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Using Commercial Bumble Bee Colonies as Backup Pollinators for Honey Bees to Produce Cucumbers and Watermelons

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SUMMARY. The effectiveness of bumble bees, *Bombus impatiens* Cresson, and honey bees, *Apis mellifera* L., on the pollination of cucumber, *Cucumis sativus* L., and watermelon, *Citrullus lanatus* (Thunb.) Matsum. & Nakai, was compared under field conditions. Comparisons were based on fruit abortion rates and seed set as influenced by bee type (honey bee or bumble bee) and the number of bee visits to treatment flowers (1, 6, 12, and 18 bee visits), plus two controls: a no-visit treatment and an open-pollinated (unrestricted visitation)

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treatment. For both crops, an increased number of bee visits had a strong positive effect on fruit and seed set. All cucumber and watermelon flowers bagged to prevent insect visitation aborted, demonstrating the need for active transfer of pollen between staminate and pistillate flowers. Bumble bee-visited flowers consistently had lower abortion rates and higher seed sets in the cucumber and watermelon studies than did honey bee-visited flowers when compared at the same bee visitation level. Only slight differences in fruit abortion rates were detected between bee types in the watermelon study. However, abortion rates for bumble bee-visited flowers were consistently less than those for honey bee-visited flowers when compared at equal bee visitation levels, with one exception at the 12 bee visit level. As the number of honey bee colonies continues to decline due to parasitic mite pests and based on the data obtained, we conclude that bumble bees have a great potential to serve as a supplemental pollinator for cucumbers, watermelons, and possibly other vine crops, when honey bees available for rental are in limited supply.

Most crops that require insect pollination to set marketable produce rely on honey bees, *Apis mellifera* L. Without these diligent pollinators, yields of many fruit and vegetables would be well below the levels required to meet the demands of an ever increasing human population, and production of bee-pollinated crops would be significantly less profitable for growers. Honey bees have certain attributes which make them dependable and efficient pollinators: they have large population sizes (up to 60,000 individuals per colony), exist on a perennial basis, can be managed using established practices, and can be transported over considerable distances to selected locations.

Over two million honey bee colonies are rented for crop pollination in the United States every year, adding an estimated \$1.6 to \$9.3 billion to the value of those crops that require insect pollination to set quality fruit (Robinson et al., 1989; Southwick and Southwick, 1992). McGregor (1976) lists >130 crops that benefit from or depend on insect pollination, the vast majority of which rely on honey bee colonies for the large numbers of pollinators necessary to adequately pollinate crop plants at typical field densities. For example,

standard field densities of predominantly gynoecious hybrid cucumbers for machine harvest range from 160,000 to 250,000 plants per hectare (Motes, 1977; Van Wann, 1993).

Unfortunately, in the last several years the availability of honey bee colonies has become a serious limiting factor in the pollination of many bee-pollinated crops. The accidental introductions of two parasitic mite species, [*Acarapis woodi* (Rennie) (Acari: Tarsonemidae) and *Varroa jacobsoni* Oudemans (Acari: Varroidae)], have decimated honey bee populations in the United States. In North Carolina, feral and managed honey bee colonies have been reduced by 90 and 30 percent, respectively (Ambrose, 1997). Other states have experienced similar reductions (Harbo and Hoopingarner, 1997). These recent losses to the pollinator force available for crop production are compounded by a steady, long-term decline in wild bee and managed honey bee populations. Over the last half-century, increased herbicide and pesticide use and depletion of nesting sites due to large-scale monoculture and urban sprawl have decreased overall bee populations to levels below those required to adequately pollinate field crops in many areas, necessitating the transportation of rental honey bee colonies into such localities (Martin and McGregor, 1973).

Bumble bees, which are social insects that live in colonies similar to honey bees, have been commercially available for pollination in the United States since mid-1992. Having replaced costly and labor-intensive manual (hand) pollination, bumble bee colonies are now the industry standard in greenhouse tomato production in Europe and the United States (Banda, 1990; Dogterom et al., 1998; Kueneman, 1995). Fisher and Pomeroy (1989) have also demonstrated the value of bumble bees as pollinators of muskmelon grown in greenhouses. Under field conditions in Tennessee, Skinner and Lovett (1992) found that wild bumble bees were more efficient pollinators of squash than were honey bees when squash flowers were subjected to single visits by either bee type. Although their sample sizes were too small to be conclusive, they noted the value of wild bumble bees as an important pollinator group.

