ON THE SIZE OF CELLS

SPECULATIONS ON FOUNDATION AS A COLONY MANAGEMENT TOOL[1]

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This two-part article is the result of an extraordinary amount of detective work following the twisted routes of many leads. It is about the numerous ways that can be found to complicate an otherwise simple issue. Our purpose is to challenge all in apiculture to question even the most basic assumptions we make when developing sound colony management strategies and interpreting research results.

Domestic honey bee colonies, which beekeepers manage and scientists study, differ in many ways from native or long-established feral (wild) counterparts. These differences are quite similar to those found in other animal species that have undergone domestication. Today, most domestic honey bees exist as artificially selected strains kept in artificial domiciles (box hives). Feral honey bees, on the other hand, exist as naturally selected populations — the colonies are entirely self-sufficient and have adapted to life in naturally occurring cavities. It is imperative that both beekeepers and researchers are aware of these differences when they develop management strategies to solve problems facing the beekeeping industry. Research results from studies using domesticated bees in Langstroth hives are not necessarily applicable to feral bees and vice versa. Periodically, we remind ourselves of this. Yet, in spite of our best intentions, it seems that we (as well as others) often overlook the obvious. So it is with the issue of comb cell size in our bee hives.

Until recently, we gave little thought to the issue of comb cell size. We presumed the subject was adequately researched in the past and all keepers of bees were using similar foundation. However, we have found this is not the case! In fact, beekeepers may be using combs drawn from foundation with differing cell sizes, either in the same apiary or, perhaps in the same hive, particularly if the foundation or combs were purchased from several sources. How can this be, you ask? To answer this question we need to first examine the issue historically.

In the beekeeping literature we found that controversy has followed the issue of optimal cell size for domestic colonies for more than 100 years. Our review starts with the invention of foundation by Mehring in 1857. By the 1880's European beekeepers were using foundation with comparatively small cell impressions. Shortly thereafter, Professor M. Baudox, through his research at Tervueren, Brussels, Belgium, concluded that this small cell size, 920 cells per square decimeter (=5.0 mm width per cell), was detrimental to colony development and productivity. He then proceeded to experiment with foundations of increasingly larger cell size. Subsequently, he demonstrated that adult honey bees were larger when reared in comb with larger cells (1). (See "Conversions" page 99 and footnote for mathematical conversions of some common cell sizes, because some early writers published incorrect conversions.)

Unfortunately, Professor Baudoux was a proponent of the now disproven Lamarkian theory of evolution which proposed that "...environmental changes cause structural changes in animals and plants by inducing new or increased use of organs or body parts..." and that such changes are inherited. This theory would suggest, for example, that the elongated neck of the giraffe is the result of each generation stretching further for the top branches of trees while feeding. Baudoux believed that he could genetically alter the size of honey bees by providing them with larger than normal cells for brood rearing. Hence, in his research he tested and later advocated the use of oversized cells (as few as 650 cells per dm^2 = 6.0 mm per cell). As proof of his theory Baudoux demonstrated, as have others, that bees reared in small cells were significantly smaller than those reared in large cells (4). However, no heritibility of size was demonstrated. Neither did he demonstrate that the ability to produce larger cells under these circumstances was genetically determined.

Charles Darwin, in his now widely accepted theory of natural selection, proposed "...that organisms tend to produce offspring varying slightly from their parents and the process of... selec-

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tion tends to favor the survival of individuals whose peculiarities render them best adapted to their environment..." and that such changes are inherited. Hence, selection for larger queens results in the production of larger daughter queens and worker bees (as well as drones). Larger bees must be reared in larger cells to maintain their size. Conversely, we can select for small bee size and then produce these smaller bees in smaller cells. We now know that ***bee size is a function of BOTH inheritance and cell size.***

It is a curious thing, this conception that bigger is better. Clearly, larger worker bees come from larger, easier to find queens. The workers have longer tongues, larger honey stomachs and store their honey in larger cells (1,2,4). However, there is no evidence that a colony made up entirely of larger bees produces a greater honey surplus than a colony of small bees.

