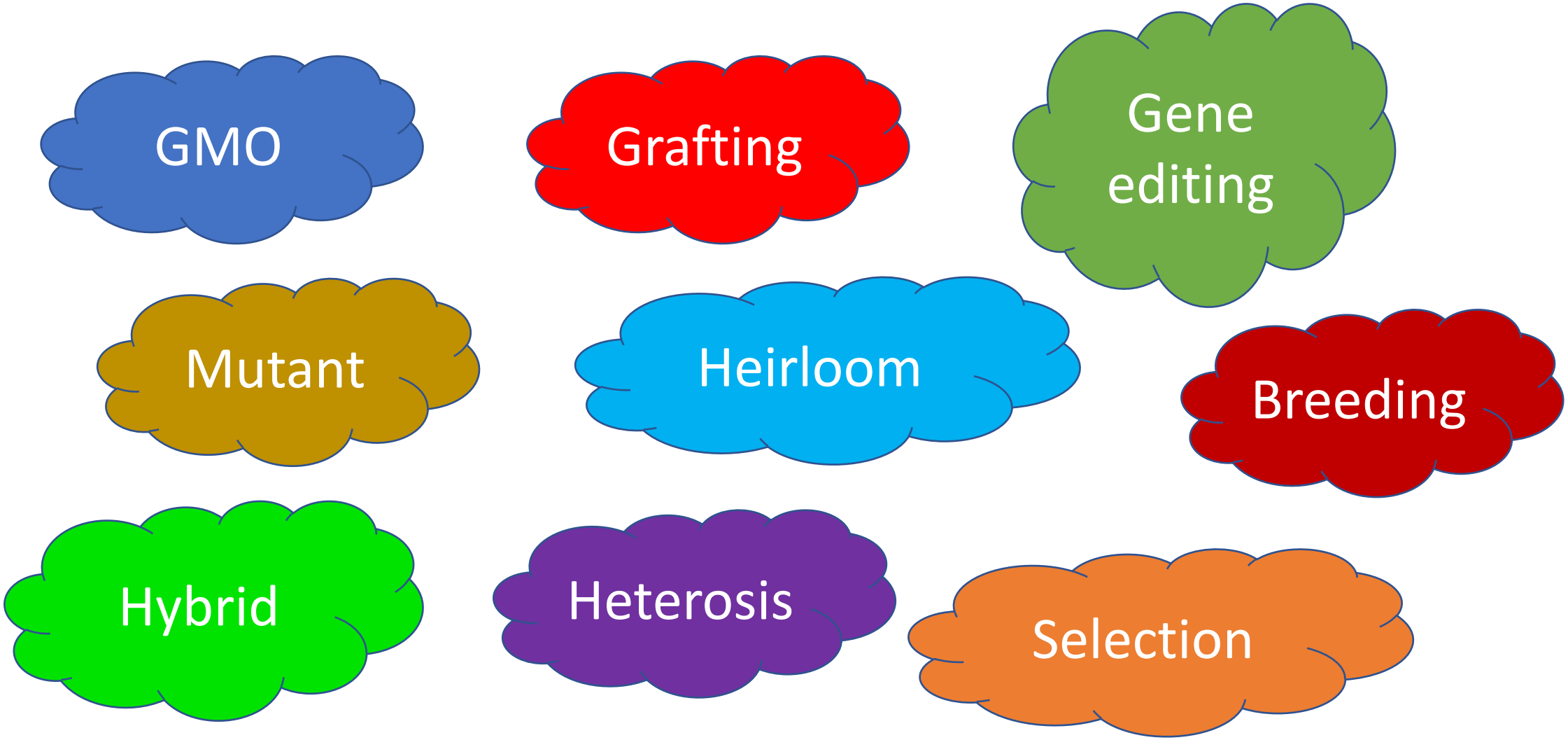
The ins and outs of heirlooms, hybrids, and GMOs

Anna Stepanova
Associate Professor
North Carolina State University

These are some of the concepts we'll talk about today



Let’s start with a quick [virtual] stop at a grocery store

- What percentage of these veggies are **genetically modified**?
- How many of these are **mutant**?
- How many of these are **heirlooms**?
- How many of these are products of **breeding**?
- How many of these are **hybrids**?

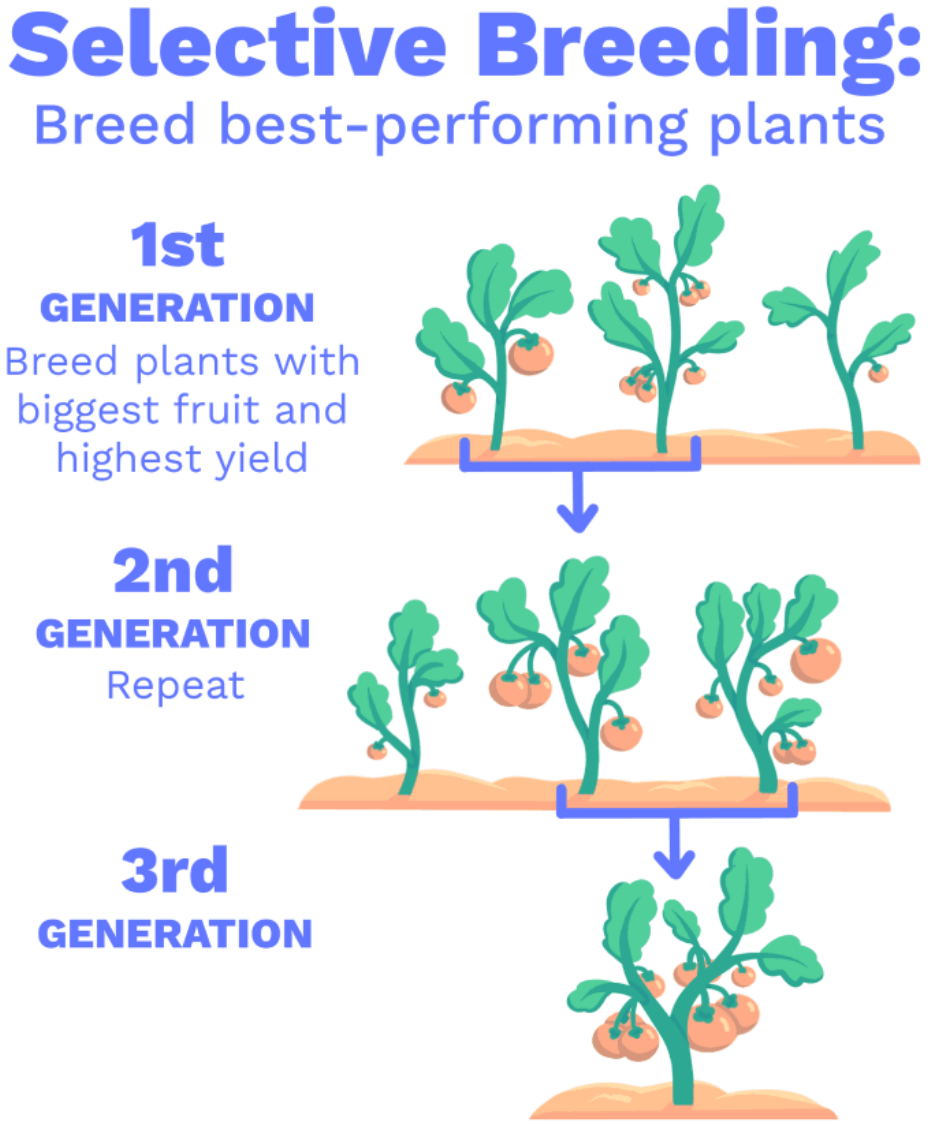
Let’s start with a quick [virtual] stop at a grocery store

