

BEE POLLINATION OF FRUIT TREES: RECENT ADVANCES AND RESEARCH PERSPECTIVES I.

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S u m m a r y

Intense research was carried out on the bee pollination of temperate zone deciduous fruit trees during the past decade. Much progress was achieved to explore the flower characters of a great number of cultivars affecting honeybee activity at flowers and their pollinating efficiency. Flower characters were found to be consequently different among apple and pear cultivars in consecutive years but in case of some stone fruits differences between consecutive years were greater than between cultivars in given years. The necessity of bee pollination was clearly demonstrated both at self-sterile and at self-fertile fruit cultivars. The rate of flower constancy of honeybee foragers was different at different fruit tree species but the role of competing plants was found to be much less deleterious than stated in the literature earlier. However, a number of questions arose partly from the results of latest pollination research and partly from practical experiences in commercial plant production. These indicate several research tasks to understand and to solve the problems possibly in the near future. The questions concentrate on the effectiveness of bee visits in the pollination of individual fruit crops and their different cultivars and on the reliable estimate of the overall amount of bees as well as on the control of bee density during the flowering period of fruit orchards for optimal, controlled honeybee pollination. Much less effort was made to manage native wild bees for fruit tree pollination, however, some mason bees seem to be promising for this purpose in Europe, The Far East and North America.

Keywords: insect pollination, honeybees, temperate zone deciduous fruit crops.

INTRODUCTION

Almost all temperate zone fruit tree species need insect pollination, the only exception is the horse chestnut, which is wind pollinated, but partly benefits insect pollination, too (Pesson and Louveaux 1984). The role of insects in fruit crop pollination has been recognized long ago. The information accumulated on this field has been reviewed by Free (1993) in the comprehensive handbook "Insect pollination of crops (second edition)" some ten years ago. After the appearance of this book fruit pollination research has remained intense. Important new information accumulated in this field, however, several new

problems arose that needs further research. The aim of this paper is to give an outlook onto the state of knowledge in this field and to point out the need for further research.

RESULTS

Improving the efficiency of honeybees in crop pollination

A number of techniques have been known to increase the pollinating efficiency of honeybees by increasing the bee visitation to target crops, increasing the ratio of pollen collecting foragers, improving their pollen dispersal, and so on (Free 1993).

However, to increase the bee visitation of the target crop is rather a hard task, hence

it depends on several characteristics of the crop and of cultivated or wild plants grown in the surroundings, on the food demand of the honeybee colonies, and of course, on the weather. This may be the explanation why a number of different methods, neither the application of bee attractants, nor sequential introduction of colonies to the flowering crop, nor feeding bees, nor diluting the nectar with overhead irrigation, nor interplant alfalfa increased the number of honeybees and increased the yield significantly at seed onion fields (Mayer and Lunden 2001).

On the other hand, Winston and Slessor (1993) reviewing their results on the recognition and the use of the queen mandibular pheromone (QMP), predicted that its most significant commercial application would be in crop pollination. This statement was based on good results obtained in field experiments. Spraying flowering crops increased the number of honeybees foraging on apple, pear, cranberry, and blueberry (Currie et al. 1992a, 1992b, 1994, Hugo et al. 1995, MacKenzie and Averill 1992). The effect of QMP, however, is greatly dependent on dosage and partly on crop. Namely, 0.1 queen equivalents/ha was ineffective, but 1000 was effective on apple and pear (Currie et al. 1992b), the same dosage failed to increase bee visits on sweet cherry (Naumann et al. 1994), while 100 was the most effective on cranberry and 100 was as effective as 1000 on blueberry (Currie et al. 1992a). In other instances, with pear and apple, QMP application increased only fruit sizes without actual yield increase, and this still resulted in higher profits (Currie et al. 1992b, Naumann et al. 1994). On the contrary, on sweet cherry a negative correlation arose between bee visits and fruit size. These experiences, however, are not consistent enough, and therefore further research is needed on this topic, not only in the US but also in other countries with different weather conditions. Also, the profitability

of the method should be analysed, as its acceptance in the practice depends on its profitability. There is one other, cheaper kind of application of QMP in crop pollination, because the pollination value of queenless "disposable" pollination units can be improved when QMP is added, which may increase the foraging activity; moreover should brood be present, even pollen collecting activity is increased (Currie et al. 1994). Other kinds of bee attractants (e.g. Beeline, Be-Q, Beehere, lavender oil, citral, geraniol, etc.), however, did not increase the bee visitation at a number of different crops (Ambrose et al. 1995, Neira et al. 1994, Ortiz-Sanchez 1993, Sing and Sinha 1996, Zvedenok 1996).

