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Effects of Honey Bee Pollination on Pumpkin Fruit and Seed Yield

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Abstract. **The objective of this study was to measure honey bee (*Apis mellifera* L.) impact on seed set, fruit set, and yield of jack-o-lantern (*Cucurbita pepo* L.), large-sized (*C. maxima* Duch.), and processing pumpkins (*C. moschata* Duch. ex Poir.) under field conditions. There were sufficient natural pollinators [including bumblebees (*Bombus* spp.), carpenter bees (*Xylocopa* spp.), honey bees, and squash bees (*Peponapis pruinosa* Say)] provided under field conditions to induce fruit set of jack-o-lantern pumpkins as fruit number obtained per hectare was not affected by the addition of a honey bee colony. However, the addition of honey bees did increase fruit number per hectare of the *C. moschata* and *C. maxima* cultivars evaluated. Honey bee pollination resulted in larger-sized fruit, increasing individual fruit size of all but small-sized pumpkins (<0.5 kg). Individual pumpkin fruit weights of the *Cucurbita pepo*, *C. moschata*, and *C. maxima* cultivars evaluated increased by about, 26%, 70%, and 78%, respectively, when honey bee colonies were included. Natural pollination was insufficient to stimulate maximum fruit size development and seed number and seed weight per fruit. Although pumpkin fruit set will occur with natural pollinators, the addition of honey bee colonies will ensure the presence of pollinators to maximize fruit size. Since pumpkins are generally sold on a weight basis, growers may generate greater revenues with the addition of honey bee colonies in pumpkin fields.**

Cucurbit vegetables require insects, such as honey bees, to transfer pollen from staminate (male) to pistillate (female) flowers (Delaplane and Mayer, 2000; Robinson and Decker-Walters, 1997). Honey bees and squash bees are two of the most important insect pollinators of pumpkin (Delaplane and Mayer, 2000). Squash bees tend to buildup in areas where *Cucurbita* spp. are repeatedly grown over several consecutive years (Schuler et al., 2005). Although squash bees are better pollinators of pumpkins than honey bees, their natural populations fluctuate year to year and cannot be relied upon as the sole pollinator in most geographical locations (Stanghellini, personal communication, 2005). Nonetheless, in 2000, the economic value of honey bees as pollinators of crops was estimated at about $14.6 billion and yields of fruit, seed, and nut crops would be significantly reduced without the pollination services that honey bees provide (Morse and Calderone, 2000).

Previous research has indicated that cucumber and watermelon fruit set and seed number per fruit increase as the number of bee visits to pistillate flowers increase (Stanghellini et al., 1997). Seed formation in *C. pepo* fruit was shown to increase as the number of pollen grains deposited on the stigma increased (Winsor et al., 1987). Jaycox et al. (1975) indicated that as the number of bee visits to pistillate processing pumpkin (*C. moschata*) flowers increased from 1 to 12, fruit set increased 58% and numbers of seed per fruit increased 75%. In watermelons, Brewer (1974) found a high correlation between both seed number ($r = 0.722$, $P \leq 0.05$) and seed weight ($r = 0.868$, $P \leq 0.05$) with final individual fruit weight. These results indicate that large honey bee populations ensure maximum flower visitation, pollen deposition, and tend to increase yields of cucurbit crops.

Despite recommendations for use of at least 2.5 honey bee colonies per ha (Conner, 1979; Delaplane et al., 1994; Egel et al., 2003; Hodges and Baxendale, 1991; Schultheis, 1998), the use of honey bee colonies was not recommended for cucurbit fields less than a hectare in size that were located near forested areas where feral honey bee populations were found (Delaplane and Mayer, 2000). However, the infestation of honey bee populations by tracheal (*Acarapis wood* Rennie) and varroa (*Varroa destructor* Anderson & Trueman) mites has generally reduced the pollination traditionally expected from feral honey bee colonies (Delaplane and Mayer, 2000). Therefore, it may be necessary to provide commercial honey bee colonies even to small fields (<1 ha) to achieve maximum yields of cucurbit vegetables. The objective of this study was to determine the influence of honey bee pollination on seed set, fruit set, and yield of processing, jack-o-lantern, and other ornamental pumpkins.

