**Be the Bee, Part 1: Do Classroom-grown Tomatoes that are "Buzz-Pollinated" by Hand Produce More Fruits than Untouched Plants?**

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**Grade levels targeted:** 6-8

**Estimated time required to conduct the experiment:**

- 30 minutes to set up on first day
- 20 minutes / day to water plants, sonicate (= vibrate) flowers, clip mature fruits, count and weigh fruits, and record data
- Variable time to tally data and discuss results

**Introduction:**

Many garden plants will produce fruits only if they are visited by insects. The fruits contain the seeds needed to produce the next generation of plants, and are also sometimes the plant parts that we eat. In many cases, it is bees that do the pollination work although other animals, such as butterflies, moths, flies, beetles, bats, and hummingbirds, can also be important pollinators.

Adult bees visit flowers partly to feed on nectar, which fuels their own activities. But the main reason that adult female bees visit flowers is to collect the nectar and pollen that they feed to their larvae back at the nest. Note that male bees do not participate in bee "child rearing" and the larvae themselves are incapable of gathering their own food. Pollen is particularly important to larvae because it contains protein needed for them to grow.

Many common garden fruits and vegetables require *cross-pollination* to produce fruits and / or seeds. Cross-pollination occurs when the pollen from one plant is transferred to another plant of the same species. This is where bees come in. As they forage on flowers, the female bees' bodies can become dusted with pollen that is then incidentally carried from one plant to plant. This is how pumpkins, for example, are pollinated. However, some garden plants, such as beans etc., have flowers that are **self-fertile**. Self-fertile flowers are capable of producing viable seeds with their own pollen, so insect pollinators are not required to move pollen about. For a list of common garden plants and whether they need pollination, see this page.

The exception to this rule is self-fertile plants that are **buzz-pollinated**. This group includes blueberries and some plants in the nightshade family, such as tomatoes, eggplants, potatoes, and peppers, all plants that are frequently visited by bees. Although these plants have self-fertile flowers, they require vibration of their flowers to release pollen from their anthers (male parts) and shake it onto the stigma (female part that receives the pollen).

These types of flowers are manipulated by bees in a deliberate way to release pollen so that the bee can collect some for its own use. The bee lands on the flower, contacts the central portion, and then creates a burst of intense vibration by trembling its flight muscles, thereby shaking its whole body without moving its wings. The muscles tremble at up to 400 Hz (Hz equals "hertz", or vibrations per second), a vibration that is easily heard by an observer. (Note that 400 Hz is about twice the maximum frequency at which hummingbirds beat their wings during flight! It is also faster than guitar strings vibrate when they are plucked). To see buzz-pollination in action, view this video: http://www.youtube.com/watch?v=rMvQSx2429U

Tomato flowers are much smaller and perhaps not as pretty as a rose or sweet pea, but they have the same basic structure (http://www.geochembio.com/biology/organisms/tomato/#flower). The anthers of tomato flowers are hollow tubes with pores at the tip, much like little salt shakers, filled with pollen. On the plant, tomato flowers hang downward on a flexible stem (call a *pedicle*), so when a visiting bee lands it pulls the flower into an upside-down position.

MORE ABOUT BUZZ-POLLINATING BEES:

- When it comes to buzz-pollination, not all bees are equal. Honey bees, for example, do not buzz-pollinate.
- Effective buzz-pollinators include many common bees among the bumble bees, and among the solitary bees.
- Wind and incidental shaking can also sometimes cause pollination to occur in plants like tomatoes. However, this is not as effective at fertilizing all of the flowers, and thus fruits tend to be fewer, smaller, and late-setting (i.e., the fruits start forming too late in the year to complete ripening).

About Grow Lights. Tomatoes, cucumbers, and many other garden crops require full summer days of natural lighting from the seedling stage all the way through flowering and fruiting. In the winter, ambient light shining in from the outdoors is not sufficient. Tomatoes grown indoors in the winter without abundant supplemental light will be weak and spindly, and will not flower. There are several different lighting options, all of them rather expensive if purchased new. The least expensive is a fluorescent T5-type grow light system. Grow lights must be fitted with lamps that cast blue spectrum light (for the seedling stage) and red spectrum light (for the reproductive stage). More expensive HID-type grow lights provide better light intensity and quality, and will result in healthier plants with better flowering and fruit set. Newer types of LED lights are another promising option to explore.