Since May 1995, we have been conducting studies that explore the efficiency of bumble bee vs. honey bee

pollination of cucumbers and watermelons under field conditions in North Carolina (Stanghellini et al., 1997; Stanghellini et al., 1998). Fruit set (in terms of fruit abortion rates) and seed production (seed set influences fruit quality) were chosen as the determining factors for comparison between the two bee species. In this report we have summarized the data we obtained in two years of research and comment on the potential of commercial bumble bee colonies as supplemental, or backup, pollinators for honey bees in the production of vine crops such as cucumber and watermelon.

Materials and methods

CULTIVATION PRACTICES AND EXPERIMENTAL DESIGN. From mid April to early October in 1995 and 1996, studies were conducted to compare the effects of honey bee and bumble bee visitation and bee visit number on fruit and seed set in cucumber (1995) and watermelon (1995 and 1996). Bee type was also compared with two controls: a no-visit (no entomophilous pollination) treatment and an unrestricted-visit (open-pollinated) treatment. The field, located at the Horticultural Field Laboratory in Raleigh, N.C., measured 92 × 164 ft (28 × 50 m). Sequential plantings of both crops were made on raised, plastic-covered beds 164 ft (50 m) in length. Soil type in the field was an Appling Sandy Loam (Clayey Kaolinitic Thermic Typic Kanhapludult). The plants were drip irrigated and fertilized in accordance with standard commercial practices (Sanders et al., 1995; Schultheis, 1993a, 1993b).

CUCUMBER STUDY. Two predominantly gynoecious cultivars, 'Calypso' and 'Dasher II', were evaluated since they are the predominate cultivars grown in North Carolina for pickling and slicing cucumbers, respectively (Toth et al., 1990). The monoecious cultivar, 'Sumter', was included as a pollinizer. A split-plot design was used with cultivar as the main plot factor and treatment type as the subplot factor. Each replication, based on planting date, was comprised of two double-row beds where each bed contained one full row of pollinizer and one full row of either 'Calypso' or 'Dasher II'. In this way, pollen produced from the male flowers of 'Sumter' was not a limiting factor and was uniformly available to the individual plants of each test cultivar. The field was directly seeded with three to five seeds per hill, then thinned to one plant per

hill upon emergence. Spacing between beds was 4.9 ft (1.5 m), while between row and in-row spacing on the bed was 1 ft (0.3 m), giving 320 plants per bed, half of which were the test cultivars. Four replications were planted (13 April, 4 and 25 May, and 20 June) in 1995, but due to adverse weather and plant disease, data were obtained from only two replications (13 April and 25 May). The dates of treatment (bee visitations) were 31 May through 11 June and 18 June through 28 June for replications 1 and 2, respectively.

WATERMELON STUDY. Sequential plantings of 'Royal Jubilee', a recommended cultivar in North Carolina (Schultheis, 1995), were made in 1995 and 1996 in the same field as the cucumber study. The experimental design was a randomized complete-block design with four replications. Containerized transplants were grown in a greenhouse for 21 d, hardened for about a week, then planted into the field with a row spacing of 4.9 ft (1.5 m) and in-row spacing of 3 ft (0.9 m), giving 53 plants per bed (2 beds per replication, 106 plants per replication). In 1995, the field planting dates for the four replications were 18 May, 30 May, 13 June, and 27 June, respectively. Bee visitation dates for the four replications were as follows: 3–20 July (replication 1); 24–26 July (replication 2); 28 July through 3 Aug. (replication 3); and 4–6 Aug. (replication 4). In 1996, another four replications were planted on 21 April, 6 May, 22 May, and 7 June. As with the 1995 cucumber study, excessive rain resulted in diseased plants and no data were obtained from the 22 May and 7 June replications. The dates of treatments (bee visitation) were 7 June through 1 July and 7–18 July for replications 1 and 2, respectively.

TREATMENT. In mid-May 1995 and 1996, two honey bee colonies (≈20,000 bees per colony) and two commercial bumble bee colonies (≈50 to 75 bees per colony) were placed along the edge of the field when most of the test plants in the first replications had reached anthesis. Hives of both bee species were replaced periodically throughout the season. The honey bee colonies were from the North Carolina State University (NCSU) apiary. The bumble bee colonies contained a common native American species (*Bombus impatiens* Cresson) and were provided by Koppert Biological Systems, Inc., Ann Arbor, Mich. The bumble bee colony housing

was designed for in-greenhouse use (cardboard exteriors); therefore, they were placed in protective wooden stands 3.2 ft (1 m) in height. Voucher specimens for both bee species used in these studies were placed in the NCSU insect collection.

