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GREENHOUSE HEATING WITH A WOOD GASIFIER FURNACE[1]

L. N. SHAW
Frazier Rogers Hall,
IFAS, Agricultural Engineering Department,
University of Florida,
Gainesville, FL 32611

D. M. POST
IFAS, School of Forest Resources and Conservation,
University of Florida,
Gainesville, FL 32611

C. E. ARNOLD
IFAS, Agricultural Research Center,
R. 4, Box 63,
Monticello, FL 32344

Abstract. **The expense of fuel for greenhouse heating has greatly escalated since the OPEC oil embargo of 1974 and operators have been searching for less expensive and more dependable fuel sources. Wood or other biomass is a logical substitute because it is readily available and is usually a waste material.**

A wood fueled, gasified furnace has been evaluated for heating a greenhouse in north Florida. This unit heats water that is stored in a large insulated tank located under the middle bench in the house. The hot water is circulated throughout the house heating system as needed by a thermostatically controlled pump.

During one season of evaluation the system shows promise of considerable savings in heating costs.

Costs of greenhouse heating have risen drastically with oil prices increasing from $2.00 a barrel in 1971 to over $32.00 per barrel in 1981. LP gas and electricity costs for heating greenhouses have generally paralleled the escalating oil prices. Greenhouse operators have been looking for alternative heating methods as well as ways to reduce heating requirements. Utilization of solar energy has been demonstrated to be practical (1). Heat energy from the sun can be stored for use as needed in rock beds or solar ponds. Research on the utilization of wood and other biomass as a replacement for petrochemical fuel is being conducted by researchers at the University of Florida. Work has been concentrated on production of methane (2) and producer gas (3) for heating and for fueling internal combustion engines. The availability of ample supplies of wood prompted this study to investigate ways to substitute this fuel for heating oil or LP gas for heating a greenhouse in north Florida.

Materials and Methods

The greenhouse selected for this study was one of three identical 77m² (830 ft²) units at the University of Florida Agricultural Research Center at Monticello, Florida. The other three houses are heated with LP gas and solar energy with a rock bed heat storage system. The solar and wood heated greenhouses have LP gas backup heating systems.

The wood-fueled heating system consists of a 137,000 kJ/hr (130,000 BTU/hr) wood gasifier hot water furnace coupled to a hot water storage system and heat exchangers around the perimeter of the greenhouse (Fig. 1). Circulation pumps in the system force water through the furnace when it is operating and through the heat exchangers when the

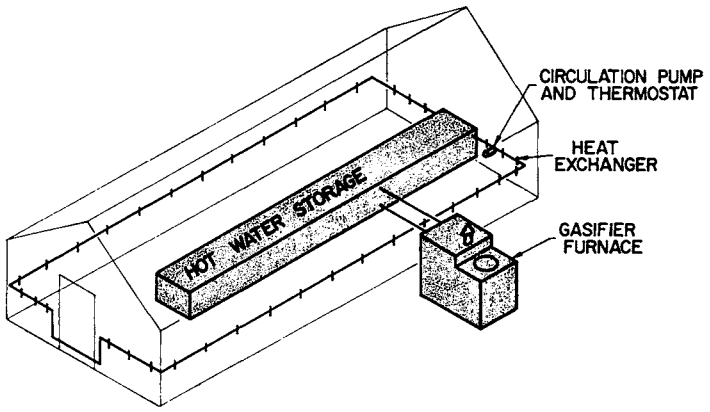

Fig. 1. Schematic of wood gasifier furnace heating system for a greenhouse.

house thermostats call for heat. The furnace heats the 3862 liters (1,022 gal) of water contained in an insulated storage tank under the middle bench of the greenhouse and this water is circulated by a pump through the heat exchangers around the perimeter of the house. In order to obtain clean and efficient combustion, a gasifier furnace must operate at one combustion rate and cannot be modulated in accordance to the heat requirements of the structure. To overcome this heating system limitation, the heat storage system is used and the hot water is drawn from the storage tank as needed to maintain the desired temperature in the house.

Results

Sufficient heat energy can usually be stored in the water to meet the heating needs of the house for at least a 24-hr period so the furnace usually only needs to be "fired" during daylight hours even during the coldest weather. A record of the heating system performance and ambient temperature for a 48 hr period during January 1982 is shown in Fig. 2.

