

Purple Nutsedge (*Cyperus rotundus* L.): A Case for Augmentation

by
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ABSTRACT

Although 57 insect species are known to feed on purple nutsedge, *Cyperus rotundus* L., one-half have been reported to feed on crop plants also. Four have been studied in detail; three species of *Bactra* (Olethreutidae) (*minima minima* Meyrick and *venosana* (Zeller) in the Indian Subcontinent and *verutana* Zeller in the United States) and *Athesapenta cyperi* Marshall (Curculionidae) in southeast Asia. Each is adequately host-plant-specific and offers some promise as a biocontrol agent. However, none has proved sufficiently effective in the field, even when introduced into new geographical locations. Augmentation by mass rearing and inundation early in the growing season is indicated. A diet and culture method have been developed for *B. verutana* and the preliminary greenhouse and field tests indicate that larger-scale field tests of augmentation are justified —

Ideally, phytophagous insects to suppress or control weeds should not require augmentation, that is, methods or techniques should not be necessary to increase their effectiveness. Indeed, according to the classical model of biological control of weeds, host-plant-specific suppressants are introduced minus the natural enemies (parasites, predators, diseases) present in the native environment and so will be able to rapidly increase and reach a population explosion within a few years. However, these agents often achieve only a partial reduction in the vigor or density of the host weeds and so do not eliminate them as problems. For example, the 52 successes with the biological control of weeds with insects listed by the National Academy of Sciences (1968) involved 30 insect species used against 24 weed species in 14 countries. Of these only 17% gave complete control, 33% gave substantial control, and 50% gave only partial control.

One additional weed, purple nutsedge, *Cyperus rotundus* L., which is generally considered to be the world's most troublesome (Holm 1969), was omitted from the National Academy of Sciences list, probably because the attempt to control it in Hawaii in 1925 by importing a moth, *Bactra veno-*

sana (Zeller), and a weevil, *Athesapenta cyperi* Marshall, from the Philippines (Williams 1931) was considered unsuccessful (Andres and Davis 1973; Pemberton 1948; Poinar 1964b). Subsequently, both of these species were considered for release in Australia but not used because of the feeling that they would provide insufficient suppression (Cashmore and Campbell 1946). In fact, the introductions of *B. venosana* and *A. cyperi* into Fiji (Parham 1940; Sankaran and Rao 1972) resulted in at most only a slight degree of control by the moth and no establishment of the weevil (Parham 1940; Kamath, personal communication).

When a particular effort, as with purple nutsedge, seems unlikely to produce satisfactory control, it is sometimes terminated. If it is continued, the continuation may take either the form of further field exploration for other biological suppressants or may involve an attempt at augmentation of the effect of the suppressing insect. This augmentation may be a matter of increasing its numbers or, when the insect species is poorly synchronized with the host plant, of providing large numbers at the most susceptible phenological stages of the plant. Thus, after *B. venosana* and *A. cyperi* gave unsatisfactory control of purple nutsedge, both additional exploration for control agents and augmentation were attempted.

FURTHER FIELD EXPLORATION

Insects and other organisms that attack purple nutsedge have been studied in Pakistan, India, Philippines, Australia, Fiji, and the United States (Hawaii, California, Mississippi). A total of 57 species of insects were found attacking this weed: 17 in India and Pakistan (Fletcher 1920, 1932; Ghosh 1922; Rao *et al.* 1971; Sankaran and Rao 1972; Sankaran and Srinath 1966), 1 in Fiji (Kamath, personal communication), 3 in Australia (Common, personal communication; Summerville 1933), and 36 in the United States (Frick, unpublished records; Poinar 1964a, 1964b; Satterthwait 1931). Twenty-two of the American in-

sects have been reared in the mid-South (Table 1). I reared 14 of them through at least one entire generation, *i.e.*, from adult to adult, and another 5, all Lepidoptera, from larvae to adult.

