have a stage duration of about one day. Few first instar larvae were collected in the samples due to the short (one day) developmental time of this instar (Table 2), its sheath feeding behavior, and the sampling interval (every 3-4 days). The number of larvae collected in the samples increased from the second through fourth instars due to the longer duration of these stages.

Spatial Distribution. Taylor's power law and Iwao's $\overset{*}{m}$-m regression indicated clumped distribution patterns for immatures on both genotypes in both years of this study (Tables 3 and 4). Mean/variance slopes of the immatures on both varieties in both years differed significantly ($p<0.01$) from the Poisson slope and indicated that the distribution of all immatures was clumped. A large proportion of the variance in the immature count data was accounted for by the fitted lines obtained from both methods. Use of the power law (Table 3) on PI 321264 resulted in r^2 values of 0.94 to 0.97 (1981), and 0.75 to 0.92 (1982). The r^2 values on Saturn ranged from 0.91 to 0.98 (1981), and from 0.89 to 0.94 (1982). Values of r^2 using Iwao's method (Table 4) ranged from 0.93 to 0.99, and from 0.72 to 0.99 on PI 321264 in 1981 and 1982, respectively. On Saturn, r^2 values ranged from 0.71 to 0.99, and from 0.87 to 0.96 in 1981 and 1982, respectively. The intra-varietal range of differences in the r^2 values may be due to differences in RWW infestation levels between the two years. Since all immature categories

Table 2. Duration estimates of *L. oryzophilus* Kuschel larval instars. Crowley, Louisiana.

Larval Instar	Duration ± SD (Days)1/
I	1.20 ± 0.39
II	2.56 ± 0.59
III	7.14 ± 2.09
IV	10.34 ± 2.19
Total	21.24 ± 5.26

1/ 27.1 ± 5.6°C

Table 3. Regression of log variance (s^2) on log mean (m) for L. *oryzophilus* immatures on PI 321264 and Saturn rice at Crowley, Louisiana. 1981-1982.

Year	Immature Category	PI 321264			Saturn		
		Intercept, a	Slope, b 1/	r^2	Intercept, a	Slope, b	r^2
1981	Small	1.66	1.35	0.95	1.75	1.27	0.98
	Medium	1.73	1.29	0.96	2.04	1.34	0.96
	Large	1.47	1.28	0.97	1.65	1.31	0.96
	Pupae	1.51	1.21	0.95	1.35	1.28	0.91
	Total	1.21	1.46	0.94	1.10	1.53	0.95
1982	Small	1.45	1.42	0.92	1.69	1.44	0.94
	Medium	1.59	1.21	0.90	1.82	1.23	0.89
	Large	1.09	1.15	0.86	1.33	1.33	0.90
	Pupae	1.24	1.31	0.75	1.62	1.37	0.91
	Total	1.22	1.42	0.87	0.78	1.63	0.88

1/ all slopes differed significantly from the Poisson slope, b=1 ($p<0.01$)

Table 4. Regression of mean crowding ($\overset{*}{m}$) on mean density (m) for L. *oryzophilus* immatures on PI321264 and Saturn rice at Crowley, Louisiana. 1981-1982.

Year	Immature Category	PI 321264			Saturn		
		Intercept, α	Slope, β [1/]	r^2	Intercept, α	Slope, β	r^2
1981	Small	0.06	1.42	0.96	0.23	1.27	0.98
	Medium	0.05	1.38	0.97	0.40	1.40	0.97
	Large	0.76	1.27	0.97	0.44	1.21	0.98
	Pupae	0.14	1.27	0.93	-0.46	1.50	0.71
	Total	0.18	1.22	0.99	0.26	1.23	0.99
1982	Small	0.10	1.36	0.94	-0.09	1.51	0.87
	Medium	0.15	1.22	0.93	0.48	1.23	0.93
	Large	-0.97	1.14	0.97	0.93	1.15	0.93
	Pupae	-0.13	1.54	0.72	-0.42	1.71	0.87
	Total	0.65	1.10	0.99	1.12	1.14	0.96

1/ all slopes differed significantly from the Poisson slope, b=1 ($p<0.01$).

had clumped distributions, they were pooled to yield overall intercept, slope, and r^2 values.

Intercept values for both varieties did not differ significantly ($p>0.05$ and $p>0.01$) from zero in the single classification ANOVA of the pooled data for both years. Slopes of the immature categories on both PI 321264 and Saturn in 1981 and 1982 exceeded unity, indicating a departure from the Poisson expectation, and a clumped RWW larval distribution. Values of r^2 explain much of the variance in the distribution for both varieties in both years. Values of b, also tested by using single classification ANOVA, were not significantly ($p>0.01$) different in all variety, year, and variety-year combinations. Additionally, Iwao's β values were tested against Taylor's b values with single classifcation ANOVA. Again, there were no significant ($p>0.01$) variety, year or variety-year differences, indicating that both methods support Taylor's (1965) idea of the species specificity of this parameter.