Materials and Methods

The influence of honey bee pollination on processing, jack-o-lantern, and other ornamental pumpkins was measured in separate experiments from 2000 to 2003. Standard cultural practices for pumpkin production were used (Egel et al., 2003; Foster et al., 2000, 2001, 2002). Before planting, 47 kg·ha^{-1} nitrogen (N), 60 kg·ha^{-1} phosphorus (P), and 112 kg·ha^{-1} potassium (K) were applied to plots. Plots were side-dressed with 56 kg·ha^{-1} N 6 weeks after planting. Recommended pest control consisted of spraying a tank mixture of permethrin (Pounce 3.2 EC; FMC Corp., Philadelphia, Pa.) at 0.3 L·ha^{-1} or esfenvalerate (Asana XL; E.I. du Pont de Nemours and Co., Wilmington, Del.) at 0.5 L·ha^{-1} and chlorothalonil [Bravo Weather Stik (6F); Zeneca, Inc., Wilmington, Del.] at 2.9 L·ha^{-1} every 7 to 10 d for the duration of the test. Weeds were controlled by a preemergence application of clomazone (Command 3ME; FMC Corp., Philadelphia, Penn.) at 1.2 L·ha^{-1}, and subsequent mechanical or hand cultivation.

A strong honey bee colony (about 25,000 bees) was placed in the treated plots at first flower each year, about July 20. All experiments were blocked east-to-west and the colony was placed near the middle of the test site along the north side. Honey bee activity in control plots was minimized by providing about 1.2 km between control and honey bee treatments. Control and treated areas were separated by field corn (*Zea mays* L.), soybean (*Glycine max* L.), tall fescue (*Festuca arundinacea* Schreb.), and white clover (*Trifolium repens* L.).

Pollinator activity was recorded twice (late July to early August) during each growing season in both treatment areas. At each evaluation for pollinator activity, about four to six pistillate flowers in close proximity to each other were observed near the center of the test site with pollinator type and visit number per flower recorded during peak flowering (from 900 to 1300 HR); and, each time a pollinator landed on a flower (regardless of the amount of time the pollinator remained on the flower), it was counted as a visit.

Jack-o-lantern cultivar experiment. Honey bee colony presence was compared to honey bee colony absence for influence on jack-o-lantern pumpkin yields and seed characters at the Southern Illinois University Belleville Research Center, Belleville, Ill., during 2000 and 2001. The experiment was set up as split-plot treatment arrangement in a randomized complete block design, with honey bee treatment (presence or absence of honey bee colonies) as the main plot and pumpkin cultivar as the subplot. The experiment had one replication per year and was replicated over the two growing seasons. Eight jack-o-lantern pumpkin cultivars: 'Appalachian', 'Aspen', 'Autumn King', 'Gold Rush', 'Gold Strike', 'Howden', 'Ichabod', and 'Motherlode' were replicated four times within each main plot. All seed were obtained from Seedway (Elizabethtown, Pa.). Pumpkins were direct seeded on about 15 June each year, and spaced 1.2 m apart in the row with rows spaced 1.5 m apart. Ten plants of each cultivar were grown in each replication. Main plots were 12 m long × 12 m wide.

Numbers and weights of pumpkins were measured at harvest on 16 and 28 Sept. 2000, and 13 and 27 Sept. 2001. Seed number and seed

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dry weight were measured on three pumpkins randomly collected from each cultivar replicate at the first harvest.

Pumpkin species experiment. Honey bee colony presence was compared with honey bee colony absence for influence on pumpkin yields and seed characters of three different *Cucurbita* species [*C. moschata* 'Libby's Select', *C. maxima* 'Mammoth Gold', and *C. pepo* 'Applachian' and 'Jack-Be-Little'] at the Southern Illinois University Horticultural Research Center, Carbondale, Ill., during 2002 and 2003. The experiment was set up as split-plot treatment arrangement in a randomized complete block design, with honey bee treatment (presence or absence of honey bee colonies) as the main plot and pumpkin species/cultivar as the subplot. The experiment had one replication per year and was replicated over the two growing seasons. Seed of 'Libby's Select' was obtained from Nestlé/Libby's (Morton, Ill.) while all others were obtained from Seedway (Elizabethtown, Pa.). Each pumpkin species/cultivar was replicated four times within each honey bee treatment.

Pumpkins were direct seeded on about 25 June each year at 1.2 m in-row spacings with 1.5 m row centers with 10 plants per plot; however, 'Jack-Be-Little' was grown at 0.6 m in-row spacings (20 plants per plot). Main plots were 12 m long × 6 m wide.

Numbers and weights of pumpkins were measured at harvest on 9 and 25 Sept. 2002, and 10 and 25 Sept. 2003. Seed number and seed dry weight was determined from three pumpkin fruit randomly collected from each cultivar replicate at the first harvest.

