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THE COSTLY CROP POLLINATION CRISIS

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ABSTRACT

Floral diversity in crops calls for an adequate diversity of pollinators. In practice, however, all animal pollination is often and simplistically ascribed to a single uniform organism, the honeybee, Apis mellifera. These bees are clearly overcharged with the demand to pollinate flowers worldwide and poor fruit set results in many crops. Growers usually try to remedy this pollination crisis through the application of expensive assisting techniques. When these also fail, they may (for some high value crops) resort to hand-pollination with hand-collected pollen, which forces extremely high prices. Use of natural pollinators, on the other hand, is free of charge. As some knowledge about these beneficial interactions is already available for many species, it is recommended to discriminate it via an Internet-based database. In order to inform individuals of the basic biology of pollination, teaching programs are also suggested. These investments would be worth while through avoiding wasted effort and recurrent costs from ineffective and "assisted pollination." It pays to apply and promote diversity in crop pollination.

INTRODUCTION

Most crops need pollination, even in the times of genetic engineering and progress in plant propagation via cell culture or cuttings. This applies to the production of fruit and seed for consumption as well as to the provision of (hybrid) seed for sowing.

Although biodiversity has been widely discussed for more than a decade, pollination of the immense diversity of flowers (not only crops but of many other plants) is simplistically often and erroneously credited worldwide to a single organism, the honeybee (*Apis mellifera* L.). For its honey production, this species of African and southern European origin was brought into domestication over much of the world long ago, so bee-keeping techniques are well known. It is an eager flower visitor, but a often poor pollinator (Westerkamp 1991). It is simply overcharged with the demand that it pollinate the entirety of flowers, whether wild or domesticated. With the decline of natural pollinators caused by increasing environmental destruction, this dependency on a single ill-adapted pollinator consequentially leads to the current pollination crisis in nature as well as in agriculture. For the time being, the high cost of this dependency, is only beginning to be recognized in crop production. To the general public, the pollination crisis became apparent only with the recent decline of beekeeping, especially in North America. Even in the scientific community, the crop pollination crisis is mainly perceived as a honeybee-related problem (e.g., Allen-Wardell *et al.* 1998; Kearns *et al.* 1998).

Expensive Uniformity

Honeybees are not available free of charge. As they form perennial colonies, the hives have to be tended year-round which nowadays often even includes the expensive application of remedies for pest control. Thus, it costs to hire and maintain honeybees, colony by colony. As crop fields or orchards do not flower year round and often cover large areas, hives have to be moved into them in large numbers. This in some cases includes long-distance transportation, e.g. from Florida, Texas or South Carolina to the Californian almond orchards (Watanabe 1994).

When pollination problems arise, one of the first reactions by growers is to increase the number of bees per area. This is partially based on the correct observation that novice bees, which are still learning how to handle a flower, are better pollinators than experienced bees. Crops then are inundated with colonies in order to saturate them with bees. Tens of hives per hectare result in huge numbers of bees, which by far outnumber the insect quantity the crop can nourish. This can lead to starvation of the colonies. In a few cases, this "pollination by brute force" (Morse 1991) works by the principle that many poor pollinators are, of course, better than no pollinators at all. These numbers of hives have to be multiplied by the basic hiring and transport charges per colony.

Some crop flowers do not meet all requirements of the bees, so food has to be added to nourish the colonies and to avoid a drift of the bees to other flowers. In the case of flowers that provide only pollen, sugar syrup has to be fed to the bees. In kiwi orchards, for example, up to 800 honeybee colonies per square kilometer have to be provided, which requires the employment of extra personnel during kiwi bloom.

Competing bloom can be often much more attractive than the target crop. Measures then are taken to get rid of the rival, e.g., mowing or the application of herbicides. Other alternatives are to augment attractivity of the crop and/or reduce that of the competitor. Repellents are used on non-crops while attractants (sugar water, flavored by floral odors or bee pheromones) are sprayed onto the target. For examples readers should refer to Free (1993).