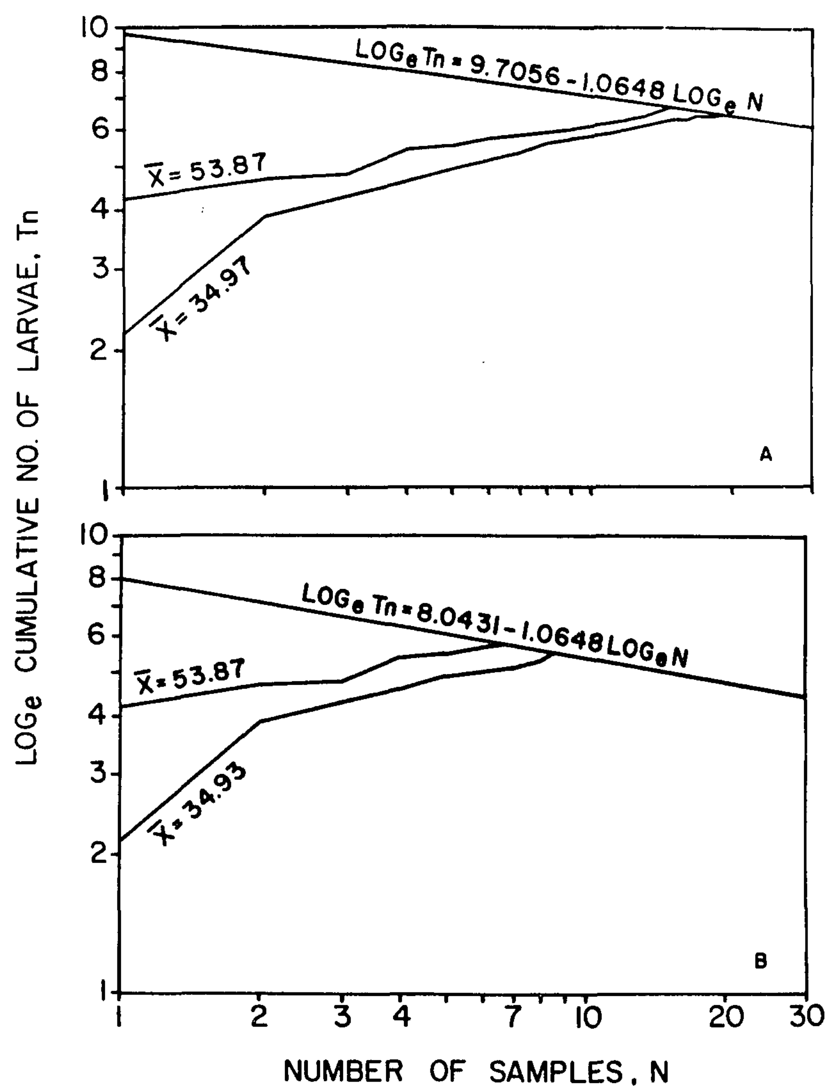
A total of 68 mean-variance linear regressions of RWW immatures on PI 321264 and Saturn (17 on each genotype in both years) were tested for conformation to the Poisson distribution. Twenty seven (79.41%) of the PI 321264 regressions fit the clumped distribution, and seven (20.59%) were random. On Saturn, 26 (76.47%) of the regressions fit the clumped distribution, while eight (23.53%) were random. In most circumstances, insects are seldom distributed at random, and have been described as fitting the negative binomial distribution, especially in the Coleoptera. Examples include the Egyptian alfalfa weevil, *Hypera brunniepennis* (Boheman)(Christensen et al. 1977); wireworms, *Ctenicera destructor* (Brown), and *Hypolithus bicolor* Eschscholtz (Doane 1977); and clover root curculio, Sitona hispidula (Fabricius)(Ng et al. 1977).

The linear regression data cited above indicate that the distribution of RWW immatures is clumped. A strong linear correlation was obtained on a log/log plot of total RWW larval and pupal count variances on means ($r^2 = 0.94$ and 0.92 on PI 321264 and Saturn, respectively in 1981; $r^2 = 0.87$ and 0.92 on PI 321264 and Saturn, respectively in 1982) demonstrating a strong dependence of the variance on the mean, and further indicating the existence of a clumped larval distribution.

Optimum Sample Size. Using Green's (1970) equation, the results indicate that 15 samples are needed to reach the stop line for Saturn ($\bar{x} = 54$ larvae/core) and that 19 samples are needed to reach the stop line for PI 321264 ($\bar{x} = 35$ larvae/core) at a precision level of 0.10 (Fig. 3a). Using a precision level of 0.15, seven and eight samples are needed for Saturn and PI 321264, respectively (Fig. 3b). These results were from larval counts taken five weeks after permanent flood at peak RWW population density.

It appears that the interactions of PI 321264, Saturn, RWW, and environmental factors are complex and multidimensional. The results of this study indicate that only a moderate level of resistance is present in PI 321264, and that this resistance is expressed in the early stages of RWW infestation. Taylor's power law and Iwao's $\overset{*}{m}$-m regression describe RWW immature spatial distribution as clumped. Using the optimum number of samples calculated in this study, a resistant and susceptible variety can be accurately sampled in 2½ to 3 hours, depending on the date of sampling. This procedure estimates population

Figure 3. Sequential sampling scheme for larvae of *Lissorhoptrus oryzophilus*. Crowley, Louisiana. A: Precision level 0.10; B: Precision level 0.15.


LOGe Tn = 9.7056 - 1.0648 LOGe N
X̄ = 53.87
X̄ = 34.97
A
LOGe Tn = 8.0431 - 1.0648 LOGe N
X̄ = 53.87
X̄ = 34.93
B
LOGe CUMULATIVE NO. OF LARVAE, Tn
NUMBER OF SAMPLES, N
10
8
6
4
3
2
1
2
3
4
7
10
20
30

levels with a precision of 0.10, without an inordinate amount of processing time.