Additionally, there are no reports of studies comparing the rate of population growth or peak population size between colonies comprised of small versus large bees. Even so, researchers have shown that colonies of smaller, Africanized bees (AHB) do build up more rapidly than colonies comprised of larger European bees: however, research is needed to determine whether or not cell size is a factor. Finally, and perhaps most importantly, no one has investigated the influence of cell size on the developmental rate of individual bees, susceptibility to disease and parasitic mites, overwintering survival, or other biotic and abiotic stress-inducing factors.

"It is a curious thing, this conception that bigger is better."

The cell size of "natural" worker comb, as measured among the various races of bees, is reported to be variable, ranging from 700 to 950 cells per square decimeter. However, there seems to be a consensus suggesting that, for most races of honey bees, natural worker comb cell size is 857 cells per dm^2 (5.1 mm per cell) (5) and ranges from about 830 to 920 cells per dm^2 (= 5.0 to 5.3 mm per cell). (Note also that 920 cells per dm^2 was the size which Baudoux argued *against* See "Cell Tell".)

In the United States, from the late 1800's to the early 1900's, the "standard" cell size for manufactured foundation was 857 cells per dm^2. However, in the early 1900's there began a subtle transition to larger cell size by some but apparently not all manufacturers of comb foundation. By 1913 at least 2500 foundation presses with 736 cells/dm^2 (=5.6 mm per cell) were sold in Europe by the Rietsche Co. in West Germany. As a result, the current world industry "standard" for worker cell size is between 725 cells per dm^2 (= 5.6 mm per cell) and 800 cells per dm^2 (5.4 mm per cell). Most foundation currently manufactured in the United States ranges from 700 to 857 cells per dm^2 (=5.2 - 5.7 mm per cell).

We have examined twenty-five samples of foundation from a number of foundation manufacturers in the United States and around the world. We have also examined three

CONVERSIONS

Relative values for cell size using various popular units of measure.

# cells/dm^2 (2 sides)	# cells/ inch	# cells/in^2 (2 sides)	cell width in mm^2
650	4.3	41.9	6.0
700	4.4	45.2	5.7
725	4.5	46.8	5.6
750	4.6	48.4	5.5
800	4.7	51.6	5.4
830	4.8	53.5	5.3
850	4.9	54.8	5.2
920	5.1	59.4	5.0
950	5.2	61.3	4.9
1050	5.4	67.7	4.7

Cells per square decimeter (dm^2) is a useful unit of measure for understanding colony population dynamics and for developing management strategies, but, for practical field diagnostics it is easier to measure the width of a row of 10 cells measured side to side. A dm^2 is an area 10 cm by 10 cm; cells on both sides of the comb area are counted. To convert cells per dm^2 to cells per linear dm and then to mm per cell use equation 1:

Equation 1:

cells/dm^2 = 2.31 X N^2 (where N is the number of cells per linear dm)

Example: 850 = 2.31 x $(19.18)^2$

Divide 100 by cells per linear dm to obtain mm per cell

Example: 100 divided 19.2 = 5.2

To convert cells per in^2 to inches per cell:

Equation 2:

cells/in^2 = 2.31 X N^2 (where N = number of cells per inch)

Example: 54.8 = 2.31 x $(4.87)^2$

To convert cells per dm^2 to cells per in^2:

Equation 3:

cells/dm^2 = 15.5 X cells/in^2

Example: 850 = 15.5 x 54.8

The values in this column represent the width of a single cell as measured between centers of opposing cell walls. The actual cell interior width is one cell wall thickness less than this value.

mills, which we were able to obtain for comparison. The cell size of each is summarized elsewhere and is based on 10 measurements each of 10 linear cell impressions (see "How Big").

Foundation with 700 cells per dm^2 has cells 10.7 % wider than natural comb cell size. Colonies utilizing the smaller natural cell size (857 cells per dm^2) could produce 22.4 % more brood per given area of comb than colonies on 700 cells per dm^2. Similarly, such colonies could rear 7.1% more brood than colonies on 800 cells per dm^2. Utilization of 857 comb would, almost certainly, require less metabolic energy expended per bee to maintain optimal temperature and humidity for brood rearing. It is possible that developmental time might also be shortened. Both factors would translate into more rapid spring buildup and recovery from bee losses due to parasites, disease or pesticides.

