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ABSTRACT Manipulation of the honey bee (*Apis mellifera* L.) drone population near a mating apiary was investigated as a method for increasing the frequency of European drones that mate with European queens in an area of Africanized honey bees. Thirty percent of the matings were controlled with only four European drone source colonies, and 40% were controlled with seven colonies. If queen producers can tolerate low levels of mismating, they may not have to drastically alter their management practices.

KEY WORDS Insecta, *Apis mellifera*, drone saturation

PROBLEMS IN SOUTH and Central America and Mexico related to Africanized honey bees[1] have focused attention on the need for production of European queens[2] in Africanized areas. Closed-breeding technology, based on the instrumental insemination of queens, has been suggested as a solution (Page & Laidlaw 1982, Page et al. 1982). Instrumental insemination, however, is not yet practical on a commercial scale because it requires specialized skills, and because inseminated queens often are inferior to naturally mated queens (Harbo & Szabo 1984, Harbo 1985). Attempts to control natural matings of honey bees have been based on the principle of isolating queens from undesirable drones. This principle dates to 1771 when Anton Janscha discovered that honey bee queens do not mate inside the hive, but rather away from the hive while flying (Fraser 1951). Since then, isolated matings have been achieved with varying degrees of success by locating mating apiaries on plains, deserts, islands, or high in the mountains (Laidlaw 1979). Extensive work by European researchers indicates that complete isolation of queens is achieved rarely (Ruttner 1966). A significant degree of isolation, though, can be attained if mating stations are surrounded by a drone-free area 6–7 km in radius (Böttcher 1970). When isolation is not complete, the frequency of mismatings can be reduced by increasing the number of desirable drones near mating stations (Böttcher 1969, Woyke 1971, Jasinski 1972).

Our study was done to evaluate the possibility of mating European queens to a high percentage of European drones in an Africanized area. It uses the principle of reducing mismatings by increasing the number of desirable drones in mating areas.

Materials and Methods

The experiment was conducted 40 km southeast of Barquisimeto, Venezuela, an area of tropical dry forest and savanna. Queen-mating units were five-frame Langstroth hives (44 by 23-cm frames) that contained approximately 0.5 kg (≅4,000 individuals) of European workers. Each unit was given a virgin queen (0–24-h old), grafted from light-colored European stock, that was marked on the thorax with enamel paint. Marking avoided confusion with queens that might be produced by the mating units. Each queen was caged on a comb in a mating unit for 2 d before being released. Colonies were checked 14 d later to determine the egg-laying status of queens, to remove all queens, and to add virgin queens for the next trial. Twenty-four mating units were used during each of the four trials. The trials were identical, except that the number of European drone source colonies placed in the mating apiary during each trial was varied, that is, 0, 4, 7, and 7 drone source colonies, respectively.

European drone source colonies were prepared approximately 3 wk before the first trial. Each colony had two 10-frame Langstroth chambers that contained a laying queen, all stages of brood, and 3–4 kg of bees. Each colony was given the equivalent of 1–1.5 frames (≅2,000–3,000 cm²) of drone brood. These frames were collected from several light-colored European colonies and had drone brood of variable developmental stages. Drone colonies were inspected approximately every 2 wk throughout the experiment. Drone brood was added to a colony when the total amount of drone brood

[1] Africanized honey bees are descendants of *Apis mellifera scutellata* (Lepeletier) imports and their hybrids with various European subspecies previously imported to South America.

[2] European queens have mixed European subspecies representatives (predominately *A. m. ligustica* Spinola).

