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Article · January 1977

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The pollination of coffee (Coffea arabica) *by honeybees*

A. RAW* and J. B. FREE†

Plant Protection Division, Ministry of Agriculture, Kingston, Jamaica

Caging coffee bushes with and without honeybee colonies demonstrated that, whereas the presence of pollinators had little effect on the initial set, it increased the yield of mature berries by approximately a half.

INTRODUCTION

THE PLANT *Coffea arabica* L. is tetraploid and self fertile (FREE, 1970). Although numerous insects, especially bees, visit the flowers (MCDONALD, 1930; NOGUEIRA-NETO *et al.*, 1959) estimates of the amount of cross-pollination that occurs differ widely, for example 39 to 93 per cent (TASCHDJIAN, 1932), 40 to 50 per cent (KRUG and COSTA, 1947), four to nine per cent (CARVALHO and KRUG, 1949), and any benefit from insect pollination to the yield is uncertain. However, bushes that were caged to exclude visitors to the flowers had smaller sets than did bushes that were not caged and whose flowers were visited by insects (AMARAL, 1952, 1960, 1972; NOGUEIRA-NETO *et al.*, 1959; SEIN, 1959). Although the results of these experiments are suggestive, the larger crops from the uncaged bushes may reflect better growing conditions outside the cages.

We have made similar experiments but, to ensure a surplus of insect visitors and to neutralize any effect on the yields of caging the bushes, colonies of honeybees were enclosed with some of the caged bushes. In addition, the times of opening of selected flowers and the development of their berries were recorded in the treatments.

METHODS

A coffee plantation 17km north west of Kingston, Jamaica was used for the investigation. The locality receives about 1300mm of rainfall annually. The plantation contained 360 bushes in four pairs of rows. The two rows of a pair were 0·9m apart while the pairs were 1·8m apart. Eight plots of six

* Present address; Laboratório de Ecologia, Departamento de Biologia Vegetal, Universidade de Brasília–Brasília D.F.
† On secondment from Rothamsted Experimental Station, Harpenden, Herts., U.K.

bushes each (three pairs of rows) and a single row of three bushes were selected. Six of the plots were enclosed in 2·3m high cages of nylon mesh (1mm diameter) and three were not caged. Four of the caged plots (two with bees) and two of the plots not caged had bushes 1·5 to 1·7m high; two of these caged plots and one plot not caged received much sunshine, while the others were shaded for most of the day. The two remaining caged plots (one with bees) and the one not caged (of three bushes only) contained large bushes (1·9 to 2·2m high) that were usually shaded.

The ripe berries were gathered from all the bushes in the plots on 2 and 29 October and 20 November 1974, and in addition they were gathered from the larger bushes on 18 December 1974 and on 20 January 1975. The berries from each bush were counted, oven-dried and weighed.

Sometimes only one of the two ovules in a coffee flower develops into a bean, a condition known as 'pea berry'. One hundred berries from each bush were selected at random and dissected in order to measure the proportion of pea berries in each treatment.

In addition to measuring the yields of individual bushes, the proportion of flowers that developed into mature berries was determined for plots caged with bees, caged without bees and not caged. Five bushes were selected at random from each of these treatments and three branches labelled on each. Three branches were subsequently broken, so data were obtained from a total of 42 branches. The leaves of coffee are located in pairs along straight branches and the flowers are borne in clusters of up to 16 in the leaf axils (ALVIM, 1973). Every axil on each of the 42 branches was numbered and every 18 to 20 days during flowering and early berry development (7 March to 28 July) the buds, flowers and berries in each axil were counted. During their later development berries were counted every six weeks. The berries were classified as small (<4 mm in diameter), medium (4 to 8mm) and large (>8mm in diameter).

RESULTS

Plots caged with bees yielded more berries and a greater weight of berries ($P<0·02$ for each comparison) than plots caged without bees (*Table 1*).

There were five flushes of flowers between the first week in March and the last in May. However, two major flushes occurred, one between 18 and 25 March when 27 per cent of the flower buds opened and another between 9 and 19 April when 58 per cent opened. By 26 July all the small berries had either fallen or grown to medium or large size. Berries of medium size were present on 11 June and 26 July, and large ones from 26 July onwards.