The question that must now be raised is why has the

beekeeping industry, in the United States and elsewhere, accepted foundation with 700-800 cells per dm^2 (= 5.7-5.4 mm per cell) as a size standard. We may never know, but it seems likely that it has its roots in the mistaken Lamarkian theories which guided the early studies of Baudoux. These studies were followed by those of Gontarski who found that the greatest percentage of bee size change occurs using a cell size of 700 cells per dm^2 (5.7 mm per cell) (5). Our investigation suggests that many of the rollers used in mills manufacturing foundation in he United States are made in Europe and the producers of these rollers follow the precepts of Baudoux and Gontarski. At least one of these companies currently making rollers (Rietsche in West Germany) was making flat molds for foundation in 1899. Another explanation might lie in Baudoux's contention that combs with small cells contribute to swarming (1). However, Baudoux also advanced the opposing view that larger bees would produce more body heat leading to increased brood production. Certainly, larger bees resulting from selection and breeding require larger cells for development. There has also been concern that the buildup of larval debris and cocoons in cells reduces cell size. Thus, there is perceived benefit to be gained from starting with a larger cell.

Clearly, reported differences in cell size and in bee size between domestic (European) bees reared in large cells and Africanized honey bees reared in naturally built comb have often been misinterpreted. It is not so much that AHB cells are somehow smaller, but rather the cells built by bees from domestic strains are abnormally large. It is worth noting that the cell size range reported as 'natural' for feral bees has varied little from the 1600's to the present time (see "Cell Tell"). Also noteworthy is the fact that the size range currently cited by various authors as indicative of Africanization (e.g., reported averages = 4.9 - 5.1 mm; range = 4.5 - 5.4 mm)

CELL TELL

Documentation of natural cell size.

Source	Year	Original Unit of Measure	Cell Width in mm	Range
Swammerdam	1600's	cells/dm^2	51	
Maraldi	--	"	--	5.0-5.4
Reaumur	1700's	"	5.3	
Klugel	--	"	5.3	
Castillon	--	"	--	5.3-5.5
Latreille	1800's	"	5.4	
Vogt	--	"	--	5.3-5.5
Collin	1865	"	5.2	
Langstroth/ Dadant	--	"	5.3	
Root	1876	cells/inch	5.2	
Chesire	1886	"	5.1	5.06-5.45
Cowan	1898	cells/in^2	5.1	4.72-5.36
Cook	1904	"	5.1	5.06-5.45
Miller	1910	"	5.1	5.11-5.29
Grout	1937	cells/dm^2	--	4.95-5.49
Taber & Owens	1970	mm/cell	5.2	4.99-5.45
Dadant	1946	cells/dm^2	5.2	5.06-5.20
Dadant	1975	"	5.2	
Messange & Goncalves	1985	mm/cell	5.1	5.07-5.11

significantly overlaps that of natural cells built by European bees (e.g., reported averages = 5.1 - 5.2mm; range = 4.7 - 5.5mm) by a wide margin. □

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Part Two of this article examines the effect cell size may have on various pests and diseases and particularly what this all will mean regarding cell size and the African Honey Bee.

HOW BIG

Measurements of cell impressions from foundation and foundation mills produced by various supply houses from the late 1800's to 1989.

Type	Source	Average Cell Size in mm
wax	Africa	4.76
wax	Africa	4.89
wax	A.I. Root (circa 1929)	5.05
aluminum	unknown	5.10
mill	A.I. Root (circa 1929)	5.12
wax	L.A.Honey (1989)	5.15
wax	Miller (circa 1888)	5.18
wax	Mexico	5.18
wax 5-3/8"	A.I. Root (1989)	5.18
wax	Glorybee, OR	5.19
wax	Tom Industries, CA	5.19
wax	Honey Acres, WI	5.19
mill	A.I. Root (1989)	5.20
wax 8-3/8"	A.I. Root (1989)	5.20
plastic	Arnaba, HI	5.21
plastic	unknown	5.23
plastic	unknown	5.28
wax	W.T. Kelley, KY	5.28
mill	A.I. Root (circa 1910)	5.29
wax	Brushy Mountain	5.30
plastic	unknown	5.35
wax 8-5/16"	Dadant (med. brood)	5.36
wax	Honey Acres, WI	5.39
wax 5-1/2	Dadant (med. brood)	5.39
Duraguilt	Dadant	5.40
wax	Bolivia	5.44
7-11	W.T. Kelley, KY	5.53
Perma-dent	Draper's, NE	5.56
Perma Comb	Perma Comb	5.64