However, one of the 24 species included in the table, the mealybug *Chorizococcus rostellum* was described from "nutgrass" in Mississippi by Lobdell (1930). Poinar (1964a) felt that this host was probably purple nutsedge, but he collected *C. rostellum* only from yellow nutsedge, *Cyperus esculentus*, in southern California. I too found it only on yellow nutsedge at Stoneville. Also when I infested a flat of both purple and yellow nutsedge with *C. rostellum* the insect heavily attacked the yellow nutsedge plants, but none was found on

the purple nutsedge. According to Lavigne (1974), *C. rostellum* still has not been recorded from purple nutsedge.

Approximately one-half of the insects reported from purple nutsedge are also known to feed on crop plants and so are dropped from consideration as potential biological control agents. And, to date the other half contains no biological suppressant that provides more than partial control (Frick and Garcia 1975; Keeley *et al.* 1970; Poinar 1964a, 1964b; Sankaran and Srinath 1966). Among these insects, moths in the genus *Bactra* and the weevil *Athesapenta cyperi* still appear to be the most effective. Rao *et al.* (1971) reported that in India and Pakistan, they are important enemies. In ad-

Table 1. Insects reared from, or associated with, purple nutsedge in Mississippi or adjacent states.

Order and family	Species	Remarks
Thysanoptera Thripidae	<i>Frankliniella fusca</i> (Hinds)	Common name: the tobacco thrips; scarce
Homoptera Cicadellidae	<i>Deltocephalus sonor</i> Ball <i>Draculacephala portola</i> Ball <i>Exitianus exitiosus</i> (Uhler) <i>Graminella nigrifrons</i> (Forbes) <i>Macrostelus fascifrons</i> (Stal) <i>Paraphlepsius abruptus</i> (DeLong)	The blackfaced leafhopper The aster leafhopper
Delphacidae	<i>Delphacodes puella</i> (Van Duzee)	
Aphididae	<i>Rhopalosiphum rufiabdominalis</i> (Sasaki)	Also in Hawaii (Poinar 1964b)
Pesudococcidae	<i>Chorizococcus rostellum</i> (Lobdell)	"nutgrass" (Lobdell 1930) ¹
Coleoptera Chrysomelidae	<i>Chaocnema pulicaria</i> Melsheimer	The corn flea beetle; not reared, but found in association annually at Stoneville
Curculionidae	<i>Anacentrinus blanditus</i> (Casey) <i>Sphenophorus callosus</i> (Olivier) <i>Sphenophorus cariosus</i> (Olivier) <i>Sphenophorus scoparius</i> Horn <i>Sphenophorus venatus vestitus</i> Chittenden	Develops on <i>Zea mays</i> L. (Vaurie 1951) Also in Hawaii (Poinar 1964b) Adults feed on <i>Zea mays</i> (Vaurie 1951) Found in association annually at Stoneville; positively reared in Louisiana ² ; develops on <i>Triticum aestivum</i> L. (Satterthwait 1931)
Lepidoptera Ctenuchidae	<i>Cisseps fulvicollis</i> (Hübner)	Completed several generations in a greenhouse
Glyphipterygidae	<i>Glyphipteria impigritella</i> (Clemens)	Develops on <i>Cyperus esculentus</i> also
Hesperiidae	<i>Lerema accius</i> (Smith)	Develops on <i>Zea mays</i>
Noctuidae	<i>Spodoptera ornithogalli</i> (Guenée) <i>Spodoptera frugiperda</i> (J. E. Smith) <i>Pseudaletia unipuncta</i> (Haworth)	The yellowstriped armyworm The fall armyworm The armyworm; also in Hawaii (Poinar 1964b)
Olethreutidae	<i>Bactra verutana</i> Zeller	Also in California (Poinar 1964a)
Pyrilidae	<i>Elasmopalpus lignosellus</i> (Zeller)	The lesser cornstalk borer

¹ Positively collected only from yellow nutsedge, *Cyperus esculentus* (Frick unpublished record; Lavigne 1974; Poinar 1964a).

