

Comparisons of Bean Varieties Currently Being Used to Culture the Mexican Bean Beetle (Coleoptera: Coccinellidae)

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ABSTRACT Lima and snap bean varieties that are currently being used to culture the Mexican bean beetle (MBB) and its parasite, *Pediobius foveolatus* (Crawford), were examined to identify the most efficient variety for the culture of MBB. 'Top Crop,' 'Provider,' 'Spartan Arrow,' and 'Burpee's Stringless' snap beans and 'Henderson' lima beans were compared by constructing life tables for MBB on each variety. Varietal growth rates and responses to MBB culture conditions were also compared. Mean durations of immature MBB development were significantly different between all varieties, being shortest on 'Spartan Arrow' at 19.9 days. The preoviposition period was shortest and oviposition period longest on 'Provider,' being 8.9 and 27.2 days, respectively. Larval and pupal survivorships were higher on 'Henderson' (61.7%) and 'Provider' (60.4%) than on the other varieties. MBB females produced significantly more egg masses (16.5) and eggs (839.7) on 'Provider' than on any other variety. The highest net reproductive rate occurred on 'Provider' (222.5 female progeny per female), but the shorter generation times were on 'Spartan Arrow' (48.0 days) and 'Henderson' (48.1 days). As a result of these differences, MBB on 'Provider' and 'Henderson' exhibited higher intrinsic rates of increase (0.1172 and 0.1112, respectively). These results and observations on growth rates of the varieties and their responses to MBB culture conditions indicated that 'Henderson' lima beans was the best variety of those studied for culturing MBB.

THE MEXICAN bean beetle (MBB, *Epilachna varivestis* Mulsant, has been a serious pest of snap beans (*Phaseolus vulgaris* L.) and lima beans (*P. lunatus* L.) in the eastern and midwestern United States since being accidentally introduced in the 1920's (Thomas 1924). It became a serious pest of soybeans (*Glycine max* Merrill) in the 1960's, but *Phaseolus* spp. are still preferred (Kogan 1972). Its geographic distribution as a pest on soybeans is presently limited, but apparently expanding.

In 1966, the parasite *Pediobius foveolatus* (Crawford) was imported to suppress MBB densities in soybeans (Angalet et al. 1968). Although *P. foveolatus* exhibited much potential for reducing MBB densities, it was unable to overwinter in the United States (Stevens et al. 1975a). Therefore, annual inoculative release strategies were developed for soybean fields (Stevens et al. 1975a) and urban snap and lima bean gardens (Barrows and Hooker 1981).

A critical aspect of the inoculative release programs is the efficient culture of MBB and *P. foveolatus*. Artificial diets have been investigated, but none have been satisfactory for mass culturing MBB (Kogan 1971). The mass culture of *P. foveolatus* is dependent on growing large quantities of plants to maintain the MBB culture. Due to plant growth characteristics and MBB preferences, soybeans are unsuitable for culture purposes and only *Phaseolus* species are used. A culture technique was developed by Stevens et al. (1975b) using 'Henderson' lima bean foliage, but the cost of

growing and maintaining sufficient quantities of plants remains a major concern in inoculative release programs.

Despite extensive rearing of MBB by various organizations involved with *P. foveolatus* releases, little attention has been paid to the efficiency of different snap and lima bean varieties in the MBB culture, and several different ones are currently being used. Campbell and Brett (1966) reported that different snap and lima bean varieties affect MBB survivorship and fecundity in the laboratory and that 'Henderson' lima bean, the variety suggested for the culture of MBB by Stevens et al. (1975b), is relatively resistant to MBB. The purpose of this study was to increase the potential of *P. foveolatus* releases by identifying the best snap or lima bean variety for mass culturing MBB.

Materials and Methods

From discussions with other researchers who are currently rearing MBB for *P. foveolatus* field and laboratory studies, four varieties of snap bean ('Top Crop,' 'Provider,' 'Spartan Arrow,' and 'Burpee's Stringless') and one variety of lima bean ('Henderson') were selected. All plants were grown in a greenhouse at 25 to 35°C, 70 to 95% RH, and 10 to 14 h light. An overhead screen in the greenhouse reduced light intensity by 30%. Polyethylene bags (30.5 by 20.3 by 76.2 cm) were filled with ca. 5 cm of vermiculite (#3), and placed in wooden flats with six bags per flat. From 15 to 25 seeds

of a single bean variety were planted in each bag. The plants were watered as needed, but no fertilizer was applied. They were allowed to reach the first or second trifoliate stage before being used in the studies. Older plants were not used.