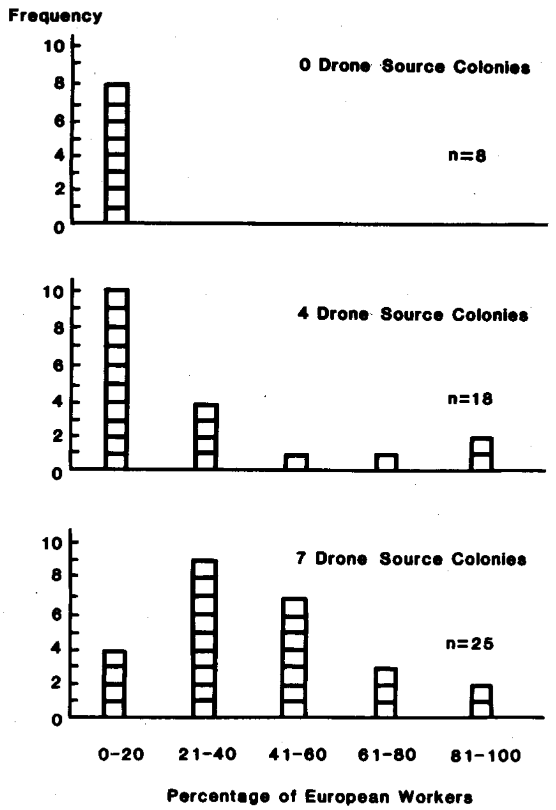

Fig. 1. Frequency histogram: percentage of European workers produced by European queens in a mating apiary in an area with Africanized bees when 0, 4, and 7 European drone source colonies were placed in the apiary (n, number of queens mated).

was below one-half frame. Colonies were fed sucrose solution (2.9 M) and pollen to ensure that workers attended drone adults and brood.

Brood from mated queens was put in an incubator until eclosion. Based on body color, 100–120 workers per queen were identified as European or hybrid. Blind comparisons were made with body color standards that were developed by instrumentally inseminating light-colored European queens with semen from light-colored European drones and with semen from several Africanized drones. Feral Africanized drones that we sampled were consistently darker than any of the European drones that were used in this experiment.

A one-way analysis of variance (ANOVA) was used to analyze progeny percentages from the four trials. Waller-Duncan K-ratio t tests (Waller & Duncan 1969) were used to separate means. The Kolmogorov-Smirnov one-sample test for goodness of fit (Kolmogorov 1933) was used to determine if mating proportions approximated a specified binomial distribution. For this distribution, we assumed that each queen mated with 10 drones. Queens normally mate with 7–17 drones (Taber & Wendel 1958, Woyke 1960, Kerr et al. 1962, Adams et al. 1977). We also assumed that the probability of a queen mating with a European drone depended on the proportion of matings controlled. An average value was calculated for each trial.

Results

Light-colored European progeny were produced more often when the apiary contained European drones than when it did not ($t = 4.60$; df = 3; $P < 0.01$). Queens from trial 1 (no European drone colonies) produced 2.2 ± 0.8% ($\bar{x} \pm$ SE) European workers, queens from trial 2 (four European drone colonies) produced 30.0 ± 7.0% European workers, and queens from trials 3 and 4 (seven European drone colonies) produced 40.0 ± 12.9 and 41.6 ± 5.2% European workers, respectively.

A majority of queens from mating yards with four European drone colonies produced 0–20% European workers, whereas the majority of those from mating yards with seven European drone colonies produced 21–40% European workers (Fig. 1). No queens produced 100% European workers. Most of them produced both European and hybrid workers. Three queens during trial 2, however, produced 100% hybrid workers. Frequency data (Fig. 1) approximate binomial distributions for trial 2 ($D = 0.20$; $n = 19$; $P > 0.20$) and trials 3 and 4 (pooled; $D = 0.15$; $n = 25$; $P > 0.20$) when the probability of a queen mating with a European drone was 0.3 (trial 2) and 0.4 (trials 3 and 4).

Discussion

Of the matings in the experiment, 30–40% were controlled (i.e., European queens mated with European drones). These matings were produced with only a few European drone source colonies even though there were Africanized bees in the area. The ratio of European drones to feral Africanized drones is not known, but we hypothesize that to control higher percentages of matings the numbers of European drone source colonies would have to increase logarithmically to produce a linear increase in controlled matings (Hellmich 1987). For example, when a queen producer controls 50% of the matings in an apiary, the influence of managed drones is equal to that of unmanaged drones. If this queen producer had 10 drone source colonies and he wanted to increase the influence of the managed drones from 50 to 70%, hypothetically, he would need approximately 23 drone source colonies. To influence 80, 90, and 99% of the matings, this queen producer would need 40, 90, and 990 drone source colonies, respectively.[3] At some point higher levels of mating control become prohibitively expensive.