² By Dr. L. C. Standifer, Horticulture Department, Louisiana State University, Baton Rouge (personal communication).

dition, Sankaran (1973) noted that the two species appeared to put some biotic pressure on purple nutsedge and thus were suitable for introduction into areas where they might be more effective. Also, in the United States, *Bactra verutana* and the weevil *Sphenophorus cariosus* likewise to be potentially useful species (Frick and Garcia 1975; Keeley *et al.* 1970; Poinar 1964a; Satterthwait 1931).

The host specificity of this genus of moths and of the two species of weevil have therefore been studied.

1. *Bactra* spp.—As far as known, moths in the genus *Bactra* have restricted host plant range. Of the 17 species in the world for which host plants have been reported, 12 are known only from the sedge family Cyperaceae, one from Juncaceae only, three from both Cyperaceae and Juncaceae, and one species from both Cyperaceae and the cattail family Typhaceae (Table 2). Of these, three species have been studied in detail: *B. minima minima* and *venosana* in India and Pakistan [Ghani (personal communication) IN Frick and Garcia 1975; Sankaran 1973] and *B. verutana* in the United States (Frick and Garcia 1975; Keeley *et al.* 1970; Poinar 1964a). The two species from southeast Asia are not known to harm any cultivated plant (Sankaran 1973) and are restricted in their host range to a few species in the genus *Cyperus* [Ghani (personal communication) IN Frick and Garcia 1975]. The one species from the United States, *Bactra verutana*, appears to be less specific, since it has been reported from a bulrush (*Scirpus* sp.), family Cyperaceae, and from a rush (*Juncus* sp.), family Juncaceae (Forbes 1923).

2. *Athesapeuta cyperi*.—No host plants other than those within the family Cyperaceae have been reported for *A. cyperi* (Poinar 1964b; Sankaran 1973; Sankaran and Srinath 1966).

3. *Sphenophorus cariosus*.—Satterthwait (1931) listed 10 species of Cyperaceae in three genera [*Cyperus* (6), *Rhynchospora* (1), and *Scirpus* (*Cyperus* (6), *Rhynchospora* (1), and *Scirpus* (3))] in which *S. cariosus* develop. He later reported this species as destructive to corn (*Zea mays* L.) in Missouri (Satterthwait 1932). The host plant relationships of *S. cariosus* and the three *Sphenophorus* species in Table 1 were subsequently clarified by Vaurie (1951). She pointed out that some species actually breed in corn (such as *S. callosus*) but that only the adults of other species (incl. *S. cariosus* and *S. scoparius*) are damaging

to corn because they puncture stems and bore into stalks.

Sphenophorus cariosus is a large billbug 8 to 13 mm long that is widespread in the southeastern United States. The larvae are very destructive to nutsedge since they consume entire basal bulbs or the tubers and also are quite mobile (they move to nearby bulbs or tubers as they develop). However, this weevil has only a single complete generation per year at Stoneville, and the rather small numbers of adults and larvae that overwinter are inadequate to inflict more than minor damage in the spring to the early and rapidly growing nutsedge (Frick and Garcia 1975; Hauser 1962). Thus, large numbers would have to be reared and released if damaging populations were to be present during the early-season growth of purple nutsedge.

In spite of the reports of damage to corn by adult *S. cariosus*, it seemed desirable to further test the host-plant-specificity of the Stoneville population. As a preliminary step, Frick (unpublished data) reared 12 larvae of *S. cariosus* ranging in size from newly-hatched to nearly grown on the wheat germ diet developed for *Bactra* larvae (Garcia and Frick 1975). Normal-appearing, full-sized adults were obtained that were used as the parent stock for second generation host-plant testing. These adults laid viable eggs on nutsedge plants. The fact that the larvae of this weevil could be so easily reared on artificial diet is not surprising in view of the statement of Vanderzant (1974) that since the introduction of the wheat germ diet in 1960, there has been a proliferation of such diets, with more than 100 species of insect reared on them.