Statistical analysis. Analysis of variance procedures were performed using general linear models procedure of SAS (Cary, N.C.) appropriate for a split-plot experimental design to determine the effects of honey bees and pumpkin cultivars over years as well as their interactions on pumpkin yield and seed characters.

Results

Pollinator activity was similar for both experiments with about 2 to 3 and 5 to 7 pollinator visits to pistillate pumpkin flowers per hour for those treatments without and with honey bee colonies, respectively (data not presented). Over the primary pollination period (900 to 1300 HR), a total of about 10 to 15 and 25 to 35 pollinator visits to pistillate pumpkin flowers were recorded for those treatments without and with honey bee colonies, respectively. Although bumble bees, carpenter bees, honey bees, and squash bees were pollinators found in both treatments, honey bees provided the most visits in the honey bee treatment, and bumble bees provided the most visits in the no honey bee treatment.

Jack-o-lantern cultivar response to honey bee pollination. The data were combined over the 2 years and analyzed. Although year main effects were significant ($P < 0.05$), no significant interactions of honey bee treatment or pumpkin cultivar were generally observed with year for most pumpkin characters evaluated. However, honey bee treatment and pumpkin cultivar interactions ($P < 0.05$) normally occurred for the pumpkin characters evaluated. Differences ($P < 0.05$) were observed between honey bee treatments for pumpkin fruit weight per hectare, average pumpkin fruit weight, and seed number and seed weight per pumpkin fruit (Tables 1 and 2). Numbers of pumpkins per hectare and weight per 100 seed were not influenced by the addition of honey bee colonies ($P > 0.05$).

Honey bees provided differing influences on the pumpkin cultivars evaluated; but pumpkin cultivar yield performance in most instances was improved with the addition of a honey bee colony. The addition of honey bees during flowering increased pumpkin yields (weight per hectare) by 30%, 42%, 43%, 47%, and 70% for 'Autumn King', 'Gold Strike', 'Gold Rush', 'Motherlode', and 'Appalachian', respectively (Table 1). Pumpkin yields with the inclusion of honey bees averaged 31,547 $kg \cdot ha^{-1}$ (41% increase) compared to 22,353 $kg \cdot ha^{-1}$ for those without honey bee colonies. Use of honey bee pollinators increased the average individual fruit weight by >25% for 'Appalachian', 'Aspen', 'Autumn King', 'Howden', 'Ichabod', and 'Motherlode', and although nonsignificant ($P > 0.05$), the fruit weights of 'Gold Rush' and 'Gold Strike' increased 13% compared to the untreated control (no honey bee colonies). The number of pumpkins obtained per hectare was not influenced by the addition of honey bees; total pumpkins per hectare (across all cultivars) averaged 4,233 (an 11% increase) with the addition of a honey bee colony as compared to 3,805 without a honey bee colony. In most instances, the addition of honey bees caused an increase in pumpkin seed numbers and seed weights, while 100 seed weights were

Table 1. Jack-o-lantern pumpkin (*Cucurbita pepo*) yields as affected by the presence or absence of honey bee colonies over the 2000 and 2001 growing seasons at Belleville, Ill.[z]

	Fruit/ha		Total wt ($kg \cdot ha^{-1}$)		Avg fruit wt (kg)	
Pumpkin cultivar	Without bees	Bees	Without bees	Bees	Without bees	Bees
Appalachian	4,765	5,955 (25%)^{NS}	26,242	44,755 (70%)*	5.5	7.6 (36%)*
Autumn King	4,595	4,765 (4%)^{NS}	27,260	35,363 (30%)*	5.9	7.5 (26%)*
Gold Rush	3,233	4,085 (26%)^{NS}	23,712	33,846 (43%)*	7.4	8.3 (13%)^{NS}
Motherlode	3,803	4,425 (16%)^{NS}	22,930	33,781 (47%)*	6.1	7.7 (26%)*
Aspen	5,105	4,340 (-15%)^{NS}	27,198	30,134 (11%)^{NS}	5.4	7.0 (30%)*
Gold Strike	3,148	3,998 (27%)^{NS}	20,136	28,754 (42%)*	6.4	7.3 (13%)^{NS}
Howden	2,638	3,403 (29%)^{NS}	14,888	24,394 (63%)*	5.7	7.2 (27%)*
Ichabod	3,148	2,893 (-8%)^{NS}	16,454	21,347 (30%)*	5.3	7.4 (41%)*
Mean	3,805	4,233 (11%)^{NS}	22,353	31,547 (41%)*	5.9	7.5 (26%)*

[z]Cultivars are ranked in descending order of pumpkin yield (total weight per hectare) with bees. Percentage yield increase/decrease (in parentheses) of each cultivar with honey bee colonies compared to no honey bee colonies.