A total of 4121 flower buds were counted on the 42 selected branches (mean of 98 flowers per branch). The number of nodes per branch and the number of flowers per branch did not differ with treatment (*Table 2*). The proportion of flowers that set was greater on branches caged with honeybees than in either of the other treatments ($P<0·001$ for each comparison). However, the proportion of berries that remained to medium size and to large size on the branches was significantly less when bees were excluded than in the other two treatments ($P<0·001$ for each comparison).

The proportions of pea berries in the samples from bushes caged with bees

Table 1. Effect on yield of caging coffee bushes with and without bees (mean ± SE)

	Mean no. of beans per bush				*Mean dry wt (g) of beans per bush*			
	a Caged with bees	*b* Caged without bees	*c* Not caged	*Degree of significance*	*a* Caged with bees	*b* Caged without bees	*c* Not caged	*Degree of significance*
Plots in sun (3 harvests)								
First harvest	369	223	312		131·2	68·6	99·7	
Second harvest	295	41	214		65·1	8·2	56·8	
Third harvest	55	92	32		16·9	26·3	8·4	
Total	719 ± 36	356 ± 22	558 ± 32	$a>b$ ($P<0·001$) $a>c$ ($P<0·01$) $c>b$ ($P<0·001$)	213·2 ± 4·5	103·1 ± 5·7	164·9 ± 2·8	$a>b$ ($P<0·001$) $a>c$ ($P<0·01$) $c>b$ ($P<0·01$)
Plots in shade (3 harvests)								
First harvest	288	157	635		137·8	53·1	218·4	
Second harvest	313	287	134		71·1	66·7	33·1	
Third harvest	65	39	35		19·6	10·7	9·5	
Total	666 ± 20	483 ± 28	804 ± 94	$a>b$ ($P<0·001$) $c>b$ ($P<0·01$)	228·5 ± 10·0	130·5 ± 2·1	261·0 ± 17·3	$a>b$ ($P<0·01$) $c>b$ ($P<0·01$)
Plots in shade (5 harvests)								
First harvest	628	285	367		293·1	98·6	195·5	
Second harvest	127	98	111		29·2	39·3	25·3	
Third harvest	58	74	205		16·3	18·9	57·9	
Fourth harvest	436	327	330		148·8	103·9	107·3	
Fifth harvest	95	89	81		33·5	32·4	32·6	
Total	1344 ± 169	873 ± 153	1094 ± 233	$a>b$ ($P<0·01$)	520·9 ± 40·1	293·1 ± 3·8	418·6 ± 61·8	$a>b$ ($P<0·01$) $a>c$ ($P<0·01$) $c>b$ ($P<0·05$)

(21·5 per cent) and those from bushes caged without bees (20·2 per cent) did not differ significantly ($P > 0{\cdot}05$). In contrast the mean proportion from the exposed bushes of 13·4 per cent was significantly less than those in the two other treatments ($P < 0{\cdot}001$ for each comparison).

Numerous insects were captured from the flowers of bushes not caged (*Table 3*), but honeybees were by far the most abundant. On 29 March the honeybees foraging on the bushes in one row were counted for 10 min at

Table 2. Effect of the presence of honeybees on the proportion of coffee flowers that set berries (mean ± SE)

	Caged with bees	*Caged without bees*	*Not caged*
No. of branches	15	13	14
No. of nodes per branch	10·8 ± 0·3	10·5 ± 0·3	9·9 ± 0·2
No. of flowers per branch	100·3 ± 3·0	98·8 ± 3·2	95·1 ± 2·3
No. of flowers per branch that:			
Set initially	90·4 ± 2·8	84·5 ± 2·8	80·3 ± 2·1
Later grew to medium size berries	65·4 ± 2·4	48·1 ± 2·3	62·1 ± 1·6
Later grew to large berries	44·9 ± 1·5	31·3 ± 1·2	45·8 ± 1·1
Percentage of flowers that:			
Set initially	90·2	85·4	84·4
Later grew to medium size berries	65·2	48·6	65·3
Later grew to large berries	44·7	31·7	48·0

