Optimising crop flowers for pollinating insects

Could strawberry flowers be easier for insects to find, and more rewarding to those that visit?

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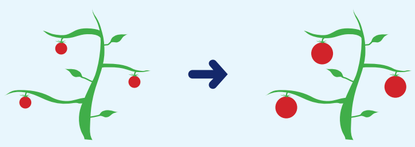
Introduction

About a third of our food production depends on insect pollination to some extent[1]. A growing world population will need more food, so farmers will need more pollination – but around the world insect numbers are generally in decline[2], exactly the opposite of what we need. How do we resolve this conflict? Potential solutions include...

REVERSE INSECT DECLINE

REDUCE DEPENDENCY ON INSECTS

SELECT FOR BIGGER FRUIT



IMPROVE SEARCH SPEED & REWARD — MY RESEARCH

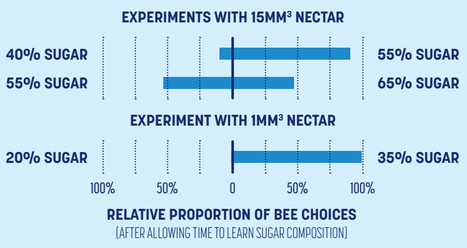
My research uses strawberry plants to ask: a) if we can make flowers easier for insects to find, increasing the number of flowers that can be pollinated per day, and b) if we can improve the nectar and pollen reward offered by flowers, so insects can better feed themselves and their colonies.

What nectar sugar percentage is 'best'?

Theoretically, the 'best' nectar sugar percentage would allow bees to maximise energy return to the colony. In practice, this depends on bee preferences, drinking and offloading rates, and flight time.

Bumblebees prefer more sugary nectar (up to a point!), even at low volumes

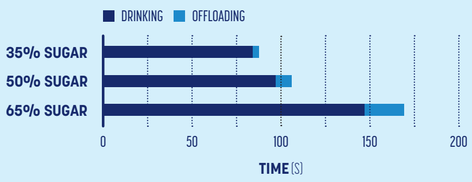
Bumblebee preferences are tested by pairing a reward with a visual feature (eg colour). Bees learn to associate the visual feature with reward quality; prolonged experiments reveal their preferences.

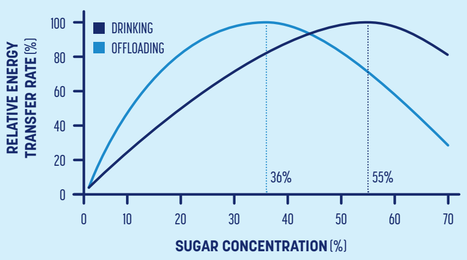


- Bumblebees prefer nectar with 55% sugar *vs* nectar with 40% sugar[3] (quantity: 15mm³)
- Bumblebees have no preference for nectar with 55% sugar *vs* nectar with 65% sugar[3] (quantity: 15mm³)
- Bumblebees prefer nectar with 35% sugar *vs* nectar with 20% sugar at field-realistic volumes (quantity: 1mm³)

Nectar viscosity affects offloading rate more strongly than drinking rate[4]

Bee foraging involves flying to flowers, drinking, then returning to offload nectar in the colony. Drinking rate is well studied, but offloading rate has historically received little attention.

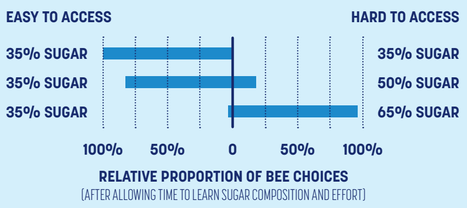




- Bumblebees drink nectar of all sugar concentrations relatively slowly, but offloading high-sugar nectar is much slower than offloading low-sugar nectar.
- Models show energy transfer is maximised at nectar with 55% sugar for drinking, but nectar with 36% sugar for offloading.
- The nectar sugar percentage that maximises energy transfer to the colony is therefore lower than predicted only from drinking.

Bumblebees can make a tradeoff between nectar sugar content and energetic cost of access[5]

The nectar studies above test preferences when all else is equal. However, bumblebees find it harder to access some flowers than others.



- When bumblebees are given two identical rewards, one easy to access and one hard to access, they choose the one that is easy to access.
- Bumblebees will choose the reward that is hard to access if the sugar percentage makes it worthwhile.

Does flower shape vary, and is it useful to insects?

Different species of insects prefer different flower shapes[6]. Existing variation in flower shape may therefore be useful in helping particular insects find flowers faster. In this study I focus on flower circularity ($4\pi \times \text{area} \times \text{perimeter}^{-2}$).

