Acoustical Detection of the Sweetpotato Weevil (Coleoptera: Curculionidae) in Sweet Potato[1, 2]

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ABSTRACT Ultrasensitive acoustical equipment was used to detect larvae of the sweetpotato weevil, *Cylas formicarius elegantulus* (Summers) (Coleoptera: Curculionidae), in the sweet potato, *Ipomoea batatas* (L.). Methods of expressing results were evaluated with *per cent audible* as the best indicator of larval presence. Sound from moderately infested sweet potatoes (8 to 20 weevils/sweet potato) varied considerably even though infestation rates above 60 weevils/sweet potato resulted in sound throughout most of the observation period. Infested sweet potatoes were detectable after two weeks of weevil development; maximum values were observed a month after infestation. However, the substantial variation of the observation data precluded descriptive mathematical models based on infestation rate or weevil development. Disease processes also caused signals that were indistinguishable from those made by sweetpotato larvae. Other factors that influence detectability are also discussed.

KEY WORDS Acoustics, sound, detection, sweet potato, weevil, *Cylas*.

The sweetpotato weevil, *Cylas formicarius elegantulus* (Summers) (Coleoptera: Curculionidae), is an important quarantine pest of the sweet potato, *Ipomoea batatas* (L.). Research on control methods have been hindered because the immature life stages of the weevil occur within the root (Sutherland 1986) so that the effects of potential treatments cannot be easily measured.

Different techniques have been investigated to discern concealed insect pests. Hansen et al. (1992) examined radiography and ultrasound to visually detect sweetpotato weevils within sweet potatoes. An alternative method is the use of ultrasensitive acoustical equipment to detect larvae in infested commodities. In this approach, subtle sounds produced by insect activity, such as feeding and movement, are amplified and filtered to be distinguished from background noise (Webb et al. 1988). The advantages of acoustical detection are that results are immediate, that data can be easily managed electronically, that the subject material can be repeatedly examined without damage, and that, after a modest investment in equipment, detection can be done in the laboratory without the need of special surroundings (Hansen et al. 1988). Acoustical methods have been applied to detect weevils in grain (Vick et al. 1988b) and fruit flies in citrus (Webb and Landolt 1984) or papaya (Hansen et al. 1988). Yet, a similar procedure has not been applied to pests of sweet potato.

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[2] This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or a recommendation for its use by USDA.

The objectives of this study were to determine if immature life stages of the sweetpotato weevil can be detected by ultrasensitive acoustical equipment, to ascertain the parameters required to measure infestations, and to provide life history information on the weevil. If detectable sounds are perceived from infested sweet potatoes, perhaps the intensity of the noise can be correlated with life stage or infestation level so as to be expressed as a descriptive mathematical model.

Materials and Methods

The studies were conducted in a specially designed sound-insulated room (Vick et al. 1988a). The sound detection equipment was developed by Webb et al. (1988) and has been used in other insect detection studies (Hansen et al. 1988, Sharp et al. 1988, Vick et al. 1988a,b). Each sweet potato was examined with an acoustical coupler containing 4 sensors on the input and a Bruël & Kjær Condenser Microphone (Bruël & Kjær, Nærum, Denmark) on the output to convert the acoustical signal to an electrical signal. The coupler was contained in a foam-lined (1.5 cm thick) lead chamber (0.8 cm thick, 25 cm diam., 42 cm long). The signal was enhanced with a Bruël & Kjær Model 2610 Amplifier and further modified with a Krohn-Hite Model 3700 Filter (Krohn-Hite, Avon, MA). Most studies were conducted with the filter between 150 and 15,000 Hz (Table 1). Settings for the last study were adjusted differently because experience demonstrated that extraneous noise was reduced, yet sensitivity maintained, when only the frequency band of 1,500 Hz was used. Most examinations were for 2 min periods, each having consecutive 1 sec observations ("gate time") with the input and output gains near the limit of the equipment (maximum gain, 100 dB); the threshold above which sound data were collected ("trigger level") was 0.3 to 0.5 v (Table 1). The filtered signal was measured using a Hewlett-Packard Model 5316A Universal Counter (Hewlett-Packard, Loveland, CO). The data were stored and organized using a copyrighted computer program developed by the U. S. Department of Agriculture (1987).

Fresh 'Boniato' sweet potatoes of similar shape (weight: 400 ± 250 g; length: 12 ± 4 cm) were obtained from a commercial packing house (J. R. Brooks & Son, Homestead, FL). They were infested in the laboratory by being placed in cages for two days with a breeding population of 100-300 adult weevils. The infestation rate per sweet potato was determined by the number of adult weevils which emerged at the end of the study. Uninfested (controls) and infested sweet potatoes were maintained separately at ambient temperature (25 ± 1°C) in glass or plastic 4-liter containers capped with paper toweling. Diseased or damaged sweet potatoes were not used.