The MBB culture was initiated by collecting adults from various soybean fields in southern Indiana. Variable numbers of field-collected adults were frequently added to the culture. Adults, larvae, and eggs were cultured separately. Culture conditions for all stages were $25 \pm 5^\circ\text{C}$, 70 to 80% RH, and a 14L:10D photo-period (cool-white fluorescent lights). Adults and larvae were maintained on 'Top Crop' snap beans, grown as described above. To obtain egg masses, 50 to 150 adults (ca. 1:1 sex ratio) were confined in a 70 by 250 by 30 cm wooden-frame cage covered with nylon screen. Three flats of plants were maintained in the cage for adult feeding and oviposition. Leaves upon which egg masses had been laid were removed from the cage every 3 to 5 days. The egg masses and supporting leaf tissue were then dipped in a 0.1% sodium hypochlorite solution to reduce microbial growth, rinsed in distilled water, and placed on moistened filter paper in 150-mm glass petri dishes. When the eggs began to hatch, the entire egg mass was placed on a flat of snap bean foliage along with 6 to 14 other hatching egg masses. MBB larvae were manually transferred to fresh flats of foliage, or new foliage was placed adjacent to old and the larvae moved from one flat to the other. Prepupae and pupae were manually removed from the foliage and placed in an oviposition cage to continue the culture.

To study the effects of the varieties on larval development and mortality, several hatching egg masses were obtained from the MBB culture. The petioles of 5 to 10 leaves (uni- and trifoliate) of each bean variety were cut to a suitable length and inserted into water-filled, 50-ml Erlenmeyer flasks. Cotton was placed around the petioles at the neck of the flask. Three flasks of foliage of a given variety were then placed in a clear plastic jar (20.3 cm in diam by 19.5 cm high) with an opaque lid. The jar was vented with four, equally spaced, cotton-organdy-covered holes, each 7 cm in diameter. The lid also possessed four vent holes, each 2.5 cm in diameter, and a 1.5-cm-diam hole plugged with a #1 rubber stopper. Twenty MBB larvae were transferred with a camel hair brush (000) from the hatching egg masses to the foliage in the plastic jar. The plastic jar was then placed in an environmental chamber ($25 \pm 1^\circ\text{C}$, 14L:10D photo-period, and 70–95% RH jar). Twelve jars were prepared for each variety of plant.

Every 24 h the numbers of each larval instar in each jar were recorded, and the flasks of foliage were replaced as necessary. When pupae developed, they were removed from the foliage and placed in a clear plastic petri dish (100 mm in diam). The petri dish was placed in the bottom of

the jar. Emerging adults were sexed and counted every 24 h.

To study the longevity and fecundity of adult MBB, 12 male/female pairs were selected from adults emerging on each bean variety. Paired adults were placed in jars containing flasks of foliage, prepared as described for the immature studies. The cultivar used for the adults was the same as that on which they had developed. The jars were placed in environmental chambers under the same conditions as in the immature studies. Every 24 h the numbers of egg masses and of eggs per egg mass were recorded for each male/female pair. Male and female deaths were also recorded. If a male died before the female, the male was replaced.

To determine the length and level of mortality in the egg stage, several egg masses from females on each bean variety were placed on moist filter paper in 100-mm plastic petri dishes and held under the same environmental conditions as in the immature and adult studies. The number of days until hatching or death were recorded.

Based on the studies of immatures, adults, and eggs, life tables were constructed and statistics calculated according to methods described by Andrewartha and Birch (1954), Birch (1948), and Southwood (1966). Statistical analyses were performed using various programs in the Statistical Analysis System (Helwig and Council 1979).

To determine the rate of growth of the different varieties, from 15 to 20 seeds of each were planted in plastic bags containing vermiculite. Six bags were planted at the same time for each variety, and maintained under the same greenhouse conditions as previously described. The plants were observed daily, and the number in each bag that possessed fully expanded unifoliate leaves (the first true leaves) were recorded. Plants of each variety were also placed under MBB culture conditions to observe plant differences with respect to artificial light and MBB feeding.