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CHAPTER III

SENSILLA OF THE RICE WATER WEEVIL, *LISSORHOPTRUS ORYZOPHILUS* KUSCHEL (COLEOPTERA: CURCULIONIDAE)

This Chapter is written in the style of
International Journal of Morphology and Embryology

ABSTRACT

Scanning electron microscopy of the antennae and venter of the rice water weevil, Lissorhoptrus oryzophilus Kuschel, revealed bifurcate sensilla trichodea, two types of sensilla basiconica, and sensilla placodea on the antennal club. All three sensilla types were also found on the rostrum. Brush-like sensilla were found on the rostrum, legs, coxae, and abdominal sternites VI and VII. All receptor types were found on both males and females, and their distribution was similar. Females possessed significantly ($p<0.001$) more sensilla basiconica and longer sensilla placodea than males.

INTRODUCTION

The rice water weevil, Lissorhoptrus oryzophilus Kuschel, is the most important insect pest of cultivated rice in the United States (Bowling 1967b). Though little information exists concerning L. oryzophilus sensory behavior, adults exhibit a nocturnal positive phototaxis and infest rice growing in thin stands more heavily than in thick stands (Rolston and Rouse 1964a). Adult host recognition therefore, may involve photoreception, hygroreception, olfaction, or some combination of these behaviors. No information exists concerning the sensory morphology of L. oryzophilus, although different sensilla types have been classified for a limited number of Curculionidae. These include the pine weevil, Hylobius abietis (L.)(Mustaparta 1973); the clover head weevil, Hypera meles (F.)(Smith et al. 1976); and the pecan weevil, Curculio caryae (Horn)(Hatfield et al. 1976). This research was initiated to determine types and distribution of sensilla present on the antennae and body of L. oryzophilus.

MATERIALS AND METHODS

Dead weevils were immersed in 80% EtOH for 10 min. and sonicated for 5 min. Specimens were then prepared for mounting as follows: 5 min. in glacial acetic acid; 15 min. in 4% Triton-X 100; and 5 min. in xylene. Specimens were then mounted on aluminum Cambridge type stubs with silver paint (intact weevils) or double stick tape (excised antennae). Stubs were coated with 200 Å of gold-palladium applied by sublimation under vacuum using a Hummer I sputter coater. Specimens were then viewed in an Hitachi S-500 scanning electron microscope, operated at an accelerating voltage of 25 kV. Sensilla types and distribution were determined using whole bodies of six males and six females, and antennae of five males and five females. Numbers of sensilla were determined by counting all sensilla of each type on the dorsal and ventral surfaces of the antennal club. Sensilla lengths were determined by measuring 15 sensilla of each type on the dorsal and ventral aspects of the antennae. Differences in sensilla numbers and lengths were determined using the t-test.

RESULTS

The antennae of L. oryzophilus are composed of six segments (Fig. 1), and the antennal club is divided into four bands of sensilla at the distal end of the club (Fig. 2). Sensilla placodea type I (Figs. 2 and 3) are bi- or multi-furcate arranged radially around the basal edge of band I. The segment of the club beneath this row of sensilla is covered by sensilla placodea type II (Fig. 4), which have 4 to 7 tines, and are appressed to the surface of the club. Exceptions are those which appear at the base of the first band of sensilla, and extend above the surface of the antennal club (Fig. 2)

Bifurcate sensilla trichodea (Fig. 5) occur in alternate rows with sickle-shaped, blunt tipped sensilla basiconica (Fig. 6) over the entire antennal club surface. The rostrum (Fig. 7) possesses four types of sensilla: sensilla basiconica, near the tip of the rostrum; sensilla placodea type I, toward the center of the rostrum; sensilla placodea type II, on the rostral surface; and proximal to these, brush sensilla. (Fig. 8). The brush sensilla are also found on the scape of the

Figure 1. The antenna of the rice water weevil, 200x.

Figure 2. The tip of the antennal club (segments I, II, III, IV), 900x.

Figure 3. Sensilla placodea type I, 1700x.

Figure 4. Sensilla placodea type II, 2000x.