Flower shape varies between strawberry varieties

I photographed several hundred strawberry plants from 20 varieties and used software[7] to measure the flowers' area and perimeter, then calculated each flower's circularity.

EXAMPLE FLOWERS										MODEL FLOWERS	
AREA (MM²)	854	471	710	471	485	724	556	299	227	519	519
PERIMETER (MM)	119	101	119	103	98	118	105	75	63	111	95
CIRCULARITY (%)	76	58	63	56	63	65	63	66	72	53	72

Flower area and perimeter varies between varieties. There is no correlation between circularity and either nectar sugar mass or pollen count or viability (see below).

Bumblebees prefer star-shaped flowers, but can't find them faster

I made plastic 'flowers' (pictured above) to test if bumblebees could make use of the variation in shape. The two shapes have the same area but are at the 5th and 95th percentiles of variation in circularity.

In our insect lab, I timed bumblebee flights between the plastic flowers.

- Bumblebees show an innate preference for the less-circular flowers (22 of 30 bees, $p = 0.0054$).
- Bumblebees do not fly faster between less-circular flowers than between rounder flowers ($p = 0.17$).

This indicates that, while the existing variation in flower shape may not be enough to improve pollination speed, it may be possible to breed flowers that better match bumblebee preferences.

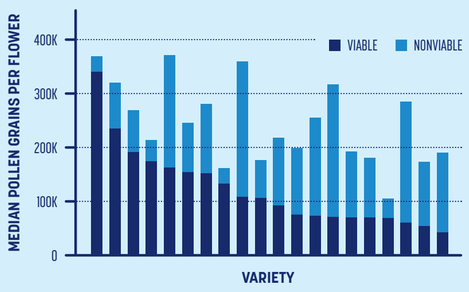
Do floral rewards vary between strawberry varieties?

To be able to select for varieties with improved nectar and pollen rewards, we first need to know the existing variation in those rewards (both between varieties and between plants within each variety).

I grew several hundred strawberry plants from 20 varieties in an insect-proof polytunnel, then extracted and analysed pollen and nectar from flowers between one and two days old.

Pollen quantity and viability varies between strawberry varieties

Pollen is the main protein source for pollinating insects. As well as quantity, pollen viability is important: bumblebees prefer to eat fertile pollen[8]. (Improving viability is also useful for increasing the effectiveness of pollination.)

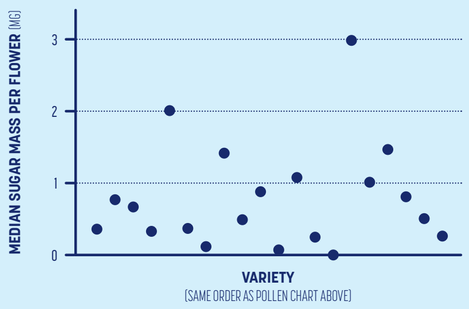


- Total pollen count and percentage viability varies between varieties.
- There is no correlation between percentage viability and total pollen count, indicating that both 'more pollen' and 'viable pollen' can be bred for separately.
- The varieties with the largest quantities of viable pollen per flower are Marshmello, Eros and Vibrant.

Pollen samples are now being analysed at the University of Sussex to identify differences in protein composition: there may be variation in the nutrition levels of pollen from different varieties.

Nectar sugar mass per flower varies between strawberry varieties

Nectar is the main carbohydrate source for pollinating insects. Total sugar mass per flower depends on both the volume of nectar produced and the percentage of sugar it contains.



- Nectar sugar mass varies between varieties.
- There is no correlation between nectar sugar mass and pollen data (above), indicating they can be bred for separately.
- Variation is driven by nectar quantity more than sugar percentage (data not shown)
- The varieties with the largest nectar sugar mass per flower are Cambridge Favourite, Malling Champion and Christine.

1 Klein *et al.* (2006), 10.1098/rspb.2006.3721 • 2 Sánchez-Bayo *et al.* (2019), 10.1016/j.biocon.2019.01.020 • 3 Bailes *et al.* (2018), 10.1002/ece3.3851
4 Pattrick & Symington *et al.* (2020), 10.1098/rsif.2019.0632 • 5 Pattrick & Symington *et al.* (2022), in prep.
6 Dafni *et al.* (1997), 10.1080/07929978.1997.10676684 • 7 Symington *et al.* (2019), 10.1186/s13007-019-0403-2 • 8 Robertson *et al.* (1999), 10.1890/0012-9658(1999)080[2594:BBSOMG]2.0.CO;2

> **"Understanding the relevance of floral traits to pollinators offers the potential to breed new varieties with flowers which are better matched to the insects that visit them."**
>
> ADAM WHITEHOUSE, STRAWBERRY BREEDER, NIAB/EAST MALLING RESEARCH

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