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Original article

Honey production of honey bee colonies infested with *Acarapis woodi* (Rennie)

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Summary — The honey production of *Apis mellifera* colonies infested with *Acarapis woodi* (Rennie) was monitored in northeastern Mexico. After 31 days of a citrus nectar flow, lightly (< 5.0%), moderately (39.8%), and heavily (86.7%) infested colonies produced on average 24.1, 11.5, and 3.2 kg of surplus honey, respectively. Honey production was positively correlated with colony size and negatively with the degree of parasitism. Significant population losses while overwintering probably affected the productivity of moderately and heavily infested colonies. Additional effects of parasitism are suggested as contributing to poor honey production. The results suggest that even moderate levels of *A. woodi* can have substantial economic consequences for susceptible populations of bees.

Additionally, infestation levels rose significantly in the lightly infested colonies, but declined in the moderately and heavily infested colonies. The percent change in parasitism was positively correlated with the degree of parasitism at the start of the test. Differential mortality of heavily infested bees is suggested as the cause.

***Apis mellifera* — *Acarapis woodi* — honey production — parasitism — overwintering**

Resumé — La production de miel chez des colonies d'abeilles (*Apis mellifica* L.) infestées par *Acarapis woodi* Rennie. *On a mesuré la production de miel de colonies d'abeilles infestées par l'acarien* Acarapis woodi. *Trois groupes de colonies ont été constitués en fonction de leur taux d'infestation : faible (< 5,0%;* N=30*), moyen (39,8%;* N=30*) et élevé (86,7%;* N=29*) et placés dans un verger de citronniers près de Santa Engracia, Nuevo Leon, Mexique. Au bout de 31 jours de butinage, les colonies faiblement, moyennement et fortement infestées ont produit en moyenne 24,1, 11,5 et 3,2 kg de miel respectivement. La production de miel est négativement corrélée avec le taux de parasitisme chez les colonies fortement infestées, mais non chez les colonies faiblement et moyennement infestées.*

Le pourcentage d'abeilles parasitées par A. woodi *a augmenté dans les colonies faiblement infestées (de 2,0 à 5,2%), mais a diminué chez les colonies moyennement (de 35,4 à 21,5%) et fortement infestées (de 89,7 à 28,0%). La variation du taux est positivement corrélée avec le degré de parasitisme en début de test. On pense qu'une mortalité variable chez les colonies fortement infestées est à l'origine de ces différences. Les observations faites sur ces colonies durant l'hivernage corroborent cette hypothèse. Les colonies fortement infestées ont perdu significativement plus d'abeilles au cours de l'hivernage (Eischen, 1987). Si les colonies fortement infestées sont plus*

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susceptibles de mourir pendant la miellée, leur faible productivité peut être due aux 3 facteurs suivants : 1) L'hivernage et le stress dû au parasite ont laissé des colonies avec une population réduite, 2) la morbidité adulte a réduit l'efficacité du butinage, 3) les colonies ont souffert d'une réduction du nombre des butineuses pendant la miellée.

Ces résultats suggèrent que même un parasitisme modéré par A. woodi *peut avoir un effet important sur la productivité.*

Apis mellifera — Acarapis woodi — *production de miel — parasitisme — hivernage*

Zusammenfassung — Honigproduktion von mit Acarapis woodi (Rennie) befallenen Völkern der Honigbiene. *Die Honigproduktion von* Apis mellifera-*Völkern, die von der Milbe* Acarapis woodi *befallen waren, wurde getestet. Drei Gruppen von Völkern mit verschiedenem Befallsgrad (leicht < 5.0%;* N=*30) mittel (10-50;* N=*30) und stark befallen (70-100%;* N=*29) wurden in einem Zitrusgarten in der Nähe von Santa Engracia, Nuevo Leon, Mexiko, aufgestellt. Nach 31 Tagen Sammelaktivität hatten die leicht befallenen durchschnittlich 24.1 kg Honig, die mittelmäßig befallenen 11.5 kg und die stark befallenen Völker ca. 3.2 kg Honig eingetragen. Die Honigproduktion war bei den stark befallenen Völkern negativ korreliert mit dem Befallsgrad, bei leicht und mittelstark befallenen Völkern zeigte sich keine Korrelation.*