Results and Discussion

There were no significant differences among the durations of larval instars or the pupal stage of MBB on different bean varieties (ANOVA, $P > 0.05$, $n = 60$). However, there were significantly different total durations of development from egg hatch to adult eclosion among MBB reared on the different bean varieties (ANOVA, $P \leq 0.05$, $n = 60$) (Table 1). Mean length of total immature development was shortest on 'Spartan Arrow' followed by 'Henderson,' 'Provider,' 'Burpee's Stringless,' and 'Top Crop.' These results contrast with those of Campbell and Brett (1966) who found no significant differences in total immature development times among MBB reared on 18 varieties of snap and lima beans. However, Campbell and Brett obtained MBB from field populations on *Phaseolus* species to perform their studies, while

Table 1. Durations of stages in the life cycle of the Mexican bean beetle on snap and lima bean varieties in the laboratory at 25°C

Variety	\bar{x} Days (<i>n</i>)			
	Immature (egg hatch to adult eclosion)	Adult preoviposition period	Adult oviposition period	Adult female longevity
'Top Crop'	23.6 (137)a	10.1 (12)b	18.2 (12)b	33.4 (12)a
'Provider'	21.2 (145)c	8.9 (12)c	27.2 (12)a	38.1 (12)a
'Henderson'	20.4 (148)d	12.0 (12)a	20.1 (12)b	38.9 (12)a
'Spartan Arrow'	19.9 (77)e	10.3 (12)b	24.2 (12)ab	40.1 (12)a
'Burpee's Stringless'	22.5 (98)b	10.1 (12)b	20.3 (12)b	36.4 (12)a

Means, within a column, followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test).

MBB from soybeans were used here. Adaptive differences could occur between populations on these two host plants.

The longevity of adult females was not significantly different among varieties (ANOVA, $P > 0.05$, $n = 60$), and the overall confidence interval was 37.4 ± 2.49 days ($P = 0.05$, $n = 60$) (Table 1). However, there were significant differences among MBB on different varieties in the lengths of preoviposition and oviposition periods (ANOVA, $P \leq 0.05$, $n = 60$) (Table 1). The mean length of the preoviposition period (i.e., days from adult eclosion to first oviposition) was significantly shorter in MBB on 'Provider' than on any of the other varieties. Preoviposition periods on 'Burpee's Stringless,' 'Top Crop,' and 'Spartan Arrow' were not significantly different, but were all significantly shorter than on 'Henderson.' The mean length of the oviposition period (i.e., days from first to last oviposition) was longer on 'Provider' and 'Spartan Arrow.' The oviposition periods on 'Spartan Arrow,' 'Burpee's Stringless,' 'Henderson,' and 'Top Crop' were not significantly different from each other (Duncan's multiple range test, $P > 0.05$, $n = 60$) (Table 1).

There were no significant differences in mean durations of development for the egg stage among MBB reared on different varieties. The confidence interval for the length of the egg stage for MBB on all varieties was 6.5 ± 0.19 days ($P = 0.05$, $n = 149$ egg masses).

Data on the duration of each developmental stage for MBB on all varieties indicated that eggs dominated ($\geq 50\%$) from day 0.5 to 6.5; first in-

stars, from 6.5 to 10.5; second instars, from 10.5 to 12.5; third instars, from 12.5 to 16.5; fourth instars, from 16.5 to 20.5; prepupae and pupae, from 20.5 to 27.5; and adults from 27.5 days.

The percentage of MBB surviving from egg hatch to adult eclosion was significantly higher on 'Henderson,' 'Provider,' and 'Top Crop' than on 'Burpee's Stringless' and 'Spartan Arrow' (Duncan's multiple range test, $P \leq 0.05$, $n = 60$) (Table 2). There were no significant differences in survival of eggs or egg masses among MBB on different bean varieties (ANOVA, $P > 0.05$), being 88.9% ($n = 2,948$) and 94.6% ($n = 72$), respectively, for all varieties.

MBB females on 'Provider' produced significantly more egg masses and eggs than on any of the other varieties (Duncan's multiple range test, $P \leq 0.05$) (Table 2). The mean number of eggs per egg mass was also highest on 'Provider,' but not significantly different from 'Henderson' and 'Spartan Arrow.'

