

Survival and Growth of *Diabrotica balteata* Larvae on Insect-Resistant Sweetpotato Genotypes^{1,2}

D. Michael Jackson and Janice R. Bohac

USDA, ARS, U.S. Vegetable Laboratory, Charleston, South Carolina 29414 USA

J. Agric. Urban Entomol. 23(2): 77–86 (April 2006)

ABSTRACT Production of sweetpotatoes is severely limited by several insect pests, and new pest-management approaches for this crop are needed. A host plant resistance research program typically depends on reliable bioassay procedures to streamline evaluation of germplasm. Thus, a laboratory bioassay procedure was developed for larvae of the banded cucumber beetle, *Diabrotica balteata* LeConte (Coleoptera: Chrysomelidae). Plugs (0.9 cm diam.) of sweetpotato peel (periderm plus cortex), cortex, or stele were placed into microcentrifuge tubes (1.5 mL) containing 1.0 mL of water–agar to prevent desiccation. One second instar, *D. balteata*, was added to each microcentrifuge tube and held at 25°C for 12 d. Surviving larvae were weighed. The peels and stele of five sweetpotato genotypes ('Beauregard', 'Charleston Scarlet', 'Liberty', 'Regal', and SC1149–19) were evaluated. *Diabrotica* larvae grew larger when they were fed stele from any of the sweetpotato genotypes than when they were fed peels of any genotype. Larval growth was not different among genotypes for any of the stele treatments. However, larval growth on the peels of the resistant genotypes ('Liberty', 'Regal', and 'Charleston Scarlet') was significantly lower than for the susceptible cultivars ('Beauregard' or SC1149–19). Larvae did not survive well or gain much weight when they were starved or fed only the scraped periderm of 'Regal.' There was no difference in the inhibition of larval growth by the cortex or the peel of 'Regal' roots. In general, survival effects were not as dramatic as differences in weight gain. These bioassays were consistent with field results, indicating that these techniques could be useful for evaluating pest resistance in sweetpotato genotypes for *Diabrotica* larvae and other insect species.

KEY WORDS host plant resistance, sweetpotato, *Ipomoea*, *Diabrotica*, bioassay

Several soil-inhabiting insect pests cause economic damage to the edible roots of sweetpotato, *Ipomoea batatas* (L.) Lam. (Convolvulaceae) (Cuthbert 1967, Schalk & Jones 1985). Control of these pests with insecticides is difficult, unreliable, expensive, and may lead to environmental or safety concerns. Thus, there is a need for integrated pest management (IPM) techniques that reduce the im-

¹Accepted for publication 19 March 2007.

²Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

pect of pesticides in sweetpotato production (Talekar 1988, Lawrence et al. 2005). Host plant resistance is one such insect control technique that could result in a more environmentally friendly IPM approach in sweetpotato production (Jansson & Raman 1991, Jackson et al. 2002).

The spotted cucumber beetle (or southern corn rootworm), *Diabrotica undecimpunctata howardi* Barber, and the banded cucumber beetle, *D. balteata* LeConte, are two of the most important vegetable pests in the Western Hemisphere (McKinlay 1992, Capinera 2001). These species belong in the highly polyphagous *fucata* species group (Coleoptera: Chrysomelidae: Galerucinae: Luperini: Diabroticina) and are nondiapausing and multivoltine (Branson & Krysan 1981). They have wide host ranges (Saba 1970, Krysan & Miller 1986), and are among the most damaging insect pests of sweetpotato in the southeastern United States (Cuthbert 1967, Chalfant et al. 1990). The spotted cucumber beetle is a more widespread pest than the banded cucumber beetle that is found only in the southern United States and further south (Pitre & Kantack 1962, Krysan & Miller 1986).

Because insect pests are seldom found when sweetpotato roots are dug, it is difficult to determine whether root injury was caused by wireworms (W) (Coleoptera: Elateridae), cucumber beetles (*Diabrotica* sp. [D]), or flea beetles (*Systema* sp. [S]) (Coleoptera: Chrysomelidae), so damage by this coleopteran pest complex is often lumped into a single category called WDS (Cuthbert & Davis 1971, Schalk et al. 1991). WDS damage can be caused by one or more of these pests, including a combination of cucumber beetle species. However, it was shown that the level of host resistance to the WDS complex could be significantly increased after only four generations of mass selection in randomly crossing populations of sweetpotato genotypes (Cuthbert & Jones 1972). Using these recurrent mass selection techniques (Jones et al. 1986) and a rating system based on a weighted index (Cuthbert & Jones 1972), several improved sweetpotato varieties and advanced breeding lines with resistance to the WDS complex have been developed and released by the USDA, ARS at the U. S. Vegetable Laboratory (USVL), Charleston, South Carolina (Schalk et al. 1991, Collins & Hall 1992, Bohac et al. 2000, 2002, 2003, Bohac & Jackson 2005).