- What percentage of these veggies are **genetically modified**? 0%
- How many of these are **mutant**? 100%
- How many of these are **heirlooms**? 0%
- How many of these are products of **breeding**? 100%
- How many of these are **hybrids**? ~50%

None of these crops are found in nature. How did we get all those plants???

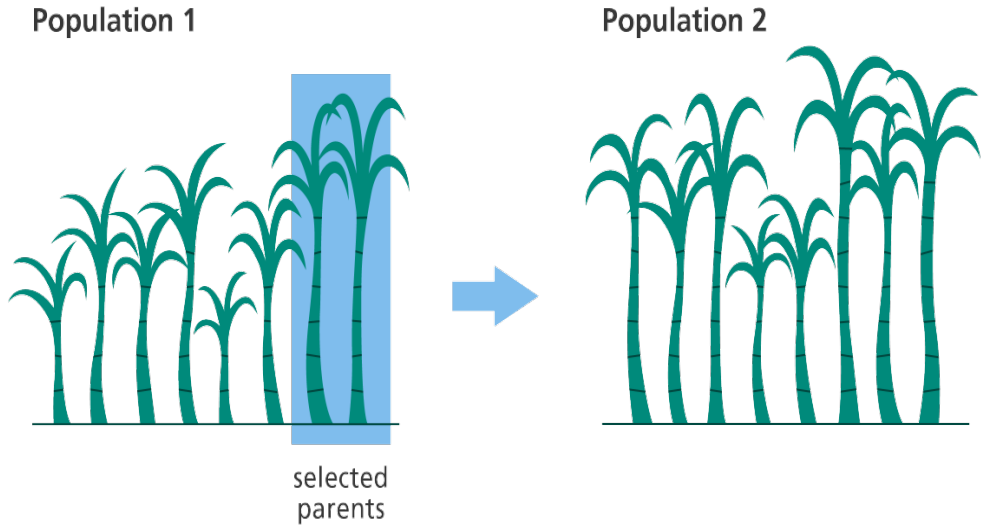
- **Artificial selection** – repeated propagation over many generations of plants or animals with desired traits (e.g., intentional seed saving and replanting of tomato plants with bigger fruits)

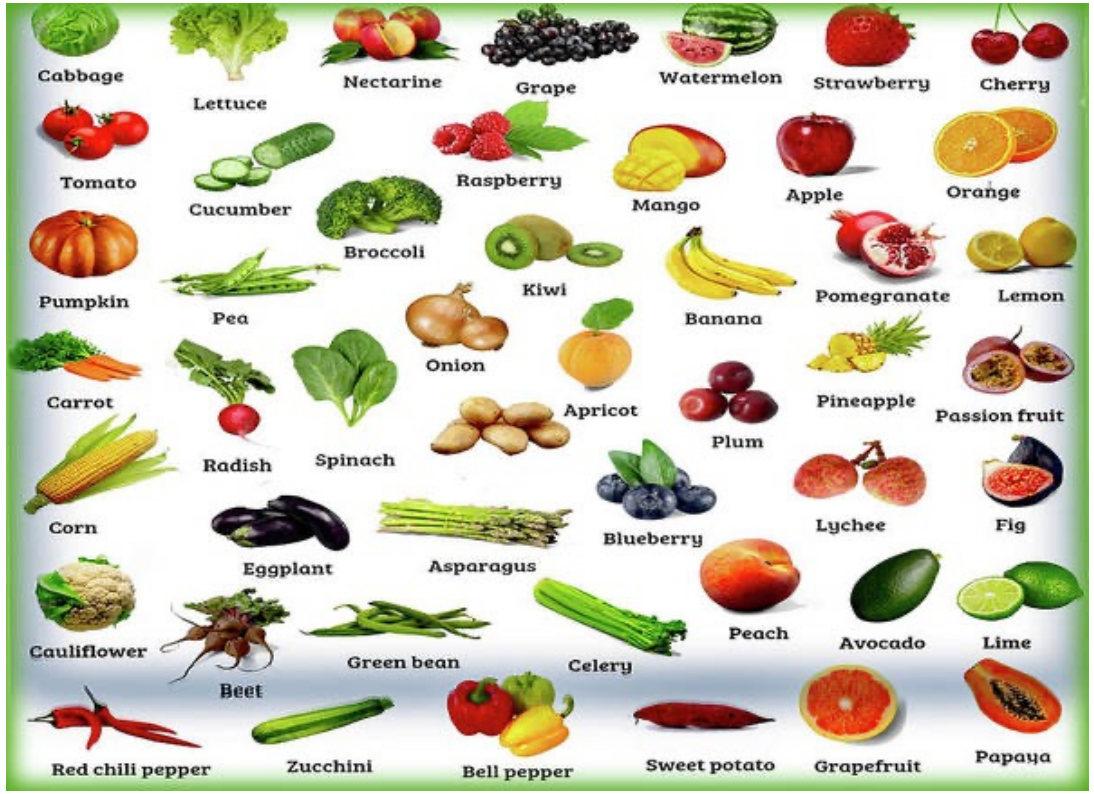
- **Breeding** – rational mating of animals or crossing of plants that intentionally focuses on best-performing individuals with desired traits (e.g., large-fruited tomato are crossed to sweetest tomato with the goal to obtain tomatoes that are both large and sweet)

