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HOW SEEDS SHAPE OUR WORLD

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Have you eaten bread or rice recently? Or maybe something with oil in it? If you said yes, then you were likely eating foods made from seeds. Seeds are an important food source for humans and animals, and they make up our grains, lentils, nuts, and cooking oils. But seeds are also important for the plant itself, as they can be planted in the ground to grow new plants. In some plants, the seeds are covered with fruit. For example, the tomato fruit is full of seeds, and the avocado has a large seed inside. Other plants like pine trees have so-called naked seeds, with no fruit covering them. What exactly are seeds, and how do they make new plants? Why do seeds grow when you plant them and not in seed packets in the store? Keep reading and you will find these answers, and learn how fascinating, complex, and extraordinarily diverse seeds can be.

THE WORLD OF SEED PLANTS

From the cereals you eat for breakfast, the coffee your parents drink, to your cotton clothes, seeds surround us and have a direct impact in our lives. Plants that make seeds (called seed plants) are all around us and they come in all shapes and sizes. In fact, seed plants are the most abundant group of plants on Earth and they can be found in all kinds of environments. It is important to know that seeds themselves have played a key role in the amazing diversity and abundance of seed plants.

A seed has three main parts: the **embryo**, a nutrient-providing tissue (often called the **endosperm**), and the **seed coat** (Figure 1). The embryo is the "baby plant", meaning it is the new generation that will come from the parent plant. In general, the majority of the seed is made of the endosperm, which provides the embryo with all the nutrients it needs to survive until it **germinates** and grows into a new plant. The seed coat forms a protective layer over the endosperm and the embryo, providing a safe environment for the embryo to develop. It acts as a barrier against environmental dangers (bacteria, viruses, or fungi) that can hurt the embryo, which helps the embryo to survive for long periods of time. The seed coat can also play a role in determining when the embryo will germinate [1, 2].

EMBRYO

Tiny plant inside the seed that will grow into a new plant.

ENDOSPERM

Nutrient-rich tissue inside the seed that provides food to the plant embryo.

SEED COAT

Outermost tissue of the seed, that covers and protects the internal tissues embryo and endosperm.

GERMINATE

When the new plant breaks out of the seed because the conditions are good for the plant to grow.

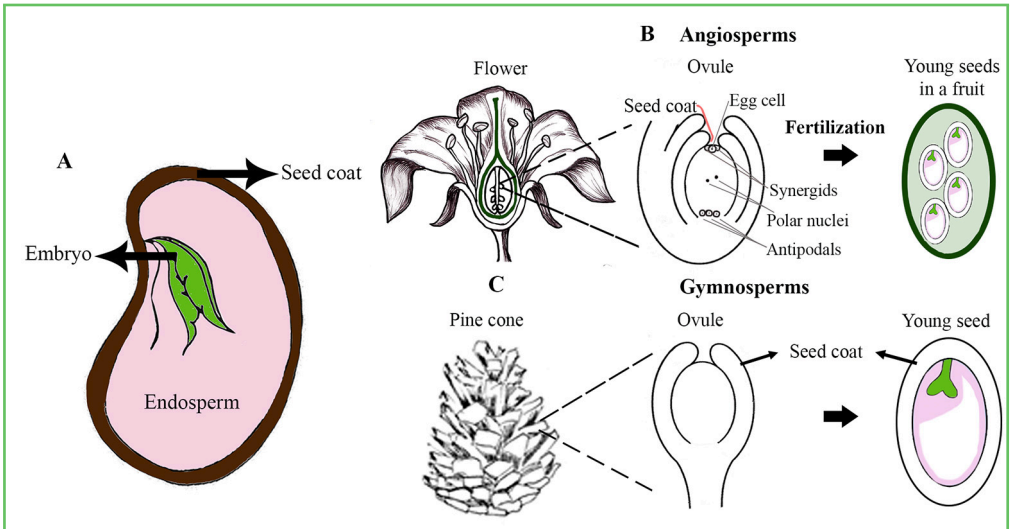

Figure 1

(A) The three main parts of a seed. **(B)** Inside the flowers of angiosperms, the ovules begin to develop. If we remove an ovule and cut it in half, we can see the seed coat has two layers and has eight cells inside. Once the ovule is fertilized by the pollen, it becomes the seed. In angiosperms, the seeds are always covered by a fruit **(C)** Seed development in gymnosperms, as illustrated with a pinecone. You can see that the seed coat has only one layer. Development of the ovule into a seed takes longer in these plants.