A host plant resistance research program typically depends on reliable bioassay procedures to streamline evaluation of germplasm (Smith et al. 1994). Also, a well-designed bioassay can be critical to advancing an understanding of the mechanisms of host plant resistance to insects in a particular crop. Thus, for the study described herein, we developed a laboratory bioassay to evaluate the survival and development of banded cucumber beetle larvae on storage roots of resistant and susceptible sweetpotato genotypes. Previously, we developed a laboratory bioassay for measuring resistance of sweetpotato genotypes to adult *Diabrotica* species (Jackson & Bohac 2007).

Materials and Methods

Five sweetpotato genotypes were evaluated in these experiments, including two insect-susceptible, orange-fleshed cultivars ('Beauregard' and SC1149-19), two insect-resistant, orange-fleshed cultivars ('Charleston Scarlet' and 'Regal'), and a dry-fleshed cultivar ('Liberty'). All of the sweetpotato entries except 'Beauregard' were from the USDA, ARS breeding program and were developed using

recurrent or mass selection techniques (Jones 1965, Jones et al. 1986). Controls consisted of treatments in which cucumber beetles were fed sprouting wheat (Schalk 1986). 'Charleston Scarlet' and 'Regal' have high levels of resistance to the WDS complex in the field (Jones et al. 1985, Bohac & Jackson 2005, USDA 2005). 'Liberty' has low-to-moderate levels of resistance to the WDS complex (Bohac et al. 2003). 'Beauregard' and SC1149-19 are susceptible to most soil insect pests, including WDS (Rolston et al. 1987, Collins & Hall 1992, USDA 2005).

Storage roots used for these experiments were grown in field plots in Bamberg County, South Carolina, 2003, using standard production practices, except that no insecticides were used. After harvest, the roots were cured at about 45°C for 7-10 d then stored at 15-17°C until needed for the bioassays. Undamaged roots of each genotype were selected for bioassays. While being careful not to scratch the periderm, roots were washed in a 0.1% solution of Tween® 20 (ICI Americas Inc., Bridgewater, New Jersey) nonionic detergent, rinsed with de-ionized water, and allowed to air-dry.

Pieces of unblemished sweetpotato peel (defined here as the periderm plus cortex with stele removed) were then cut from the sweetpotato roots using a sharp knife. Because the thickness of periderm and cortex vary among sweetpotato genotypes (Schalk et al. 1986b), care was taken to ensure that the periderm was not damaged and that no stele portion of the sweetpotato root was left attached to the peel samples. Then, plugs (0.9 cm diam.) were taken from each peel using a #5 cork-hole borer. Plugs of stele, 3-5 mm thick, also were obtained from these sweetpotato roots. Plugs of peel or stele were soaked for 30 min in a 1.5% solution of captan (Captan® Fungicide 50WP, Southern Agricultural Insecticides, Inc., Palmetto, Florida) to prevent growth of fungi. A preliminary experiment showed that there were no measurable effects on survival or feeding behavior of cucumber beetle larvae that were fed either root plugs that had been soaked for 30 min in a captan solution compared with larvae fed untreated root plugs. However, on the untreated root plugs, there often was excessive growth of fungi. The pieces of peel or stele were then allowed to air-dry for 3-4 h. During this drying period, several layers of the outermost parenchyma cells desiccate followed by a gradual suberization of the parenchyma cells below the desiccated cells (McClure 1960, Walter & Schadel 1983). Within a few days, a lignified wound-periderm layer, 3-7 cells thick, forms beneath the suberized cells (Artschwager & Starrett 1931, Morris & Mann 1955).