Based on the life-stage duration, survival, and fecundity data, life tables were constructed and statistics were calculated (Table 3). MBB on 'Provider' had the highest net reproductive rate due to significantly higher egg and egg mass production, and high immature survival. However, shorter generation times occurred on 'Spartan Arrow' and 'Henderson.' The longer generation time on 'Provider' was a result of the relatively long oviposition and immature development periods, despite a shorter preoviposition period. As a result of these differences MBB on 'Provider' had a slightly higher innate capacity for increase than on 'Hen-

Table 2. Survival and reproductive potential of the Mexican bean beetle on snap and lima bean varieties in the laboratory at 25°C

Variety	% Immature survival (egg hatch to adult eclosion) (<i>n</i>)	Egg masses/ female (<i>n</i>)	Total eggs/ female (<i>n</i>)	Eggs/ egg mass (<i>n</i>)
'Top Crop'	57.08 (120)a	10.6 (12)b	486.5 (12)b	46.0 (127)b
'Provider'	60.42 (120)a	16.5 (12)a	839.7 (12)a	50.9 (198)a
'Henderson'	61.67 (120)a	11.5 (12)b	560.1 (12)b	48.7 (138)ab
'Spartan Arrow'	32.08 (120)b	11.7 (12)b	552.2 (12)b	48.4 (137)ab
'Burpee's Stringless'	40.83 (120)b	9.7 (12)b	443.7 (12)b	45.9 (116)b

Means, within a column, followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test).

Table 3. Laboratory life table statistics of the Mexican bean beetle on snap and lima varieties at 25°C

Variety	Net reproductive rate (female progeny/female)	Generation time (days)	Innate capacity for increase
'Top Crop'	123.8	50.5	0.1006
'Provider'	222.5	50.0	0.1172
'Henderson'	153.8	48.1	0.1112
'Spartan Arrow'	80.1	48.0	0.0987
'Burpee's Stringless'	79.9	48.6	0.0950

erson,' followed in descending order by those on 'Top Crop,' 'Spartan Arrow,' and 'Burpee's Stringless.' It was assumed that the variety from which the MBB eggs were originally obtained had no effect on the subsequent MBB generation. The response of MBB to 'Top Crop' relative to the other varieties tended to support this assumption. In summary, the use of either 'Provider' or 'Henderson' would result in more rapid and higher numerical increases of MBB under culture conditions, compared with the other varieties tested.

However, a major consideration in culturing MBB is the time and costs involved in growing the plants to maintain the desired rates of MBB increase. In general, the more rapidly the plants grow, the lower are the culture costs. Studies on varietal growth characteristics under greenhouse conditions indicated major differences in rates of germination and development. Fifteen days after seed planting, 107 'Henderson' seedlings had unifoliate leaves; 101 'Burpee's Stringless'; 97 'Top Crop'; 96 'Spartan Arrow'; and 77 'Provider.' On days 9 and 12, 43 and 87%, respectively, of the 'Henderson' seedlings had unifoliate leaves relative to day 15; 8 and 57% of the 'Burpee's Stringless'; 3 and 57% of the 'Top Crop'; 1 and 52% of the 'Spartan Arrow'; and 0 and 31% of the 'Provider.' These results indicate that 'Henderson' germinated and developed leaves most rapidly, while 'Provider' did so most slowly.

The effective life of the plants under artificial conditions in the MBB culture is of major concern in determining the required amount of greenhouse space to maintain maximum numbers of all MBB stages. Observations under MBB culture conditions indicated that 'Henderson' was superior to the other varieties in retaining leaves, continuing growth, and resisting microbial deterioration. Responses to adult and larval MBB feeding indicated that 'Top Crop,' 'Spartan Arrow,' and 'Burpee's Stringless' tended to drop leaves that were from 20 to 30% consumed, as opposed to the other varieties that retained their leaves even with 70 to 80% consumption. Finally, 'Henderson' possesses leaves that are 1.5- to 3-fold larger in area, and thus can support a given number of MBB larvae

and adults for a longer period of time than the other varieties studied.

Thus, based on both MBB rates of increase and culture costs, the optimum variety of those tested for the culture of MBB is 'Henderson' lima beans. This conclusion contradicts that of Campbell and Brett (1966) who identified 'Henderson' as relatively resistant, and 'Top Crop' and 'Burpee's Stringless' as susceptible. However, their rankings of resistance were primarily based on relative defoliation in the field. Differences in varieties' responses to MBB feeding, found in the present study, together with differences in leaf surface areas indicate that defoliation data gathered in the field alone may not be a reliable indicator for judging relative resistance to MBB. Aspects of MBB population growth (fecundity, survival, and generation time) must also be considered.

Although 'Henderson' lima bean was the optimum of the varieties tested for MBB culture, other varieties need to be examined. The selection of varieties for this study was based on those currently being used in MBB cultures. Campbell and Brett (1966) found higher MBB fecundities on certain other lima bean varieties that were not tested in the present study. It is possible that other lima or snap bean varieties may be more efficient in the culture of MBB and *P. foveolatus*.

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