INQUIRY & INVESTIGATION

Exploring Carbohydrates with Bananas

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Abstract

Bananas can be used in many classroom lab activities to make carbohydrates easier for students to understand. I detail a simple series of banana activities that can be used to investigate carbohydrates across a wide range of levels of organization and that serve to connect carbohydrate concepts that might otherwise seem disparate to students. For example, the taste of a banana is linked to carbohydrate hydrolysis, as well as to organelle content within banana cells. Bananas can be used safely in any classroom, and inquiry-based learning can be used to progress through related course content. In addition, students will gain expertise in understanding cells viewed through the microscope as they try to examine the starch in the bananas.

Key Words: *Carbohydrates; plant; cells; hydrolysis; inquiry; levels of organization; dehydration synthesis; organelles; plastids; amyloplasts; starch; sugar; glucose.*

Introduction

Carbohydrates are fascinating. Glucose production and consumption can be described at the molecular, organelle, cellular, tissue, organ-system, ecosystem, and biosphere levels. However, many processes that involve carbohydrates are difficult for students to grasp, including dehydration synthesis of glucose and hydrolysis of polysaccharides. We are challenged to help our students learn about carbohydrates and integrate their roles in processes at all levels of organization. Yet experience has shown that students often find it easier to remember separate facts than to synthesize big pictures. Here, I show how to use bananas in lab to make carbohydrates less abstract to students and to integrate carbohydrate-related topics from a variety of levels of living things. The lab techniques I describe do not require knives, heat, or dangerous chemicals, so they can be done with a wide range of students.

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For most of the suggested lab activities, your students can explore carbohydrates and bananas using inquiry. To do so, you can provide leading questions to direct students toward appropriate inquiry or desired outcomes (examples of leading questions are included within the activity descriptions). If middle or high school students are generating their own experiments as part of the inquiry, that is consistent with "Planning and Carrying Out Investigations" Science and Engineering Practices of the *Next Generation Science Standards* (NGSS). Feel free to choose which portions of these suggestions and activities work for you and your classes.

The activities and experiments described here run from the organelle through organ-system levels of living things, while also providing insight into the molecular level. Such activities address many of the middle and high school NGSS standards of Life Sciences 1 (LS1) "From Molecules to Organisms: Structures and Processes," as well as many of the NGSS cross-cutting concepts. The activities are also useful for helping college students connect information across many levels of life.

Beginning the Activities

You will need two bananas: one "new" banana (often described as "green" or "raw") and one "ripe" banana (it can be overripe, appearing yellow to brownish). Simply ask your students to describe the taste (or feel or smell) of the bananas and the banana type that would taste best to them. Whether the students are tasting samples of banana or just reflecting on their prior experiences is your decision. Students may tell you that the new banana tastes raw or feels thicker or gummier, or that the ripe

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banana is too sweet. These experiences will link their personal understandings to the experiments that they are about to do, making this investigation less abstract.

○ Tissue Level

Continue the investigation of the two types of bananas with a simple iodine test. For comparison to their own experiences in tasting the bananas, the fruit, not the peel, should be tested with iodine. The new banana will test positive for starch (turning dark) while the ripe banana will not (staying yellow). Have your students describe how this relates to the taste of the bananas. The iodine test will help students understand the new banana better, especially since many students understand that starch can act as a thickener and that starch itself does not taste sweet. If you choose to use an inquiry approach, ask your students what gives bananas sweetness and which category of biological molecules that fits into. You can guide them to consider the storage of that sweetness to see whether they come up with carrying out a starch test on their own.

At this point, shift from simply identifying the presence of starch in one banana to the concept that starch can be broken down to sugar through hydrolysis reactions. Ask your students where the starch went as the banana changed from new (raw) to ripe. Most students do not think that starch left the banana, often based on the peel acting as a barrier to starch loss. This is a good time to remind them that starch is a polysaccharide and that sugars are also carbohydrate components. Through discussion, you can coax the idea that starch must have been broken down to sugar as the banana ripened. Since they already know that ripe bananas taste sweet, starch breakdown usually makes sense without needing a separate test for the presence of sugar (i.e., Benedict's test). The iodine test on the bananas can be paired with iodine tests of purified starch and sugar to mirror the banana results.

