Contribution of Insect Pollination to Macadamia and Coffee in Hawai‘i

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Introduction

Macadamia (*Macadamia integrifolia*, Proteaceae) and coffee (*Coffea arabica*, Rubiaceae) are both valuable crops in Hawaii; producing a farm gate value of $38.2 mil and $31.5 mil respectively (NASS, 2012). Macadamia (Heard and Exley, 1994; Wallace et al., 1996) and coffee (Klein et al., 2003; Raw and Free, 1977; Vergara and Badano, 2009) are two crops that benefit from insect pollination. However, the degree of insect pollination required varies; macadamia largely depending on cross pollination while coffee is capable of self-pollination.

Honeybees (*Apis mellifera*) play an important role in pollination for a wide range of agricultural crops (Roubik, 1995). Unfortunately dramatic losses of feral and managed honeybee colonies have relatively recently occurred in Hawaii, largely attributable to the invasion of *Varroa destructor* (varroa mite) in 2007 and *Aethina tumida* (small hive beetle) in 2010 (Connor, 2011). Understanding the importance of honeybees in macadamia and coffee orchards is underscored in the presence of the recent invasive impacts on bee colonies.

Objectives for macadamia and coffee study:

1) Determine richness and abundance of insect flower visitors
2) Quantify impacts of insect pollination on fruit set, retention and fruit quality
3) Estimate pollen removal/transfer efficacy of key pollinators

Materials and Methods

Study sites: Both experiments were located on the island of Oahu. The experiment for macadamia was conducted at the University of Hawaii Waimanalo Research Station (21º33” N 157º71’W), and the coffee experiment was conducted in a commercial coffee plantation in Waiahole (21º48” N 157º87’W) in 2010 and 2011.

Objective 1: Species richness and abundance

Monitoring of insects was conducted on clear sunny days, between 6:00 am and 5:00pm for macadamia and between 8:00 am and 4:00pm for coffee when orchards were in bloom. Richness was done through collection and identification of insects foraging on macadamia or coffee flowers. Abundance was assessed with a transect insect count. A fixed route was walked through the orchard at a constant pace and insects seen on macadamia and coffee flowers were recorded.

Objective 2: Fruit set, fruit retention, and quality

Two treatments were done to assess fruit production. Branches with flowers at bud stage were either 1) bagged with a fine mesh cloth bag, encompassing flower buds, which constituted the “insect exclusion” (IE); or 2) tagged with flagging tape, but not bagged during the flower receptive stage, which constituted the “open pollination” (OP) treatment (Fig. 1).

Fig. 1. Treatments: A) insect exclusion and B) open pollination

Initial fruit set count for both macadamia and coffee was done at 14 days and 21 days after flowering, respectively. A final fruit retention count was done when fruit was no longer being lost, about 3 months for macadamia and 3.5 months for coffee.
Fruit quality was assessed by recording length, and mass of individual fruits at harvest. Kernels and beans were dried at 38ºC for either seven days or three days, respectively.

Objective 3: Efficacy of insect pollen removal and transfer

Number of pollen grains on the stigma of newly open flowers were counted: 1) after one insect visit, 2) after floret was exposed for a whole day to insect visitation, or 3) with no insect visitation. Stigmas were collected, placed into individual collection tubes, and then put on ice to prevent pollen germination. McGillivray’s (1987) method for removing pollen from an insect was modified to remove pollen grains from stigmas. Pollen was counted using a hemacytometer plate, under a compound microscope (Fig. 2).

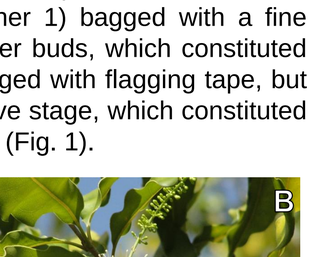


Fig. 2. Pollen slide with a counting grid on a hemacytometer plate.

Results and Discussion

Species richness

	Macadamia	Coffee
Diptera	9	9
Hymenoptera	2	4
Lepidoptera	1	2
Coleoptera	1	0

Table 1. Number of species observed on macadamia and coffee flowers during transect surveys.

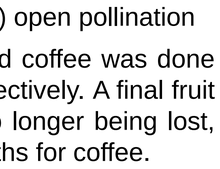


Fig. 3. *O. obesa*

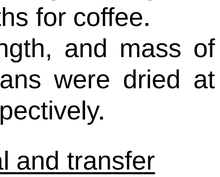
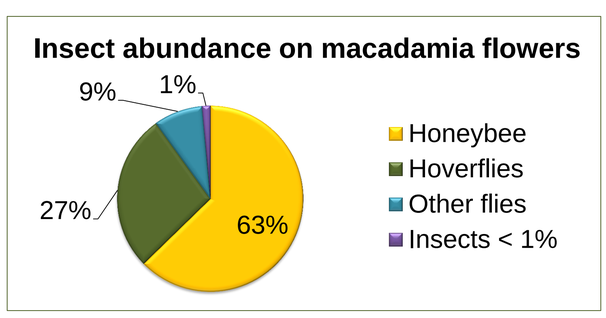


Fig. 4. *A. obliqua*

- Based on Table 1, Diptera contributed the highest number of species of flower visitors
- Syrphidae (hoverflies), the most various family, included *Ornidia obesa* (Fig. 3), *Allograpta obliqua* (Fig. 4), *Eristalis arvorum, Toxomerus marginatus*, and two *Syritta* spp.