^{NS,*}Nonsignificant or significant ($P \leq 0.05$) comparisons for percentage increase/decrease within each cultivar comparing the absence of honey bee colonies with the addition of honey bee colonies.

Table 2. Jack-o-lantern pumpkin (*Cucurbita pepo*) seed characters as affected by the presence or absence of honey bee colonies over the 2000 and 2001 growing seasons at Belleville, Ill.[z]

	Seeds/pumpkin		Seed wt (g)/pumpkin		Seed wt/100 seed (g)	
Pumpkin cultivar	Without bees	Bees	Without bees	Bees	Without bees	Bees
Motherlode	551	700 (27%)*	78.4	106.4 (36%)*	14.8	15.7 (6%)^{NS}
Autumn King	644	684 (6%)^{NS}	86.8	100.8 (16%)*	13.7	15.1 (10%)^{NS}
Ichabod	555	633 (14%)*	64.4	103.6 (61%)*	10.9	16.8 (54%)*
Gold Strike	531	609 (15%)*	75.6	86.8 (15%)^{NS}	14.3	14.3 (0%)^{NS}
Gold Rush	553	595 (8%)^{NS}	81.2	81.2 (0%)^{NS}	14.8	13.7 (-7%)^{NS}
Appalachian	506	595 (18%)*	70.0	89.6 (28%)*	13.7	15.7 (15%)^{NS}
Aspen	503	590 (17%)*	78.4	109.2 (39%)*	15.4	18.8 (22%)^{NS}
Howden	591	570 (-4%)^{NS}	78.4	86.8 (11%)^{NS}	13.4	15.7 (17%)^{NS}
Mean	554	622 (12%)*	75.6	95.2 (26%)*	13.7	15.7 (15%)^{NS}

[z]Cultivars are ranked in descending order of seed number per pumpkin with bees. Percentage seed number or weight increase/decrease (in parentheses) of each cultivar with honey bee colonies compared to no honey bee colonies.

^{NS,*}Nonsignificant or significant ($P \leq 0.05$) comparisons for percentage increase/decrease within each cultivar comparing the absence of honey bee colonies with the addition of honey bee colonies.

Table 3. Influence of honey bee colonies on various *Cucurbita* spp. yields over the 2002 and 2003 growing seasons at Carbondale, Ill.[z]

Pumpkin	Fruit/ha		Total wt ($kg \cdot ha^{-1}$)		Avg fruit wt (kg)	
species/cultivar	Without bees	Bees	Without bees	Bees	Without bees	Bees
Cucurbita pepo						
Appalachian	8,390	9,115 (8%)[NS]	42,474	54,311 (28%)*	5.1	6.0 (18%)*
Jack-Be-Little	60,015	62,195 (4%)[NS]	8,066	8,359 (4%)[NS]	0.1	0.1 (0%)[NS]
Cucurbita moschata						
Libby's Select	7,895	10,310 (31%)*	43,909	74,827 (70%)*	5.6	7.3 (30%)*
Cucurbita maxima						
Mammoth Gold	2,415	3,913 (62%)*	15,260	30,567 (100%)*	6.3	7.8 (24%)*

[z]Percentage yield increase/decrease (in parentheses) of each cultivar with honey bee colonies compared to no honey bee colonies.
[NS, *]Nonsignificant or significant ($P \leq 0.05$) comparisons for percentage increase within each cultivar comparing the absence of honey bee colonies with the addition of honey bee colonies.

Table 4. *Cucurbita* spp. seed characters as affected by honey bee colonies over the 2002 and 2003 growing seasons at Carbondale, Ill.[z]

Pumpkin	Seeds/pumpkin		Seed wt (g)/pumpkin		Seed wt/100 seed (g)	
species/cultivar	Without bees	Bees	Without bees	Bees	Without bees	Bees
Cucurbita pepo						
Appalachian	462	592 (28%)*	64.4	78.4 (22%)*	13.7	13.7 (0%)[NS]
Jack-Be-Little	124	160 (29%)*	2.8	5.6 (100%)*	2.5	3.9 (56%)*
Cucurbita moschata						
Libby's Select	660	816 (23%)*	58.8	95.2 (62%)*	9.0	11.8 (31%)*
Cucurbita maxima						
Mammoth Gold	359	579 (61%)*	53.2	92.4 (74%)*	14.8	16.8 (14%)[NS]

[z]Percentage seed number or weight increase/decrease (in parentheses) of each cultivar with honey bee colonies compared to no honey bee colonies.
[NS, *]Nonsignificant or significant ($P \leq 0.05$) comparisons for percentage increase within each cultivar comparing the absence of honey bee colonies with the addition of honey bee colonies.

generally not affected in the pumpkin cultivars evaluated (Table 2).

