Journal of Apicultural Research 27(2) : 122–125 (1988)

A MATHEMATICAL MODEL FOR THE DYNAMICS OF SPERMATOZOA ENTRY INTO THE SPERMATHECAE OF INSTRUMENTALLY INSEMINATED QUEEN HONEYBEES[1]

J. WOYKE

Bee Culture Division, Agricultural University, 02-766 Warszawa, Nowoursynowska 166, Poland

Revised typescript received for publication 14 February 1987

Summary

Queens were inseminated instrumentally with 1, 2, 4 or 8 mm^3 of semen, killed and examined at different times up to 40 h after insemination. The number of spermatozoa (S) entering a queen's spermatheca from a given dose of semen, fitted the logarithmic function, $S = a + b \cdot \ln t$ (t, time). At first, the rate of increase of the number of spermatozoa in the spermatheca was high, but later, the same increase required twice as long. As time progressed, larger doses resulted in both higher absolute numbers and higher relative increases of numbers of spermatozoa in the spermatheca. The rate at which spermatozoa entered the spermatheca fitted the function $dS/dt = b/t$. It was highest at the beginning, and decreased by half with each doubling of time. Spermatozoa from larger doses entered the spermatheca faster, but relative change of rate with time remained the same.

Introduction

A honeybee queen mates with several drones in one mating flight (Tryasko, 1951; Taber, 1954; Woyke, 1955) and many queens mate during 2 or 3 flights. One drone produces about 10 million spermatozoa and a queen returning from a mating flight carries about 80 million spermatozoa in her oviducts (Woyke, 1960). Only about 5 million of these spermatozoa enter the queen's spematheca. A question arises therefore: does the semen of each drone mating with the queen participate in the production of offspring and in what proportion? Taber (1955), counting the proportion of worker progeny from 2 types of genetically marked drones, found that the proportion varied with time within a single queen, but this finding showed nothing about the proportion of offspring produced by successive drones mating with the queen.

Woyke (1963) used several genetic markers to distinguish semen from the first, middle and last drones inseminating a queen. He concluded that semen of every drone mating with a queen entered the spermatheca. Variation in the proportion of offspring from different drones occurred between different genes as well as at different times within the same queen. The order of injection of semen had no effect on the proportion of offspring, but when queens were inseminated twice, on different days, the proportions of progeny from drones contributing to the first insemination could be higher than that from the second.

Offspring proportions were also examined by Martinho and Gonçalves (1979), Moritz (1983), and Laidlaw and Page (1984). Although variations were reported by all the investigators, their conclusions differed. Some concluded that spermatozoa in the spermatheca do not mix and others concluded that they do. All concluded that spermatozoa from the first and last drones to mate with the queen were used in offspring production. Page et al. (1984) did not find agglomeration or clumps of spermatozoa in sections of spermathecae.

The processes governing the entry of spermatozoa into the spermatheca are little known. Woyke (1983) investigated the dynamics of entry in instrumentally inseminated queens and found that the speed was highest during the first hours after insemination. This paper presents a mathematical model of the dynamics of entry of spermatozoa into a queen's spermatheca.

Materials and Methods

The observations were made on some of the queens described by Woyke (1983). They were inseminated with 1, 2, 4 or 8 mm^3 of semen and introduced to small boxes (12 × 14 × 4 cm)

[1]*This project was supported in part by funds made available from the M. Skodowska-Curie Fund, established by contributions from the governments of the USA and Poland.*

Journal of Apicultural Research 27(2) : 122–125 (1988)

A MATHEMATICAL MODEL FOR THE DYNAMICS OF SPERMATOZOA ENTRY INTO THE SPERMATHECAE OF INSTRUMENTALLY INSEMINATED QUEEN HONEYBEES[1]

J. WOYKE

Bee Culture Division, Agricultural University, 02-766 Warszawa, Nowoursynowska 166, Poland

Revised typescript received for publication 14 February 1987

Summary

Queens were inseminated instrumentally with 1, 2, 4 or 8 mm^3 of semen, killed and examined at different times up to 40 h after insemination. The number of spermatozoa (S) entering a queen's spermatheca from a given dose of semen, fitted the logarithmic function, $S = a + b \cdot \ln t$ (t, time). At first, the rate of increase of the number of spermatozoa in the spermatheca was high, but later, the same increase required twice as long. As time progressed, larger doses resulted in both higher absolute numbers and higher relative increases of numbers of spermatozoa in the spermatheca. The rate at which spermatozoa entered the spermatheca fitted the function $dS/dt = b/t$. It was highest at the beginning, and decreased by half with each doubling of time. Spermatozoa from larger doses entered the spermatheca faster, but relative change of rate with time remained the same.

Introduction

A honeybee queen mates with several drones in one mating flight (Tryasko, 1951; Taber, 1954; Woyke, 1955) and many queens mate during 2 or 3 flights. One drone produces about 10 million spermatozoa and a queen returning from a mating flight carries about 80 million spermatozoa in her oviducts (Woyke, 1960). Only about 5 million of these spermatozoa enter the queen's spematheca. A question arises therefore: does the semen of each drone mating with the queen participate in the production of offspring and in what proportion? Taber (1955), counting the proportion of worker progeny from 2 types of genetically marked drones, found that the proportion varied with time within a single queen, but this finding showed nothing about the proportion of offspring produced by successive drones mating with the queen.