The types of data produced by the computer program have been described elsewhere (Sharp et al. 1988, Vick et al. 1988b, Webb et al. 1988). Briefly, the observation period was divided into small adjustable time segments or "gates." Low intensity sound from the sweet potato was converted to voltage per gate time; when these units exceeded a set threshold or trigger level, they were reported as "spikes." The trigger level was positioned above the background noise. The value of the spike was directly related to the strength of the signal. Initially, observations were expressed as *sum of spikes, maximum spike per observation period,* and *per cent audible* (or the per cent of the observation period containing gates with

Table 1. Equipment settings used to detect larval activity of the sweetpotato weevil in sweet potatoes.

Study	Duration (min)	Total gain (dB)	Trigger level (volts)	Gate time (sec)	Filter (Hz)	
					Min.	Max.
A	2	100	0.3	1	150	15,000
B	2	90	0.5	1	150	15,000
C	2	90	0.5	1	150	15,000
D	10	100	0.3	1	1,500	1,500

spikes). These measurements were graphically compared, and one parameter was statistically selected as appropriate for data analysis of subsequent studies.

The sweet potatoes were examined periodically. To be suitable for quarantine research, the acoustical system must be accurate even with small samples because quarantine security requires postharvest treatments to be at least 99.9968% effective (Couey and Chew 1986). In Study A, 48 sweet potatoes (including 7 controls) were observed once 36 days after infestation to assure sound production from advanced developmental stages. In Study B, 6 sweet potatoes were observed once a week for 5 weeks to determine variability in sound measurements due to weevil development and infestation rates. In Study C, 4 infested and 6 control sweet potatoes were observed once a week for 8 weeks to determine detectability of the weevil from eggs to adult emergence; each week a sweet potato, infested at the same time as the sound-inspected sweet potatoes, was dissected to determine the weevil life stage. In Study D, 4 infested sweet potatoes were observed twice a week for 9 weeks; an empty chamber used as the control because previous studies demonstrated that any load on the sensors could produce extraneous noise. Other long-term studies with as many as 50 sweet potatoes were initiated in late summer, but were canceled early because of disease contamination.

Data were summarized and analyzed by using SAS procedures (SAS Institute 1988). The most reliable measurement of sound was determined by linear regression using the General Linear Model procedure; the parameter with the highest coefficient of determination (r^2) was selected. Nonlinear regression models also were examined by using TableCurve (Jandel Scientific 1991). To compensate for the non-normal data distribution and variance heterogeneity, data from Study C were first ranked by PROC RANK before conducting Student's *t* tests (PROC TTEST) which is the equivalent to a Wilcoxon rank sum test (Zar 1974, SAS Institute 1988).

Results

Study A. The number of spikes was generally related to the number of adult weevils emerged from the sweet potatoes (Fig. 1). Uninfested and infested sweet potatoes emitted some noise, but generally only highly infested sweet potatoes produced many spikes. Linear regression tests verified that the *per cent audible* value had the best correlation of the sound data with infestation rate, although the association was too weak to produce an accurate predictive mathematical model (Table 2). Nonlinear regression models, including those identified by Hagstrum et al. (1988) were inconsistent and did not have an appreciably better fit than the linear ones.

Study B. Frequency of noise during an observation period changed with both infestation rate and weevil development (Table 3). The greatest activity occurred within the first couple of weeks, then declined, perhaps due to pupation and adult emergence. Also, infestation rates above 60 weevils/sweet potato produced noise for nearly the entire observation period.

Study C. The infestation rate ranged from 22 to 120 weevils/sweet potato. Average *per cent audible* between the controls and infested sweet potatoes of the first two observation periods, when the weevils were in the egg stage, was not significantly different (Table 4). The standard error of mean (SEM) of *per cent audible* for infested sweet potatoes ranged from 1.0% for Week 1 to 28.1% for Week 6 which suggested increased variability in intensity of activity during development; maximum activity within all infested sweet potatoes was at five weeks. The SEM of *per cent audible* for the controls ranged from 4.1% in the second week to below 1% for all subsequent observation periods.

Study D. The sound detection equipment was adjusted to increase sensitivity and observation period, but to filter all except a narrow frequency band. Even with these adjustments, the results were similar to the previous study (Fig. 2). The control data indicated that the internal noise of the system contaminated up to 20% of the gates within each observation period. Yet, the sound produced by the moderate infestation rate (6 to 14 weevils/sweet potato) was detectable above that of the control observations. The greatest activity occurred in the middle of the study (between 15 and 39 days) with the *per cent audible* later decreasing due to pupation and adult emergence.