There are two main groups of seed plants: flowering plants, called angiosperms, and plants without flowers, called gymnosperms (Figures 1B, C). Angiosperms include all plants that produce flowers and fruits. The female part of the flower develops into the fruit, which protects the seeds and helps spread them to new places [1]. Fruits can do this by making themselves tasty to animals or by flying with the wind. What about gymnosperms? The name comes from the Greek phrase for "naked seed". This refers to the fact that this group

of plants does not produce a fruit, so the seeds are directly visible. Conifers (like pine trees) and ginkgo are two examples from this plant group (Figure 1C). Even though gymnosperms do not have fruits, they have developed strategies to spread their seeds. For example, many gymnosperms house their seeds inside seed cones until they are ready to be spread, at which point the cones open up.

WHERE DOES A SEED COME FROM?

OVULE

Young stage of the seed, which includes the female reproductive cell.

POLLEN

The male reproductive cell.

The earliest stage of the seed is known as the **ovule**. Ovules begin to develop into seeds through the process of fertilization. As in animals, fertilization occurs when a male reproductive cell, which in plants is the **pollen**, fuses with a female reproductive cell, which comes from the ovule, to give rise to a new plant—the embryo (Figure 1).

Interestingly, not all plants have seeds! Mosses and ferns are two examples of these. Before the emergence of seed plants around 400 million years ago, Earth was dominated by plants like mosses and ferns whose embryos are not protected by a seed coat; therefore, these species are more sensitive to harsh conditions in the environment. The origin of the seed remains unclear, and scientists are still trying to find answers. But we know that thanks to the seed coat, seeds can survived many adversities, and seed coats have given seed plants an extraordinary advantage.

WHAT CAUSES A SEED TO START GROWING?

DORMANT

When a seed is "waiting" for the proper conditions to germinate and grow.

If you have ever tried to grow plants from seeds, you may have noticed that seeds do not start growing under just any conditions. This is because mature seeds are **dormant**: their growth and development has slowed down or even stopped. Dormancy can come from the seed coat preventing water or oxygen from entering the seed, or it can come from the state of the embryo itself. Seeds can remain dormant for very long periods of time—scientists have grown plants from seeds that were over 2,000 years old [3]!

Dormancy allows embryos to wait for the right environmental signals before they germinate and grow into new plants. While every species has different requirements, most seeds will not start growing until they have received the right amounts of sunlight and water. Some plants have more extreme requirements to "break" dormancy. In cold climates, seeds that are produced in the fall often require exposure to extreme cold before they can break dormancy, to prevent the embryos from germinating too early during the winter and freezing. Seeds from environments that experience regular fires, such as prairies, often require heat or smoke exposure to break dormancy [2]. Because fires clear out much of the existing plant competition, when these seeds

come out of dormancy, the new plants have lots of space and nutrients to grow. Scientists can manipulate dormancy signals to cause seeds to germinate, or to keep seeds dormant for a long time in order to store them.

HOW DO PLANTS SPREAD THEIR SEEDS?

Seeds come in many shapes and forms, from those as large as your head to those that can only be seen with a microscope. All these seeds need ways to spread from the parent plant, which is called **dispersal** (Figure 2). There are four main types of seed-dispersal strategies [4].

DISPERSAL

The spreading of seeds to new locations away from the parent plant.