Woyke (1963) used several genetic markers to distinguish semen from the first, middle and last drones inseminating a queen. He concluded that semen of every drone mating with a queen entered the spermatheca. Variation in the proportion of offspring from different drones occurred between different genes as well as at different times within the same queen. The order of injection of semen had no effect on the proportion of offspring, but when queens were inseminated twice, on different days, the proportions of progeny from drones contributing to the first insemination could be higher than that from the second.

Offspring proportions were also examined by Martinho and Gonçalves (1979), Moritz (1983), and Laidlaw and Page (1984). Although variations were reported by all the investigators, their conclusions differed. Some concluded that spermatozoa in the spermatheca do not mix and others concluded that they do. All concluded that spermatozoa from the first and last drones to mate with the queen were used in offspring production. Page et al. (1984) did not find agglomeration or clumps of spermatozoa in sections of spermathecae.

The processes governing the entry of spermatozoa into the spermatheca are little known. Woyke (1983) investigated the dynamics of entry in instrumentally inseminated queens and found that the speed was highest during the first hours after insemination. This paper presents a mathematical model of the dynamics of entry of spermatozoa into a queen's spermatheca.

Materials and Methods

The observations were made on some of the queens described by Woyke (1983). They were inseminated with 1, 2, 4 or 8 mm^3 of semen and introduced to small boxes (12 × 14 × 4 cm)

[1]*This project was supported in part by funds made available from the M. Skodowska-Curie Fund, established by contributions from the governments of the USA and Poland.*

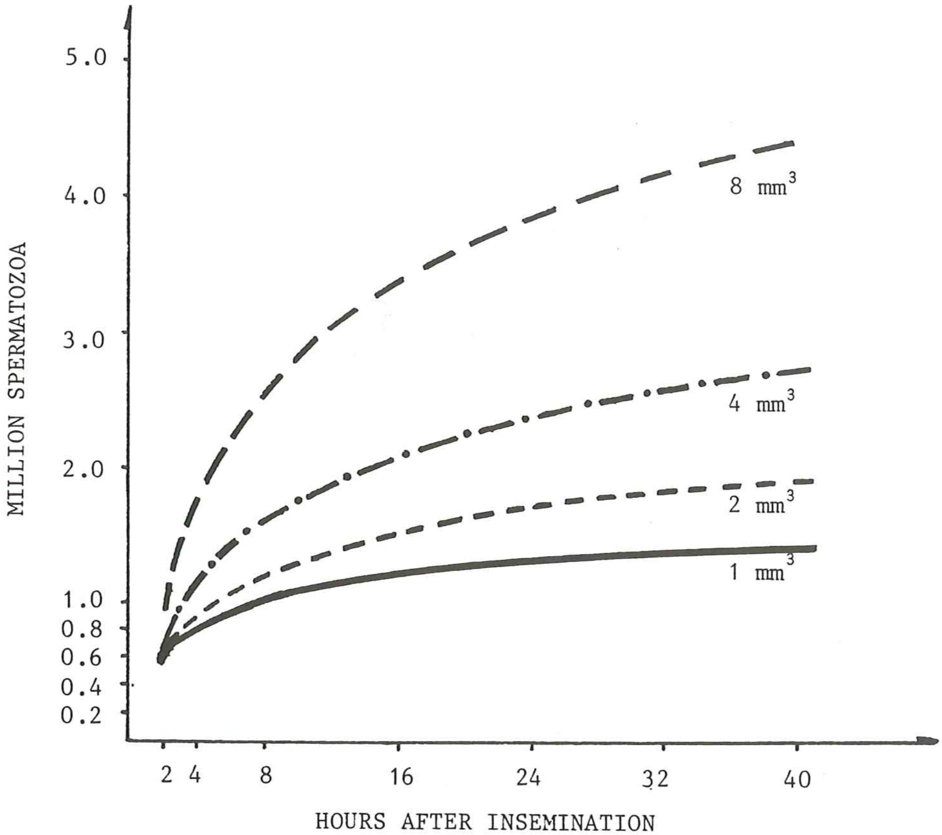

FIG. 1. Numbers of spermatozoa in spermathecae of queen honeybees at successive intervals after insemination with different amounts of semen according to the mathematical model.

TABLE 1. Mean experimental and calculated ($S = a + b \cdot \ln t$) numbers of spermatozoa (× 1000) in the spermatheca, at different times after queens were inseminated with 1–4 mm^3 of semen.

