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TRICKING THE BEES: HOW SOME FLOWERS CHEAT

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Flowers usually provide their pollinators with food, such as nectar. But some flowers trick their pollinators into pollinating without offering any food. Cheater flowers from the same species can be of different colors, and this might confuse the pollinators, because they have to visit many flowers before learning that all of the colors represent cheater flowers. To investigate this, we trained bees to visit artificial flowers that we could change the color of. The bees learned which colors represent flowers with no food, and they preferred to take a risk visiting flowers with new colors, instead of the ones they already recognized as cheaters. Also, bees visited more flowers and spent more time visiting them when flowers of two different colors were presented, compared to when only one color of flowers was available. We confirmed that presenting flowers of more colors is a good strategy for tricking pollinators and thus increasing pollination events.

FLOWERS AND POLLINATORS

If you take some time to observe a garden with flowering plants, you might see some animals visiting the flowers, including bees, butterflies, beetles, and birds. These creatures are likely to be searching for food in the flowers, probably **nectar**. When one of these animals flies from one flower to another flower of the same species, it is helping the plants to reproduce by **pollinating** them. Pollinating animals pick up and transport **pollen** grains that can fertilize the **ovules** of the next flowers they visit. Pollen grains and ovules are special cells that, when brought together through the pollination process, will form a fruit.

But how does an animal choose which flowers to visit? Similar to humans, pollinators have senses, such as vision and smell, that they can use to identify flowers. They can also learn which colors and scents are present in flowers that contain food. If they remember these signals, they can choose which flowers they should visit next, which helps them to be as effective as possible in getting food.

ARE ALL FLOWERS RELIABLE?

Not all flowers provide nectar for pollinators. Some cheating flowers trick pollinators into pollinating them, without providing any food [1]. These so-called deceptive flowers were discovered a long time ago, and scientists have been interested in them for many years. But, the same way pollinators can learn that certain colors and scents indicate the *presence* of food, they can also learn that the signals sent by cheating flowers mean that there is no food in them. So, these cheating plants need strategies to trick pollinators into pollinating them.

There are two main strategies that cheating plants use to trick their pollinators. First, deceptive flowers can imitate the colors and scents of other flowers that *do* provide food to their pollinators. Let us call this the imitation strategy. Second, cheating flowers can display general signals, such as attractive colors and scents, that do not imitate any other specific flower but that signal to the pollinators that food might be present. Let us call this the general signals strategy.

Plants that follow the general signals strategy often present their flowers in various forms [1]. For example, individual plants of the same cheating species can have flowers with different colors—one plant may have red flowers and another white, for instance. These differences in flowers of the same species are called **polymorphisms**, and they can occur not only with colors, but with scents too! In the 1970s, a scientist named Bernd Heinrich hypothesized that flowers with polymorphisms could help cheating plants because it is harder for pollinators to learn that all of the different flowers do not contain food [2]. In other words, the pollinator would have to visit *every single*

NECTAR

A sugary substance usually offered by flowers to their pollinators. Nectar is a great energy source and bees use it to make honey.

POLLINATION

The way most flowering plants reproduce. It is the action of bringing the pollen grains to the ovules, fecundating the flower. Most of the times, this is done by an animal visiting the flower, named pollinator.

POLLEN

The yellow grainy floral structure that contains the male genetic information of a plant. It can be carried by pollinators from flower to flower during pollination.

OVULE

A structure inside a flower that contains the female genetic information of the plant. It is fertilized by the pollen grains and then develops into a fruit.

POLYMORPHISMS

The different forms of the same species. For an example, the various eye colors of humans are polymorphisms.

different flower to realize that there is no food available, and in the process, the plants are more likely to be pollinated. Clever, right?!

INVESTIGATING THE CHEATING MECHANISM

Based on Heinrich's idea, we decided to investigate whether presenting differently colored flowers with no food would confuse the pollinators (Figure 1), so that they would visit more flowers than if all the cheating flowers were the same color. To study this, we used the example of a deceptive orchid with color polymorphism, which presents both white and purple flowers (Figure 2A) [3]. In Brazil, this orchid is visited by many bees, including an interesting species that is very different from the common honey bee in size (it is much smaller), color (it is all black), and its lack of a stinger (Figure 2B). We used this bee species for our experiments.

Figure 1

Figure 1

When a bee is looking for food, it must choose which flowers to visit. This can be very difficult when some flowers are cheaters with no food, and even harder if cheating flowers have more than one color that the bee needs to learn! (Image credit: Juliana Maltoni).