○ Cellular Level

The next part of the investigation moves to the cellular level. Where is the starch found inside the banana? To view banana cells, simply rub some banana flesh on a slide and coverslip with iodine; a faint smudge of banana flesh will have ample cells for viewing. Figure 1 shows a smear of iodine-stained new banana cells at 100× magnification. Notice that individual cells can be seen when the banana is smeared rather than cut, and that the positive iodine test is visible at the cellular level. Banana cells are easy to view because they tend to be very large and, without the use of knives, do not break open and spill out organelles (as potato cells do). They are also easy to make sense of, because many are shaped like tiny bananas. Have your students compare the new banana smears to the ripe banana smears and report any difference in starch content visible at the cellular level.

More cellular and organelle detail can be seen by viewing the smears at high power (400×) as in Figure 2. At this level of magnification, the stain from the iodine can be seen as restricted within subcellular regions. Note that the amount of stain visible within the cells decreases from panels A to D. When a new banana is stained with iodine for viewing, most of the cells look like the one in Figure 2A,

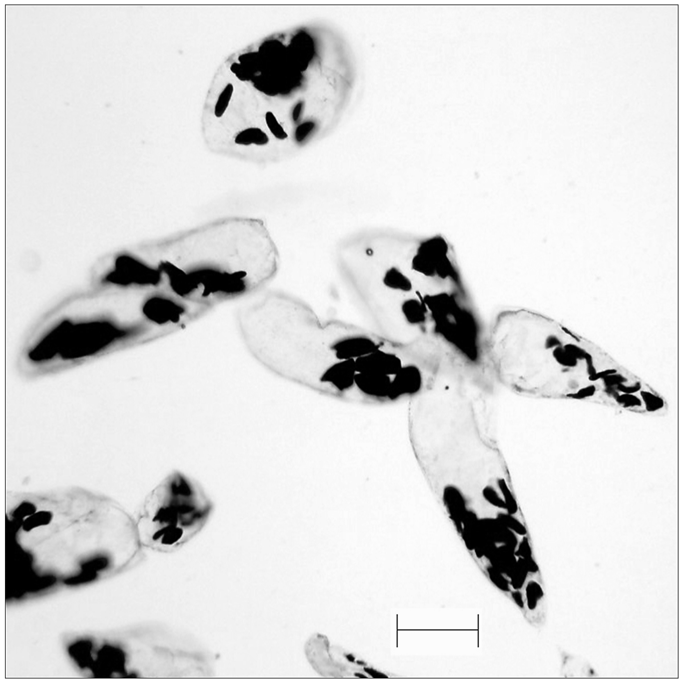

Figure 1. Photomicrograph (100× magnification) of new banana cells stained with iodine. Scale bar = 100 μm.

which seems quite heavy with stain. There are also some cells from the new banana that look like the one in Figure 2B, which have less intense staining. When a ripe banana is stained with iodine for viewing, most of the cells appear to have little stain, like those in Figure 2C and 2D. Occasionally, there are cells that lack stain in a new-banana smear and cells that maintain stain in a ripe-banana smear, but the majority reflect the state of the banana.

○ Organelle Level

Now shift to the organelle level. The organelles containing starch in banana cells (and potato cells) are amyloplasts, a type of plastid that stores starch. Other types of plastids include chloroplasts (for photosynthesis) and chromoplasts (for pigmentation). You will need to help your students understand the presence of amyloplasts (rather than chloroplasts) in banana cells. A good organelle-level question to get them started is "Are there chloroplasts in the banana cells?" Many students hold a common misconception that all plant cells contain chloroplasts and that all plant cells are green. How can they tell whether chloroplasts are there? (This may lead them to view banana cells without staining in iodine to try to see green organelles.) What is the function of chloroplasts, and why would they be unable to carry out that function in a banana cell? Which other areas of a plant might not be good at photosynthesis? All these questions lead students toward the idea that plants have different organs, each providing a specific function; only one of those functions is photosynthesis (leading to the production of glucose). They should be able to come up with other plant organs or tissues, such as roots, that do not carry out photosynthesis because they cannot encounter sunlight.