Der Prozentsatz an infizierten Bienen stieg in den leicht befallenen Völkern an (von 2.0% auf 5.2%) aber fiel bei den mittelmäßig befallenen (von 35.4% auf 21.5%) und den stark befallenen (von 89.7% auf 28.0%) ab. Die prozentuale Änderung im Parasitismus war positiv korreliert mit dem Parasitierungsgrad am Anfang des Tests. Unterschiedliche Mortalität von stark befallenen Bienen ist wahrscheinlich die Ursache für diese Differenz. Die Beobachtungen beim Überwintern dieser Völker unterstützen diese Annahme. Die stark infizierten Völker verloren signifikant mehr Bienen in dieser Zeit (Eischen, 1987). Wenn stark infizierte Arbeitsbienen eher während der Tracht sterben, so könnte die schwache Leistung der stark befallenen Völker auf folgende drei Faktoren zurückzufüren sein : 1) Überwinterung und Befallsstress bewirken einen Zurückgang in der Bienenpopulation; 2) die Krankheit reduziert die Sammelaktivität der adulten Bienen; 3) die Völker leiden unter Mangel an Sammelbienen während der Trachtzeit. Aus diesen Ergebnissen läßt sich schließen, daß selbst ein mittlerer Befall mit Acarapis woodi *einen entscheidenden Effekt auf die Produktivität eines Bienenvolkes hat.*

A. mellifera — Acarapis woodi — *Honigproduktion — Parasitismus — Überwinterung*

Introduction

Honey bee colonies in northeastern Mexico have relatively high populations of *Acarapis woodi.* Guzman-Novoa and Zozaya-Rubio (1984) found that 46% of apiaries in Nuevo Leon and 17.6% in Tamaulipas were infested. Our surveys indicate that during the winter of 1985, 61% of colonies were infested and that 42% had infestations in which 30% or more of the bees were parasitized (Eischen *et al.,* 1988b). More recently, Eischen *et al.* (1988a) and Lozano *et al.* (in press) have also found high levels of infestation in this area. The prevalence of *A. woodi* both among and within colonies in northeastern Mexico currently appears similar to those reported in England about 60 years ago (Rennie *et al.,* 1921; Morison *et al.*, 1956; Bailey and Perry, 1982).

Although economic thresholds have not been firmly established, several studies have reported adverse effects when mite populations exceeded a stated level. Rennie (1922) noted that when the infestation level was 50% or greater, colony value was doubtful. Morgenthaler (1937) had similar views, stating that a 50% infestation in the autumn was likely to result in colony death during winter. Bailey (1958, 1961) also reported that a colony's wintering success was significantly diminished when more than 30% of its bees were infested. Giavarini and Giordani (unpublished) noted high mortality in overwintering infested colonies. Similarly, Eischen (1987) found that both moderately and heavily infested colonies lost more bees and raised less brood than controls while overwintering.

Surprisingly, few productivity studies have been reported. Illingworth (1930) and Giordani (1977) noted that infested colonies produced less honey, but data were not included. Bailey (1985) reasoned that if *A. woodi* shortens bee longevity by 20%, then a colony that was 100% infested should be 20% less productive. This may, however, be an underestimation, because if bees live about 35 days in the summer, then a 20% reduction in longevity represents about a 50% reduction in foraging lifetime. Guzman-Novoa and Zozaya-Rubio (1984) found that colonies with infestations lower than 35% produced more honey than those whose infestations were higher.

Contrarily, the presence of *A. woodi* has not always been associated with decreased honey production. Rennie (1922) noted that in a good year, heavily infested colonies occasionally produced satisfactory yields. More recently Giordani (1977) made a similar observation, and Robinson *et al.* (1986) observed that a heavily infested colony was among the most productive.