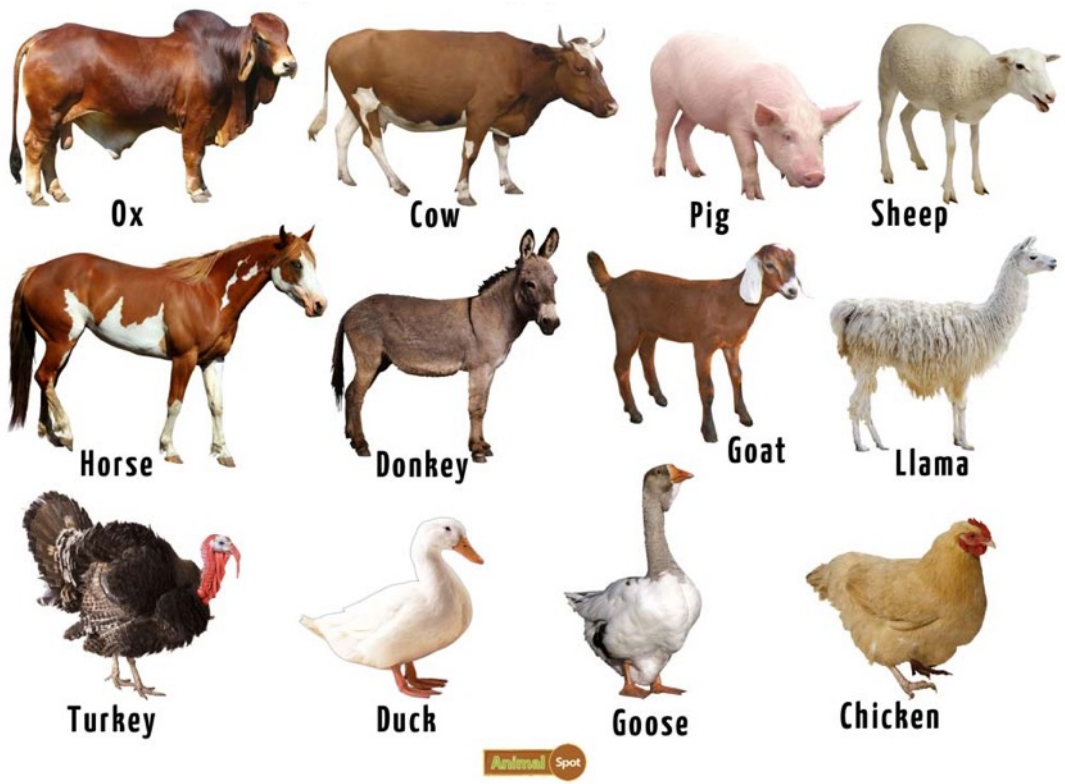


Why are some individuals inherently better than the others?

- Because individuals in a population are not all genetically identical, meaning that their DNA sequences and, accordingly, gene functions are divergent
- Differences in the DNA arise due to naturally occurring **mutations**
- Mutations in genes alter gene activity which in turn changes how an organism looks, grows, and functions (and in the case of tomato, tastes!)
- Breeders take advantage of that genetic diversity and select individuals with desired traits to develop new breeds and cultivars
- Breeding and selection is what turned some wild plants and animals into domesticated/ cultivated types we know today







Fun fact

- All domesticated plants (corn, apples, potatoes, cabbage, wheat, etc.) and animals (dogs, cats, cows, pigs, chickens, goats, etc.) we know today are **mutants** that our ancestors identified, selected and bred for hundreds or even thousands of years

Food for thought

If you were a crop farmer (or plant breeder), what traits would you select for?

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Did our ancestors succeed at crop domestication?

Let’s use some common garden plants as examples

Let’s see if you can recognize the **wild relatives** of modern fruits and vegetables

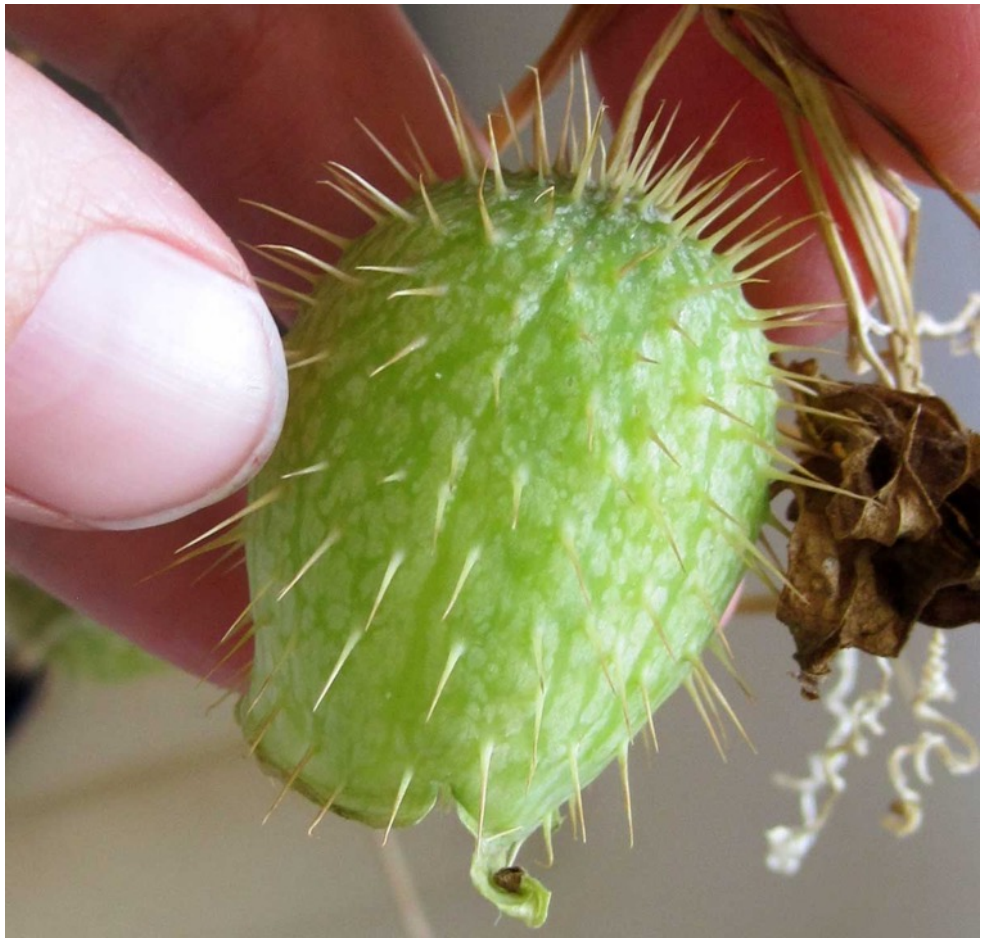
What crop is this?

What crop is this?