**Question to be addressed by the class project:**

Do tomato plants with flowers that are vibrated by hand with an electric toothbrush (to simulate vibration by a bee) produce a higher number of tomatoes than plants whose flowers are left untouched?

**Hypothesis:**

In the absence of bees, tomato flowers that are vibrated by hand will release their pollen, fertilizing the ovaries of the flower, and producing tomato fruits that are more abundant and larger than tomatoes produced on control plants without simulated buzz-pollinations.

**Materials:**

This project requires starting tomatoes from seed, because school is typically in session during the cold season when garden plants are not available.  For a summer-session class it will be easier to purchase mature flowering cherry tomato plants from a nursery.  So-called “determinate-type” tomatoes are a better choice than “indeterminate types”, because they have smaller and more compact dimensions.  You may also use garden tomatoes growing outdoors, but they must be enclosed with screening or row cover fabric to keep bees away from them (since the students will be the “bees” in this project).

| Item* | Quantity | $ Each (Approximate) | $ Total (Approximate) |
|---|---|---|---|
| Fluorescent grow lamp: 2-foot 8-lamp T5 High-Output System with four 3000K bulbs and four 6500K bulbs | 2 | 250.00 | 500.00 |
| Adjustable grow light stand | 2 | 25.00 | 50.00 |
| Indoor plug-in light timer | 1 | 15.00 | 15.00 |
| Digital kitchen scale | 1 | 15.00 | 15.00 |
| Electric vibrating toothbrush | 1 | 8.00 | 8.00 |
| 10” (5-quart) plastic plant pots with bottoms | 6 | 2.00 | 12.00 |
| Bag (32-quart) prepared potting soil | 1 | 7.00 | 7.00 |
| Box Miracle-Gro® All-Purpose Plant Food | 1 | 6.00 | 6.00 |
| Packet of cherry tomato seeds | 1 | 3.50 | 3.50 |
| Plastic bowl | 1 | 2.00 | 2.00 |
| Scissors | 2 | 3.00 | 6.00 |
| Clipboard w/ data sheet and pencil | 1 | 2.00 | 2.00 |
| | | TOTAL: | $ 626.50 |
| *OPTIONAL: Seedling heat mat, 20x20-in$^2$ | 2 | $ 50.00 | Add $100.00 |

**Methods:**

You will use a total of six plants, divided equally between two different types of experimental handling, or “treatments.”  In science, a **treatment** is a set of procedures that researchers use on a set of “subjects”, in this case the tomato plants.  In this experiment, there are two treatments. Treatment A uses a group of three tomato plants that will have all of their flowers buzzed by hand with an electric toothbrush; the flowers on the remaining three tomato plants in Treatment B will be left untouched.  Later we can compare the results of the two treatments in terms of both the number and mass of tomato fruits produced.  (Note:  if you have space for more than three plants in each treatment, then use more plants.)

Three plants are used per treatment to be sure we have good **replication**.  Although we are raising the tomatoes under the same conditions of light, temperature, and humidity etc., we can’t rule out individual variation in fruiting production among the plants.  Replication is built-in repetition within an experiment using the same or similar conditions, and it is important because its averaging effect strengthens our ability to trust the estimates we will draw from our data. (Medical researchers, for example, do not test the effect of a new drug by administering it to just one person during testing).

1. Growing the plants

Select two experimental areas in the classroom. The three tomato plants within each treatment can be clustered together, but the two treatments should be separated by at least ten feet, more if possible, so that pollen drifting from the treated (buzzed) plants to the control (untouched) plants is minimized. Areas near a window with natural light are ideal unless they are cold (below 70°F).

Arrange three pots in each treatment area underneath one grow-lamp. Mark them with numbers 1-6, corresponding to the numbers on the **data sheet**. Fill plant pots with soil and push three seeds into the soil near the center of each pot; cover with ¼" soil, and water.

Set grow lamp timers for 16 hours of illumination, overlapping with daylight hours (for example, 6:00 a.m. to 10:00 p.m.).