Results and Discussion Continued



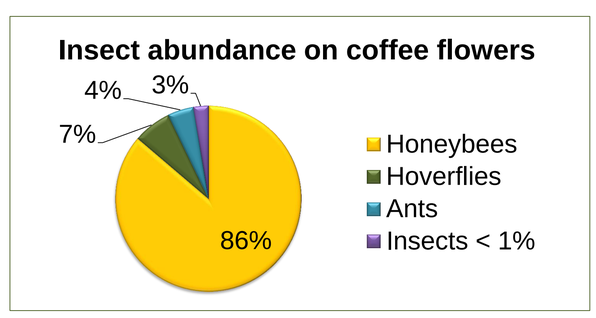
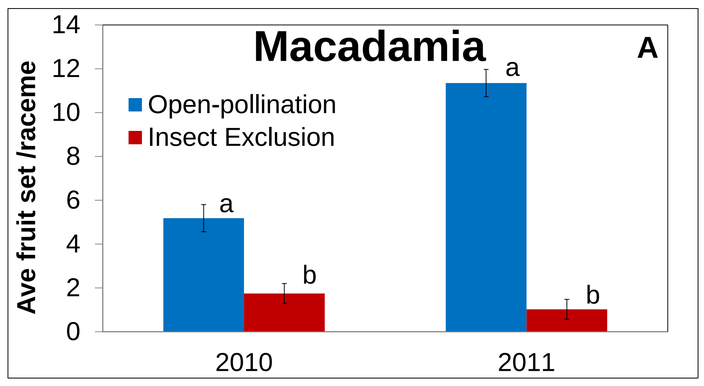


Fig. 5. Percent abundance of insects observed on macadamia and coffee flowers during transect surveys.

- Based on transect counts, honeybees were highest in abundance.

Fig. 6. Honeybees on macadamia and coffee flowers



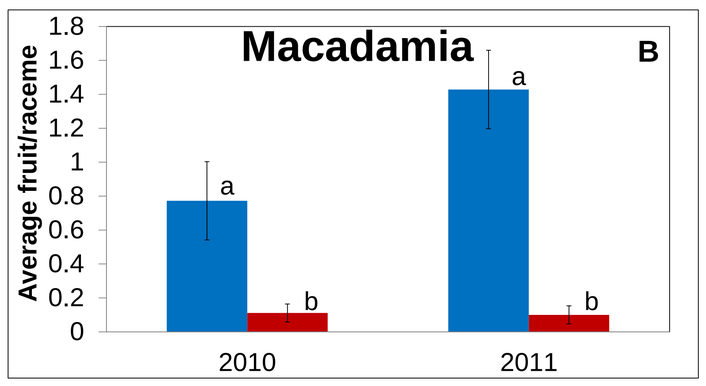
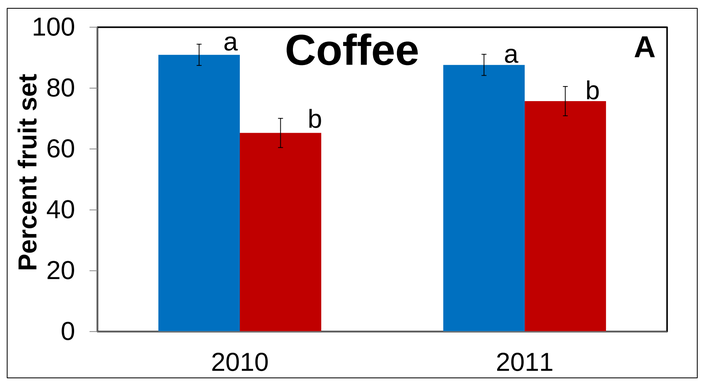


Fig. 7. A) Initial fruit set per raceme at 2 weeks after flowering, and B) fruit retention at 2 months (2010, n = 10 recemes) and 3 months (2011, n = 40 recemes). Error bars are standard errors. Bars with different letters (within a year) were significantly different ($P < 0.001$) based on Students *t*-tests.