Wild tomato

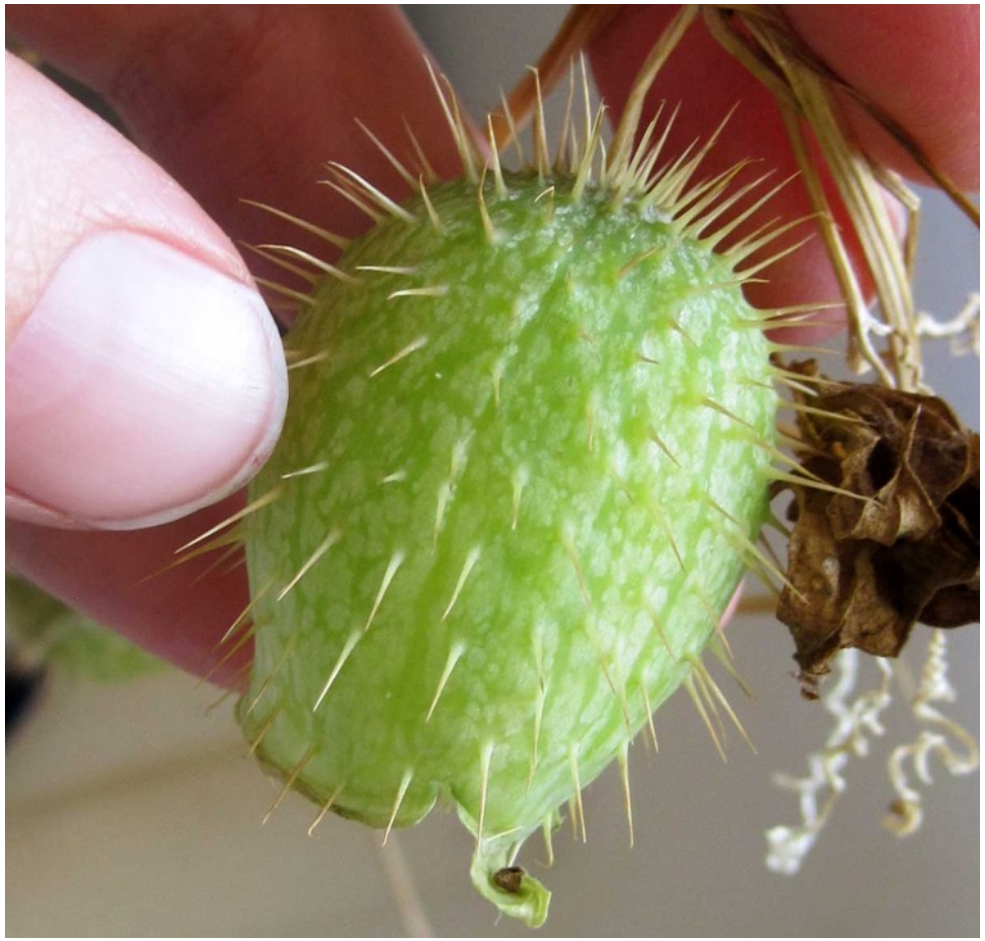
Domesticated tomato

What crop is this?



What crop is this?

Wild cucumber



Domesticated cucumber

What crop is this?

What crop is this?

Wild eggplant

Domesticated eggplant

What crop is this?

What crop is this?

Wild carrot

Domesticated carrot

What crop is this?

What crop is this?

Wild corn (teosinte)

Domesticated corn

What crop is this?

What crop is this?

Wild banana

Domesticated banana

What crop is this?

What crop is this?

Wild crab apple

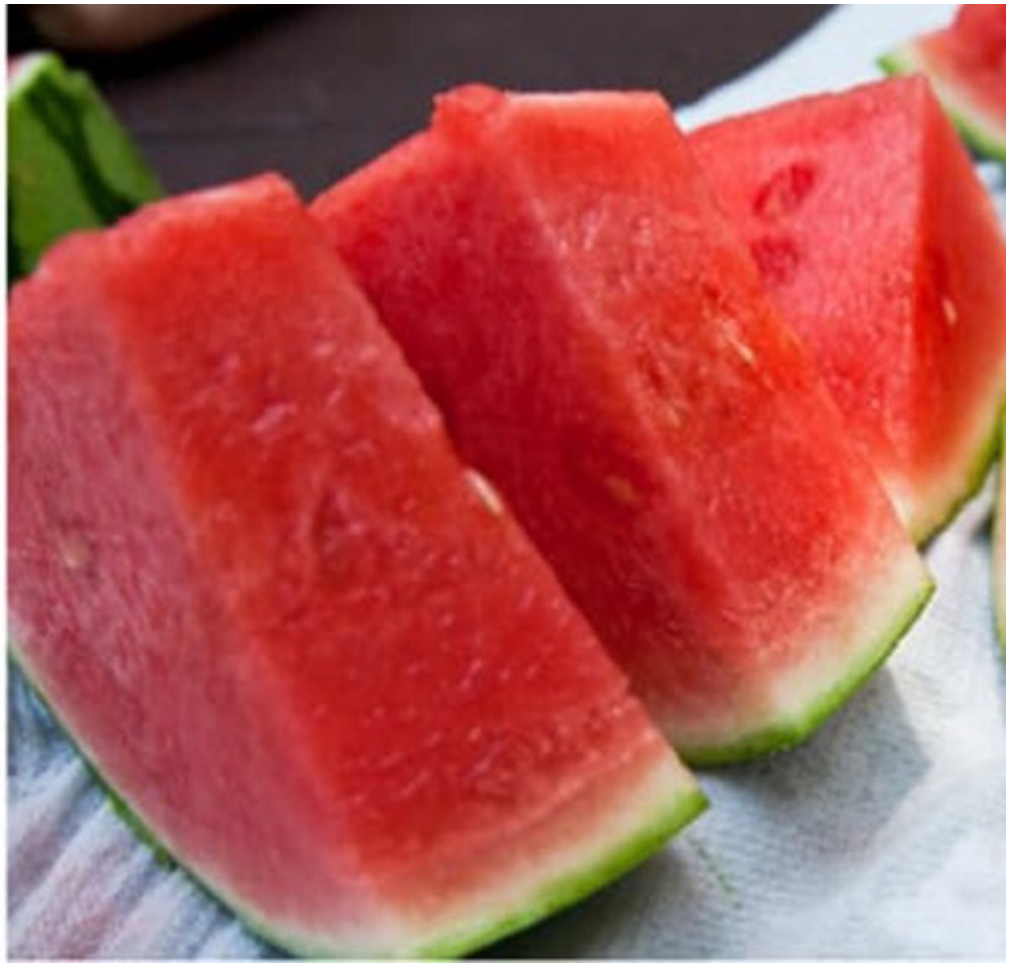
Domesticated apple

What crop is this?

What crop is this?