The often highly esteemed floral constancy of honeybees is deleterious in cases of a separation of male and female floral phases in time (dichogamy) and/or space (dicliny, dioecy). The same applies if multifloral species with self-incompatibility are considered. Compatible pollen then has to be introduced into the target plant. Similar to the classical methods of caprification in (wasp pollinated) figs or the placing of male inflorescence in wind pollinated date palms, bouquets offering compatible pollen are placed within or even grafted onto crop plants. If this also does not help transporting the right pollen to the stigma, enpollination is applied, i.e., the use of an apparatus (e.g., a pollen dispenser) that dusts bees with compatible pollen when leaving the hive. This process, however, requires the availability of hand-collected pollen which is another cost by item.

If all these methods of supplemental pollination fail, man has to take over and hand pollinate. Examples are: vanilla and in some instances atemoya, passion fruit, cacao and pears. In the simplest cases this only means selfing. Nevertheless, even this may end up in a 40% share of pollination in the production costs of (e.g. vanilla). Costs of hand pollinating vast areas of oil palm diminished greatly in Southeast Asia once the legitimate pollinating weevil was introduced (Roubik (Ed.)1995).

Often, however, hand-collected pollen is needed which doubles the manpower required. This pollen then is transferred to the female parts using, e.g., camel hair brushes, bee-sticks (bee thoraxes glued onto tooth picks), hand-held pollen guns or even large sprayers, similar to those used in crop protection. In the latter method, pollen is suspended in aqueous or dry (talc, *Lycopodium* spores) media. To escape the extremely high costs of hand pollination, a topical spraying of flowers with hormones (growth substances which make the ovary swell) has been suggested for certain crops, but this is also labor-intensive and the resulting "fruits" have only the aspect of true fruits.

All these expenses for honeybees and honeybee-derived follow-up costs arise every new season anew and for each single grower. It is, however, not astonishing that a species that has to be uniform in size and behaviour for the sake of correct data transfer during dance communication cannot cope with the extreme diversity of floral form and function world wide. This is especially true if one considers the behavioral peculiarities of the honeybee (Westerkamp 1991). As a perennial species, the honey bee colonies are more or less "immortal" and the colony of bees cannot specialize on particular species but each individual must learn how to handle actual flowers. They then prefer the path of least resistance, which provides nectar and/or pollen, but often this does not necessarily result in pollination.

Profitable Diversity

There is, however, a solution to the problems outlined above that helps to reduce costs: the use of a natural pollinator of the plant species under consideration. The diversity of flowers then is reflected in the diversity of pollinators. One can refer to Roubik (Ed.)(1995) for more detailed examples.

Most flowers in nature as well as in crops are mellitophilous, i.e., adapted to pollination by bees. But as shown above, bee does not equal honey bee. So, the choice of the right bee species depends of the requirements of the flower to be pollinated.

In passion fruit flowers (*Passiflora edulis*, Passifloraceae) it is a series of extraordinarily large bees (e.g., *Xylocopa* spp. or *Centris* spp.) that fit the flower. While drinking nectar, they neatly fill the space between the perch on the corona (the 'crown of thorns') and the "roof," first formed by the anthers and later by the stigmas. Carpenter bees (*Xylocopa* spp.) are encountered in many of the countries where the Neotropical passifloras are cultivated these days. They just have to be fostered by providing them with dead wood that they needed for nesting. Costly hand pollination can thus be avoided.

The nectar-holding tube of red clover (*Trifolium pratense*, Fabaceae) is too long for most bees. Only, e.g., long-tongued bumblebees are able to reach the food and thus pollinate. Only after the importation of these bees, which had already been suggested by Darwin, red clover (also imported from Europe) set seed in New Zealand and could be sown for cattle fodder.

Only bees that are not deterred by the exploding flowers of alfalfa (*Medicago sativa*, Fabaceae), are able to pollinate them. Althoughthere is a long list of pollinator species, the alfalfa leafcutter bee, *Megachile rotundata*, is usually employed as the main pollinator. Two to three thousand bees per hectare suffice compared to 20 to 25 hives containing tens of thousands of honeybees, as formerly suggested. These alfalfa leafcutter bees, once acquired, readily reproduce within the fields; thus they even may produce a surplus of bees which may be sold to other growers.