To determine the host preference of adults of the *Sphenophorus cariosus* population at Stoneville, I conducted a greenhouse test in which I used three pots each of the three most common grass crops in the Mississippi Delta: corn, *Zea mays*, sudangrass, *Sorghum sudanense* (Piper) Stapf, and rice, *Oryza sativa* L., plus six pots of nutsedge. These 15 pots were placed at random in a 1-m³ cage, and 36 unsexed field-collected adults were introduced over a 2-week period. The test was ended after 5 weeks when 17 immature *Sphenophorus* (from eggs to teneral adults) were collected from the six pots of nutsedge (from one to five insects in each pot). No eggs or larvae were found in the other plant species and there was no adult feeding on rice. However, the weevils had fed on both corn and sudangrass though nutsedge

was plentiful in the cage. The adult feeding resulted in vertical rows of circular punctures in the lower stems from 0 to 50, or rarely to 100, mm above the soil surface. Damage was about twice

as heavy on corn as on sudangrass, but actual counts of feeding punctures were impossible because they tended to be tightly clustered. Thus, *S. cariosus* should not be mass produced to control

Table 2. *Bactra* spp. for which host plants have been recorded.

Subgenus and species	Distribution	Host plants	References
<i>Bactra</i> Stephens 1834			
<i>bactrana</i> Kennel 1901	Southern Europe, Asia, Africa	<i>Cyperus rotundus</i>	Fletcher 1932; Diakonoff 1973; Sankaran and Srinath 1966
<i>clarkei</i> Diakonoff 1964	South America (Guyana)	<i>Cyperus</i> sp.	Diakonoff 1964
<i>furfurana</i> (Haworth 1811)	North America, Europe, Asia, North Africa	<i>Scirpus</i> sp. (Cyperaceae) <i>Juncus</i> sp. (Juncaceae)	Diakonoff 1964; Forbes 1923
<i>honesta</i> Meyrick 1909	India, Japan	<i>Cyperus serotinus</i> Rothb., <i>Juncus effusus</i> L.	Diakonoff 1964; Shibata 1971
<i>lanceolana</i> (Hübner 1796)	North America, Europe, Asia, North Africa	<i>Juncus</i> spp.	Heinrich 1926
<i>robustana</i> (Christoph 1872)	Europe, Asia, North Africa	<i>Scirpus maritimus</i> L. (Cyperaceae)	Diakonoff 1956
<i>Chiloides</i> Butler 1881			
<i>cpidotis</i> Meyrick 1909	India, Sri Lanka	<i>Cyperus rotundus</i>	Diakonoff 1964; Fletcher 1932; Sankaran and Srinath 1966
<i>philocherda</i> Diakonoff 1964	USA (Florida), New World tropics, Africa	<i>Cyperus</i> sp.	Diakonoff 1964
<i>simpliciana</i> Chretien 1915	North Africa, Saudi Arabia	<i>Cyperus conglomeratus</i> Rothb.	Diakonoff 1959
<i>straminea</i> (Butler 1881)	Hawaii	Sedges, but not <i>Cyperus rotundus</i> (Cyperaceae)	Diakonoff 1956; Williams 1931
<i>venosana</i> (Zeller 1847)	Southern Europe, North Africa, Asia, Australia, South Pacific, Hawaii	<i>Cyperus</i> spp., <i>Kyllingia</i> spp. (Cyperaceae)	Diakonoff 1956, 1967; Ghosh 1922; Poinar 1964b; Sankaran and Srinath 1966
<i>Nannobactra</i> Diakonoff 1956			
<i>blepharopsis</i> Meyrick 1911	Australia	<i>Cyperus rotundus</i>	I. F. B. Common, personal communication
<i>cultellana</i> Zeller 1877	USA (Florida), Columbia, Paraguay	<i>Cyperus esculentus</i> L.	Diakonoff 1964
<i>maiorina</i> Heinrich 1923	USA	<i>Scirpus fluviatilis</i> (Torr.) Gray, <i>Typha latifolia</i> L. (Typhaceae)	Diakonoff 1964; Heinrich 1926
<i>minima minima</i> Meyrick 1909	Southeast Asia, South Pacific	<i>Cyperus rotundus</i>	Diakonoff 1956, 1964; Sankaran and Srinath 1966
<i>oceani</i> Diakonoff 1956	Fiji	<i>Cyperus rotundus</i>	Diakonoff 1956; Kamath, personal communication
<i>verutana</i> Zeller 1875	USA, Mexico, Caribbean Region, South America, (Paraguay), South Africa	<i>Cyperus</i> spp., <i>Scirpus</i> spp., <i>Juncus</i> spp.	Diakonoff 1964; Forbes 1923; Frick and Garcia 1975