Wild watermelon

Domesticated watermelon



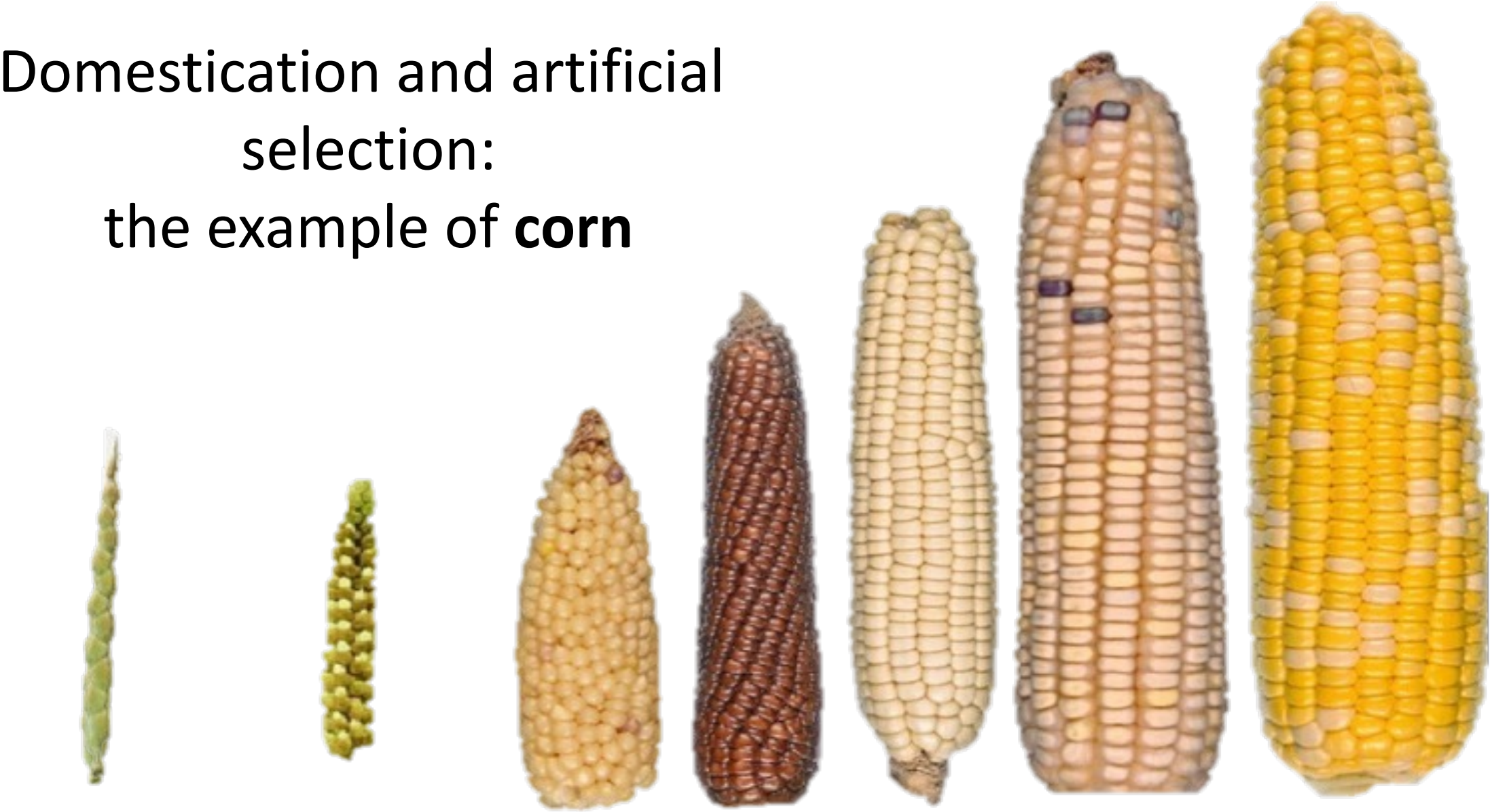
What crop is this?

What crop is this?