[3] These numbers are derived from $m = up/(1 - p)$, where m = number of managed drone source colonies; u = influence of unmanaged drone source colonies—here $u = 10$; and p = proportion of matings queen producer wishes to control (for further information see Hellmich [1987]).

Table 1. Percentage of European queens expected to yield European progeny in percentages equal to or greater than designated values when controlled matings of an apiary range from 40 to 99.9% in an Africanized area. For example, when 60% of the matings in a European apiary are controlled, 0.6% of the queens are expected to produce 100% European progeny; 83.4% of the queens are expected to produce at least 50% European progeny. These values are based on the sampling distribution of the binomial.[a] For these calculations, queens are assumed to mate randomly with 10 drones

Percentage of European progeny	Percentage of matings controlled								
	40	50	60	70	80	90	95	99	99.9
10	99.4	99.9	~100						
20	95.4	98.9	99.8	~100					
30	83.3	94.5	98.8	99.8	~100				
40	61.8	82.8	94.5	98.9	99.9	~100			
50	36.7	62.3	83.4	95.3	99.4	~100			
60	16.6	37.7	63.3	85.0	96.7	99.8	~100		
70	5.5	17.2	38.2	65.0	87.9	98.7	99.9	~100	
80	1.2	5.5	16.7	38.3	67.8	93.0	98.8	~100	
90	0.2	1.1	4.6	14.9	37.6	73.6	91.4	99.6	~100
100	0.01	0.1	0.6	2.8	10.7	34.9	59.9	90.4	99.0

[a] $P(x) = \sum_{i}^{x} \binom{N}{i} p^i (1-p)^{N-i}$

$P(x)$ = probability of a queen mating with x or greater number of European drones; x = number of European drones with which queen mates, $0 \leq x \leq 10$; $i = 10, 9, 8, \ldots$; N = total number of drones (European and Africanized) with which queen mates, here $N = 10$; p = probability of queen mating with European drones, which depends on the proportion of matings controlled for a given apiary, here $0.4 \leq p \leq 0.999$.

Many U.S. queen producers argue that any mismating in their operation is unacceptable. In Africanized areas, such a demand is unrealistic with present technology. Even when there are small numbers of Africanized drones, 100% production of purebred European queens is impossible in practice because queens mate with multiple drones. If a queen from our experimental apiary mated 10 times when 40% of the matings were controlled, she would have one chance in 10,000 of mating only with European drones (Table 1).

Queen production in Africanized areas becomes more realistic, however, when some hybrid progeny are tolerated. If a queen producer could control 90% of the matings, approximately three-quarters of the queens would be expected to produce 90% or more European progeny, and nearly all of them would produce 50% or more European progeny (Table 1). If low levels of mismatings are tolerable, then perhaps the impact Africanization will have on Mexican and U.S. queen producers will not be as devastating as predicted (McDowell 1984, Taylor 1985). Recommendations for acceptable levels of mismating have not yet been determined. Recent research, however, indicates that defensive behavior of colonies populated by F_1 hybrid workers is intermediate to that of the parental lines, which indicates that dominance is not apparent (unpublished data). This and related research will facilitate the development of recommendations for acceptable levels of mismating.

Africanization will affect queen production operations differently depending on local feral drone densities. These densities will vary, even in the same latitude, depending on climate, season, nest site availability, predators, and nectar and pollen sources. More information is needed concerning feral drone densities in different habitats and changes that occur in these densities during and after Africanization. This information would help queen producers in Africanized areas to use the most appropriate methods to produce high-quality queens. Results from this paper are encouraging for queen producers because significant levels of matings in an Africanized area were controlled with only a few drone source colonies. This information suggests that some queen producers may not have to drastically alter their management practices if they can tolerate low levels of mismating.

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