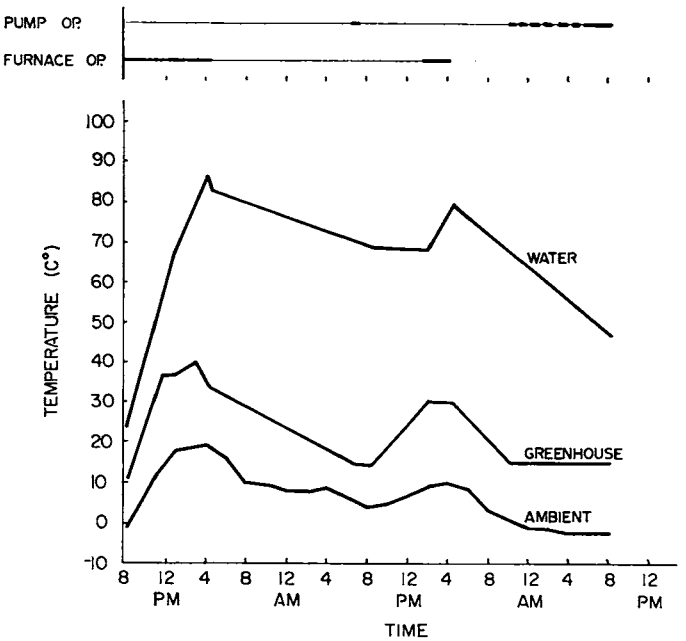

Fig. 2. Heating system performance.

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The furnace operated about 8 hr the first day to get the water initially heated to about 80°C (176°F) and then about an hour the second day. During the second cold night the water temperature dropped from nearly 80°C (176°F) to 47°C (117°F) because water had been circulated intermittently from 10:10 PM to 5:30 AM and then continuously until 8:15 AM. The circulation pump started when the temperature of the air in the house dropped to 14°C (57°F).

Thermostatically controlled exhaust fans on the house set to come on at 33°C (91°F) cycled every few minutes between 11:00 AM and 3:00 PM on the first day and several times during the afternoon of the second day. This overheating of the house is due to solar heating, heat radiating from the hot water storage tank and possibly some thermal cycling of the water through the south loop of the house. The tanks were insulated with rigid glass fiber insulation having a total R value of 3.5 $\frac{M^2C^\circ}{W}$ (20F° hr ft²/BTU) and this could be increased if overheating continues to be a problem. Thermal cycling of the water could be prevented by changing the level of the heat exchanger relative to the tank or by installing a check valve.

During the period reported on in Fig. 2, 176.2 kg (389 lb.) of wood was consumed in the system. This would be equivalent to about 72 liters (19 gal) of LP gas or 51 liters (13.5 gal) of fuel oil. It should be noted that a supplementary LP gas heater set to come on at 8°C never operated during the heating season. It is estimated that 5 cords of wood costing $175.00 will replace about $1200.00 of fuel oil or about $1600.00 of LP gas for the estimated 2000 hr of heating required during the season in this north Florida greenhouse.

Discussion

Due to the complete combustion of wood in this gasification process, there is no visible smoke from the furnace except for a short period during startup. Most, if not all of the tars that cause creosote buildup in the chimneys with wood burning, are consumed in the gasification process resulting in very efficient combustion and a minimum of air pollution.

Heating with wood is not as convenient as using oil, gas or electrical heating since the wood must be cut into 76 cm (30 inch) lengths and hand fed into the furnace. There is very little ash resulting from the combustion of this fuel because of the very high combustion temperatures but the ash must be removed after each 2500 kg (5000 lb) of wood is consumed.

Monitoring of this greenhouse heating system will continue during the 1982-83 heating season but it can be concluded after one season of operation, that heating costs can be drastically cut and that it is practical to heat a greenhouse with wood when the fuel is available.