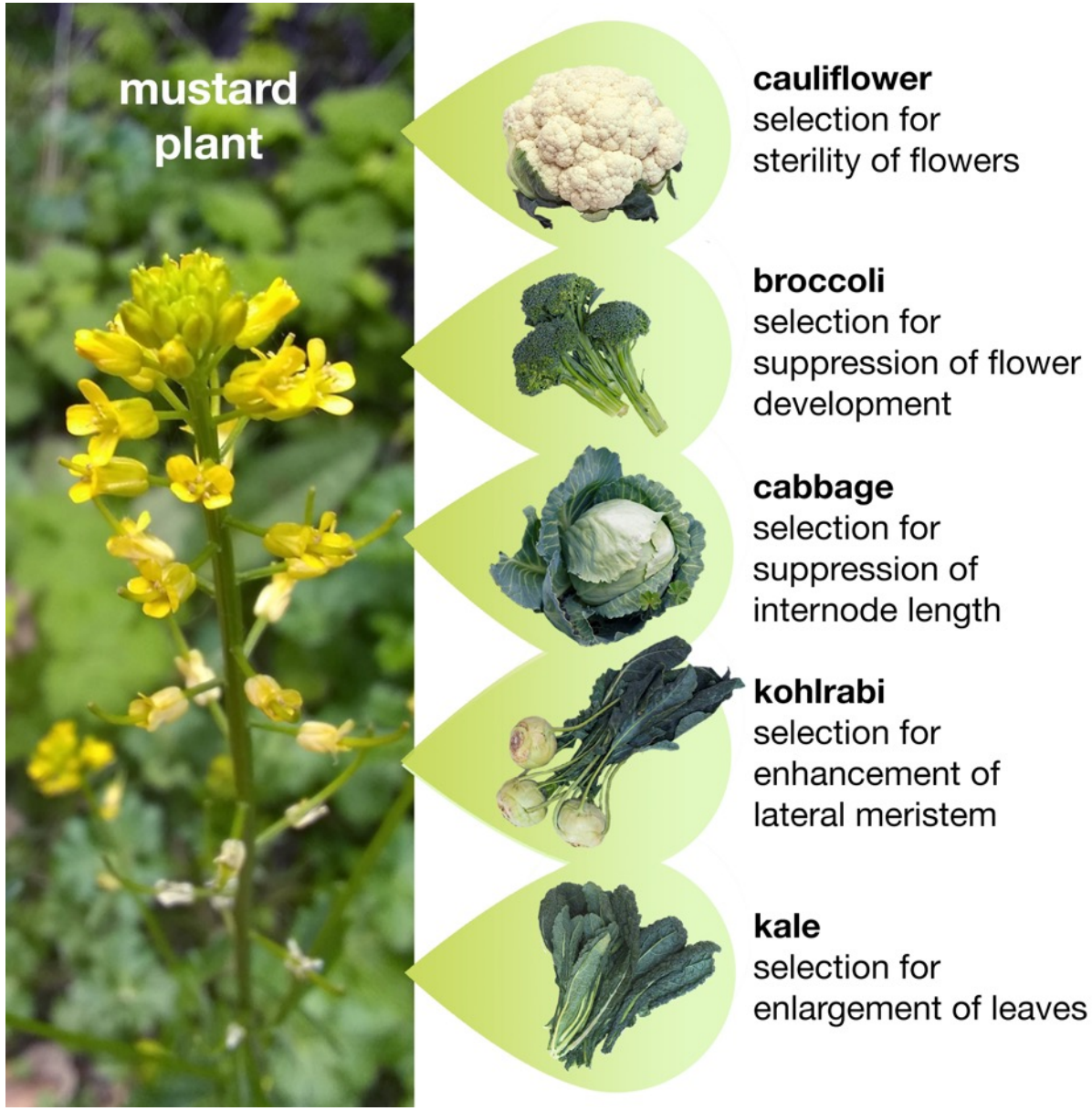
Wild strawberry

Domesticated strawberry

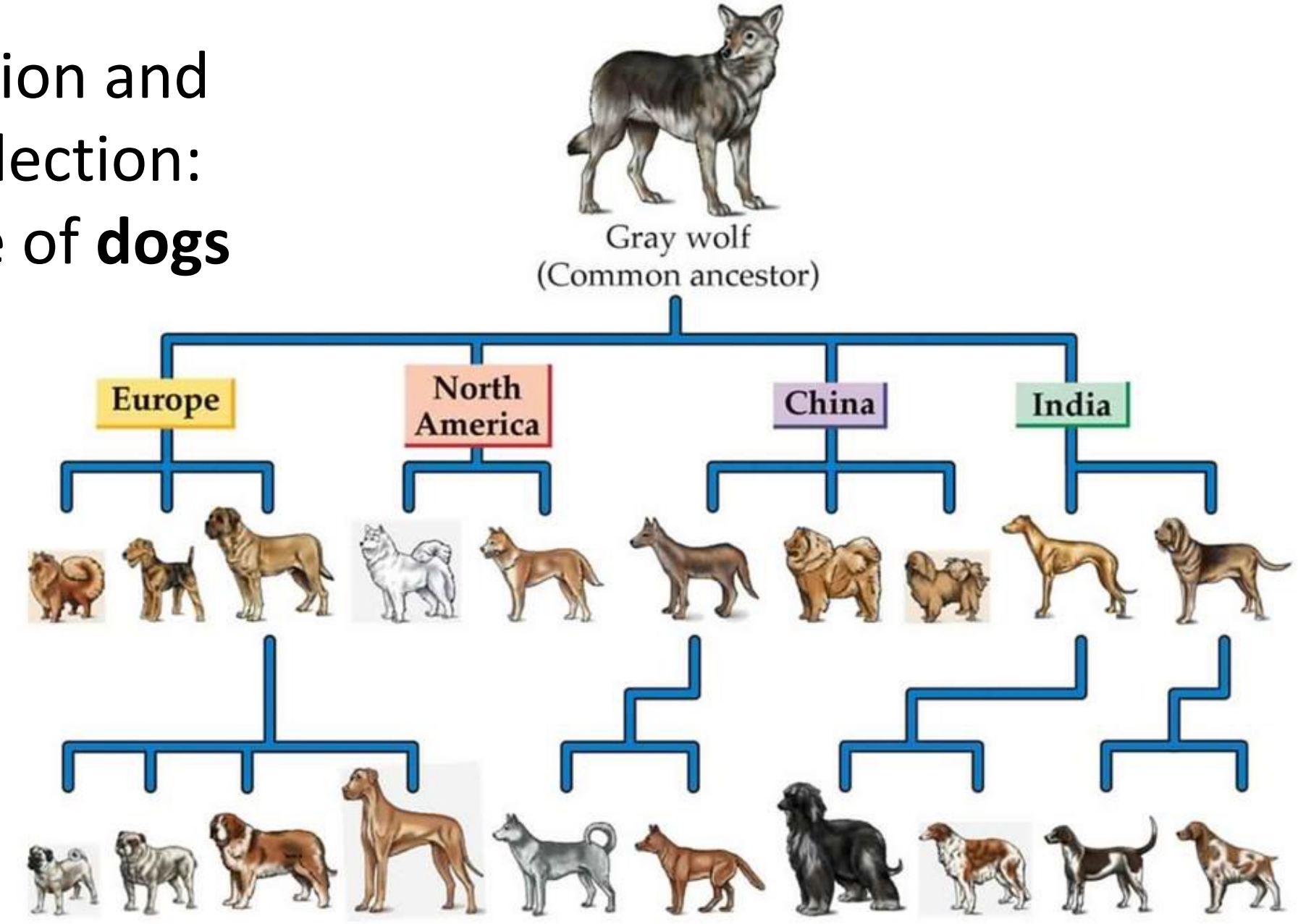
Domestication and artificial selection: the example of **corn**



Domestication and artificial selection: the example of **cabbage**



Domestication and artificial selection: the example of **dogs**



Domestication and artificial selection: **domestic animals**

When did humans first domesticate animals?

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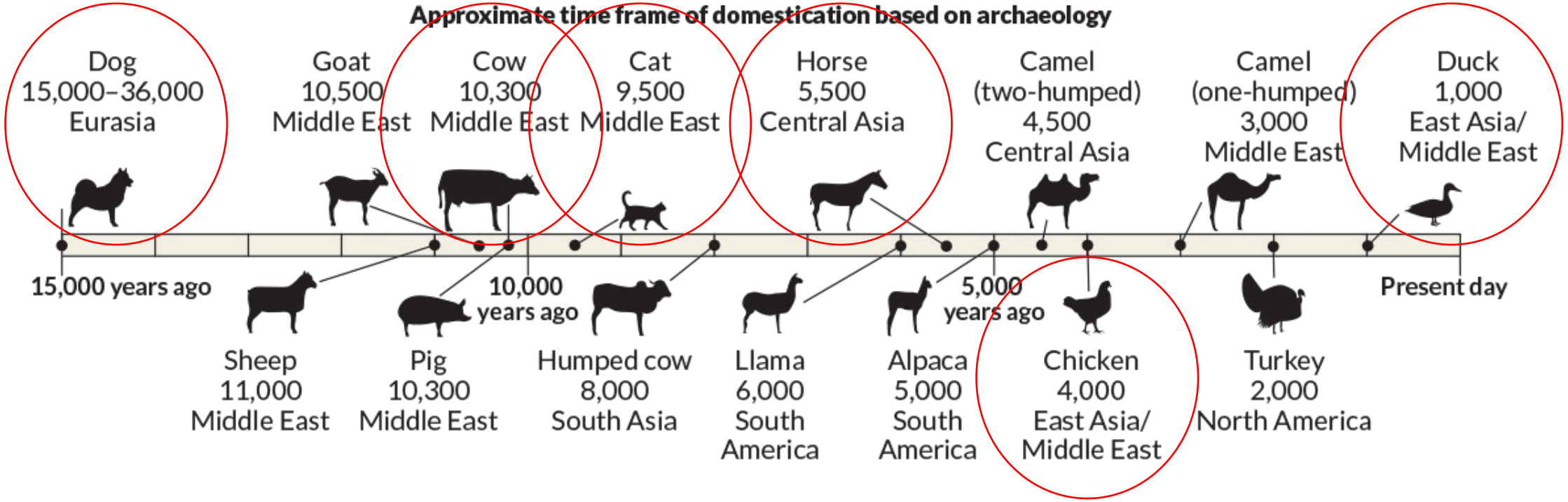