Next, ask your students to identify the iodine-stained subregions within the banana cells. They will not find the structures in

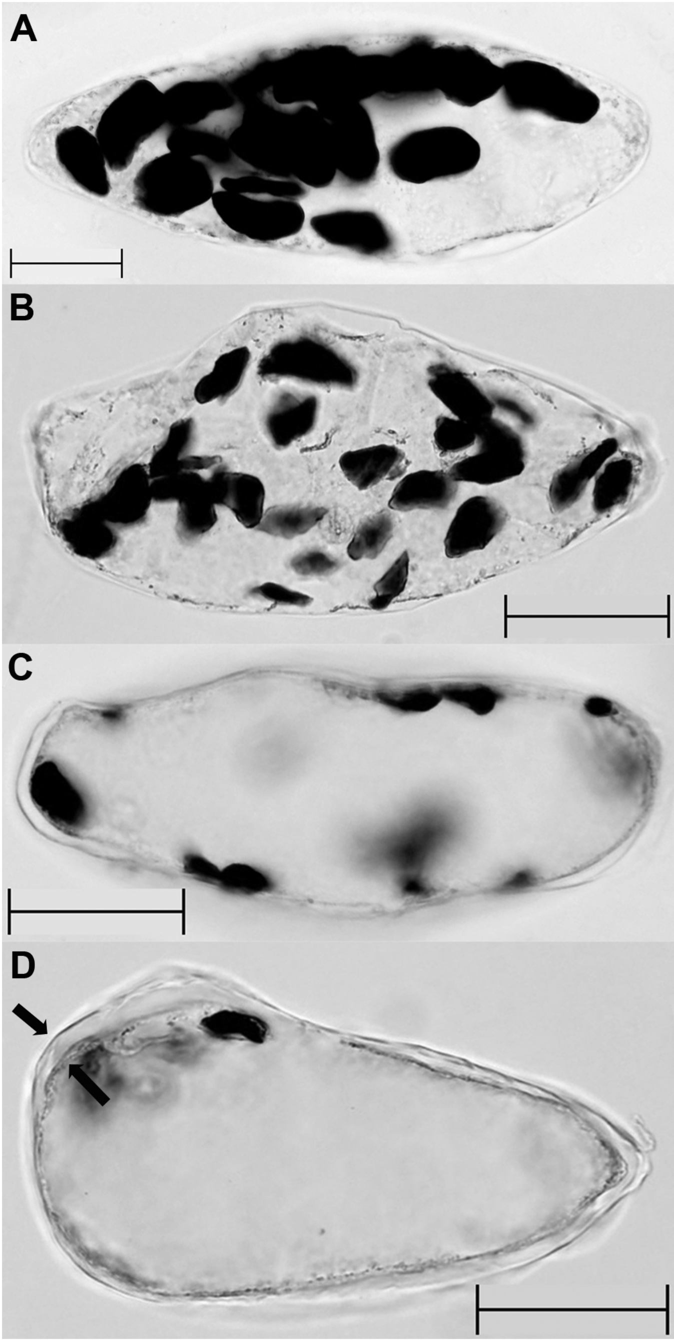

Figure 2. Photomicrographs (400× magnification) of banana cells stained with iodine: (**A** and **B**) cells taken from a new banana and (**C** and **D**) cells taken from a ripe banana. Arrows in **D** indicate where the cell membrane and cell wall can be seen separately. Scale bar = 50 μm.

standard drawings depicting the structure of a "typical plant cell." This is an opportunity for a brainstorming session or for development and testing of hypotheses. Get them started with the question "Is the starch within an organelle or not?" The observations that the stain is compartmentalized and that the compartments have clear edges should lead them to understand that the subregions must be membrane-bounded organelles. The presence of individual starch compartments when banana cells are cut open also suggests that starch is within a membrane-bounded region. In addition, since starch is soluble, it would spread through the cytosol if not trapped by a membrane. Students may even question whether the iodine is what forces the clumping; coverslipping new-banana smears in water will reveal shiny, clear compartments within the cell.