Each piece of sweetpotato was placed, periderm-side up, into an autoclaved 1.5-mL graduated microcentrifuge tube (clear copolymer polypropylene, Product No. 1415-2500, USA Scientific, Ocala, Florida) that was 20 mm in diameter, 40 mm in height, and had a flat cap. To help prevent desiccation, each microcentrifuge tube was filled with 1.0 mL of water-agar prepared by adding 3.75 g of agar (Fisher Scientific Worldwide, Hampton, New Hampshire) to 250 mL of boiling water. The sweetpotato plug was pushed firmly onto the water-agar. The sweetpotato plug was slightly smaller in diameter than the inside of the microcentrifuge tube. These sweetpotato pieces tended to swell slightly and would become dislodged if they initially fit too tightly. Additional water-agar was placed around the edge of the plug with a pipette to prevent insect larvae from getting underneath it and tunneling into the water-agar below. Care was taken to ensure that only periderm was exposed, and that the edges of the cut pieces were completely covered by the water-agar, which was then allowed to dry. Thus, the insects were

forced to initially feed through the unblemished periderm before reaching the cortex of the sweetpotato peel.

A laboratory colony of *D. balteata* was originally started from adults collected from cucurbit fields at the USVL, Charleston, South Carolina. The colony has been maintained continuously for more than 25 years at the USVL (Schalk 1986, Schalk & Peterson 1990). Rearing procedures require germinating wheat sprouts to support the first two instars, but the remainder of the larval development is on a commercial artificial diet (wheat germ and casein base with no antibiotics; product no. F9760B, Bio-Serv, Frenchtown, New Jersey). Adults also were fed this dry artificial diet. More than 100 *D. balteata* adults that had been collected from sweetpotato fields at the USVL were added to the laboratory colony in 2002.

Every 2 days, cheese-cloth egg pads were collected from the *D. balteata* colony and incubated inside plastic bags containing sprouted wheat. Larval cohorts of a uniform size were collected from the sprouted wheat and used for each replication of an experiment. One second instar *D. balteata* was added to each microcentrifuge tube using a wet brush, and a small hole was punched into the top with a probe to provide ventilation. Twenty microcentrifuge tubes per treatment were set up for each replicate of the two bioassay experiments described below. Tubes were put into 24-hole racks, and the racks were placed in an environmental growth chamber at 25°C for 12 d. Then, surviving larvae were weighed to five decimal places using an A&D GR-202 Semi Micro Balance (A&D Company, Limited, Tokyo, Japan; accurate to 0.01 mg). Initial weights of larvae were too small to be weighed accurately as individuals. Therefore, 5 groups of 10 larvae were weighed at the beginning of each replication of the experiments, but because these larvae could have been damaged during handling, they were not used for the bioassay experiments. The laboratory bench, brushes, core-hole borer, and other handling equipment were frequently sterilized with 70% ethanol during the bioassay procedures.

Data for weight gain and survival were subjected to analysis of variance (ANOVA). When there were significant treatment effects, means were separated by Fisher' least significant difference at the 5% probability level (PROC GLM, SAS Institute 1989).

Experiment 1. Treatments evaluated in this experiment in 2004 were: (i) sprouted wheat, (ii) stele of SC1149–19, (iii) peel of SC1149–19, (iv) peel of 'Beauregard', (v) peel of 'Regal', (vi) peel of 'Charleston Scarlet', and (vii) peel of 'Liberty'. Sprouting wheat (Schalk 1986) was used as a control treatment. In a preliminary test, larvae did not survive on wheat sprouts that had been removed from the wheat kernel, probably because the sprouts decomposed rapidly. Thereafter, two whole wheat kernels with new sprouts were placed in each microcentrifuge tube. Also, two layers of autoclaved paper toweling were placed on the water-agar surface before the wheat was put inside the tubes. This experiment was repeated eight times, with each time repetition being treated as a replication for data analysis (= 160 larvae per treatment).

Experiment 2. Roots from only four of the aforementioned sweetpotato genotypes were evaluated in the second experiment, as the moderately resistant 'Liberty' was deleted. Treatments were: (i) sprouted wheat, (ii) stele of SC1149–19, (iii) peel of SC1149–19, (iv) stele of 'Beauregard', (v) peel of 'Beauregard', (vi) stele of 'Charleston Scarlet', (vii) peel of 'Charleston Scarlet', (viii) stele of 'Regal', (ix) peel of 'Regal', (x) cortex of 'Regal', (xi) periderm of 'Regal', and (xii) starved

larvae. The periderm treatment was made by scraping the periderm from the unblemished surface of whole sweetpotatoes with a scalpel (Peterson et al. 1998, Jackson & Peterson 2000, Harrison et al. 2003a). Periderm from about 4 cm² was placed into each microcentrifuge tube directly on a piece of autoclaved paper towel. The cortex treatment was prepared by first scraping off the periderm from a whole root with a scalpel and then preparing the sweetpotato plug as described above. Starved larvae were simply placed on a piece of autoclaved paper towel on top of the water-agar. This experiment was repeated 13 times, with each time repetition being treated as a replication for data analysis (= 260 larvae per treatment).