When did humans first start farming?

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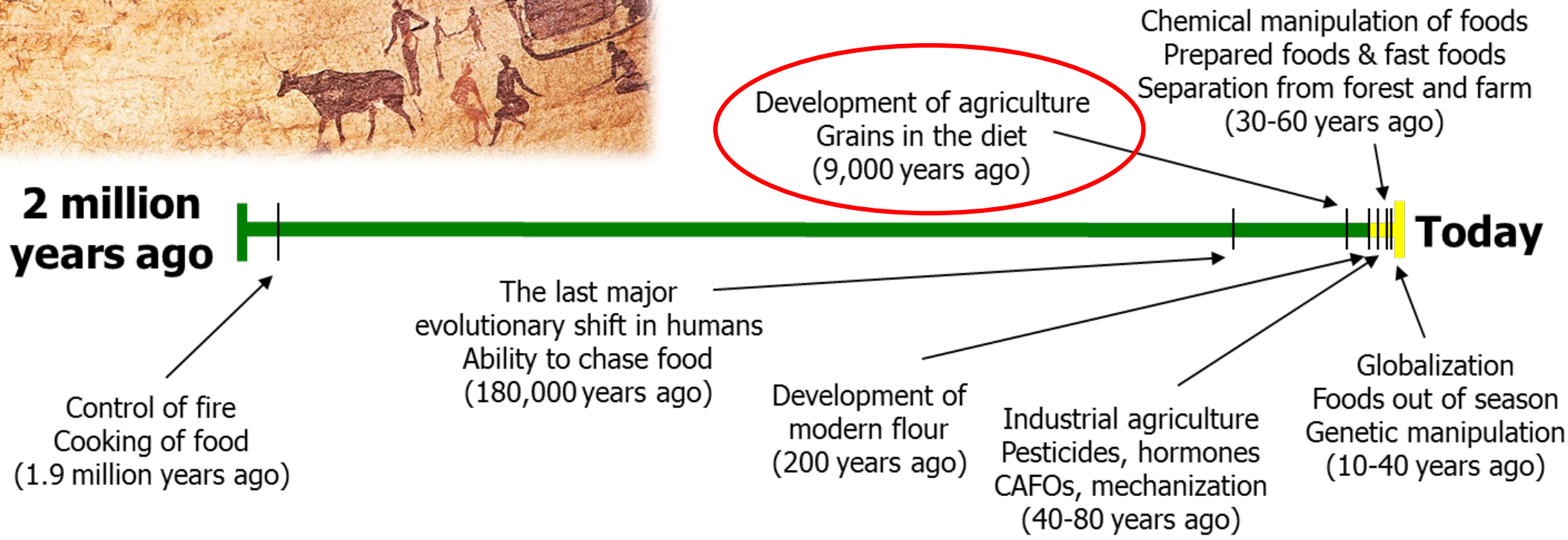
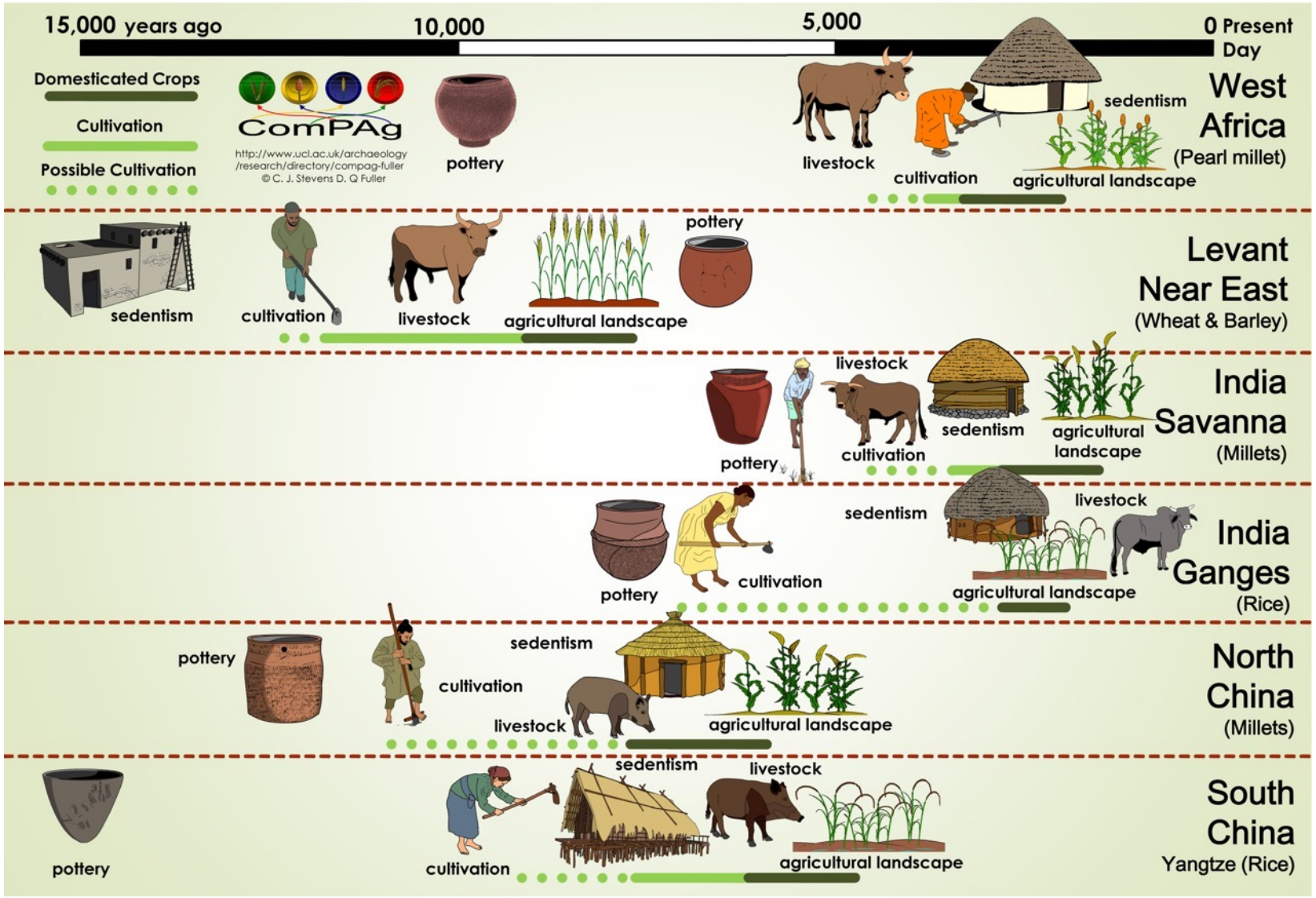
Less than 10,000 years ago!