Pistillate flowers of each crop intended for treatment were bagged in the early evening before anthesis to control bee visitation the following day. Bags were fashioned from nylon pollination cage netting and measured 10.2 × 10.2 inches (26 × 26 cm) in the closed position. The edges of the bags were bordered by Velcro-like strips to enclose the pistillate flower and thus prevent unwanted visitation prior to treatment. Shaped aluminum wire was used to keep the sides of the bag from contacting the blossom.

Bee visitation treatments began when air temperatures reached 70 °F (21 °C) on the day of anthesis; bags on pistillate flowers were opened and 1, 6, 12, or 18 bee visits were allowed on each flower by either honey bees or bumble bees. Each time a bee landed on the flower, it was counted as a visit. An individual bee could be responsible for more than one visit. An approaching forager of the wrong bee type or any other insect was prevented from landing on the flower by using an aluminum pole with plastic forestry ribbon attached to one end to repel the insect. Data from flowers that were contaminated with the wrong bee type, i.e., visitation by an insect other than the one designated for that particular flower, were discarded. Foragers from wild bumble bee colonies were present in the field and had a variable range in body size. These foragers were sometimes not readily distinguishable from the Koppert (commercial) colonies; thus, uniformity of *Bombus* treatments was established by restricting flower visitation to those bumble bees that were of average body size of the commercial bumble bee foragers, ≈0.6 to 0.8 inches (1.5 to 2 cm) in length.

After each flower had received the desired number of visits, the bag was resealed and tagged with treatment type and date. The open-pollinated controls, those flowers that were not monitored with respect to visitor type or visitation number, were opened for the duration of the sampling period and then resealed when the controlled visitation treatments for that day were completed. The no-visit controls remained bagged the entire day of anthesis. All bags were

removed from the flowers after 1930 HR the day of treatment when no bee activity in the field was observed. Bags were placed on new pistillate flowers in the preanthesis stage at this time for treatment the following day.

For the cucumber and watermelon experiments, treatments were not started until the flowering had reached the fifth or sixth node. Before treatments were made, all previously set fruit were removed since developing fruit inhibit additional fruit set in cucumber (Connor, 1969; Handel and Mishkin 1984) and watermelon (Cunningham, 1939; Hibbard, 1939). All subsequent pistillate flowers that developed after the treatment were removed from the test plants for the next 5 to 7 d, ensuring that the treated flowers were given an optimum chance for development as they constituted first-set fruit.

The sampling period per day was restricted to a morning interval starting at 70 °F (21 °C) and ending between 1200 and 1300 HR based on research on anther dehiscence (Seaton and Kremer, 1939), pollen viability (Barnes, 1947), stigmatic receptivity (Seaton et al., 1936), and peak bee foraging activity (Ambrose et al., 1995; Brett and Sullivan, 1972; Collison and Martin, 1979). Individual plants of the test cultivars were chosen randomly each day for treatment. Treatment type was also allocated randomly; however, those of the same bee visit number (e.g., six honey bee vs. six bumble bee) were done simultaneously or back-to-back to alleviate or reduce any time-of-day effects. Each of the 10 treatments, honey bee or bumble bee at bee visit numbers 1, 6, 12, 18, plus the two controls, were repeated on 10 plants per replication for cucumber and watermelon.

HARVEST. For cucumber and watermelon in 1995, and for watermelon in 1996, the developing fruit were allowed to mature to maximum size in order to compare viable seed set resulting from pollination by the two bee types. Treatment flowers were checked every other day until maturity for fruit growth and were considered having set if the fruit reached at least 6 inches (15 cm) in length. All treatment and control flowers that aborted were recorded. In the 1995 cucumber experiment, the fungus *Pythium aphanidermatum* (Edson) Fitz. rotted some fruit while still on the vine; however, these developing fruit were still counted as having set as they would have reached maturity

in the absence of the fungus. Upon harvesting mature fruit, the seeds were extracted by hand and placed in a container of water. All seeds that sank to the bottom were counted as viable; those that floated were considered to be non-viable (empty seedcoats).