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RESPONSES OF CERTAIN FLOWERING AND FOLIAGE PLANTS TO EXOGENOUS ETHYLENE

F. J. Marousky
U.S. Department of Agriculture, ARS, Ornamental Horticulture Department, Gainesville, FL 32611
AND
B. K. Harbaugh
University of Florida, IFAS, Agricultural Research and Education Center, Bradenton, FL 33508

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Abstract. **Various flowering and foliage plants were held in light for 3 days at 23.5°C in chambers with flow-through air containing 0, 1, 5 or 10 ppm ethylene. Toxicity symptoms varied depending on plant species and ethylene concentration. Most foliage plants exposed to 1 ppm ethylene were slightly injured, while those exposed to 5 ppm ethylene were more severely injured (leaf abscission, chlorosis, and epinasty). The most critical symptom, leaf abscission, was apparent on** Aphelandra squarrosa, Brassaia actinophylla, Celosia cristata, Coleus Blumei, Crassula argentea, Ficus benjamina, Iresine herbstii, Peperomia obtusifolia, **and** Pilea involucrata. Dieffenbachia maculata **'Rudolph Roehrs' developed severe leaf chlorosis. Plants that developed epinasty during exposure reverted to normal appearance 3-4 days after removal from ethylene atmospheres. Most flowering plants were sensitive to 1 ppm ethylene and had flower abscission or wilting (sleepiness).**

The production of ornamental potted plants in Florida has increased dramatically the past few years. Most of these plants are packaged and shipped to northern markets via truck. With little knowledge about post harvest handling of ornamental plants available (3, 7), few guidelines have been developed for shipping.

Ethylene, a product of natural senescence, is frequently found in shipping environments (1). Ethylene toxicity symptoms can vary from epinasty (1, 5, 15),leaf abscission (3, 5, 8, 9, 12, 13, 14), flower abscission (1, 2) to flower closure (sleepiness) (1, 10). Plant deterioration also can occur in darkness (3, 11, 12) and at elevated temperatures (6, 8, 9, 11, 12), symptoms mimicing ethylene toxicity. Ethylene concentration, duration of exposure and interactions with various environmental parameters (temperature, darkness-light and carbon dioxide) can influence physiological effects of ethylene on plants (1, 5, 6, 7, 9, 11, 12), therefore, determination of the effects of ethylene under standard en-

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vironmental conditions is important when comparing species or cultivars for injury.

In this paper, we report the responses of certain ornamental plants exposed to ethylene for 3 days at 23.5°C in light.

Materials and Methods

Various ornamental plants in pot sizes from 7.5 to 15 cm were obtained from commercial sources, brought to AREC, Bradenton, and held in a greenhouse for 1 to 7 days. At the beginning of each test, plants were selected for uniformity in size and quality. Plants were placed in chambers with flowing air containing 0, 1, 5, or 10 ppm ethylene in a laboratory maintained at 23.5°C. All plants were exposed for 3 days except *Begonia* x *semperflorens–cultorum* Hort. which were exposed for 1 day; begonia plants were also held in the greenhouse as a control. Light was supplied by cool white fluorescent tubes to provide 400 μw/cm^2 (ca. 125 ft-candles for 12 hr/day. There were 6 plants (replications) per treatment in each test. The general procedure for mixing ethylene and air into chambers was similar to that previously reported (9). Air flow in each chamber was regulated to provide one complete change every 45-60 min. Species tested are listed in Tables 1, 3, 4, and 5.

Leaves on each plant were counted prior to and after the 3 day ethylene exposure. In some instances, leaves did not abscise and plant injury was expressed as the number of chlorotic leaves per plant or the degree of epinasty. Epinasty was recorded as 0=no visible damage; 1=slight downward bending of leaf petiole; 2=moderate downward bending of leaf petiole (10-25° increase in size of angle between stem and leaf petiole); and 3=severe downward bending of petiole over 25° increase).

Results

Different ornamental plant species varied in their response to ethylene (Tables 1, 2, 3, 4, and 5). Principal ethylene toxicity symptoms were epinasty, leaf and flower abscission, and leaf chlorosis. *Caladium* x *hortulanum* Birdsey, *Chlorophytum comosum* (Thunb.) Jacques, 'Variegatum', *Dracaena sanderana* Hort. Sander ex. M. T. Mast., *Gynura*

Table 1. Epinastic response of various ornamental plants exposed to 5 ppm ethylene at 23.5°C for 3 days in light.

Plant species	Epinastic response[z]
Caladium x *hortulanum*	1
Celosia cristata	3-4[y]
Chamaedorea elegans	0
Chlorophytum comosum 'Variegatum'	1
Coleus blumei	3-4[y]
Dracaena sanderana	1
Epipremnum aureum	1
Euphorbia pulcherrima	4
Gynura aurantiaca 'Purple Passion'	1
Hemigraphis alternata	1
Hoya carnosa 'Variegata'	1
Maranta leuconeura var. *Kerchoviana*	1
Nephrolepsis exaltata 'Fluffy Ruffles'	0
Pilea cadierei	3
Pilea 'Moon Valley'	4
Plectranthus australis	1[x]
Rumohra adiantiformis[w]	0
Syngonium podophyllum 'Green Gold'	1

[z]0=no apparent epinastic response; 1=slight response; 2=moderate response; 3=severe response.
[y]Response varied with cultivar, also had leaf abscission.
[x]Also some flower and leaf abscission.
[w]Cut fronds rather than intact plant exposed to ethylene.