If you are teaching differentiation (see NGSS HS-LS1-4), plastids are especially useful. Plants begin as zygotes, and each zygote contains a proplastid from its parent. As the zygote divides and cells begin to differentiate, the proplastids in cells that will end up involved in photosynthesis (e.g., in leaves) will differentiate into chloroplasts. Meanwhile, the proplastids in cells that will end up storing starch (e.g., in a banana) will differentiate into amyloplasts. Also, the proplastids in cells that will end up being pigmented (e.g., in flower petals or colorful fruit) will typically differentiate into chromoplasts. This means that all plastids are genetically equivalent to one another within the same individual, even when functionally different. Whether a proplastid differentiates into an amyloplast or a chloroplast depends on the location of its cell within the organism.

To complete the lesson on organelles that involve carbohydrates, consider also having your students examine plant cell walls. Ask students to identify whether the banana cells have both cell walls and cell membranes. At 400× magnification, the distinction between the cell membrane and cell wall is often apparent (arrows in Figure 2D). Banana cells have very thin, but still noticeable, cell walls. Students can usually relate to this because they have experienced the soft texture of banana flesh. See whether your students can remember that cellulose is also a polysaccharide, like starch, composed of glucose. For an inquiry approach, you can ask students why a cell wall was not revealed by iodine; this may lead them to examine the cells for the presence or absence of a cell wall and to evaluate what material composes the cell wall. To complete this organelle lesson, consider having your students prepare a wet mount of red-pepper peel in water. The red-pepper cells contain bright red chromoplasts and have very thick cell walls (that will not stain in iodine). This preparation provides students with an opportunity to view other plastids and more obvious cell walls (since pepper peel is much tougher than a banana).

○ Organ & Organ Systems Levels

To bring your class to the organ-system level, ask them to explain how the banana can make starch (and cellulose) if it does not make the glucose. Explaining this requires that students reconsider where glucose is assembled (in green organs like leaves) and that such a distant physical location would require a transport system to deliver glucose to the banana. The necessity of a vascular system in plants to transport anything other than water can be abstract, but the students will come up with it themselves when they have been playing with bananas and you have directed their inquiries. You can take this a step further to question the need for glucose. Why is glucose transported and what is it for? Since your students have just viewed cell walls, they may quickly remember the need for glucose in cellulose production. They may also be able to link it to the need for cellular respiration to obtain ATP; if you remind them that cellulose synthesis or plant growth requires energy, they may reach this understanding sooner. This is one more way to break the misconception that plant cells only undergo photosynthesis. Finally, have your students consider why there is so much chemical energy stored in bananas; they may be able to link the presence of chemical energy to the need for the banana plant to attract animals to spread its seeds.

○ Conclusions

By using new and ripe bananas, students can work with carbohydrates from the organelle level through the organ-system level and connect this information with their personal experiences of taste. They can relate this to the process of starch hydrolysis, an otherwise abstract concept. Students get to question what is considered an organelle and learn that the notion of a "typical cell" is an enormous generalization. Students can gain a sense of plant tissues, organs, and organ systems that they might otherwise ignore. The lessons that can develop from this lab range from molecular through organismal levels. Your students can all work on the same problem at the same time or you can split up the class into groups that carry out investigations at different levels, with classroom presentations by students to share all the information with their classmates. Bananas in the biology lab enable a wonderful variety of lessons – it is up to you to tailor your use of bananas to the specific needs of your class.

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