As in-hive pollen transfer is recognized to be an important factor in pollen dispersal among compatible but self-sterile or self-fertile but readily cross-fertilizing cultivars of some crops (e.g. Dag and Kammar 2001, DeGrandi-Hoffman et al. 1984, DeGrandi-Hoffman and Martin 1993, 1995, McLaren et al. 1996), the methods increasing pollen exchange between foragers of the honeybee colonies can be regarded to be very important. Following the pioneer work of Free et al. (1991), several kinds of hive entrance devices were used lately to brush pollen from incoming and deposit on departing bees (Hatjina 1996, Eijnde and Velde 1995, Szalai 2000). This type of research should be continued in order to develop the most effective devices without harming foragers and without decreasing germination capacity of the pollen.

However, the mechanism and the effectiveness of in-hive pollen exchange are not adequately studied and its role in crop pollination is probably underestimated. Latest research on the fruit set of large single-cultivar blocks of apple indicates that in-hive pollen exchange (or possibly carrying pollen on the body hairs of bees from one foraging trip to the next) could be much

more important in the effective pollination of orchards than believed so far, because even large and very large single-cultivar blocks in apple plantations can effectively be pollinated in lack of pollinizer cultivars inside the block (Blažek 1996, Benedek unpublished). Therefore, the in-hive pollen transfer among bees needs to be studied thoroughly with fruit trees and other crop plants.

Recently, the role of electrostatic charges for non-contact pollen detachment between pollinating honeybees and flowers is confirmed, and this can be utilized for supplementary pollination in commercial production (Vaknin et al. 2000), this new approach, however, needs further research to base commercial implementation.

A need of controlled honeybee pollination

As successful pollination may be a limiting factor of a good yield, growers would like to know how many honeybee (or bumblebee) colonies are needed and how to organize them for optimal pollination at the field. We can give general instructions based on experiments and/or measurements about timing the placement and the arrangement of the location of the bee colonies inside or round the target crop, but the number of bee colonies needed is much more difficult to define on a reliable basis.

On the other hand, the recommendations on the stocking rates of bee colonies needed to pollinate the crop plants are based on assumptions rather than on experimental results. There is very little information in the literature how to estimate the necessary number of bee visits/flower or the necessary bee density/per unit area of optimal pollination or about the optimal set of various crops (the examples are sunflower, cotton, hairy vetch as well as fruit plantations to some extent: see in Free 1993). This kind of information would, however, be very important in the practice, because not only the inadequate activity of pollinating insects,

but their excessive activity can also be disadvantageous to the yield.

The unpleasant consequences of oversetting, numerous but too small fruits, poor quality, the need of laborious and expensive thinning, are well known for some fruit trees in the practice, for peach and nectarine for example. Lately, both insufficient and excessive visiting of bees (honeybees and bumblebees) for pollination of strawberry have been found to be undesirable, both causing faulty pollination under cover. A density of 10 - 15 thousands of worker bees/1000 sq. metres in plastic tunnels or glasshouses is recommended, but neither the lower nor the higher densities are desirable (Lieten 1993). Similar results were obtained with cucumber; fruit set and the number of filled seeds were the higher when there were some 0.5 honeybee colonies per some 2000 plants, reduced number of bees was resulted in lower yields, on the contrary overpopulation caused so strong competition for flowers (for pollen) which reduced the yield (Cervancia and Forbes 1993). In case of sunflower crops some 10 thousand bees/hectare was found to be optimal for pollination in Hungary, however, increased bee visitation did not affect the yield (Benedek 1972). Similarly, additional extra hives at flowering pear increased bee numbers in the orchard, but not the fruit set in New Zealand (McLaren et al. 1996).