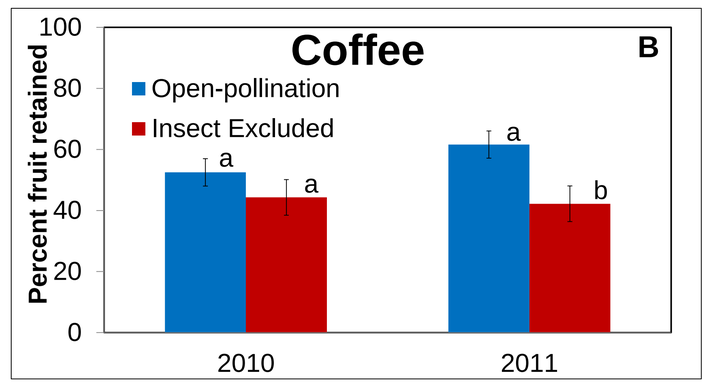


Fig. 8. A) Initial fruit set at 21 days after flowering, and B) fruit retention at 3.5 months after flowering. Error bars shown are standard errors. Bars with different letters were significantly different ($P < 0.01$) based on Students *t*-tests in 2010 (n = 10 branches) and 2011 (n = 20 branches).

- Based on results, shown in Fig. 7 and 8, insect visitation for both macadamia and coffee plants significantly increased fruit set and fruit retention compared to recemes and branches that had no insect visitation.
- Macadamia had 7 (in 2010) and 14 (in 2011) times more fruit in OP than in IE, at harvest (Fig. 7B).
- Coffee had 5% (in 2010) and 27% (in 2011) more fruit in OP than in IE, at harvest (Fig. 8A).
- It is clear that insects were important in fruit production for both crops.

Kernel and bean quality

		2010 Treatments	
		Open pollination	Insect exclusion
Macadamia	Nut length (mm)	15.30a (± 0.37)	15.84 a (± 0.90)
OP (n=27), IE (n=4)	Kernel mass(g)	2.19 a (± 0.12)	2.64 a (± 0.11)
Coffee	Bean length	12.33 a (± 0.05)	11.73 b (± 0.12)
OP (n=244), IE (n=86)	Dry bean mass	0.20 a (± 0.003)	0.14 b (± 0.01)
		2011 Treatments	
Macadamia	Nut length	17.56 a (± 0.16)	16.82 a (± 1.26)
OP (n=90), IE (n=7)	Kernel mass	3.08 a (± 0.07)	3.00 a (± 0.51)
	Dry kernel mass	2.67 a (± 0.06)	2.52 a (± 0.43)
Coffee	Bean length	13.83 a (± 0.06)	13.51 b (± 0.13)
OP (n=178), IE (n=74)	Dry bean mass	0.26 a (± 0.004)	0.24 b (± 0.007)

Table 2. Means (±SEM) for kernel and bean parameters for macadamia and coffee pollination experiments. Treatment means with different letters in the same row were significantly different ($P < 0.05$) based on Students *t*-tests.

Based on the parameters measured in Table 2, insect pollination did not increase kernel quality in macadamia; however, bean quality in coffee was significantly improved with insect pollination.

Pollen removed or transferred from stigma by insect

		Sample #	Mean pollen grains/stigma	% pollen grains removed by insects
Macadamia	All day	27	796 a (± 189.9)	94.8
	Honeybee (single visit, pollen)	7	2939 a (± 1314.4)	80.8
	Honeybee (single visit, nectar)	23	13902 b (± 1447.0)	9.1
	Ornidia obesa (single visit, nectar)	5	14514 b (± 2781.5)	5.1
	No insect	22	15298 b (± 1379.2)	0.0
				Estimated pollen grains transferred by insects
Coffee	No insect	8	299 b (± 83.7)	0
	All day	17	889 a (± 158.1)	591
	Honeybee (single visit)	13	659 a (± 116.0)	360

Table 3. Pollen removal or transfer rate of insects on insect exposed macadamia and coffee flowers. Treatment means within each crop with different letters in the same column were significantly different ($P < 0.0001$) based on Waller-Duncan tests for pairwise comparisons.

- For macadamia, honeybees foraging for pollen removed the most pollen per visit compared to other insect forager types.
- In macadamia, for nectar foragers to have significant pollen removal from a stigma many visits are required, potentially increasing the chances for cross-pollination.
- For coffee, transfer of pollen by a single honeybee visit was not different than for stigmas exposed to pollinators all day, indicating the importance of maintaining honeybees in coffee plantations.

Conclusions

Honeybees were the most abundant flower visiting insect and appeared to contribute extensively to the movement of pollen in macadamia and coffee orchards. Results indicate that it is important to have insect visitation to increase fruit set and retention.

The main implications of this study is that macadamia and coffee farmers would benefit from maintaining honeybee hives in orchards. Despite the low abundance of hoverflies their potential as pollinators should not be ignored.

Acknowledgements

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