Field evaluations (1997–2004). The five sweetpotato entries used in the first bioassay experiment were grown in 16 replicated field experiments at the USVL during 1997–2004. Each sweetpotato entry was planted in 3–4 replications of single row, 25-plant plots arranged in a randomized complete block experimental design. Local production practices were followed, except that no insecticides were applied. When rainfall was not adequate during the growing season, supplemental overhead irrigation was applied. Plots were harvested in the fall when roots had reached maturity.

After harvest, all individual roots were scored for insect damage by previously published procedures (Schalk et al. 1991, Lawrence et al. 1999, Jackson et al. 1999, 2002). The severity index for the WDS complex was calculated by averaging the rating given to each root (1 = 1–5 holes or scars, 2 = 6–10 holes or scars, 4 = >10 holes or scars). Because there were significant yearly fluctuations in the levels of WDS injury and because not every sweetpotato genotype was grown in each experiment, WDS severity index data were weighted by multiplying each data point by a weighting factor calculated as a proportion of the average WDS rating for that experiment against the average for all experiments during the eight years of evaluations. A combined data set for all sweetpotato genotypes was subjected to ANOVA. Means were separated by Fisher' least significant difference at the 5% probability level (PROC GLM, SAS Institute 1989).

Results

Experiment 1. For the first experiment, there were highly significant treatment effects for weight gain ($F = 547.5$; $df = 6, 672$; $P < 0.0001$) and survival ($F = 6.14$; $df = 6, 1150$; $P < 0.0001$) of *D. balteata* larvae. Larvae gained nearly four times as much weight on the sprouted wheat control as they did on any other treatment (Table 1). Larvae had significantly higher weight gain on the stele of SC1149–19 than on any of the peel treatments. Larvae also grew larger on the peels of the susceptible genotypes (SC1149–19 and 'Beauregard') than on the peels of the resistant genotypes ('Charleston Scarlet', 'Liberty', and 'Regal'; Table 1). There was an average loss of weight for larvae on the peel of 'Regal', but survival on 'Regal' peel was no lower than for other peel treatments. Survival effects were not as dramatic as differences in weight gain, and survival of larvae on the sprouted wheat control was not significantly different from any of the treatments except for the peel of 'Charleston Scarlet.'

Experiment 2. For experiment two, ANOVA indicated that there were highly significant treatment effects for weight gain ($F = 811.1$; $df = 11, 1476$; $P < 0.0001$) and survival ($F = 71.5$; $df = 11, 2964$; $P < 0.0001$) of *D. balteata*

Table 1. Weight gain and survival of banded cucumber beetle larvae in a laboratory bioassay, experiment 1, Charleston, South Carolina, 2004.

Treatment	Average weight gain (mg \pm SE) ^a	Survival (% \pm SE)
Sprouted wheat	8.03 \pm 0.37 a	62.5 \pm 4.0 ab
SC1149-19 stele	2.09 \pm 0.19 b	70.8 \pm 4.7 a
SC1149-19 peel	0.57 \pm 0.07 c	60.4 \pm 3.5 b
'Beauregard' peel	0.48 \pm 0.07 cd	71.4 \pm 3.3 a
'Charleston Scarlet' peel	0.18 \pm 0.05 de	46.9 \pm 3.6 c
'Liberty' peel	0.09 \pm 0.05 e	57.8 \pm 3.6 b
'Regal' peel	-0.01 \pm 0.03 e	53.6 \pm 3.6 bc

Means within columns followed by a common letter are not significantly different ($P = 0.05$, LSD) (SAS 1989).

^aAverage initial weight of larvae was 0.59 mg as determined by weighing 5 groups of 10 larvae before each of the eight times this experiment was repeated.

larvae. Larvae grew larger when they were fed stele from any of the sweetpotato genotypes than when they were fed the peels of any of the genotypes (Table 2). Larval growth differed little among the stele treatments of any of the genotypes. Similar to the first experiment, larvae also grew larger on the peels of the susceptible genotypes (SC1149-19 and 'Beauregard') than on the peels of the resistant genotypes ('Charleston Scarlet' and 'Regal'). Starved larvae, those that were fed 'Regal' periderm alone, and larvae fed 'Regal' peel all lost weight. Larvae that were fed 'Regal' cortex gained little weight, which was not significantly different from 'Regal' peel (Table 2).