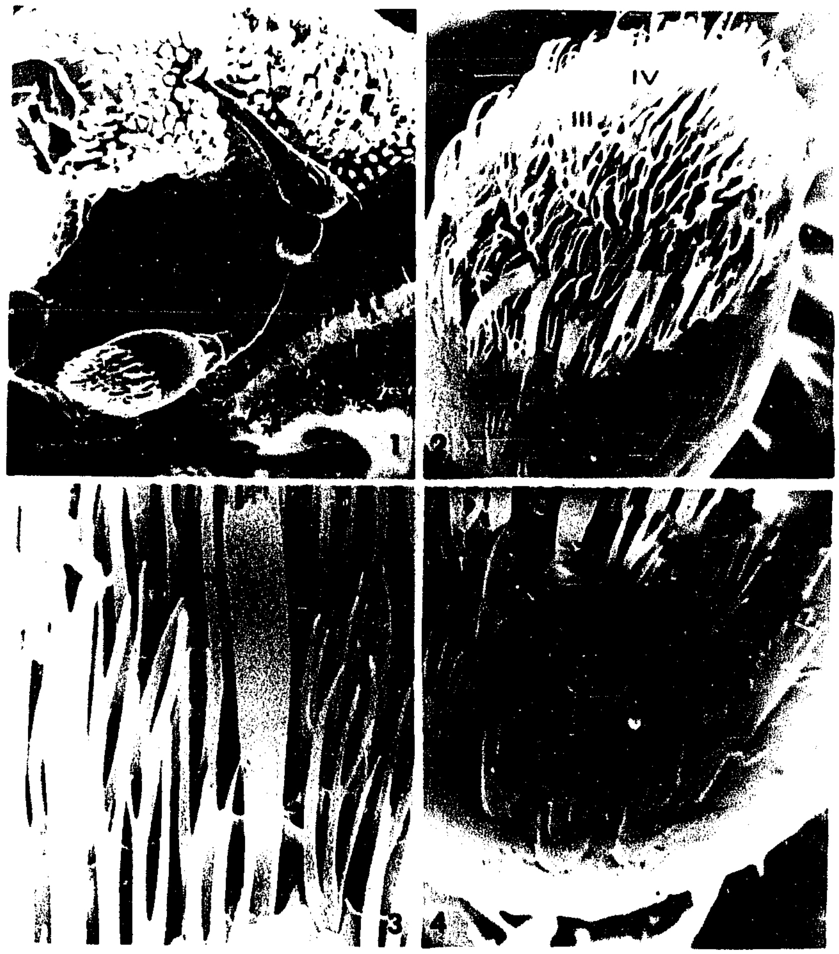
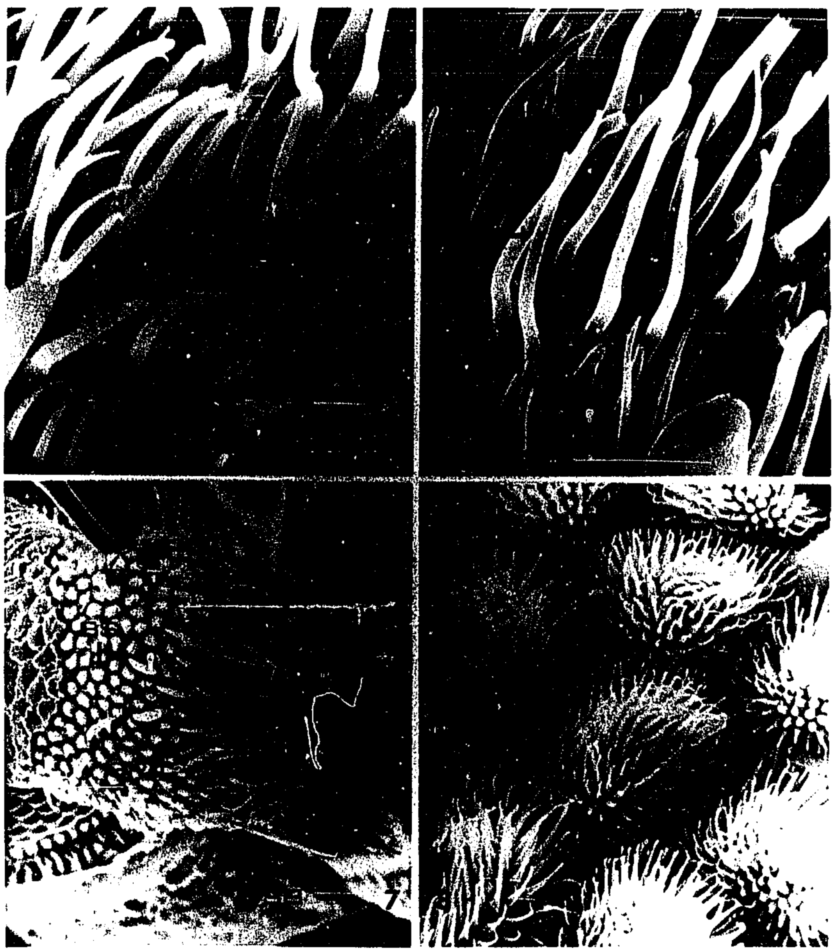

IV
III
1
2
3
4

Figure 5. Sensilla trichodea, 4000x.

Figure 6. Sensilla basiconica, 4000x.

Figure 7. Rostrum of the rice water weevil, 200x.

Figure 8. Brush-sensilla, 2000x.



antennae, the distal end of the tibiae, the base of all coxae, and on abdominal sternites VI and VII.

Significantly ($p<0.01$) more sensilla basiconica were found on females than on males (Table 1), but there were no differences between sexes in the number of any other types of sensilla. The mean lengths of sensilla placodea types I and II were significantly ($p<0.01$) greater on females than on males, while males possessed significantly ($p<0.05$) longer sensilla trichodea than females (Table 2).

DISCUSSION

The general arrangement of the sensilla types on the antennal club of *L. oryzophilus* is much different than that of other Coleoptera that have been studied, however, most of the types of sensilla are similar. Trichoid sensilla of similar lengths have been reported for *H. abietis* (Mustaparta 1973), *H. meles* (Smith *et al*. 1976), *Trypodendrum lineatum* (Olivier) (Moeck 1968), and other scolytidae (Payne *et al*. 1973). Borden and Wood (1966) and Moeck (1968) suggested that trichoid sensilla function as olfactory receptors in *T. lineatum* and *Ips confusus*. Grasse (1975) reported that sensilla trichodea are sensitive to mechanical stimuli, such as touch, pressure, and traction, for insects in general. The large number of sensilla trichodea found on *L. oryzophilus* (Table 1) may also serve as chemo- or mechanoreceptors.