Discussion

The acoustical detection system requires that larvae within a commodity continuously make sounds by feeding and movement. Intermittent and isolated spikes come from other sources not related to larval behavior. For example, an individual large spike may originate from gases escaping from a structure within the commodity. If this occurred, then the use of the values *sum of spike* (Fig. 1a) or *maximum spike* (Fig. 1b) would confound the observation of weevil activity. However, *per cent audible* (Fig 1c) would be a better measurement; a high value would indicate larval behavior because feeding and movement are continuous activities whereas a low value may include only spurious spikes.

Although *per cent audible* may be a good indicator of the presence of infestation, this value is a poor measure for estimating infestation rates. In Study B, the *per*

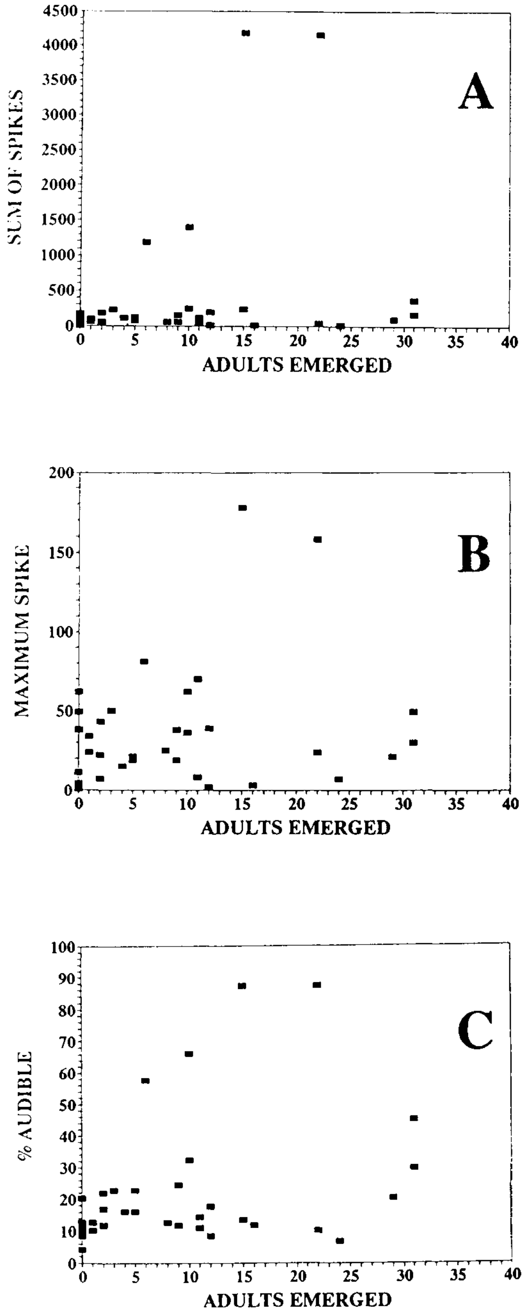

Fig. 1. Comparison of different expressions of sound detection from individual infested sweet potatoes with their number of emerged adult weevils (Study A): A, *sum of spikes;* B, *maximum spike;* C, *per cent audible.*

Table 2. Regression analysis between types of sound measurements of examined sweet potatoes and number of emerged adult weevils (Study A).

Parameter	df	*F*	Intercept	Slope	r^2
Per cent audible	44	12.27†	2.64	0.23	0.222
Total spikes	44	5.85*	68.84	34.23	0.120
Maximum spike	44	4.76*	27.54	1.47	0.100

* Significant at $P < 0.05$.
† Significant at $P < 0.01$.

Table 3. Comparison of *per cent audible* from individual infested sweet potatoes over five weeks (Study B).

Sample	Weight	Length	Emerged	Week				
(#)	(g)	(cm)	Adults	1	2	3	4	5
1	320	10	1	5	8	25	9	33
2	159	8	8	8	30	3	30	3
3	477	12	14	42	9	16	10	30
4	153	8	20	25	90	37	25	5
5	221	12	61	62	100	87	96	23
6	386	14	90	78	88	34	29	74
7	280	13	122	100	100	78	58	42
8	287	16	142	98	100	93	64	48
$\bar{x}$	285.4	11.6	57.3	52.3	65.6	46.6	40.1	32.3
SEM	39.1	1.0	19.5	13.5	14.9	12.2	10.6	8.2

Table 4. Comparison of weekly *per cent audible* ($\bar{x} \pm$ SEM) between control (n = 5) and infested (n = 3) sweet potatoes by the equivalent of the Wilcoxon rank sum test (Study C).