Larval survival was highest on the sprouted wheat control and the stele from the resistant genotypes. The stele from 'Beauregard' and SC1149-19 degraded faster than the stele from 'Charleston Scarlet' and 'Regal', which contributed to larval mortality. Larval mortality was not significantly different among the peel treatments. Larvae survived poorly when starved or fed 'Regal' periderm alone (Table 2).

Field evaluations (1997-2004). There were highly significant treatment effects for WDS severity index ($F = 59.6$; $df = 4, 119$; $P < 0.0001$) and percent uninfested roots ($F = 102.4$; $df = 4, 119$; $P < 0.0001$) in the field. These measurements of WDS injury (Table 3), which encompass damage by cucumber beetle larvae, were consistent with results of the larval bioassay, indicating that these techniques could be useful for evaluating pest resistance in sweetpotato genotypes to *Diabrotica* species.

Discussion

In this study, *D. balteata* larvae survived well on the sprouted wheat control; however, they performed poorly on the peels of the insect-resistant sweetpotato cultivars. In our bioassay procedure, larvae were required to feed through the periderm to reach the cortex of the peel treatments. *D. balteata* larvae gained

Table 2. Weight gain and survival of banded cucumber beetle larvae in a laboratory bioassay, experiment 2, Charleston, South Carolina, 2004–2005.

Treatment	Average weight gain (mg \pm SE) ^a	Survival (% \pm SE)
Sprouted wheat	8.39 \pm 0.91 a	84.1 \pm 2.0 a
'Regal' stele	0.92 \pm 0.06 b	71.5 \pm 2.8 b
'Beauregard' stele	0.82 \pm 0.01 bc	39.2 \pm 3.0 d
SC1149-19 stele	0.73 \pm 0.08 c	50.7 \pm 3.1 c
'Charleston Scarlet' stele	0.69 \pm 0.06 c	67.3 \pm 2.9 b
SC1149-19 peel	0.31 \pm 0.04 d	57.3 \pm 3.1 c
'Beauregard' peel	0.31 \pm 0.05 d	66.2 \pm 2.9 bc
'Regal' cortex	0.11 \pm 0.01 de	54.2 \pm 3.1 c
'Charleston Scarlet' peel	0.03 \pm 0.03 e	57.3 \pm 3.1 c
'Regal' peel	-0.01 \pm 0.03 e	55.0 \pm 3.1 c
'Regal' periderm	-0.08 \pm 0.02 e	6.7 \pm 1.0 e
Starved larvae	-0.10 \pm 0.01 e	19.6 \pm 2.5 e

Means within columns followed by a common letter are not significantly different ($P = 0.05$, LSD) (SAS 1989).

^aAverage initial weight of larvae was 0.55 mg as determined by weighing 5 groups of 10 larvae before each of the 13 times this experiment was repeated.

Table 3. Average WDS severity index and percent uninfested roots for five sweetpotato genotypes from field trials, Charleston, South Carolina, 1997–2005.

Sweetpotato genotype	WDS index (\pm SE) ^a	Percent uninfested roots (\pm SE)
SC1149-19	1.16 \pm 0.10 a	11.7 \pm 2.1 a
'Beauregard'	0.97 \pm 0.09 b	25.2 \pm 3.1 b
'Liberty'	0.39 \pm 0.03 c	51.1 \pm 4.2 c
'Regal'	0.40 \pm 0.05 c	59.8 \pm 4.0 d
'Charleston Scarlet'	0.31 \pm 0.05 c	64.5 \pm 4.3 d

Means within columns followed by a common letter are not significantly different ($P = 0.05$, LSD) (SAS 1989).