For this reason, it is important to explore the relationship between the number of bee visit/flower and the set. In case of pumpkin, for example, latest results show that some 10 insect visits are needed so that enough pollen grains are deposited onto the stigma needed for a good set (Masierowska and Wien 2000). In case of squash each plant requires at least one honeybee visit during the optimum pollination time (that is between 06.00 and 09.00 in this case) (Al-Fattah 1991), and some 5-6 bee-visits/flower are needed for maximum

productivity of raspberry (Oliveira et al. 1991). Based on experimental results 6-12 bee visits were necessary in Hungary during the life of a single apple flower to set a fruit (Benedek et al. 1989). Both fruit set and quality were related to the number of bee visits/flower in experiments with apple in Canada, but an other experiment gave inconclusive result due to overall poor fruit set caused by bad weather (Brault et al. 1995).

In fact, the present practice to move certain number of bee colonies to the target crop just prior to, or at the start of flowering, and to leave them on site until petal fall, is an inadequate solution to crop pollination problems. This can be exemplified by a sequential introduction of honeybee colonies to pear pollination; namely, placing additional bee colonies in pear orchards at 50 % flowering resulted in more bees visiting the flowers for at least one day which significantly increased fruit set in 10 out of the 14 experimental orchards (Mayer 1994). However, growers need some kind of method, as simply as possible, to decide if they should do something with bees during the flowering period of crops. A simple solution was suggested in Hungary. Taking some factors, the number of bee visits per flower necessary to set a fruit, the length of the receptive period of the flowers, the required ratio of fruit set and the patterns of the daily bee activity into account, 3-6 bee visits per 50 opening flowers during a ten minutes period was recommended as the optimal intensity of bee visitation in apple orchards to get a good crop (Benedek 1996). The growers were recommended to control the intensity of bee pollination during the flowering period and to move additional colonies to the orchard immediately, when the bee visitation was much lower than the proposed optimal level thus avoiding insufficient, low sets. At other instances, however, excessive bee visitation was decreased during the flowering period

to avoid unwanted oversetting at some crops. This kind of bee pollination management should be implemented during the flowering period of crops, which would lead to controlled bee pollination in the agriculture.

Consequently, intense research is needed to base controlled bee pollination experimentally for those crop plants, of different fruits first of all, where lower and higher than optimal sets are equally undesirable for profitability reasons. Growers should be recommended to carry out simple observations or should be given sophisticated, but user-friendly computer simulations, as the well-known PC-REDAPOL for example, which can reliably predict the apple yield (DeGrandi-Hoffman et al. 1995). This enables growers to decide what to do during the flowering period for the optimal pollination of their insect pollinated crops. The problem is especially crucial in the new type, high density orchards with semi-dwarf or dwarf fruit trees being the productive life much shorter, 10 to 15 years at most, than of traditional, large crown fruit plantations, which can stand and produce fruit for decades. During the short productive period of high density orchards no single year with bad yield or with bad fruit quality can be suffered, because the investment cost of this type of orchards is very high and also their cultivation is much more expensive than of a traditional plantation, consequently the production must be profitable each year of their short productive life. Accordingly, pollination must not be an unstable element of their management system.

There is a host of factors affecting the general behaviour of bees towards the rewards that different crops and competing other plants, flowering simultaneously offer to them. Other environmental factors affect also the foraging behaviour, and consequently the pollinating efficiency of bees visiting the flowers of crop plants (more of social than of solitary bees). Weather and

competitor plants seem to have the most decisive influence on bee activity. The effect of weather conditions is fairly well known, but the effect of competing plant species is contradictory and confusing. Lately, even massive appearance of flowering dandelion, that is known to have very strong competitive effect on honeybees in fruit orchards, failed to affect bee visitation in pear orchards, neither sour cherry attracted bees from pear (Benedek et. al. 1998a). There are some other indications that the effect of competitor plants is not sufficiently explored, accordingly this item needs further studies to understand why certain plant species are strong competitors in some cases and no similar effect can be recognized at other instances.