Sensilla basiconica similar to those on the antennal club of *L. oryzophilus* have been described for *T. lineatum* (Moeck 1968), *H. abietis* (Mustaparta 1973), and several scolytid species (Payne *et al*. 1973). Electrophysical and/or behavioral studies conducted by these researchers, as well as the presence of pores on the surface of the sensillum suggest an olfactory function. Mustaparta (1975) demonstrated

Table 1. Mean number of sensilla on the antennal club of *Lissorhoptrus oryzophilus*.1/

Surface	Sex	Sensillum Type: Placodea Type I	Placodea Type II	Trichodea	Basiconica
Dorsal	Male	10	42	70	102
	Female	12	49	60	130*
Ventral	Male	10	43	70	104
	Female	8	55	58	128*

1/ Mean of 5 individuals of each sex.
* $p<0.01$, t-test.

Table 2. Mean lengths (μm) of various sensilla types on the antennal club of *Lissorhoptrus oryzophilus*.1/

Sex	Sensillum Type			
	Placodea			
	Type I	Type II	Trichodea	Basiconica
Male	17.55	11.86	15.54	14.43
Female	23.13*	25.16**	13.32*	13.88

1/ Mean of 5 individuals of each sex.
* $p<0.05$, t-test.
** $p<0.01$, t-test.

electrophysiologically that this sensillum type acts as a pheromone receptor in H. abietis. Other researchers (Slifer 1954, 1967, Schneider and Steinbrecht 1968, Payne et al. 1973, Norris and Chu 1974, Grasse 1975), report chemoreceptive functions for Coleoptera as well as other insect orders.

Placoid sensilla have not been reported to occur in the Curculionidae. In L. oryzophilus, these sensilla are restricted in both number and distribution. Twenty sensilla placodea type I occur on the proximal end of the first antennal segment at the edge of the first band of sensilla, while 85 to 104 sensilla placodea type II occur in the area of the first antennal segment. This type of sensillum functions as an olfactory receptor in Homoptera and Hymenoptera (Lacher and Schneider 1963, Slifer et al. 1964), and as a hygroreceptor (Schneider 1964) and mechanoreceptor (Thurm 1964) in Apis mellifica. Additionally, Callahan (1973) has postulated that this type of sensillum may "be a specialized sensor which resonates by shape to some infrared line or lines from attractant or host plant scents". Therefore, it seems likely that sensilla placodea act as chemo- or mechanorecptors in L. oryzophilus.

Brush sensilla have been found in other species of Coleoptera, and referred to as setiferous punctures (Casey 1905, Halstead 1963), a patch of yellow setae (Triplehorn 1952), and fovea (Wheeler 1979). As with L. oryzophilus, these structures have been reported to occur on metathoracic tibiae, abdominal sternites, antennal segments, coxae, femora, and head appendages (Murray 1864, Casey 1905, Triplehorn 1952, Halstead 1963, Wheeler 1979). Unlike other Coleoptera that have been studied, where only males possess brush sensilla, these sensilla occur on both male and female L. oryzophilus. Because of their occurrence on many of the ventral parts of the body of L. oryzophilus, it is possible that these sensilla act as mechanoreceptors to aid females during oviposition, and males during copulation. Since L. oryzophilus is semi-aquatic, brush sensilla may also help individuals orient in or detect movement in water.

Four types of sensilla exist on the antenna, rostrum, tibia, coxa, and abdomen of L. oryzophilus. Trichoid sensilla found on the antennae may serve a chemoreceptive function, based on their resemblance to sensilla trichodea with this function in other insects. Basiconic and placoid sensilla on the antennae may have olfactory or hygroreceptive functions for similar reasons. This is the first report of the occurrence of placoid sensilla on a curculionid. The function of the brush sensillum is unknown at this time, but is thought to be related to mechanoreception, or orientation. In order to determine the functions of the various types of sensilla, electrophysiological, behavioral, and transmission electron microscopic investigations are necessary.

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SUMMARY AND CONCLUSIONS

The rice water weevil, Lissorhoptrus oryzophilus Kuschel, is a problem in the rice producing regions of the United States and Japan. The studies reported herein have added important information to the seasonal history of this pest. There are four larval instars; the head capsule widths being: I, 0.14 to 0.18 mm; II, 0.20 to 0.26 mm; III, 0.28 to 0.38 mm; IV, 0.40 to 0.60 mm. The duration of each instar is estimated as being: I, 1.20; II 2.56; III, 7.14; IV, 10.33 days, respectively. Based on these studies, it will now be possible to time plant resistance sampling to coincide with peak density for any given instar.

Plant resistance studies revealed that the plant introduction PI 321264 possesses moderate resistance, expressed as low-level antibiosis to first instar larvae; and adult feeding non-preference.
L. oryzophilus larval populations are distributed in a clumped fashion under the conditions described in this study. Due to this clumped distribution, it was shown that 15 samples of Saturn (susceptible) and 19 samples of PI 321264 (resistant) will estimate L. oryzophilus populations with a relative variance of 10%.

Scanning electron microscopy revealed sensilla basiconica, sensilla placodea, and sensilla trichodea on the antennal club and rostrum of L. oryzophilus. Additionally, brush-like sensilla were found on the rostrum, legs, coxae, and abdominal sternites VI and VII. Using these electron microscopical studies as a baseline, further research can now be conducted to identify the functions of each type of sensillum. These studies may ultimately benefit olfactory discrimination studies related to plant resistance research.

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APPENDICES

APPENDIX I. Means and variances of larval count data on PI 321264 and Saturn, Crowley, LA. 1981.