This report presents additional observations on the honey production of colonies harboring light, moderate, and heavy infestations of *A. woodi*.

Materials and Methods

The following terms are used to describe infestations : prevalence (c), the percentage of colonies infested in an area; prevalence (w), the percentage of workers infested in a colony; parasite load, the number of mites in an individual bee; parasite load score, an estimate of the parasite load (see Margolis *et al.*, 1982; Eischen, 1987).

Colonies employed in this study had been used earlier in an overwintering experiment (Eischen, 1987). Three groups of colonies were selected; *i.e.* lightly infested (Group I, 0—5%; *N*=30), moderately infested (Group II, 10—50%, *N*=30), and heavily infested (Group III, 70—100%, *N*=29). One-half of the colonies in each group were randomly assigned to medicated subgroups. During late November, they received prophylactic treatments of fumigillin and oxytetracycline. All colonies were overwintered in two Standard Langstroth hive bodies. Colony population and food reserves were assessed during late November 1985 and again in late February 1986. Estimates were made in frame equivalents using the methods described by Kulinčević *et al.* (1982). Overwintering temperatures averaged 7.1, 5.2, and 8.9°C during December, January, and February, respectively. Colonies were moved from the mountain wintering location on Cerro El Potosi, Nuevo Leon, Mexico (lat. 24°53'N long. 100°13'W, altitude 2800 m) on 3 March to Santa Engracia, NL (lat. 25°24'N long. 99°32'W, altitude 220 m). The citrus trees in this area had just begun to flower. Colonies were grouped according to infestation level, and placed in a single row with entrances facing a nearby citrus grove. Colonies were routinely managed for honey production. Thirty-one days later (2 April), honey production was measured by weighing the honey supers. The average weight of 5 empty supers was used to estimate tare for the filled supers. Supers were weighed to the nearest 0.5 kg with a Detecto® spring scale. Colonies were also given a cursory examination at this time.

Data within the main infestation groups pooled as productivity differences within subgroups were not found to be significant. Pooled data were then examined with ANOVA and Duncan's Multiple Range Test. Prevalence (w) data were given an arcsine transformation.

Results

Table I shows the prevàlence (w) of *A.woodi* on 5 February, 3 March and 2 April. Mite prevalence (w) in the lightly infested colonies (Group I) increased

Table I. Change in percent of *A. woodi* infestation in honey bee colonies during the interval February 5 — April 2, 1986.

Infestation group	*N*[1]	*February* $\bar{X} \pm SE$	*March* $\bar{X} \pm SE$	*April* $\bar{X} \pm SE$
Light (I)	30	2.0 ± 0.5[2]	—	5.2 ± 1.3 **
Moderate (II)	30	35.3 ± 4.4	39.8 ± 5.0	21.5 ± 4.5 **
Heavy (III)	29	89.7 ± 2.4	86.7 ± 2.5	28.0 ± 4.5 **

[1] By the end of the test 1, 4, and 1 colonies and died in the light, moderate, and heavily infested colonies, respectively.
[2] Values are percentages of bees infested (prevalence [w]).
** Mean April infestations were significantly smaller than those in February ($P < 0.005$).

significantly during the interval 5 February to 2 April (2.0 to 5.2%; $P < 0.005$). During the same interval, prevalence (w) declined significantly in both the moderately and heavily infested colonies (Group II, decreased from 35.3 to 21.5%; $P < 0.005$; Group III, decreased from 89.7 to 28.0%; $P < 0.005$). Similar changes occurred in the prevalence (w) of bilateral infestations in Group I (Table II), where it increased slightly, but significantly between 5 February — 2 April ($P < 0.02$). Nonsignificant changes occurred in Group II, but in Group III bilateralism dropped from 66.3 to 5.9 ($P < 0.001$). The prevalence (c) of colonies exhibiting bilateralism during this time increased by 16% in Group I, but declined by 47% and 63% in Groups II and III, respectively.