Table 3. List of insects observed visiting flowers of Coffea arabica *at Caymanas Estate in 1974*

Hymenoptera		Lepidoptera *continued*	
Apidae	*Apis mellifera* (L.)	Heliconiidae	*Heliconius charitonius* Röber
Anthophoridae	*Centris dirrhoda* Moure		*Dryas iulia* F.
	Exomalopsis sp.	Nymphalidae	*Siproeta stelenes* (L.)
Halictidae	*Dialictus* sp.	Hesperiidae	*Urbanus proteus* (L.)
Vespidae	*Polistes crinitus* Felt.		*Proteides mercurius* Skinner
Lepidoptera			*Astraptes jaira* (Butler)
Pieridae	*Phoebis sennae* (L.)		*Polygonus leo* Evans
	Ascia monusto Godart		*Cymaenes tripunctus* (Herrich-Schäffer)
	Eurema sp.		
Papilionidae	*Battus polydamas* Rothschild and Jordan		*Panoquina sylvicola* Watson

hourly intervals. The numbers recorded were: 11 at 09.00 hours; 11 at 10.00 hours; 20 at 11.00 hours; 17 at 12.00 hours; 14 at 13.00 hours; 18 at 14.00 hours, and 10 at 15.00 hours. At 10.00 and 11.00 hours most of the bees had pollen loads (22 with pollen and 9 without), but at other times most bees had nectar only (a total of 29 with pollen and 41 without).

Honeybees sometimes failed to touch the inner receptive surfaces of the stigmas of the flowers that they visited, but their behaviour was mostly such that pollination could have occurred. Samples of 20 bees with pollen loads and 20 bees without were examined to determine the amount of pollen which they carried on their bodies, excluding any in their corbiculae. Bees with pollen loads had a mean of 12600 coffee pollen grains on them and no grains of any other species, whereas bees without pollen loads had means of 5555 coffee pollen grains and 250 of other species.

DISCUSSION

The yields of berries from coffee bushes caged with honeybees were much greater than those were from bushes caged without bees. The larger numbers of berries obtained illustrates both the need for *C. arabica* flowers to be pollinated and the ability of honeybees to do so.

The initial set of berries in each treatment was high, but it was significantly higher on bushes caged with honeybees than it was in either of the other treatments. When the berries had grown to medium size the difference in set between the two treatments visited by honeybees was no longer significant ($P > 0{\cdot}05$), nor was it when the berries had ripened. Presumably the microclimates were similar in all of the cages, but the densities of honeybees inside the cages were probably greater than outside them which might have resulted in an initial set in excess of the numbers of berries that the bushes caged with honeybees could carry to ripening.

Bushes of both treatments visited by honeybees bore significantly higher sets of medium sized berries than those which were not and the difference became greater as the berries grew. Approximately half of the flowers available to honeybees produced ripe berries compared with only one-third of those not visited by bees. Similarly, comparing the two caged treatments, the presence of honeybees resulted in an average of 52 per cent more ripe berries per bush being produced. The benefit from bee pollination in our experiments is greater than would be expected from the differences obtained in several previous experiments between the yields from exposed bushes and from bushes caged without bees (AMARAL, 1952, 1960; NOGUEIRA-NETA *et al.*, 1959; SEIN, 1959). It may therefore be supposed that the uncaged bushes in those experiments were not adequately pollinated; a suggestion supported by AMARAL (1972) who also caged honeybee colonies with coffee bushes.

The numbers of flowers that produced mature berries in the absence of bees indicates that *C. arabica* may be amphicarpic, which is the condition where some flowers on a plant must be cross fertilized whereas others can be self fertilized. As a result some fruits are produced in the absence of pollinators, but greater numbers can be produced in their presence.

The proportion of pea berries produced did not seem to be related to the amount of pollination that occurred. It was higher on caged bushes than on exposed ones and might have resulted from the effects of the cages or from the reduced amount of cross pollination among the plants, there being six bushes in each cage.

Our results are in accord with those of MCDONALD (1930) and AMARAL (1972), and likewise we suggest that coffee farmers should keep honeybee colonies in their fields during flowering to obtain greater yields of berries.

(*Received March 1976*)

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