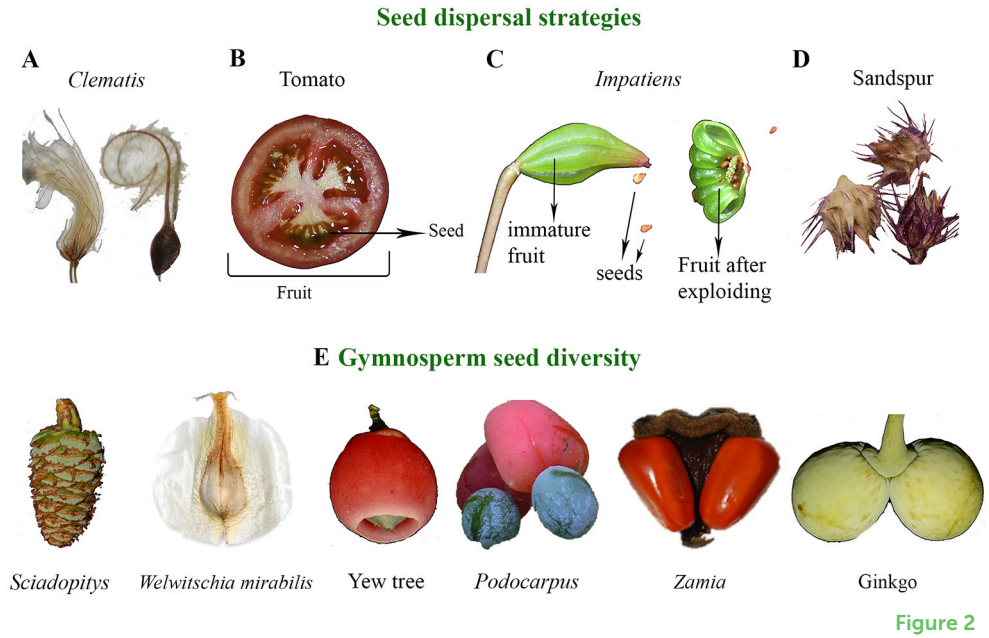

Figure 2

Seeds have a variety of structures and functions. Seeds from angiosperms can be dispersed by **(A)** wind; **(B)** animals; **(C)** ballistic release; and **(D)** hitchhiking. **(E)** Examples of seed forms that have evolved among gymnosperms, commonly known as "naked seeds". Even though they do not have fruits to help with dispersal, they have similar dispersal strategies to angiosperms (Image credit for D: CC BY-SA 4.0, https://commons.m.wikimedia.org/wiki/File:Sandspurs_1.jpg).

First, seeds can be dispersed by the wind. If you have ever blown on a dandelion puff, you were helping disperse its seeds! Those white tufts carry the seeds, and they can fly as far as the wind takes them. Other examples of plants with seeds dispersed by wind are orchids, swan plants, maples, cottonwoods, and *Clematis* (Figure 2A).

Second, seeds can be dispersed when animals eat them. This method is often found among plants with fruits or berries around their seeds. These structures are usually tasty or attractive, to entice animals to eat them. The animal swallows the seeds as well, which then pass through the animal's digestive tract and are spread to new locations through the animal's droppings. Some animals eat the fruit (like cherries and peaches) and throw the seeds away. Humans also spread seeds this way (Figure 2B)! This dispersal method does not work for all plants

though—some plants produce highly toxic seeds to prevent animals from eating them.

Third, some plants use a fun and dramatic way to disperse their seeds, called ballistic release. In these plants, the fruit splits open and explosively catapults the seeds with great force, so the seeds fall to the ground some distance away from the parent plant. This ensures that the new plants will not compete with the parents. One example is a plant called impatiens or Busy Lizzies, which you might see decorating gardens (Figure 2C).

Finally, some seeds have special thorns or barbs that stick to feathers, animal fur, or a person's clothing as they pass by, until they eventually fall off in a new location. Examples of plants that use this "hitchhiking" method include burdock and sandspur, commonly called "stickers", which are abundant in the southern United States (Figure 2D).