	PI321264				Saturn			
t	Untransformed (x)		Transformed ($x^{0.24}$)		Untransformed (x)		Transformed ($x^{0.24}$)	
	$\bar{x}$	s^2	$\bar{x}$	s^2	$\bar{x}$	s^2	$\bar{x}$	s^2
1	0.53	0.70	0.37	0.30	0.60	1.26	0.32	0.31
2	1.07	2.21	0.56	0.39	3.93	11.64	1.21	0.28
3	4.13	14.27	1.20	0.30	9.93	46.21	1.69	0.06
4	6.07	5.35	1.53	0.02	11.87	30.84	1.76	0.04
5	19.33	106.95	1.96	0.16	26.67	159.81	2.17	0.07
6	20.07	126.35	2.01	0.09	34.13	330.70	2.28	0.13
7	24.73	278.21	2.08	0.14	26.80	399.17	2.00	0.49
8	34.93	256.21	2.32	0.08	53.87	697.70	2.56	0.12
9	29.00	176.71	2.21	0.08	36.73	231.21	2.34	0.12
10	25.13	153.55	2.14	0.07	25.00	107.14	2.15	0.04
11	14.67	101.95	1.75	0.33	21.67	199.52	2.04	0.09
12	10.80	31.74	1.74	0.05	12.47	47.84	1.79	0.06
13	7.20	15.17	1.50	0.21	8.53	29.41	1.55	0.24
14	5.80	7.46	1.49	0.04	6.33	9.38	1.52	0.05
15	3.80	6.74	1.27	0.16	4.93	13.07	1.35	0.19
16	4.53	9.98	1.27	0.29	4.73	7.78	1.41	0.05
17	9.00	10.71	1.68	0.02	7.93	11.21	1.62	0.03
18	1.53	1.70	0.91	0.24	2.27	3.35	1.06	0.22
19	1.47	2.84	0.78	0.35	3.20	7.46	1.14	0.26
20	1.33	3.10	0.64	0.41	2.93	4.92	1.12	0.25
21	2.53	2.27	1.10	0.22	1.67	3.10	0.81	0.37
22	1.47	4.41	0.65	0.42	2.33	3.67	1.12	0.14
23	0.53	0.55	0.42	0.29	0.87	1.12	0.59	0.33
24	0.67	0.52	0.56	0.30	1.07	0.92	0.74	0.30
	r^2 = 0.941 ($p<0.01$)		r^2 = 0.274 ($p>0.01$)		r^2 = 0.923 ($p<0.01$)		r^2 = 0.320 ($p>0.01$)	

APPENDIX II. Means and variances of larval count data on PI 321264 and Saturn, Crowley, LA. 1982.

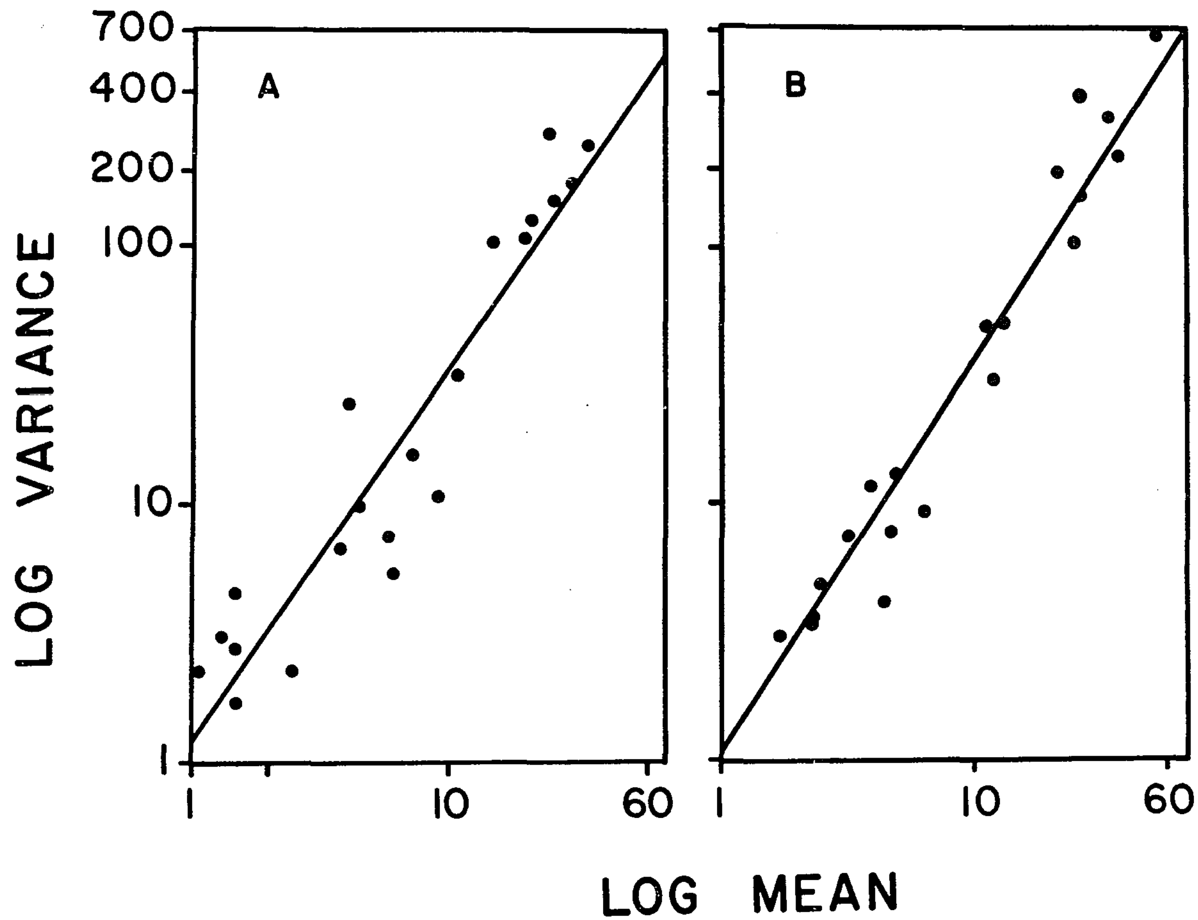
	PI321264				Saturn			
t	Untransformed (x)		Transformed ($x^{0.24}$)		Untransformed (x)		Transformed ($x^{0.24}$)	
	$\bar{x}$	s^2	$\bar{x}$	s^2	$\bar{x}$	s^2	$\bar{x}$	s^2
1	1.50	2.28	0.74	0.41	1.80	1.96	0.87	0.37
2	6.70	26.68	1.30	0.52	16.10	174.10	1.81	0.23
3	10.70	34.01	1.72	0.07	19.30	163.79	2.00	0.07
4	24.80	131.51	2.13	0.08	24.30	241.57	2.08	0.14
5	13.90	41.88	1.85	0.06	21.40	164.27	2.02	0.14
6	22.40	64.04	2.10	0.03	28.80	101.07	2.23	0.04
7	28.30	160.90	2.21	0.06	35.70	143.12	2.35	0.04
8	24.90	82.10	2.16	0.03	29.60	130.49	2.24	0.06
9	19.90	95.21	2.01	0.08	39.60	284.49	2.40	0.05
10	13.00	19.56	1.84	0.02	19.60	84.27	2.02	0.06
11	18.00	76.22	1.97	0.06	23.20	163.73	2.04	0.18
12	11.90	8.54	1.81	0.01	16.30	29.34	1.95	0.03
13	15.00	40.89	1.90	0.03	14.80	42.84	1.89	0.04
14	6.70	11.57	1.55	0.04	5.00	6.00	1.45	0.03
15	3.70	7.12	1.23	0.22	4.70	8.68	1.22	0.42
16	1.90	6.77	0.92	0.28	2.20	3.51	0.99	0.30
17	1.20	1.29	0.78	0.30	2.10	3.21	1.06	0.18
	r^2 = 0.874 (p<0.01)		r^2 = 0.163 (p>0.01)		r^2 = 0.919 (p<0.01)		r^2 = 0.102 (p>0.01)	