Parasite load scores made similar shifts (Table II). Scores rose significantly in Group I from 0.05 to 0.14 ($P < 0.02$), declined from 0.91 to 0.56 in Group II ($P < 0.05$) and dropped from 3.87 to 0.55 in Group III ($P < 0.001$). Parasite load scores cannot be converted into precise values of mites/bee, but multiplication by 10 gives an approximation. A significant positive

Table II. Changes in *A. woodi* bilateral infestations and parasite load scores during the interval February 5 — April 2, 1986.

Infestation group	*% Bilateral infestation*		*Parasite load scores* [1]	
	February	*April*	*February*	*April*
	X ± SE	*X ± SE*	*X ± SE*	*X ± SE*
Light (I) [2]	0.0	0.9 ± 0.4 *[3]	0.05 ± 0.001	0.14 ± 0.04 *
Moderate (II)	8.2 ± 1.7	5.6 ± 2.0	0.91 ± 0.14	0.56 ± 0.15 *
Heavy (III)	66.3 ± 4.6	5.9 ± 2.0 ***	3.87 ± 0.25	0.55 ± 0.12 ***

[1] Numbers of mites were estimated by assigning the following values to each of 20 bees dissected per colony : 0 (uninfested), 1 (< 10), 2 (> 10 ≤ 20), 3 (> 20 ≤ 30), or 4 (> 30).
[2] $N = 30$ for all groups in February, and 29, 26, and 27 for groups I, II, and III, respectively in April.
[3] February and April means are significantly different (paired t-test).
* $P < 0.02$; *** $P < 0.001$.

correlation (pooled data of Groups II and III, r=0.494, P < 0.001, N=53) was found between the estimated parasite load scores in February and the percent of change observed in April.

By the end of the test one colony had died in both Groups I and III. Four had died in Group II. Additionally, 4 queens in Group I had either died or become drone layers. These colonies produced little or no honey. Light, moderate, and heavily infested colonies produced on average 24.1, 11.5, and 3.2 kg of honey, respectively (all significantly different P < 0.001; Table III). Three percent of the colonies in Group I produced no surplus honey, while 12 and 82% of the colonies in Groups II and III yielded no honey. Though heavily infested colonies generally produced little or no honey, one such colony produced 36 kg. Table III also shows that in Group III honey production was negatively correlated with the prevalence (w) that occurred in November, 1985 (r = –0.612; P < 0.001), February 1986 (P < 0.01), and March, 1986 (P < 0.05; for infestation data see Eischen, 1987). Similar correlations for Groups I and II were not significant. No correlations were significant for the April infestation levels, *i.e.* after the nectar flow.

Significant positive correlations were found between bee populations and honey produced for all three groups of colonies (Table IV). This was true for both the November, 1985 and February, 1986 values. Correlations were consistently higher for the heavily infested bees. Why this is so is not clear. Additionally, honey production in groups II and III was positively correlated with the size of the late winter brood nest.

Discussion

The decrease of *A. woodi* populations in the moderate and heavily infested colonies during a nectar flow has been reported previously (Howorth, 1928; Bailey, 1958; Bailey and Perry, 1982; Eischen *et al.*, unpublished). Its cause is unclear. Morison *et al.* (1956) noted that mite infestations were lowest during the summer months and attributed this to elevated brood rearing and activity in the host bees. Bailey (1958) and Bailey and Perry (1982) elaborated on this by suggesting that during nectar flows contact between infested foragers and susceptible young workers within the hive is reduced. Our

Table III. Colony honey production and correlations with *A. woodi* populations.