Table 2. Leaves abscised from *Celosia cristata* and *Coleus blumei* cultivars exposed to 10 ppm ethylene for 3 days at 23.5°C in light[z].

Ethylene level (ppm)	Leaves abscised (no.)				
	Celosia cristata[y]			*Coleus blumei*[y]	
	'Fairy Fountain'	'Fiery Feather'	'Gold Torch'	'Light Green Saber'	'Pink Dragon'
0	0	0	0	0	0
10	3.5	3.8	2.5	43.8	0.5

[z]400 μW/cm^2 for 12 hr/day.
[y]Also had severe epinasty.

Table 3. Leaves abscised from various foliage plants exposed to ethylene for 3 days at 23.5°C in light[z].

Ethylene level	Initial no. of leaves	Leaves abscised (no.)	
		After exposure	1 day after exposure
	Aphelandra squarrosa 'Dania'		
0	25.0	0	0.2
1	29.2	5.4	6.2
5	25.0	19.5	20.8
10	25.3	23.0	24.3
	Peperomia obtusifolia		
0	12.7	0	0.2
1	11.8	0.6	0.6
5	11.8	1.5	1.8
10	10.5	2.3	2.3
	Ficus benjamina		
0	24.2	0	—
1	24.5	0	—
5	23.8	8.8	—
10	24.3	9.0	—
	Iresine herbstii		
0	25.2	0	—
1	22.8	4.6	—
5	24.0	9.2	—
10	22.3	9.2	—
	Pilea involucrata		
0	45.8	0	—
1	38.8	2.6	—
5	37.2	8.9	—
10	41.7	10.7	—

[z]400 μW/cm^2 for 23 hr/day.

Table 4. Chlorotic and abscised leaves from various foliage plants exposed to ethylene for 3 days at 23.5°C in light.

Ethylene level (ppm)	Leaves or leaflets abscised (no.)	Chlorotic leaves (no.)
	Crassula argentea	
0	0	—
1	1.7	—
5	17.0	—
10	24.0	—
	Brassaia actinophylla	
0	0	0
1	0	0
5	36.0	9.7
10	48.0	7.3
	Dieffenbachia maculata 'Rudolph Roehrs'	
0	0	0
1	0	1.3
5	0	2.3
10	0	3.0

Table 5. Number of bud and open flowers on *Exacum affine* and *Begonia semperflorens* after exposure to ethylene at 23.5°C in light for 12 hr/day.[z]

Ethylene level (ppm)	Initial no.			No. after exposure		
	flower buds	open flowers	total bud & open flowers	flower buds	open flowers	total buds & open flowers
			Exacum affine			
0	16.3	3.0	19.3	14.7	4.7	19.4
1	17.5	3.3	20.8	16.8	4.0	20.8
5	20.5	3.0	23.5	19.3	4.2	23.5
10	16.8	3.7	20.5	16.0	4.5	20.5
			Begonia semperflorens			
0	8.7	3.0	11.7	8.7	2.3	11.0
1	7.3	4.0	11.3	6.3	1.3	7.6
5	7.3	3.7	11.0	5.3	0	5.3
10	6.0	3.0	9.0	4.3	0	4.3
Greenhouse control	6.7	2.7	9.4	6.7	2.0	8.7

[z]*Exacum affine* exposed to ethylene for 3 days; *Begonia semperflorens* exposed for 1 day.

aurantiaca (Blume) DC, *Hemigraphis alternata* (Burn f.) T. Anderson, *Hoya carnosa* (L.f) R. Br., *Maranta leuconeura* E. Morr. var. *Kerchoviana, Plectranthus australis* R. br., *Epipremnum aureum* (Linden & André) Bunt., and *Syngonuim podophyllum* Schott 'Green Gold' had a slight epinastic response to ethylene (Table 1). High levels of ethylene (10 ppm did not appear to increase epinasty in these plants. *Celosia cristata* L., *Coleus blumei* Benth., *Euphorbia pulcherrima* Willd. ex Klotzsch, *Pilea cadieri* Gagnep & Guill., and *Pilea* 'Moon Valley' had severe epinastic responses to ethylene (Table 1). In addition to severe epinasty, *Coleus* and *Celosia* plants abscised leaves (Table 2). *Coleus* cv. Light Green Saber abscised more leaves than 'Pink Dragon'. Plants that responded epinastically returned to normal appearance 1 to 3 days after ethylene exposures.