purple and yellow nutsedge because of the damage that dispersing adults could cause to corn and sorghum.

THE NECESSITY FOR AUGMENTATION

At present no known host-plant specific insect has been found in the world that has proven capable of satisfactorily suppressing purple nutsedge, including species of *Bactra* and *Athesapeuta cyperi*. The reasons for the general lack of success reported for *Bactra* species were recently reviewed by Frick and Garcia (1975). Factors present in all geographical areas where *Bactra* have been studied are as follows: (1) it is rare that more than one larva develops per shoot, in part because of cannibalism, (2) the larvae do not feed on the tubers, and the feeding on the basal bulbs is limited so a high percentage of basal bulbs survive and produce new aerial shoots; and (3) parasitism reduces the numbers of *Bactra* (Andres and Davis 1973; Poinar 1964a, 1964b; Rao *et al.* 1971). In addition, the moth populations are poorly synchronized with the growth cycle of the host plant in temperate climates. For example, Frick and Garcia (1975) found that low winter temperatures reduced overwintering populations of *B. verutana* by 85 to 90% in the Mississippi Delta. Thus, in central Mississippi and also in central California, there is a delay of about four months from the start of spring growth of nutsedge until damaging populations of *Bactra* appear [in early July in California (Keeley *et al.* 1970) and in early August in Mississippi (Frick and Garcia 1975)].

The situation with *A. cyperi* is quite different. The larvae of *A. cyperi* consume the basal bulbs (Ghosh 1922; Williams 1931). Near Bangalore, India, Sankaran and Srinath (1966) found 16 to 20% of the shoots attacked, which compared favorably with the percentages of shoots attacked by *B. m. minima*. But in the Philippines, the weevil was reported to be somewhat more promising than *B. venosana*. However, after introduction into Hawaii, *B. venosana* dispersed more rapidly and became the more damaging species (Williams 1931). Reasons for the general ineffectiveness of *A. cyperi* are unknown but Poinar's observation that the preoviposition period "may last up to two months or longer" suggest a relatively low reproductive potential.

However, introductions of species of *Bactra* or *A. cyperi* appear to be warranted, but only in locations lacking ecological homologues. For example,

exotic species of *Bactra* should not be introduced in the United States, even though our native *B. verutana* fails to provide satisfactory control, because the life cycle and type of larval feeding damage of these species that have been studied are similar and do not seem to be superior to those of *B. verutana*. Likewise, there appears to be no need to import *A. cyperi* into the United States because the larvae of several species of *Sphenophorous* already occupy and destroy in a similar way the same plant part, namely, the basal bulb.

Instead, the need for augmentation is apparent, and with a plant having the reproductive adaptability of purple nutsedge, it can only be achieved by mass release. In fact, inundation is indicated because of the ability of purple nutsedge to send up new shoots from injured basal bulbs and from the isolated tubers that are all inter-connected by a system of rhizomes.

As for the selection of a natural suppressant, the guidelines laid down by Wieczorek (1973) appear to be pertinent. He stipulated two basic conditions necessary for effective biological control: (1) a host-plant-specific suppressant, and (2) the possibility of rearing it in sufficient quantity to efficiently suppress the target weed. *Bactra verutana* meets both criteria since artificial diets have been developed independently in California (Sieckert *et al.* 1974) and in Mississippi (Garcia and Frick 1975).