Infestation group	*N* [2]	*Honey (kg)*	*Infestation* [1]		
			November 1985	*February 1986*	*March 1986*
Light (I)	29	24.1 ± 6.0	0.0	– 0.63	—
Moderate (II)	26	11.5 ± 1.5	– 0.222	– 0.383	– 0.224
Heavy (III)	28	3.2 ± 1.7	– 0.612 ***	– 0.549 **	– 0.4752 *

[1] Values are correlation coefficients *(r)* between production and infestation. After the nectar flow (April 1986) no significant correlations were found. See Eischen (1987) for infestation rates during November 1985.
[2] By the end of the test 1, 4, and 1 colonies had died in groups I, II and III, respectively. While overwintering one colony died in group III.
* P < 0.05; ** P < 0.01; *** P < 0.001.

Table IV. Correlation between colony measurements and honey production.

Colony measurement	*Infestation groups* [1]		
	Light (I)	*Moderate (II)*	*Heavy (III)*
1. Bees, Nov. 1985	+ 0.497 *	+ 0.461 *	+ 0.520 **
2. Brood, Nov. 1985	– 0.136	– 0.086	+ 0.059
3. Honey, Nov. 1985	+ 0.313	+ 0.005	+ 0.540
4. Bees, Feb. 1986	+ 0.457 *	+ 0.595 **	+ 0.730 ***
5. Brood, Feb. 1986	+ 0.205	+ 0.413 *	+ 0.716 ***
6. Honey, Feb. 1986	+ 0.209	– 0.080	+ 0.513 **

[1] Values are correlation coefficients (*r*).
* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

observations show that there was a distinct difference in how mite populations changed among the three groups of infested colonies. *A. woodi* populations fell dramatically in the heavily infested colonies (Group III). Smaller reductions occurred in the moderately infested bees (Group II). However, prevalence (w) increased in the lightly infested colonies (Group I). Further, we found a small but significant positive correlation between the degree of infestation and the relative decrease in mite levels. If the foraging intensity of the lightly infested colonies was at least as intense as the heavily infested colonies, then it seems unlikely that decreased contact time between foragers and susceptible young bees can account for the decline in mite populations. A more parsimonious explanation is that as parasite loads increase there is an increased probability of bee mortality during the honey flow, perhaps as a result of foraging stress. Differential bee mortality based on the degree of infestation would result in : 1) reduced mite loads and lower percentages of bees infested; 2) a positive correlation between the degree of infestation and subsequent decline in mite populations; 3) similar postflow mite populations due to the elimination of bees harboring mite loads beyond a certain threshold; 4) reduction in bee populations commensurate with the number of parasitized bees harboring mite populations in excess of the threshold value. We did not assess colony populations at the end of the test and thus cannot address the fourth prediction. However, the data do confirm the first three. Additionally, the suggestion that differential mortality among bees caused the mite population changes is supported by the fact that while overwintering, moderate and heavily infested colonies lost significant portions of their adult bee population, *i.e.* differential mortality occurred (Eischen, 1987).

It appears that light infestations had no measurable effect on productivity. Moderately infested bees produced 48% as much as lightly infested colonies, while heavily infested colonies produced little or no honey. The cause for the reduced productivity appears to be the result of an interaction between the degree of infestation and colony size. Groups I, II, and III lost 12, 20, and 46% of their adult bees, respectively, while overwintering. These losses doubtlessly had a negative effect on productivity. The level of parasitism was negatively correlated with overwintering performance in Group III (Eischen, 1987). Productivity during the nectar flow was also negatively correlated with both the degree of parasitism and colony size. If the argument presented above is correct, then these colonies may have been triply handicapped in their foraging efforts. That is, 1) they may have suffered differential mortality during the nectar flow; 2) they may have been less productive foragers; and 3) they started the test with a smaller population due to poor overwintering.

Based on the mite levels at the end of the nectar flow and the productivity values, our data suggest that infestation levels > 25% can result in economic damage. The data also suggest that a parasite load estimate is a better indicator of colony performance than prevalence (w). Presumably this is because lightly infested bees are much less affected.

In conclusion, causality has not been shown, but the data suggest that even moderate levels of infestations by *A. woodi* can substantially reduce honey production. They further indicate that efforts should be made to protect colonies from infestation, or failing that, to reduce mite populations prior to overwintering, possibly by chemical treatment.

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