APPENDIX III. Raw count data of <u>Lissorhoptrus</u> <u>oryzophilus</u> eggs, larvae, and pupae. Crowley, Louisiana 1981.

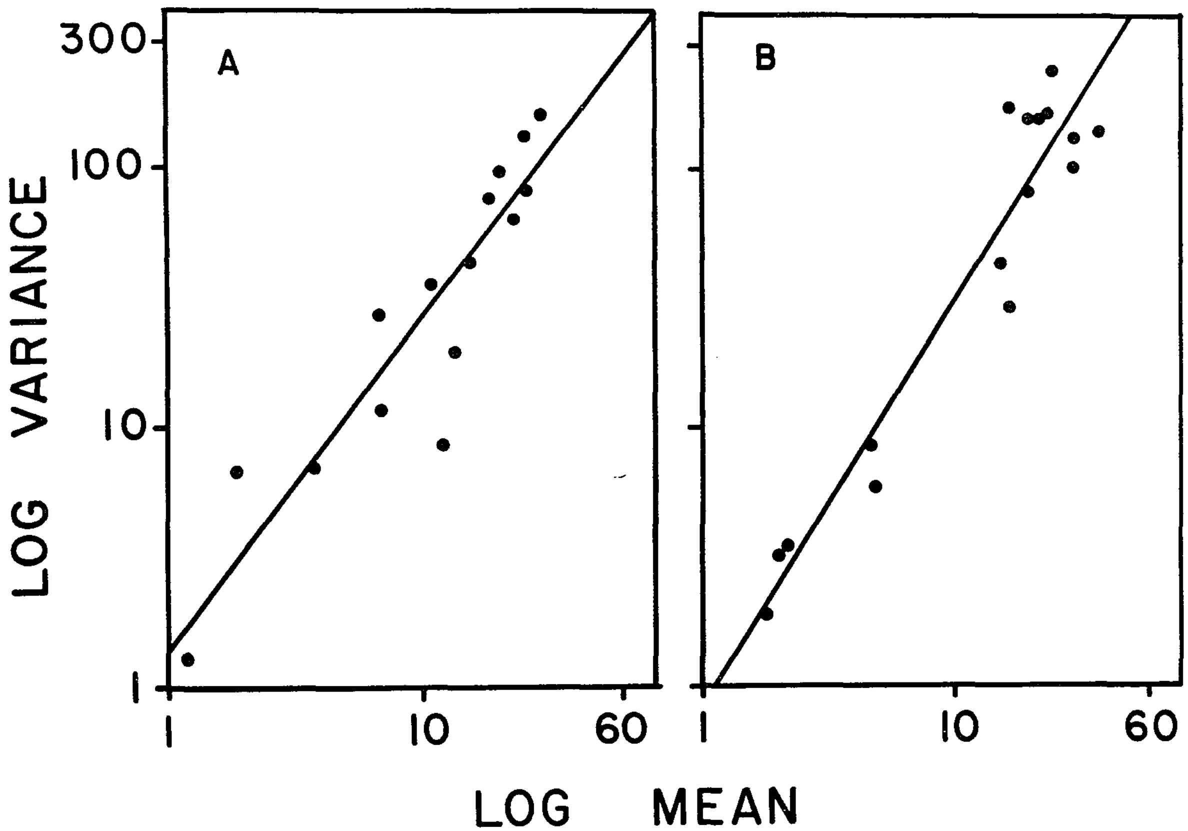
	PI 321264							Saturn						
		Instar							Instar					
Date	Eggs	I	II	III	IV	Pupae	Total	Eggs	I	II	III	IV	Pupae	Total
6/26	215						215	421						421
6/30	343						343	8						8
7/3	333	1	3	1			338	203		4	1	3		211
7/7	248	2	6	2	5		263	538	17	23	11	8		597
7/10	1013	11	21	15	9		1069	902	28	51	47	29		1057
7/14	519	2	3	4	5		533	766	6	16	19	12		819
7/17	712	50	89	72	70	2	995	486	45	125	120	104	1	880
7/21	554	29	55	64	156	1	859	264	20	89	156	206	4	739
7/24	287	19	49	98	144	10	607	356	9	40	127	195	10	737
7/28	186	3	31	108	322	52	702	216	11	69	159	492	64	1011
7/31	22	6	21	54	284	80	467	61	3	34	88	327	94	607
8/4	22		10	38	217	107	394	22	0	6	35	220	104	387
8/7	5		3	14	107	104	233	3	3	5	26	189	100	326
8/11			0	10	68	78	156			3	7	82	99	191
8/14			1	7	44	52	104				2	54	75	131
8/18			0	7	26	51	84				4	18	69	91
8/21			0	4	16	37	57				2	15	55	72
8/25			3	4	16	49	72				3	14	51	68
8/28			2	4	12	52	70				2	12	48	62
9/1				2	6	14	22				1	8	22	31
9/4				0	5	19	24				1	8	39	48
9/8				1	8	12	21					1	41	42
9/11				1	4	31	36					3	22	25
9/15				2	2	19	23					8	27	35
9/18					3	5	8					2	11	13
9/22					5	6	11					1	15	16
Total	4459	122	295	514	1535	781	7706	4246	142	465	811	2011	951	8626