Week	Life stage	Control (%)	Infested* (%)	T
1	Egg	2.7 ± 0.9	4.0 ± 1.0	0.904
2	Egg	6.6 ± 4.1	3.1 ± 1.6	0.143
3	Early instar	0.3 ± 0.2	5.1 ± 4.7	0.366
4	Early instar	0.3 ± 0.2	6.8 ± 5.5	2.957†
5	Early & middle instar	0.3 ± 0.3	28.0 ± 13.6	5.071‡
6	Middle & late instar, pupa	0.5 ± 0.3	42.9 ± 28.1	1.341
7	Pupa & adult	0.7 ± 0.3	3.1 ± 0.7	3.304†
8	Pupa & adult	0.3 ± 0.2	7.6 ± 7.2	0.977

* Infestation rate was 22 to 120 weevils per sweet potato.
† Significant at $P < 0.05$.
‡ Significant at $P < 0.01$.

cent audible within an observation period was usually high, even for moderate infestation rates (8 to 20 weevils/sweet potato) (Table 3). Furthermore, the lack of fit ($r^2 < 0.3$) for any mathematical model precludes predicting infestation rates by sound alone. Hagstrum et al. (1988) developed mathematical models to estimate populations of the lesser grain borer, *Rhyzopertha dominica* (F.), by using acoustical methods, but wheat may be a better medium for sound detection than sweet potatoes.

The logistics of sound detection in sweet potatoes differs from that of other commodities such as grain. The bulk of sweet potato tissue probably facilitates sound absorption from the small internal-feeding larvae. Although the purpose of the trigger level is to eliminate background noise, interference can come from uncontrolled sources (Hansen et al. 1988). Because the acoustical detection equipment does not recognize types of sound, feeding noises should be monitored by earphones before data collection. Noises by sweetpotato weevil larvae were distinct; adjusting the filter to only 1,500 Hz seemed to isolate their sounds. However, the gain, which had to be increased to compensate for faintness, also increased equipment static. Added sensitivity may require accepting some internal noise. No specific setting is suitable for all situations.

In conclusion, sweet potato infestations were detected by the ultrasensitive acoustical equipment. However, different factors became apparent that affect

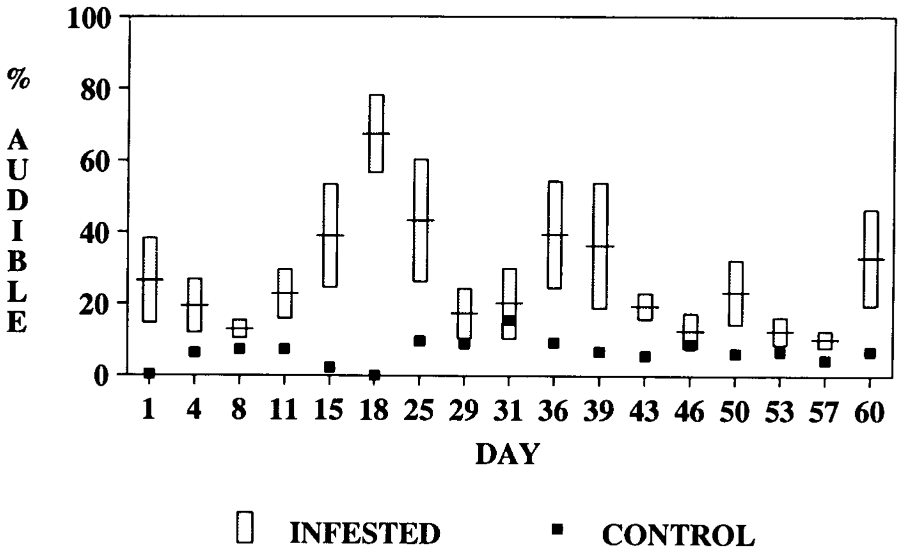

Fig. 2. Comparison of *per cent audible* ($\bar{x} \pm$ SEM) per observation of infested sweet potatoes (n = 5) with an empty chamber used as a control (filled square) (Study D).

the quality of detection. The acoustical system depends on larval activity; other mediating variables are larval stadium, size, location, density, and physiological state. Likewise, the condition of the sweet potato, particularly size and shape, are involved as are aging and disease. Fungal growth and host structure deterioration cause sound, but at patterns that are inseparable from those caused by weevil. Improvements in the software and equipment are needed to differentiate sources of sound. Abiotic factors that affect the detection system include the internal electrical noise within the equipment and adjustments to signal filtration and amplification. These sources of variability make predicting biological elements (e.g., infestation rates) so difficult that accurate mathematical models are impossible. If the intent is merely to determine weevil presence, then the system may be suitable. Also, the ability of the system to detect disease and physiological state of the sweet potato should be further investigated.

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