CONCLUSIONS

Based on the above discussion there seem to be a number of topics that greatly needed intense research in the near future to improve the knowledge on as well as the technology of the insect pollination of crop plants cultivated in temperate zone regions. These are partly related to the pollination requirements of selected crops and to managing some solitary wild bee species for crop pollination. The problems, however, concentrate on the effectiveness of bee visits in the pollination of individual fruit crops (and their different cultivars) and on the reliable estimate of the stocking rates of bees for crop pollination as well as on the management of actual bee density during the flowering period of fruit orchards for optimal controlled bee pollination. The following topics are proposed as the subject of further research in the coming years:

1. Improving the efficiency of honeybees in crop pollination
 - The effect of the queen mandibular pheromone sprays is to be further studied to increase the pollination efficiency of honeybees at target crops

in flower.

- Further research is needed on the mechanism and the effectiveness of in-hive pollen exchange among honeybees during crop plant pollination.
 - Further research is required to develop the most effective devices increasing pollen exchange between foragers of honeybee colonies for pollination.
2. A need of controlled honeybee pollination
 - Intense research is needed to base controlled bee pollination experimentally for those crop plants, of different fruits first of all, where lower and higher than optimal sets are equally undesirable for profitability reasons. Growers should be recommended to carry out simple observations or should be given sophisticated, but user-friendly computer simulations to manage flower visiting bee populations at an optimal level during the flowering period of insect-pollinated crop plants.
 - Further studies are needed on the effect of competing plant species to understand why certain plant species are strong competitors in some cases and no similar effect can be recognized at other instances.

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ZAPYLANIE DRZEW OWOCOWYCH PRZEZ PSZCZOŁY: OSTATNIE POSTĘPY I PERSPEKTYWY BADAŃ I.

B e n e d e k P .**S t r e s z c z e n i e**

Podczas minionej dekady prowadzono wiele szczegółowych badań dotyczących zapylania przez pszczoły drzew owocowych strefy umiarkowanej. Wielki postęp został osiągnięty kiedy odkryto, że kwiaty wielu odmian posiadają cechy oddziałujące na aktywność pszczół miodnych na kwiatkach i ich wydajność jako zapylaczy. Odnaleziono cechy kwiatów były zdecydowanie różne w przypadku odmian jabłoni i gruszy w poszczególnych latach ale w przypadku niektórych odmian gruszy różnice między kolejnymi latami były większe niż między odmianami w danych latach. Konieczność zapylania przez pszczoły została wyraźnie wykazana zarówno w przypadku obcopylnych jak i samopylnych odmian owoców. Stopień wierności kwiatowej zbieraczki pszczoły miodnej był różny na poszczególnych gatunkach drzew owocowych ale rola pożytków konkurencyjnych okazała się być mniej szkodliwa niż stwierdzano to wcześniej w literaturze. Jednakże, pewna liczba pytań powstała częściowo w wyniku najnowszych badań nad zapylaniem i częściowo z praktycznych doświadczeń w polowej produkcji roślin. Pytania te wskazują kilka zagadnień do badania, by zrozumieć i rozwiązać problemy prawdopodobnie w najbliższej przyszłości. Koncentrują się one na skuteczności wizyt pszczół w zapylaniu poszczególnych upraw owoców i różnych ich odmian oraz na wiarygodnej ocenie całkowitej liczby pszczół jak również na kontroli zagęszczenia pszczół podczas okresu kwitnienia sadów owocowych dla optymalnego, kontrolowanego zapylania ich przez pszczoły. Dużo mniej wysiłku zrobiono, by wykorzystać rodzime dzikie pszczoły samotnice dla zapylania drzew owocowych, jednakże, niektóre murarki wydają się być odpowiednio do tego w Europie, na Dalekim Wschodzie i Ameryce Północnej.

Słowa kluczowe : zapylanie przez owady, pszczoły miodne, plonowanie owoców w strefie umiarkowanej.