Aphelandra squarrosa Nees., *Peperomia obtusifolia* (L.) A. Dietr., *Ficus benjamina* L., *Iresine herbstii* Hook. f., *Pilea involucrata* (Sims) Urb., *Crassula argentea* Thunb. had little or no leaf abscission (0-10%) when exposed to 1 ppm ethylene but, severe leaf abscission when exposed to 5 or 10 ppm ethylene (Tables 3 and 4). *Brassaia actinophyla* Endl. abscised leaves at 5 and 10 ppm ethylene, but not at 1 ppm; intact leaves became chlorotic (Table 4).

Dieffenbachia maculata (Lodd.) G. Don 'Rudolph Roehrs' developed severe leaf chlorosis when exposed to ethylene (Table 4). Plants exposed to 1 ppm ethylene had fewer chlorotic leaves than those plants exposed to higher ethylene levels. The chlorotic leaves on plants exposed to 5 and 10 ppm ethylene turned bronze and eventually became necrotic.

Flower buds on *Begonia* x *semperflorens–caltorum* plants abscised when exposed to 1 ppm ethylene but were not as sensitive to ethylene as open flowers (Table 5). All open flowers on plants exposed to 5 or 10 ppm ethylene abscised but only 25-30% of flower buds abscised. Leaves on plants exposed to 5 and 10 ppm, ethylene had a slight epinastic response. *Exacum afine* Balf. f. did not abscise flowers, leaves, or develop chlorotic leaves.

Discussion

Twenty-four of the 28 species evaluated in these tests had one or more symptom of injury when exposed to air containing ethylene at concentration greater than 1 ppm. The most common symptom of ethylene toxicity was epinasty with 15 of the test species showing this disorder. The most devastating disorder was leaf abscission expressed in 7 species. One species, *Dieffenbachia maculata* 'Rudolph Roehrs', had severe leaf chlorosis. Some plant species had 2 or more toxicity symptoms. Three species, *Rumorha adiantiformis* (G. Ferst.) Ching, *Nephrolepsis exaltata* (L.) Schott 'Fluffy Ruffles', and *Exacum affine* were not visibly injured by ethylene. The longevity of *Exacum* and ferns may be due to their tolerance to ethylene (4).

Different cultivars of the same species varied in their response to ethylene (Table 2). Plants that responded epinastically, returned to normal appearance in 1 to 3 days. Effect of ethylene on subsequent plant growth was not evaluated in these tests, however, in early tests, *Philodendron* (9) and geranium (12) plants exposed to ethylene during postharvest periods grew poorly when placed in a greenhouse. Some species exposed to ethylene in these tests may have grown poorly because of leaf abscision and chlorosis.

Ethylene sensitive species are probably more susceptible to damage while in the marketing channel than tolerant species. Such an example is poinsettia (15). Sleeved poinsettia plants generated higher levels of ethylene than unsleeved plants. No efforts were made to sleeve plants in these tests; but, sleeving conceivably could increase ethylene production and initiate or increase ethylene damage as in poinsettia.

Conversely these data could also indicate that those species which are relatively tolerant to ethylene would be relatively easy to ship, eg. *Chamaedora eleganns* Mart., *Chlorophytum comosum 'Variegatum', Dracaena sanderana, Gynura aurantiaca, Hoya carnosa 'Variegata', Exacum affine* (5).

There was no general pattern or method observable to predict possible plant responses to ethylene. Symptoms of injury could increase in severity depending on temperature and light. The plants in these tests were evaluated only in standard temperature and light conditions.

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METHODS FOR GROWERS TO EVALUATE EFFECTS OF THEIR CULTURAL PRACTICES ON LIRIOMYZA TRIFOLII LEAFMINERS IN A SIMPLE LABORATORY[1]

LORA D. KETZLER AND JAMES F. PRICE
IFAS, University of Florida,
Agricultural Research & Education Center,
5007-60th Street East,
Bradenton, FL 33508-9324

Additional index words. Agromyzidae, Diptera, chrysanthemum, rearing techniques.