STATISTICAL ANALYSIS. Fruit set, in terms of percent fruit abortion, and seed set comparisons between bee types, averaging over cultivars in the cucumber study, were made using analysis of variance (Type I SS) in both experiments (SAS Institute, 1989; Steele and Torrie, 1980). Percent fruit abortion and seed set comparisons between the eight bee type by visit number combinations (i.e., honey bee at one visit, bumble bee at one visit, etc.) were then tested individually against the two controls (no-visit and open-pollinated treatments) using the least significant difference procedure ($P \leq 0.05$) (SAS Institute, 1989; Steele and Torrie, 1980).

Results

All data discussed in these two studies are presented in Table 1.

CUCUMBER STUDY. Rain prevented treatments on 4, 6, 19, 22, and 25 June. Air temperature ranged from 62 to 91 °F (16.6 to 32.8 °C) during the experiment, but bee counts were only recorded at ≥ 70 °F (21 °C).

For 'Calypso' and 'Dasher II', fruit abortion decreased and seed set increased as bee visitation (number of bee visits) to treatment flowers increased. All pistillate flowers bagged to prevent bee (or other insect) visitation aborted within a week of anthesis. With a single visit by either bee type, percent fruit abortion decreased to about half of that found for the no-visit treatments in both cultivars. As visit number increased from 1 to 18, percent fruit abortion decreased significantly. However, for 'Dasher II', only after 18 visits by either bee type were abortion rates similar to (did not differ significantly from) the open-pollinated treatments. Averaging over cultivars, fruit abortion rates for bumble bee-visited flowers were consistently less than (at lower visitation levels) or equal to (at higher visitation levels) abortion rates for honey bee-visited flowers.

Seed set also increased as bee visit number increased for both cultivars. No fruit, and therefore no seed, were produced from flowers bagged to prevent bee visitation. For 'Calypso', 12 or more visits by either bee type resulted in seed sets that did not differ significantly from

Table 1. Sample size, percent fruit abortion and mean seed set for eight bee-pollination treatments and two controls for two cucumber cultivars and one watermelon cultivar.

Bee type	Visits (no.)	Cucumber						Watermelon		
		Calypso			Dasher II			Royal Jubilee		
		Sample size ²	Fruit abortion ³ (%)	Mean seed set ³	Sample size	Fruit abortion (%)	Mean seed set	Sample size	Fruit abortion (%)	Mean seed set
No-visit control	---	0 ^x	100*	0*	0 ^x	100*	0*	0 ^x	100.0*	0*
Honey bee	1	8	60*	175*	9	55*	126*	16	73.3*	171*
Bumble bee	1	10	50*	259*	10	50*	164*	27	55.0*	235*
Honey bee	6	11	45*	250*	12	40*	192*	28	53.3	217*
Bumble bee	6	16	20*	291*	14	30*	220	29	51.7	251*
Honey bee	12	15	25*	386	16	20*	197*	31	48.3	233*
Bumble bee	12	15	25*	416	16	20*	216	30	50.0	287
Honey bee	18	16	20*	254*	18	10	197	30	50.0	279
Bumble bee	18	17	15*	430	18	10	240	33	45.0	322
Open-pollinated control		19	5	430	18	10	243	34	43.3	305

²Sample size was the number of fruit reaching maturity based on 20 fruit possible for both cucumber cultivars (10 flowers per replication; 2 replications in 1995) and on 60 for watermelon (10 flowers per replication; 4 replications in 1995, 2 replications in 1996).

³Treatment means per fruit across replications for cucumber and across years and replications for watermelon.

^xAll flowers not receiving bee visitation aborted.

*Percent fruit abortion and mean seed set comparisons between treatments and the open pollinated control within the same column were significant at $P \leq 0.05$ (LSD procedure).

the open-pollinated control (note: the honey bee 18 visit mean seed set did differ from the open pollinated treatment because several of these fruit were misshapen and had low seed contents). For 'Dasher II', 6 or more bumble bee visits or 12 or more honey bee visits were required to obtain seed sets that were comparable to the open-pollinated control. As in the fruit abortion comparison between bee types, bumble bee-visited flowers consistently had higher seed sets than did honey bee-visited flowers when compared at equal bee visit numbers ($P \leq 0.0001$).

WATERMELON STUDY. Rain prevented treatment on 5, 7, 8, 11, 18, 19, and 31 July in 1995, and 10–14, 17, 18, 23–25 June and 11–15 July in 1996. Air temperature ranged from 62 to 95 °F (16.8 to 35 °C) during the experiment, but bee counts were only recorded at ≥ 70 °F (21 °C).