Water pots every other day or as needed, being sure to water all pots equally. Seedlings will appear in 5-10 days post-planting. After emergence, choose the strongest seedling to keep and pull the other two out. Continue with the watering schedule, and feed the plants with Miracle-Gro as directed on the label.

The first flowers will appear at about six to seven weeks post-planting, but this will vary with growing conditions and tomato variety. By seven to eight weeks, the first little tomatoes will be forming on flowers that have been successfully pollinated.

2. Sonication and data collection

The experiment will commence when the first tomato flowers are open. The experimental schedule involves:

- Sonicating mature flowers (Treatment A **only**)
- Clipping, counting, and weighing mature fruits
- Recording data

*Day One:* In the three Treatment A plants, locate all fully open flowers. Turn on the electric toothbrush and gently contact the **back** of each flower (Fig. __) for one full second. **Do not touch the plants in Treatment B and be careful not to disturb the plant pots as that could cause some pollen to be dislodged.** Please note that placing the toothbrush on the outside of the flower will be enough to shake the pollen loose. Vibrating toothbrushes vibrate at a higher frequency and intensity than buzz-pollinating bees. Contacting the tips of the flowers, as the bees do, could damage the flowers' reproductive parts.

*Every M-W-F:* Unfertilized flowers will eventually **absciss** (shrivel and drop off) without developing any fruit. This can take as little as four days, although modern tomato cultivars will often retain viable flowers for longer. To minimize early flower drop, the flowers in Treatment A should be sonicated two to three times per week. A Monday-Wednesday-Friday schedule works well, but the schedule can be flexible to accommodate school holidays.

It is okay if the same flowers are sonicated more than once during the week. After the flowers begin to wilt, they should be left alone. Over time, the fertilized flowers will shed their petals, style, and stigma, and you will see the ovaries swell into small green early tomatoes.

On the selected experiment days, mature and fully-red tomatoes from both treatments are clipped from each plant and counted. After counting the tomatoes on each plant, weigh them together on the scale before moving to the next plant. To do this, put the plastic bowl on the scale. Then reset the scale to zero (called "taring the scale") before putting the tomatoes in the bowl, in order to get the net mass of the fruits minus the mass of the bowl.

3. Recording Data

Use the data sheet to record the date, the name(s) of the observer(s), the number of tomatoes collected per plant that day, and the combined mass of the tomatoes collected per plant that day.

After several weeks of collecting mature fruits the experiment can be stopped at any point.

**Results:**

- Add up the total number and mass of tomatoes produced by each plant.
- Calculate the average number and mass of tomatoes produced by each treatment.
- Create a graph of your data. You can do this on-line using "Kids' Zone Create A Graph" at http://nces.ed.gov/nceskids/createagraph/. You can choose to make a bar graph on the "Design" tab, and then on the "Data" tab you can list your six values organized into two groups of data (buzzed and not buzzed). This is a fun program to use, and you can really see what your data looks like.

**Discussion:**

Discuss your results and whether your results appear to confirm or reject your hypothesis. Was there much variation within each treatment? Can you say anything about how well artificial buzz pollination works? Discuss future experiments you may want to perform based on your results. Discuss what you have learned about the importance of bumble bees and solitary bees in food production.

**References and Resources:**

Information on tomato buzz pollination:
http://www.xerces.org/wp-content/uploads/2008/10/factsheet_cherry_tomato_pollination.pdf

Short movie of bumble bee buzz-pollination behavior on blueberry flowers:
http://www.youtube.com/watch?v=Nv_xncrZfCg

Information on different types of grow-lights: http://en.wikipedia.org/wiki/Grow_light

Source for economically-priced fluorescent grow lights, 2-pack:
http://www.htgsupply.com/Product-2-Pack-of-GrowBright-2-Foot-Single-Lamp-T5-Light.asp

On-line graph creation with elementary-aged students: http://nces.ed.gov/nceskids/createagraph/

http://www.google.com/patents/EP1501345A1?cl=en – a patent study showing that wild-type unfertilized tomato flowers abscissed four days after anthesis.

Site for commercial tomato producers:
http://nwrec.hort.oregonstate.edu/tomatogh.html

Tutorial on greenhouse supplementary lighting
http://www.arguscontrols.com/articles/Light%20and%20Lighting%20Control%20in%20Greenhouses.pdf