^aAverage from 16 field experiments, 1997–2005 at the U.S. Vegetable Laboratory, Charleston, SC. WDS (wireworm + *Diabrotica* spp. + *Systema* spp.) severity index: 1 = 1–5 scars, 2 = 6–10 scars, 4 = >10 scars, averaged over all roots; maximum score = 4.0.

little or no weight on 'Regal' periderm alone, 'Regal' cortex alone, or whole 'Regal' peels (periderm plus cortex). Larval survival was significantly lower on the periderm, cortex, and peel of 'Regal' roots than it was on 'Regal' stele. Survival on the scraped periderm treatment was significantly lower than any other treatment, except for starved larvae. These results are not surprising because antibiotic

components from the periderm and cortex have been identified from these genotypes (Cuthbert & Davis 1971, Schalk et al. 1986a, Peterson et al. 1998, 2003, 2005, Jackson & Peterson 2000, Harrison et al. 2003a, 2003b). However, this is the first report of a laboratory bioassay for *D. balteata* larvae on the isolated individual components of sweetpotato roots. It should be noted that weight gain of *D. balteata* larvae on sprouted wheat was much higher than on the stele of any of the sweetpotato genotypes, suggesting that additional resistance factors also may be present in sweetpotato stele.

Although Cuthbert & Jones (1972) first showed that the level of resistance to the WDS complex could be increased incrementally using recurrent selection, they did not attempt to simultaneously select for other desirable characteristics. Jones (1990) reported that sweetpotato germplasm could be developed that was resistant to several insect pests and disease pathogens, using a systematic approach. Progress toward improved sweetpotato cultivars must be done through simultaneous evaluation procedures for all desirable characteristics, including pest resistance (Jones et al. 1986). As part of the evaluation procedure, each new sweetpotato genotype must be assessed to see if it has retained its resistance to insect pests. Schalk & Jones (1982) developed a field evaluation technique for banded cucumber beetles in the field. However, this technique requires large, replicated field plots. The results of the present study demonstrate that a laboratory bioassay with *D. balteata* larvae could be useful as part of the evaluation process for resistance to *Diabrotica* species.

Acknowledgments

We thank John Fender, Jennifer Cook, and Louise Cauthen, U. S. Vegetable Laboratory, Charleston, South Carolina, for their excellent technical assistance. This research was supported in part by a grant from the McKnight Foundation, Collaborative Crop Research Program.

References Cited

- Artschwager, E. & R. C. Starrett. 1931.** Suberization and wound-periderm formation in sweetpotato and gladiolus as affected by temperature and relative humidity. *J. Agric. Res.* 43: 353–364.
- Bohac, J. R. & D. M. Jackson. 2005.** Notice of release of ‘Charleston Scarlet’, a very sweet, orange fleshed sweetpotato, with high resistance to insects. USDA, ARS, Washington, DC.
- Bohac, J. R., D. M. Jackson, J. D. Mueller, M. Sullivan & P. D. Dukes. 2003.** Notice of release of ‘Liberty’, a multiple pest resistant, dry fleshed sweetpotato cultivar. USDA, ARS, 15 September 2003, Washington, DC.
- Bohac, J. R., D. M. Jackson, J. D. Mueller, P. D. Dukes & J. M. Schalk. 2000.** Notice of release of ‘Patriot’, an insect-resistant, copper-rose skinned, orange-fleshed sweetpotato cultivar. USDA, ARS, 19 December 2000, Washington, DC.
- Bohac, J. R., D. M. Jackson, P. D. Dukes & J. D. Mueller. 2002.** ‘Ruddy’: a multiple-pest-resistant sweetpotato. *HortScience* 37: 993–994.
- Branson, T. F. & J. L. Krysan. 1981.** Feeding and oviposition behavior and life cycle strategies of *Diabrotica*: an evolutionary view with implications for pest management USA. *Environ. Entomol.* 10: 826–831.
- Capinera, J. L. 2001** Handbook of Vegetable Pests. Academic Press, New York.