Gymnosperms have also found unique ways to protect and disperse their seeds, and their seeds also come in an enormous diversity of shapes and colors (Figure 2E). The typical cones found in pine trees are difficult to break, protecting the seeds inside. There are also winged seeds from plants like Welwitschia that use wind dispersal, and colorful and fleshy seeds that are dispersed by animals.

SEEDS WE EAT

It is easy to think of eating sesame or sunflower seeds, but there are many other common foods that also come from seeds! Grains such as rice, wheat, and corn can be cooked and eaten directly or ground up into flour. In fact, grains make up most of the food eaten by humans around the world! Beans, lentils, and nuts are also commonly eaten seeds (Figure 3). Even an adult's morning cup of coffee or your favorite chocolate bar are made using the seeds of the coffee and cacao plants. Many common oils used for cooking, such as canola oil and peanut oil, are made from pressing seeds to squeeze the oils out. Although uncommon, gymnosperms also produce **edible seeds**, such as pine nuts and ginkgo nuts (Figure 2). Seeds can make good foods because the endosperm holds lots of nutrients. However, these nutrients vary from plant to plant, and some species produce seeds that are not edible (like avocado) or are poisonous to eat (like castor bean). The next time you are outside or at the grocery store, see how many kinds of seeds you can identify, and remember the wonderful diversity of seeds that exist and how important they are to the lives of plants, too.

EDIBLE SEEDS

Seeds that can be safely eaten by humans.

Figure 3

Examples of seeds that are important food sources. It is important to note that the seeds in this image have been treated so that they are edible and will last a long time—this is not what the seeds look like on the plant.

Figure 3

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

MOAB CHARTER SCHOOL, AGES: 9–12

We are a 5th and 6th grade class at the Moab Charter School located in...you guessed it...Moab, Utah! We have a wide range of interests: dogs, pickles, grammar, art, ghosts, football, beyblades, video games, hiking, and watermelon. We feel lucky to live in such a beautiful place!

OWEN, AGE: 10

I am 10 years old, and I am interested in science and physics. In fact, I keep them as pets! One of my favorite things to do is to read. I also love science and gardening. I am interested in growing carnivorous plants and mushrooms.

AUTHORS

VERONICA M. SONDERVAN

I am broadly interested in how plants make the foods we eat, and in studying and preserving the wide diversity of plants and foods in the world. After working in several university and USDA labs and getting my undergraduate degree in plant science from the University of Minnesota-Twin Cities, I am now pursuing a joint Ph.D. from New York University and the New York Botanical Garden in Dr. Gloria Coruzzi's lab. My current research focuses on seed evolution and identifying genes involved in how plants build ovules across different species, especially gymnosperms.

CECILIA ZUMAJO-CARDONA

I have always been fascinated by plants and the enormous diversity of shapes, colors, and structures that have allowed them to be so successful and important for our entire ecosystem. I became interested in understanding the genes involved in that diversity while earning my undergraduate degree at the Universidad de Antioquia (Colombia) in the Pabón-Mora lab, where I looked at genes involved in fruit development. I obtained my Ph.D. from the New York Botanical Garden and the City University of New York in the Ambrose lab, mainly working on seed evolution and development in the first plants that appeared with seeds (like pine trees), to better understand the genes underlying the vast diversity of seed shapes.

BARBARA AMBROSE

I am the director of laboratory research and curator of plant genomics at the New York Botanical Garden (NYBG). I investigate plant morphology, the genes that build plant structures, and how changes in genes can explain the huge amount of plant diversity that exists. I use tools that allow me to see plant structures at a very small scale (scanning electron microscopy and plant tissue sections) as well as even smaller scale molecular tools to study genes. I investigate the evolutionary genetics of flowers and fruits, and more broadly the reproductive structures of all land plants. Much of my current research is focused on the evolution and development of the seedless plants: lycophytes (clubmosses) and ferns. *bambrose@nybg.org