In Mississippi, as a result of having a continuous supply of *B. verutana* available (Garcia and Frick 1975), the effects of augmentation were examined in a series of greenhouse (Frick and Garcia 1975; Frick and Quimby 1976) and field tests under cages (Frick and Chandler 1974). In preliminary tests, the introduction of freshly-emerged adult moths into cages did not produce consistent infestations. In the field, the percentages of infestation were proportional to the numbers of adults used: field cages (2x2x2 m or 2x4x2 m) receiving 2, 10, and 60 pairs of adults had 0, 33, and 100% of the caged purple nutsedge infested, respectively. In the greenhouse, two pairs of adults introduced into small cages in two series of tests produced infestations in 60 and 66% of the cages. The erratic results probably reflect a lack of food and of moisture in the cages that killed or weakened the females during their 2-day preoviposition period (Garcia and Frick 1975). However, uncaged moths would be free to disperse before and during the oviposition period, which would reduce effectiveness.

The use of first-instar larvae generally gave consistent results. In the greenhouse, an infestation of shoots with a single application of 2 or 5 larvae per shoot (Frick and Garcia 1975) or with 3 larvae per shoot (Frick and Quimby 1976) generally did significant damage to purple nutsedge. Repeated (weekly) introductions were more damaging than a single one: single infestations averaged 55% reduction in dry weight of shoots; 2, 3, or 4 introductions gave an average reduction of 77%, and 8 introductions reduced top growth 98% (Frick and Quimby 1976).

Less damage was done by the introduced larvae in the field than in the greenhouse. For example, in the greenhouse, the number and weight of tubers were reduced 86 and 88%, respectively (Frick and Garcia 1975), but in the field, these reductions amounted to only 26 and 38% (Frick and Chandler 1974). The difference may result in some degree from the closer confinement of the larvae on the potted plants than on plants in the large field cages. Importantly, early applications increased damage in the field, since the dry weight of shoots was reduced 42% if 9-day old shoots (2.5 to 5 cm tall) were infested, but was reduced only 23% when the shoots were 14 or 20 days old (7.5 to 10 or 12.5 to 17.5 cm tall). These data support the conclusion of Loustalot *et al.* (1954) that the most vulnerable period in the life history of purple nutsedge is within 3 weeks after the appearance of the earliest shoots. During those first 3 weeks, the plants are growing rapidly and have not formed new underground tubers for the storage of nutrients.

PROSPECTS FOR THE FUTURE

Despite the efforts that have been expended on the classical method of the biological control of purple nutsedge since the 1925 introduction of insects into Hawaii, purple nutsedge still cannot be added to the list of successes. Neither is there any real prospect that classical biological control of purple nutsedge will ever be successful. The difficulty is not the lack of host-plant-specific suppressants; several are capable of significantly damaging individual shoots and basal bulbs. Rather it is the reproductive flexibility of the weed, which can sprout new shoots from basal bulbs, even injured ones, or from underground tubers, all of which are connected by rhizomes. The known insect biological control agents are unable to satisfactorily suppress this proliferation of shoots, at least early

in the growing season in temperate climates (or at the start of a cropping season in more tropical regions).

The direction that biological control of purple nutsedge may eventually take may be indicated by the greenhouse and field tests conducted with *B. verutana*. In these studies, increased amounts of damage generally resulted from: (1) the greater the number of larvae (1, 2, or 5) used per shoot (Frick and Garcia 1975), (2) the greater the number of applications of larvae (Frick and Quimby 1976), and (3) the earlier the applications were made after the shoots appeared above-ground (Frick and Chandler 1974). Thus, wherever purple nutsedge is a problem, biological control with insects probably will involve the manipulation of the local population of a native species of *Bactra*, or of an introduced one if no indigenous *Bactra* species exists. This manipulation should consist of an early-season inundation so the larvae can attack the plants early in the growth cycle and before a crop is established. Once a crop is up sufficiently to shade purple nutsedge, the weed will be suppressed because it is shade-intolerant (Lewis and Worsham 1970). However, the procedure has yet to be proved on a field scale and, even if successful there, would be feasible only if the cost were comparable to that of mechanical or chemical control.