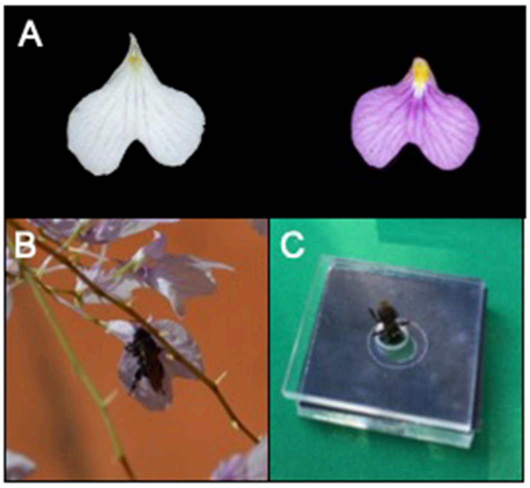

Figure 2

Figure 2

(A) Flowers of the deceptive orchid come in white and purple polymorphisms. **(B)** The bee species we used in our study, visiting an orchid flower. **(C)** A bee visiting an artificial flower with a gray-colored paper. The paper was changed to white or purple in our experiments, to mimic the orchid. The bee is marked with two yellow dots, so we know which bee we are training at that moment.

Scientists have known for years that bees can see colors [4]. So, we used a special piece of equipment to measure the exact colors of the orchid flowers, so that we could reproduce those colors in our experiments.

TRAINING THE BEES

Did you know that bees can be trained to do tricks (kind of like dogs) in exchange for a reward [5]? In fact, this is how scientists first discovered that bees could see in color [4, 6]. These scientists trained bees to visit differently colored papers, in experiments very similar to the ones we used in our research. In our experiment, we created an artificial flower that we could change the color of, using differently colored pieces of paper. The colors matched the colors of the deceptive orchid (Figure 2C). As a reward, we placed sugar water inside the artificial flowers. If we wanted the bees to learn that the flowers had no food, we used plain water instead.

RISKING THE UNKNOWN

For our experiments, we used beehives in the garden in front of our research lab. One good thing about training bees is that they always come back to their hive, so we do not need to worry about them escaping during the experiment! It took a lot of hard work and about 2 years to finish all of the experiments.

First, we trained the bees to visit artificial flowers with sugar water, but without any colored paper, so they would learn that the artificial flower was a food source. We used a special kind of sugar water with no odor, so the bees could not smell it. We did this so that the bees would not learn the smell of the sugar—because we wanted them to focus on the colors of the artificial flower instead. After the bees learned how to use the artificial flowers, we changed the colors to match one color of the orchid flowers (let us use white as an example). We also replaced the sugar water with plain water, so we could teach the bees that the white color meant no food.

After the bees visited 10 flowers during this learning period, we removed all of the white flowers and replaced them with two flowers with plain water: one white and one purple (matching the purple of the orchid). We wanted to see if the bees, knowing that white means no food, would be more likely to visit a *new* color while in search of food. This simulated what the cheating orchid does in nature—presenting differently colored flowers, all with no food. We found that, during the training, the bees learned not to visit the color without sugar (Figure 3A). When we tested them with two colors of flowers, they remembered which color *not* to visit—they took a chance on the new color, even though they did not know if they would find food there (Figure 3B).