Pumpkin species response to honey bee pollination. The data were combined over the two years and analyzed. Generally, no significant interactions ($P > 0.05$) of honey bee treatment or pumpkin species/cultivar were generally observed with year for most pumpkin characters evaluated, although year main effects were significant ($P < 0.05$). However, interactions ($P < 0.05$) were normally observed for honey bee treatment with pumpkin species/cultivar for the characters evaluated. Furthermore, differences ($P < 0.01$) between honey bee treatments generally occurred for most pumpkin yield and seed characters evaluated. The addition of honey bees increased fruit weight per hectare of *C. moschata* 'Libby's Select' and *C. maxima* 'Mammoth Gold' 70% and 100%, respectively, compared to no honey bees (Table 3). In contrast, the addition of a honey bee colony during flowering provided only 28% and 4% increase in fruit weight per hectare for *C. pepo* 'Appalachian' and 'Jack-Be-Little', respectively. The small-fruited 'Jack-Be-Little' did not respond to the addition of honey bees. Although fruit numbers per hectare of the *C. pepo* cultivars were not influenced by the addition of honey bees, use of honey bees increased the fruit numbers per hectare of *C. moschata* 'Libby's Select' and *C. maxima* 'Mammoth Gold' by 31% and 62%, respectively. Furthermore, the addition of a honey bee colony increased average fruit weight for all except *C. pepo* 'Jack-Be-Little'.

The addition of a honey bee colony increased proportionally the seed number per pumpkin in *C. maxima* 'Mammoth Gold' twice as much (61% vs < 30%) compared to *C. pepo* 'Appalachian' and 'Jack-Be-Little', and *C. moschata* 'Libby's Select' (Table 4). The honey bee pollinators consistently increased total seed weights per fruit from 22% to 100% compared to those without honey bee colonies. Weights per 100 seed of the *Cucurbita* spp. evaluated tended to be higher with the addition of honey bees.

Discussion

The number of pollen grains deposited on the stigma by pollinators is directly related to seed formation, which often determines fruit size (Delaplane and Mayer, 2000). Results from this study indicate that increased pollen deposition on the stigma may optimize pumpkin fruit size, and a high pollinator density (primarily influenced by honey bee colonies placed in fields) may provide greater fruit yields. Additionally, honey bee colonies should be introduced into fields at the peak of pumpkin flowering to achieve maximum pollination activity (Stapleton et al., 2000). Pumpkin fruit set will occur with an insufficient amount of pollen placed on the stigma as seen in treatments without a honey bee colony that provided lower pumpkin seed numbers and weights in smaller fruit; but, the addition of honey bee colonies will ensure sufficient bee visits to maximize pollen deposition and fruit size.

Our study indicated that the fruit development of small-sized pumpkins (e.g., 'Jack-Be-Little') appears not to be influenced as much as larger-sized pumpkins by the addition of honey bee colonies in production fields. Apparently, the smaller fruit are able to grow to their maximum size with minimal pollen deposition on the stigma or attract alternate pollinators, while larger-fruited pumpkins need multiple bee visitations to maximize pollen deposition, thus maximizing their genetic potential for fruit size.

Results indicated that while there were sufficient natural pollinators to induce pumpkin fruit set under field conditions during the study, the use of honey bees increased tonnage produced per hectare, primarily by increasing individual fruit size (Tables 1 and 3). Honey bees are one of the most important pollinators of *Cucurbita* spp., and fruit set and seed number generally increase as the number of bee visits to *Cucurbita* flowers increase (Delaplane and Mayer, 2000). Jaycox et al. (1975) indicated that the percentage of pistillate *C. moschata* 'Dickinson Field' flowers setting fruit is improved by repeated visits of honey bees, with fruit size and yields increasing as pollinators complete multiple visits to flowers. We estimate investing less than \$200 per hectare to provide honey bee colonies would increase jack-o-lantern wholesale gross revenues by \$460 (at 5¢/kg), \$919 (at 10¢/kg), or \$1,839 (at 20¢/kg) per hectare based on the average jack-o-lantern yield increase (9,194 $kg \cdot ha^{-1}$) (Table 1). In years when natural pollination is very low, the importance of honey bees in revenue generation could be increased even further. Since pumpkins are generally sold on a weight basis, growers may realize greater revenues with the inclusion of honey bee colonies in pumpkin fields.

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