- Chalfant, R. B., R. K. Jansson, D. R. Seal & J. M. Schalk. 1990.** Ecology and management of sweet potato insects. *Annu. Rev. Entomol.* 35: 157–180.
- Collins, W. W. & M. R. Hall. 1992.** Sweetpotato breeding and genetics, germplasm and cultivar development, pp. 16–28. *In* A. Jones & J. C. Bouwkamp [Eds.], Fifty years of cooperative sweetpotato research. South. Coop. Ser. Bull. No. 369.
- Cuthbert Jr., F. P. 1967.** Insects affecting sweet potatoes. USDA Agric. Handb. No. 329.
- Cuthbert Jr., F. P. & A. Jones. 1972.** Resistance in sweet potatoes to Coleoptera increased by recurrent selection. *J. Econ. Entomol.* 65: 1655–1658.
- Cuthbert Jr., F. P. & B. W. Davis. 1971.** Factors associated with insect resistance in sweet potatoes. *J. Econ. Entomol.* 64: 713–717.
- Harrison Jr., H. F., J. K. Peterson, D. M. Jackson & M. E. Snook. 2003a.** Periderm resin glycoside contents of sweetpotato, *Ipomoea batatas* (L.) Lam. clones and their biological activity. *Allelopathy J.* 12: 53–60.
- Harrison Jr., H. F., J. K. Peterson, M. E. Snook, J. R. Bohac & D. M. Jackson. 2003b.** Quantitation and potential biological activity of caffeic acid in sweetpotato [*Ipomoea batatas* (L.) Lam] storage roots. *J. Agric. Food Chem.* 51: 2943–2948.
- Jackson, D. M. & J. K. Peterson. 2000.** Sublethal effects of resin glycosides from sweetpotato skins on larvae of the diamondback moth. *J. Econ. Entomol.* 93: 388–393.
- Jackson, D. M. & J. R. Bohac. 2007.** Resistance of sweetpotato genotypes to adult *Diabrotica* beetles. *J. Econ. Entomol.* 100: 566–572.
- Jackson, D. M., J. R. Bohac, J. Lawrence & J. D. Mueller. 1999.** Multiple insect resistance in dry-fleshed sweet potato breeding lines for the USA and Caribbean, pp. 274–280. *In* Progress in IPM CRSP Research, Proceedings of the Third IPM CRSP Symposium, 15–18 May 1998, Virginia Tech Univ., Blacksburg, Virginia.
- Jackson, D. M., J. R. Bohac, K. M. Dalip, J. Lawrence, D. Clarke Harris, L. McCormie, J. Gore, D. McGlashan, P. Chung, S. Edwards, S. Tolin & C. Edwards. 2002.** Integrated Pest Management of Sweetpotato in the Caribbean, pp. 143–154. *In* T. Ames [Ed.], Proceedings of the First International Conference on Sweetpotato Food and Health for the Future, 26–30 November 2001, Lima, Peru. *Acta Horticulturae* No. 583.
- Jansson, R. K. & K. V. Raman. 1991.** Sweet Potato Pest Management: A Global Perspective. Westview Press, Inc., Boulder, Colorado, 458 pp.
- Jones, A. 1965.** A proposed breeding procedure for sweetpotato. *Crop Sci.* 5: 191–192.
- Jones, A. 1990.** Breeding sweetpotato for resistance to multiple insect pests. *HortScience* 25: 1177–1178.
- Jones, A., P. D. Dukes & J. M. Schalk. 1986.** Sweet potato breeding, pp. 1–35. *In* M. J. Bassett [Ed.], Breeding Vegetable Crops. AVI Publ. Co., Westport, Connecticut.
- Jones, A., P. D. Dukes, J. M. Schalk, M. G. Hamilton, M. A. Mullen, R. A. Baumgardner, D. R. Paterson & T. E. Boswell. 1985.** ‘Regal’ sweet potato. *HortScience* 20: 781–782.
- Krysan, J. L. & T. A. Miller. 1986.** Methods for the Study of Pest *Diabrotica*. Springer Verlag, New York, 260 pp.
- Lawrence, J., D. M. Jackson & J. R. Bohac. 1999.** Evaluation of USDA sweetpotato breeding lines as a potential tactic for managing sweet potato pests in the Caribbean and USA, pp. 298–304. *In* Progress in IPM CRSP Research, Proceedings of the Third IPM CRSP Symposium, 15–18 May 1998, Virginia Tech Univ., Blacksburg, Virginia.
- Lawrence, J., S. Tolin, C. Edwards, S. Fleischer, D. M. Jackson, D. Clarke-Harris, S. McDonald, K. Dalip & P. Chung. 2005.** Developing IPM packages in the Caribbean, pp. 95–119. *In* G. W. Norton, E. A. Heinrichs, G. C. Luther & M. E. Irwin [Eds.], Globalizing Integrated Pest Management: A Participatory Research Process. Blackwell Publ., Ames, Iowa, 338 pp.
- McClure, T. T. 1960.** Chlorogenic acid accumulation and wound healing in sweet potato roots. *Am. J. Bot.* 47: 277–280.
- McKinlay, R. G. 1992.** Vegetable Crop Pests. CRC Press, Inc., Boca Raton, Florida.