Barbados cherries or acerolas (*Malpighia glabra*, Malpighiaceae) provide fatty oils as attractants. They are dependent on oil-collecting bees mainly of the genus *Centris* but also other genera.

Instead of vibrating tomato (*Solanum lycopersicum*, Solanaceae) flowers manually with hand-held vibrators ('electric bees'), buzz-foraging bees can do the job. Since it was learned how to circumvent bumblebee hibernation, *Bombus terrestris* colonies are commercially produced for year-round tomato pollination even in greenhouses.

Honeybees are poor pollinators of apples (*Malus domestica*, Rosaceae), pears (*Pyrus* spp., Rosaceae), cherries (*Prunus* spp., Rosaceae), and almonds (*Prunus amygdalus* Batsch, Rosaceae). Instead of trucking them over long distances, applying 2-6 colonies per hectare, which are replaced every fourth day to have as many novice bees as possible, the use of certain megachilid bees is advocated. As few as 300 blue orchard bees (*Osmia lignaria*) or 80 hornfaced mason bees (*Osmia cornifrons*) suffice (Batra 1994).

Pollinator diversity should by no means be restricted to bees, however. All floral syndromes are also represented in crops to a certain extent ranging from wind to vertebrate pollination.

Nitidulid beetles are the only pollinators of sugar apple (*Annona squamosa*), cherimoya (*Annona cherimola*) or atemoya (hybrid between these two species). Only these beetles are attracted to and able to open the neatly closed floral chambers, which serve as copulation sites. This pollinator force might be simply augmented by providing the beetles with rotting fruit for breeding.

The curculionid beetle, *Elaeidobius camerunicus,* not only pollinates, but also breeds in (spent male) inflorescence of its target plant, the oil palm (*Elaeis guineensis*, Arecaceae). Its introduction from their native home, west Africa, to the main recent growing area of oil palms, southeast Asia, resulted in annual savings of ca. US$ 100 million because hand pollination was no longer needed and fruit set improved.

Cacao (*Theobroma cacao*, Sterculiaceae) is pollinated by tiny midges of the Ceratopogonidae and the papaya (*Carica papaya*, Caricaceae) depends on night-flying moths for pollen transfer.

Pineapple guava (*Feijoa sellowiana*, Myrtaceae), on the other hand, relies on large, fruit-eating birds as pollinators. These birds consume the succulent sweet petals of the large flowers while honeybees foraging for pollen just act as thieves. Durian (*Durio zibethinus*, Bombacaceae) depends on pollinating bats.

Natural pollinators are available free provided that they are not exterminated by overuse of pesticides or by other farm management practices and that the crop is cultivated in its native area. To survive, pollinators, of course, need environmental conditions suitable for them. The conditions must satisfy all behavioral needs and these are usually more than just "crop-only-deserts". Considering that in most cases the active period of solitary bees, which form the most essential group of pollinators, coincides with the flowering time of the target crop, these pollinators need only short-term investment and not year-round care, as do honeybees. So, in some cases, set-asides are needed (Banaszak 1992) to provide, amoung other things, sufficient nesting sites and additional food plants. If pollinators are totally missing, they have to be re-established there. One should refrain, however, from the worldwide faunal and floral adulteration through importation of exotic species are practiced since colonial times.

Consequences

The knowledge about the right pollinators for most crops is already available, in some cases, since ancient times. It just has to be applied. In those cases where information is missing, it is, of course, cheaper to invest once in research by specialists than go on paying dearly and yearly for non-functioning pollinators, as outlined above.

Since the information on pollinators is widely scattered in the technical literature, in different languages and even indirectly between the lines, it is not easily accessible to the particular growers or to local and regional agricultural advisers. They are simply unable to review the wealth of knowledge in scientific publications. To spread the fundamental information, an Internet-based data bank should be set up as soon as possible in a joint effort from all pollination biologists willing to share data.

For some crops even basic knowledge on floral functioning and on pollination is missing. Therefore, teaching program should be established to impart the basics of pollination science so that gaps in knowledge can be filled. The dissemination of information that diversity pays, not only in crop pollination but also in nature is important to global productivity and sustainability (Kevan 1993, 1999).

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