Abstract. **A method is described for growers to rear** Liriomyza trifolii **(Burgess) leafminers on 'Henderson' bush lima beans in a 2 ft (61 cm) cube cage for experimentation. Methods for evaluating effects of horticultural practices on leafminer responses when the test leafminer flies are confined to each treatment or when all subject flies have equal accss to all treatments are discussed. By either method, advanced development of the second leafminer generation can be observed and pupae can be isolated individually to develop data on individual flies. These methods will help growers evaluate their current or anticipated cultural practices for influence on the leafminer before the practice is initiated on a large scale.**

The leafminer (*Liriomyza trifolii* (Burgess)) has been an important pest of horticultural crops in Florida since production methods, including applied insect control practices, changed after the late 1940's (14). On chrysanthemums (*Chrysanthemum* x *morifolium* Ramat.), for example, various cultural practices, including fertilization, cultivars, pesticides and pesticide use patterns and chrysanthemum pinching practices affect the leafminer's biology (4, 5, 6, 8, 10, 11), and the severity of damage. Differences in crop cultural methods may determine why some farms with susceptible crops experience serious leafminer damage while similar farms growing the same crop nearby may have few leafminers. Since production methods vary widely among crop species, growers and regions of the state, it would be beneficial for producers of affected crops to evaluate key components of their production systems for effects on the leafminer. Through such a process, practices favoring leafminer development could be identified and altered. Such observations should not be difficult, particularly for the many producers of horticultural crops who maintain diagnostic and investigative laboratories.

The effects of cultural practices on the leafminer are measured best in the laboratory where the subject leafminers are of a known species and are developed under known environmental conditions. Therefore it is important to initiate and maintain a colony of the species of interest. This paper specifically describes methods of investigations that the authors have adapted during studies of the response of *L. trifolii* to various cultivars of chrysanthemums. These procedures can be further modified to provide growers of chrysanthemums and other horticultural crops with insight into the effects of their existing or planned cultural practices on the leafminer.

Laboratory Facility

The laboratory used by the authors was an 11 x 11 ft (3.5 x 3.5 m) room provided with an air conditioner and small resistance heater to maintain the temperature at ca. 80°F (27°C). Work benches were installed with fluorescent lights above to provide 8,600 lux on the bench surfaces 2.5 ft (76 cm) from the nearest fixture. Lights were operated on a 24 hr cycle. A humidifier operated by evaporating water (12 gal or 45 liters per day) with an air current (Sears and Roebuck and Co., Chicago, IL) maintained humidity usually between 60-80% relative humidity.

Establishment and Maintenance of a Leafminer Colony

The authors initiated their colony from ca. 100 flies captured on a commercial chrysanthemum farm using manual aspirators (Bioquip® Products, Santa Monica, CA) or a powered aspirator (D-Vac® Co., Riverside, CA). Captured flies were identified (12) and placed into a 2 ft (61 cm) cube oviposition (egg laying) cage (Bioquip Products) made of window screen frames outfitted with window screen material backed with organdy cloth. Flies were provided with three 6-inch (15 cm) pots of 5-10 'Henderson' bush lima bean (*Phaseolus limensis* Maof.) plants with 2 fully expanded leaves each and were given access to a stick hung in the cage and smeared with a thin layer of honey. Access to the cage was through an organdy sleeve tied with a rubber band to prevent the escape of flies or entry of parasites or spiders.

Host bean plants were replaced into oviposition cages at 1 to 3 day intervals. Once mines had developed fully (ca. 5-6 days after introducing beans to flies) leaves were cut from the bean plants and placed in single layers on 5/16 inch (0.8 cm) mesh hardware cloth elevated 1 inch (2.5 cm) above the bottom of a 1 ft x 1 ft x 5 inch high (30 x 30 x 12.7 cm) sealed Tupperware® (Kissimmee, FL) storage container modified as described by Schuster and Burton (9). About 150 ml of sand (smaller than 45 mesh) was spread over the bottom of the storage container. Fully developed larvae dropped from the leaves onto the sand to pupate. Sand and pupae were sifted each day in a 35 mesh sieve (Fischer Scientific Co., Orlando, FL) that retained only the pupae. To maintain the colony, some pupae were placed into vials for adult emergence. Each vial was provided with a thin smear

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