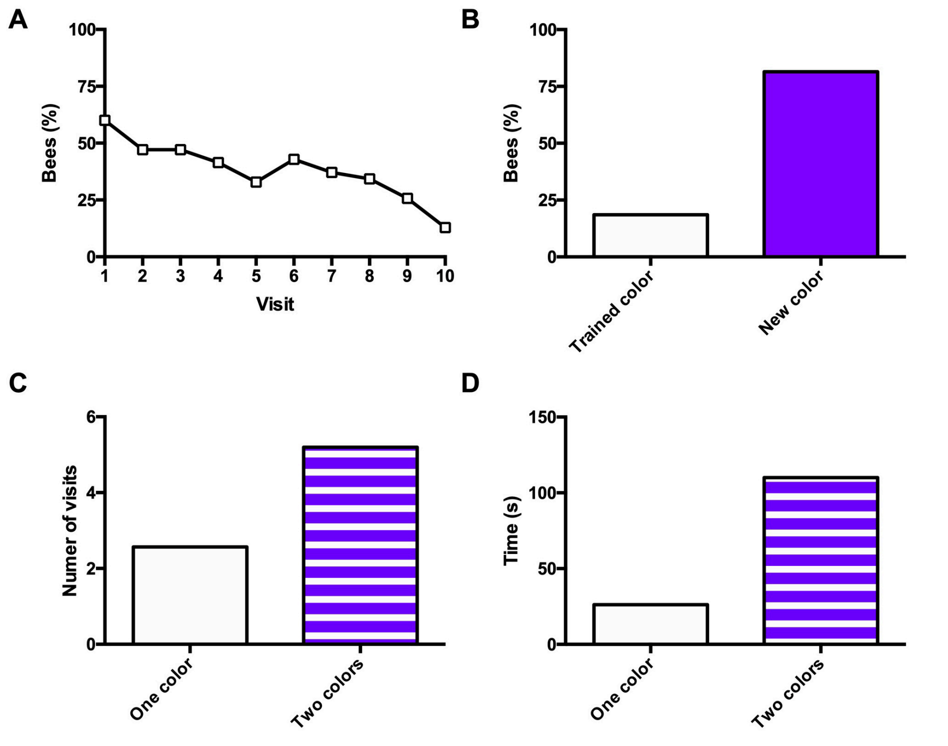

Figure 3

Figure 3

(A) The percentage of bees visiting the color without food decreased after 10 visits, meaning that they learned to avoid this color. **(B)** The trained bees preferred to visit a new color, instead of the one they learned has no food. **(C)** If two colors of cheating flowers were available, bees made more visits to the flowers and **(D)** spent more time visiting them than when only one color was presented. Bees prefer to take a risk on an unknown color, which makes it harder for them to learn which flowers have no food, increasing pollination chances.

MORE COLORS MAKE MORE POLLINATION

In another experiment, after teaching the bees to visit the artificial flowers, we replaced all of the flowers with new flowers that were either all white or all purple, or with a group of flowers in which half were white and half were purple. In both cases, all the flowers had plain water. We expected that, when two colors of flowers were present, the bees would visit more flowers and take more time to learn that the two different colors meant no food, compared to when only one color was presented. That was what we saw! When two different colors of flowers were available, the bees made more visits (Figure 3C) and took more time to realize that the flowers had no food (Figure 3D), compared to when only one color was available.

THE CONCLUSION: GREAT CHEATERS COME IN DIFFERENT COLORS!

Plants are usually honest with their pollinators, by offering them food in exchange for pollination services. But, in nature, there are also some cheating flowers that do not provide food for their pollinators. In our experiments, we showed that presenting differently colored flowers can make it more difficult for pollinators to learn that a plant is cheating. The more difficult it is for a pollinator to learn this, the more likely that pollinator is to visit more flowers from the cheating plant—and pollinate them! This idea was originally hypothesized by

Bernd Heinrich in the 1970s, and we were very excited to confirm his ideas!

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ORIGINAL SOURCE ARTICLE

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REFERENCES

1. Jersáková, J., Johnson, S. D., and Kindlmann, P. 2006. Mechanisms and evolution of deceptive pollination in orchids. *Biol. Rev.* 81:219–35. doi: 10.1017/S1464793105006986
2. Heinrich, B. 1975. Bee flowers: a hypothesis on flower variety and blooming times. *Evolution.* 29:325–34. doi: 10.2307/2407220
3. Aguiar, J. M. R. B. V., Giurfa, M., and Sazima, M. A cognitive analysis of deceptive pollination: associative mechanisms underlying pollinators' choices in non-rewarding colour polymorphic scenarios. *Sci. Rep.* 10:9476. doi: 10.1038/s41598-020-66356-4
4. Dyer, A. G., and Arikawa, K. 2014. A hundred years of color studies in insects: with thanks to Karl von Frisch and the workers he inspired. *J. Com. Physiol. A.* 200:409–10. doi: 10.1007/s00359-014-0913-3
5. Giurfa, M. 2007. Behavioral and neural analysis of associative learning in the honeybee: a taste from the magic well. *J. Com. Physiol. A.* 193:801–24. doi: 10.1007/s00359-007-0235-9
6. Giurfa, M., de Brito, A. G., de Brito, T. G., and de Brito Sanchez, M. G. 2021. Charles Henry Turner and the cognitive behavior of bees. *Apidologie*. 52:684–95. doi: 10.1007/s13592-021-00855-9

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