- Morris, L. L. & L. K. Mann. 1955.** Wound healing, keeping quality, and compositional changes during curing and storage of sweet potatoes. *Hilgardia* 24: 143–183.
- Peterson, J. K., H. F. Harrison Jr. & A. E. Muckenfuss. 1998.** Sweetpotato [*Ipomoea batatas* (L.)] resin glycosides: Evidence of antibiosis effects in the diamondback moth *Plutella xylostella* L. (Lepidoptera: Plutellidae). *Allelopathy J.* 5: 43–52.
- Peterson, J. K., H. F. Harrison Jr., D. M. Jackson & M. E. Snook. 2003.** Biological activities and contents of scopolin and scopoletin in sweetpotato clones. *HortScience* 38: 1129–1133.
- Peterson, J. K., H. F. Harrison Jr., M. E. Snook & D. M. Jackson. 2005.** Chlorogenic acid content in sweetpotato germplasm: possible role in disease and pest resistance. *Allelopathy J.* 16: 239–249.
- Pitre, H. N. & E. J. Kantack. 1962.** Biology of the banded cucumber beetle, *Diabrotica balteata*, in Louisiana. *J. Econ. Entomol.* 55: 904–906.
- Rolston, L. H., C. A. Clark, J. M. Cannon, W. M. Randell, E. G. Riley, P. W. Wilson & M. L. Robbins. 1987.** 'Beauregard' sweetpotato. *HortScience* 22: 1338–1339.
- Saba, F. 1970.** Host plant spectrum and temperature limitation of *Diabrotica balteata*. *Can. Entomol.* 102: 684–691.
- SAS Institute. 1989.** SAS/STAT User's Guide, Version 6, Fourth Edition, Volumes 1 and 2. SAS Institute, Inc., Cary, North Carolina.
- Schalk, J. M. 1986.** Rearing and handling of *Diabrotica balteata*, pp. 49–56. In: J. L. Krysan & T. A. Miller [Eds.], *Methods for the study of pest Diabrotica*. Springer Verlag, New York, 260 pp.
- Schalk, J. M. & A. Jones. 1982.** Methods to evaluate sweet potatoes for resistance to the banded cucumber beetle in the field. *J. Econ. Entomol.* 75: 76–79.
- Schalk, J. M. & A. Jones. 1985.** Major insect pests, pp. 59–78. In: J. C. Bouwkamp [Ed.], *Sweet Potato Products: A Natural Source for the Tropics*. CRC Press, Boca Raton, Florida.
- Schalk, J. M. & J. K. Peterson. 1990.** A meridic diet for banded cucumber beetle larvae (*Diabrotica balteata* LeConte). *J. Agric. Entomol.* 7: 333–336.
- Schalk, J. M., A. Jones & P. D. Dukes. 1986a.** Factors associated with resistance in recently developed sweet potato cultivars and germplasm to the banded cucumber beetle, *Diabrotica balteata* Leconte. *J. Agric. Entomol.* 3: 329–334.
- Schalk, J. M., A. F. Jones, P. D. Dukes & J. K. Peterson. 1991.** Approaches to the control of multiple insect problems in sweet potato in the southern United States, pp. 283–301. In: R. K. Jansson & K. V. Raman [Eds.], *Sweet potato pest management: A global perspective*. Westview Press, Boulder, Colorado.
- Schalk, J. M., J. K. Peterson, A. Jones, P. D. Dukes & W. M. Walter Jr. 1986b.** The anatomy of sweet potato periderm and its relationship to wireworm, *Diabrotica*, *Systema* resistance. *J. Agric. Entomol.* 3: 350–356.
- Smith, C. M., Z. R. Khan & M. D. Pathak. 1994.** *Techniques for Evaluating Insect Resistance in Crop Plants*. Lewis Publ., CRC Press, Boca Raton, Florida.
- Talekar, N. S. 1988.** How to control sweetpotato weevil: A practical IPM approach. AVRDC Publ. 88-292, Taiwan, Republic of China, 6 pp.
- [USDA] U.S. Department of Agriculture. 2005.** USDA, ARS, National Genetic Resources Program. Germplasm Resources Information Network (GRIN). National Germplasm Resources Laboratory, Beltsville, Maryland. Available at <http://www.ars-grin.gov/cgi-bin/npgs/html/croplist.pl>, accessed 24 November 2006.
- Walter Jr., W. M. & W. E. Schadel. 1983.** Structure and composition of normal skin (periderm) and wound tissue from cured sweet potatoes. *J. Am. Soc. Hortic. Sci.* 108: 909–914.
-