APPENDIX IV. Raw count data of <u>Lissorhoptrus oryzophilus</u> eggs, larvae, and pupae. Crowley, Louisiana 1982.

	PI 321264							Saturn						
		Instar							Instar					
Date	Eggs	I	II	III	IV	Pupae	Total	Eggs	I	II	III	IV	Pupae	Total
7/1		5	4	2	4		15		6	2	7	3		18
7/5		9	20	24	14		67	8	25	68	40	38		179
7/8		3	35	47	21	1	107	46	25	56	64	48		239
7/12		17	63	80	88	0	248	0	9	52	92	89	1	243
7/15		0	10	40	79	10	139	0	7	28	59	111	9	214
7/19		6	27	45	130	17	225	5	14	61	75	119	19	293
7/22	11	8	30	75	154	16	294	0	9	51	73	198	26	357
7/26	18	8	24	48	144	25	267	78	4	38	67	150	37	374
7/29	24	2	11	37	129	30	233	127	4	43	118	180	51	523
8/2	9	0	3	30	61	28	131	0	0	3	10	135	48	196
8/5		5	15	63	83	14	180	4	8	18	62	109	35	236
8/9		0	9	30	69	11	119		1	8	32	78	34	158
8/12		2	3	34	80	31	150		0	4	19	71	44	138
8/16		2	8	15	29	13	67		1	4	13	21	11	50
8/19		2	3	13	16	3	37			2	3	28	14	47
8/23			2	3	5	9	19			1	4	2	15	22
8/26				1	4	7	12				3	3	15	21
Total	62	69	267	587	1110	215	2310	268	113	439	741	1383	359	3303



APPENDIX V. Relationship of log variance to log mean for larval counts of *Lissorhoptrus oryzophilus*. Crowley, Louisiana, 1981.



APPENDIX VI. Relationship of log variance to log mean for larval counts of <u>Lissorhoptrus</u> <u>oryzophilus</u>. Crowley, Louisiana, 1982.

VITA

Gary Leonard Cave was born to Elvira Marie Tortorici Cave and Emory Leonard Cave on August 25, 1952 at Waterbury, Connecticut. At the age of six weeks, he forced his parents to move to Florida in order to escape the cold. He graduated from Maynard Evans High School, Orlando, Florida in 1970. In 1974, he graduated form Florida Technological University (now the University of Central Florida) with a B.S. in Fresh Water Ecology. He earned his M.S. in Entomology from Virginia Polytechnic Institute and State University in 1977.

He has held a graduate research assistanceship in the Department of Entomology at Louisiana State University since September 1979. In December 1981, he married Michelle Jeanine Schlueter.

He is a member of the American Registry of Professional Entomologists, the Entomological Society of America, the Entomological Society of Canada, and Beta Beta Beta Biological Honor Society.

He is currently a candidate for the degree of Doctor of Philosophy.

EXAMINATION AND THESIS REPORT

Candidate: GARY LEONARD CAVE

Major Field: ENTOMOLOGY

Title of Thesis: BIOLOGICAL, ECOLOGICAL, AND MORPHOLOGICAL INVESTIGATIONS OF THE RICE WATER WEEVIL, LISSORHOPTRUS ORYZOPHILUS KUSCHEL, ON TWO RICE GENOTYPES

Approved:

C. Michael Smith
Major Professor and Chairman

William Boyer
Dean of the Graduate School

EXAMINING COMMITTEE:

James B. Graves

W. D. Newsom

Kurt A. McKenzie

John F. Robinson

John B. Baker

Date of Examination:

May 18, 1983