REFERENCES

- Andres, L. A., and C. J. Davis. 1973. The biological control of weeds with insects in the United States. *Commonw. Inst. Biol. Control Misc. Publ.* 6: 11-25.
- Cashmore, A. B., and T. G. Campbell. 1946. The weeds problem in Australia: a review. *J. Aust. Council Sci. Ind. Res.* 19: 16-31.
- Diakonoff, A. 1956. Records and descriptions of Microlepidoptera (8). *Zool. Verh. Riiks Mus. Nat. Hist. Leiden* 29: 1-60.
- Diakonoff, A. 1959. Further records and descriptions of *Bactra* species chiefly in Dr. H. G. Amsel Collection. *Bijdr. Dierk.* 29: 173-186.
- Diakonoff, A. 1964. Further records and descriptions of the species of *Bactra* Stephens. *Zool. Verh. Riiks Mus. Nat. Hist. Leiden* 70: 3-81.
- Diakonoff, A. 1967. Microlepidoptera of the Philippine Islands. *U.S. Natl. Mus. Bull.* 257, p. 463.
- Diakonoff, A. 1973. The South Asiatic Olethreutini. *Zool. Mon. Riiks Mus. Nat. Hist. Leiden* 1: 355-356 (*B. bacrana* Kennel only).
- Fletcher, T. B. 1920. Life-histories of Indian insects. Microlepidoptera. IV. *Dept. Agric. India Mem.* 6: 97-116.
- Fletcher, T. B. 1932. Life-histories of Indian Microlepidoptera (Second Series). *Imp. Council Agric. Res. Sci. Monogr.* 2, p. 58.