Hours after insemination	*1 mm^3*		*2 mm^3*		*4 mm^3*		*8 mm^3*	
	Exp.	*Cal.*	*Exp.*	*Cal.*	*Exp.*	*Cal.*	*Exp.*	*Cal.*
1	340	509	268	284	306	186	384	122
2	726	683	649	593	681	665	920	939
4	914	856	859	901	1069	1144	1221	1755
8	1269	1031	1289	1211	1514	1624	2746	2572
16	1237	1205	1388	1520	1866	2103	3506	3388
24	1188	1307	1935	1701	2692	2384	3976	3866
32	1524	1378	—	1829	—	2583	4268	4205
40	1214	1435	—	1929	—	2737	4329	4468
r		0·72		0·92		0·85		0·90
SE		312		220		496		730

the rate of spermatozoa penetrating the spermatheca was very high in the first hours after insemination and decreased by half for consecutive periods doubling in length. With regard to different doses, larger ones resulted in higher rates of entry but the relationship between the speed resulting from different doses is the same throughout the whole period of spermatozoa entering. For doses of 1, 2, 4, and 8 mm^3 of semen, the speed ratio was 1 : 1·8 : 2·8 : 4·7.

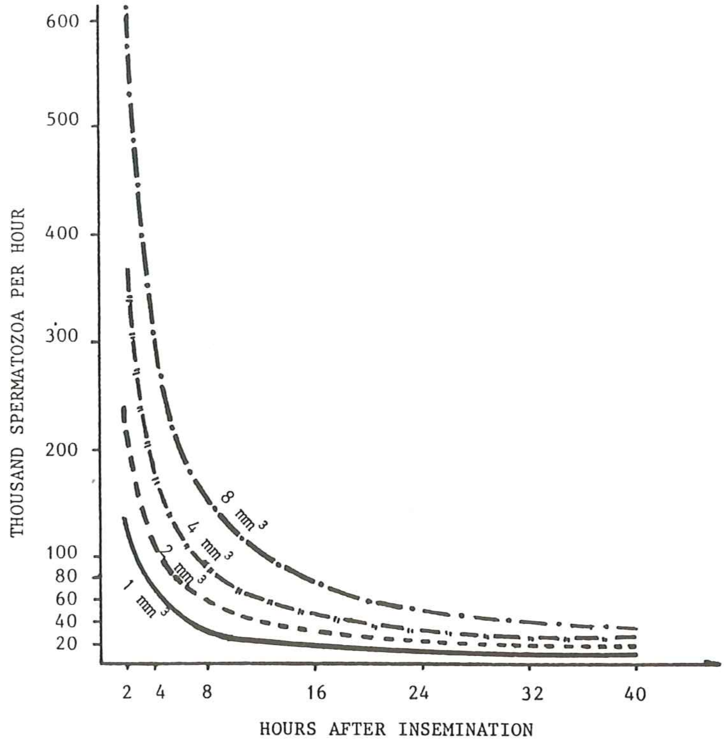

FIG. 2. The speed of entry of spermatozoa into the spermathecae of queens inseminated with different amounts of semen according to the mathematical model.

Discussion

The calculated data agree quite well with the experimental ones (Woyke, 1983). Although the rate at which spermatozoa enter the spermatheca decreases with the progress of time, similar proportions of spermatozoa of successive drones inseminating the queen enter the spermatheca (Woyke, 1963; Martinho & Gonçalves, 1979; Laidlaw & Page, 1984; Moritz, 1986).

References

LAIDLAW JR., H. H.; PAGE JR., R. E. (1984) Polyandry in honey bees (*Apis mellifera* L.): Sperm utilization and intracolony genetic relationships. *Genetics* 108 : 985–997

MARTINHO, M. R.; GONÇALVES, L. S. (1979) Migration of spermatozoa to the spermatheca, and competition between subspecies of *Apis mellifera*. *Apiculture em Clima quente, Florianopolis, Brasil* : 139–143

MORITZ, R. F. A. (1983) Homogeneous mixing of honeybee semen by centrifugation. *J. apic. Res.* 22 : 249–255

PAGE JR., R. E.; KIMSEY, R. B.; LAIDLAW JR., H. H. (1984) Migration and dispersal of spermatozoa in the spermatheca of queen honeybees (*Apis mellifera* L). *Experientia* 40 : 182–184

TABER III, S. (1954) The frequency of multiple mating of queen honey bees. *J. econ. Ent.* 47 : 995–998

———(1955) Sperm distribution in the spermatheca of multiple-mated queen honey bees. *J. econ. Ent.* 48 : 522–525

TRYASKO, V. V. (1951) [Signs indicating the mating of queens] *Pchelovodstvo* 28 : 25–31. *In Russian*

WOYKE, J. (1955) Multiple mating of the honeybee queen (*Apis mellifica* L.) in one nuptial flight. *Bull. Acad. pol. Sci. II* 3 : 175–180

———(1960) [Natural and artificial insemination of queen honeybees.] Pszczel. Zesz. nauk. 4 : 183–175. Summarized in *Bee Wld* (1962) 43 : 21–25

———(1963) Contribution of successive drones to the insemination of a queen. *19 Int. Beekeep. Congr.* : 152–154

———(1983) Dynamics of entry of spermatozoa into the spermatheca of instrumentally inseminated queen honeybees. *J. apic. Res.* 22 : 150–154