As in the cucumber study, abortion was 100 percent for flowers receiving no visitation and then decreased as the number of bee visits increased from 1 to 12. In contrast to the cucumber study, only bee visit number was found to be significant by analysis of variance at the $P < 0.01$ level. Fruit abortion rates were consistently lower for bumble bee-visited flowers than for honey bees, except at the 12 bee visit level. Only the no-visit control, honey bee at one visit, and bumble bee at one visit treatments differed significantly from the open-pollinated control.

For the watermelon seed set analysis, the two-replication 1996 data were

combined with the 1995 data as neither the year main effect nor its interactions were significant. Averaging over years and replications, the bee type main effect and bee visit number main effect were highly significant for watermelon. When compared over visit number, seed sets obtained from fruit of bumble bee-visited flowers were consistently higher than those produced in fruit of honey bee-visited flowers, and increased bee visits by either bee type significantly influenced mean seed set. Fruit receiving 12 or more bumble bee visits or 18 or more honey bee visits did not differ significantly from the open pollinated control. All flowers receiving bee visits, including the open-pollinated treatments, were significantly different from the no-visit controls as no seeds were obtained from the aborted fruit.

Discussion

The fact that unpollinated cucurbit flowers, with the exceptions of parthenocarpic cucumbers and squash, fail to produce either seed or fruit has been well established (Free, 1993; McGregor, 1976). These experiments further document the necessity of insect pollination for crop and seed production in the cultivars we tested.

In the cucumber study, fruit and seed set were strongly influenced by bee visit number. As visit number increased from 1 to 18 by either honey bees or bumble bees, there was a highly significant decrease in the number of fruit that aborted and a highly significant increase in the number of mature seeds that

developed in both cultivars tested. For 'Calypso' and 'Dasher II', bee type greatly influenced fruit abortion rates and seed sets. Fruit from bumble bee-visited flowers had typically lower abortion rates and consistently higher seed sets than honey bee-visited flowers.

Seed production in watermelon was similar to what was found in the cucumber study: as the number of bee visits increased by either bee type, seed set increased. Seed sets were also consistently higher in fruit (flowers) visited by bumble bees than were fruit visited by honey bees. Fruit abortion rates were also significantly influenced by the number of bee visits, although there was a rapid decrease in abortion even after only single visits, stabilizing at six or more bee visits. Abortion rates for bumble bee-visited flowers were consistently less than or similar to those of honey bee visited flowers when compared at equal bee visit numbers.

The results of these cucumber and watermelon studies demonstrate that bumble bees are equally or more efficient pollinators of these crops than are honey bees, at least at the level investigated (individual and multiple bee level). Our future research will examine the effects of whole colonies (honey bee vs. bumble bee) on the pollination of selected vine crops to determine if the results presented here translate to larger-scale crop and/or seed production.

Although there are breeding efforts to produce parthenocarpic vine crops other than cucumbers (e.g., squash), commercial realization of these

plant lines is not in the near future. For now, the standard practice of using bees as pollinators is the surest way to obtain quality crop production.

This study clearly demonstrates 1) the need for adequate honey bee or other entomophilous pollination in the production of vine crops such as watermelons and nonparthenocarpic cucumbers, 2) the value of efficient and abundant pollinators to increased seed production, and 3) the potential value of bumble bees in the field pollination of cucumber and watermelon and possibly other vine crops.

Appendix

Commercial bumble bee colonies may provide a reliable, readily available, supplementary pollinator system for certain crops when honey bee colonies are in limited supply. However, the following points should be emphasized. There are large differences in population sizes between honey bees ($\approx 25,000$ to $30,000$ individuals per colony) and bumble bees (≈ 100 to 150 individuals per colony), and the difficulty and labor involved in producing bumble bee colonies tends to make them relatively expensive. The cost of purchasing a bumble bee colony is roughly 4 to 7 times that of the current average honey bee rental fee of \$40 per hive (based on vine crop pollination fees in North Carolina). Also, because bumble bees have an annual life cycle, the colonies need to be replaced with new colonies each year.

On the positive side, unlike honey bees, bumble bee colonies require less maintenance once placed in the field for pollination. Bumble bees are also known to be active under temperature and wind conditions that typically impede or prevent honey bee activity. Finally, our ongoing research has demonstrated that bumble bees are more efficient pollinators than are honey bees for certain crops such as cucumber and watermelon.

There are several companies in the United States that produce and sell bumble bee colonies, and they can possibly be contacted through state and county extension agencies. For more general information on bumble bee biology, see Alford (1975).

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