- Forbes, W. T. M. 1923. The Lepidoptera of New York and neighboring states. Cornell Univ. Agric. Exp. Stn. Mem. 68, p. 729.
- Frick, K. E., and J. M. Chandler. 1974. Culture and early release of *Bactra verutana*, a biological agent for purple nutsedge control. Abstr. Weed Sci. Soc. Am. 1974: 66-67.
- Frick, K. E., and C. Garcia, Jr. 1975. *Bactra verutana* as a biological control agent for purple nutsedge. Ann. Entomol. Soc. Am. 68: 7-14.
- Frick, K. E., and P. C. Quimby, Jr. 1976. Biocontrol of purple nutsedge by *Bactra* in a greenhouse. Weed Sci. (in press).
- Garcia, C., Jr., and K. E. Frick. 1975. *Bactra verutana*, a possible biological control agent for purple and yellow nutsedge: large scale rearing on artificial diet. Ann. Entomol. Soc. Am. 68: 15-18.
- Ghosh, C. C. 1922. Supplementary observations on borers in sugarcane, rice, etc. Agric. Res. Inst., Pusa, Bull. 134: 105-136.
- Hauser, E. W. 1962. Development of purple nutsedge under field conditions. Weeds 10: 315-321.
- Heinrich, C. 1926. Revision of the North American moths of the subfamilies Laspeyresiinae and Olethreutinae. U.S. Natl. Mus. Bull. 132, p. 209.
- Holm, L. 1969. Weed problems in developing countries. Weed Sci. 17: 113-118.
- Keeley, P. E., R. J. Thullen, and J. H. Miller. 1970. Biological control studies on yellow nutsedge with *Bactra verutana* Zeller. Weed Sci. 18: 393-395.
- Lavigne, R. 1974. A preliminary bibliography of insect-grass relationships in North America, exclusive of corn, sorghum, rice, sugarcane, oats, rye, and barley. Bull. Entomol. Soc. Am. 20: 11-23.
- Lewis, W. M., and A. D. Worsham. 1970. The ten worst weeds of field crops—nutsedge. Crop Soils 22: 14-16.
- Lobdell, G. H. 1930. Twelve new mealybugs from Mississippi. Ann. Entomol. Soc. Am. 23: 209-236.
- Loustalot, A. J., T. J. Muzik, and H. J. Cruzado. 1954. Studies on nutgrass (*Cyperus rotundus* L.) and its control. Puerto Rico Federal Exp. Stn. Bull. 52, p. 30.
- National Academy of Sciences—National Research Council. 1968. Principles of Plant and Animal Pest Control. Vol. 2, Weed Control. Natl. Acad. Sci. Publ. 1597, p. 471.
- Parham, B. E. 1940. Notes on weeds in Fiji—IV. Fiji Dep. Agric., Agric. J. 11: 101-103.
- Pemberton, C. E. 1948. Nutgrass insects. Hawaii. Plan. Rec. 52: 78-79.
- Poinar, G. O., Jr. 1964a. Studies on nutgrass insects in southern California and their effectiveness as biological control agents. J. Econ. Entomol. 57: 379-383.
- Poinar, G. O., Jr. 1964b. Observations on nutgrass insects in Hawaii with notes on the host range of *Bactra truculenta* Meyrick and *Athesapenta cyperi* Marshall. Proc. Hawaii. Entomol. Soc. 18: 417-423.
- Rao, V. P., M. A. Ghani, T. Sankaran, and K. C. Mathur. 1971. A review of the biological control of insects and other pests in southeast Asia and the Pacific Region. Commonw. Inst. Biol. Control Tech. Commun. 6, p. 149.
- Sankaran, T. 1973. Biological control of weeds in India; a review of introductions and current investigations of natural enemies. Commw. Inst. Biol. Control Misc. Publ. 6: 82-86.
- Sankaran, T., and V. P. Rao. 1972. An annotated list of insects attacking some terrestrial and aquatic weeds in India, with records of some parasites of the phytophagous insects. Commonw. Inst. Biol. Control Tech. Bull. 15: 131-157.
- Sankaran, T., and D. Srinath. 1966. Observations on the biology of *Bactra* (*Nannobactra*) *minima minima* Meyrick and the damage caused by it to nutgrass, *Cyperus rotundus* L. Commonw. Inst. Biol. Control Tech. Bull. 7: 139-147.
- Satterthwait, A. F. 1931. Key to known pupae of the genus *Calendra*, with host-plant and distribution notes. Ann. Entomol. Soc. Am. 24: 143-172.
- Satterthwait, A. F. 1932. How to control bullbugs destructive to cereal and forage crops. U.S. Dep. Agric., Farmers' Bull. 1003, p. 22.
- Shibata, H. 1971. The olethreutid moth, *Bactra honesta* Meyrick, as a borer of flat-sedge plant, *Cyperus serotinus* Rottb., in paddy field. Proc. Assoc. Plant Prot. Hokuriku 19: 122-123.
- Sieckert, E. E., G. L. Ritenour, and H. G. Davis. 1974. An artificial medium and rearing techniques for colonization of *Bactra verutana*. Environ. Entomol. 3: 196-197.
- Summerville, W. A. T. 1933. Two insect enemies of nutgrass. Queensland Agric. J. 40: 284-287.
- Vanderzant, E. S. 1974. Development, significance, and application of artificial diets for insects. Annu. Rev. Entomol. 19: 139-160.
- Vaurie, P. 1951. Revision of the genus *Calendra* (formerly *Sphenophorus*) in the United States and Mexico. Bull. Am. Mus. Nat. Hist. 98(2): 29-186.
- Wieczorek, H. 1973. Zur Kenntnis der Adlerfarninsekten. Ein Beitrag zum Problem der biologischen Bekämpfung von *Pteridium aquilinum* (L.) Kuhn in Mitteleuropa. Z. Angew. Entomol. 72: 337-358.
- Williams, F. X. 1931. Enemies of nutgrass, p. 308-313. IN F. X. Williams (ed.), Handbook of the Insects and Other Invertebrates of Hawaiian Sugar Cane Fields. Exp. Stn. Hawaii. Sugar Plan. Assoc., Honolulu, p. 400.