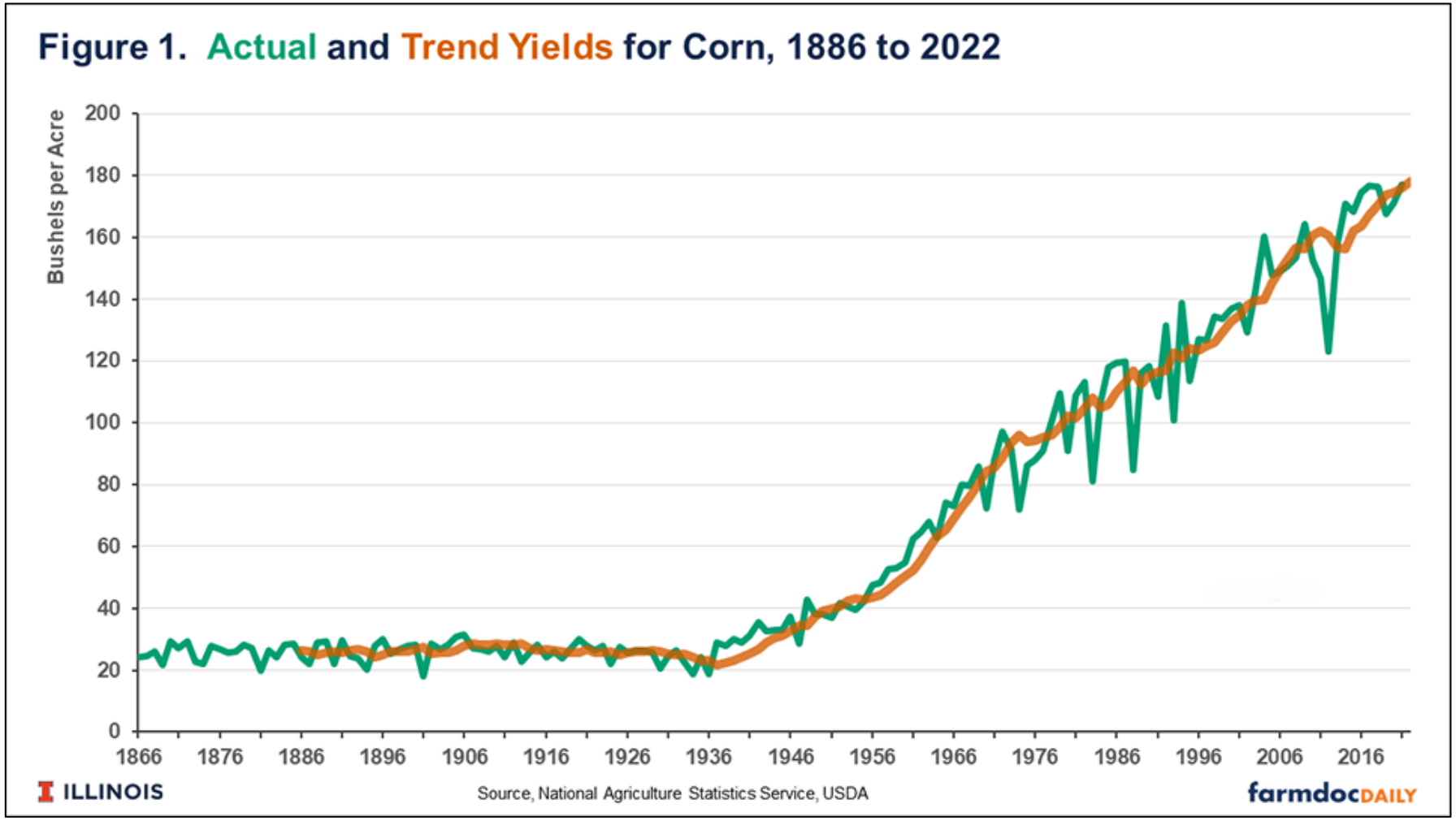


Wild plant cultivation preceded crop domestication



- **Cultivation** refers to intentional planting, caring for and harvesting of plants (wild or domesticated).
- **Domestication** refers to gradual changes in a plant species achieved through many generations of artificial selection for desired characteristics (e.g., for bigger, tastier fruit)
- Domesticated plants are typically **visually distinct** from their wild-type predecessors and usually **ill-adapted** to growing in the wild

Modern plant varieties and farming practices increase crop yield



What innovations brought about higher yield?

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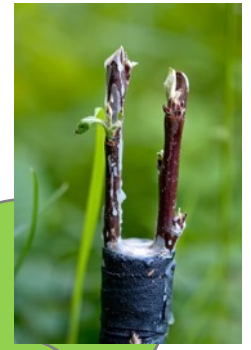
Herbicides & pesticides



Grafting

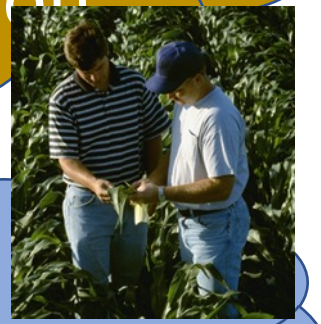
Mechanization & automation

Synthetic fertilizers

Hybrids

New cultivars

Higher density of planting



Better management practices

Plant grafting

- **Grafting** is the process of joining parts of two plants together
- Grafting is used as a method of plant propagation, to enable cross-pollination, to control plant stature, to confer disease and stress resistance, enhance plant vigor, and for esthetic reasons
- Grafting is most common in fruit and ornamental trees, tomatoes, eggplants, peppers, cucumbers, melons and squashes

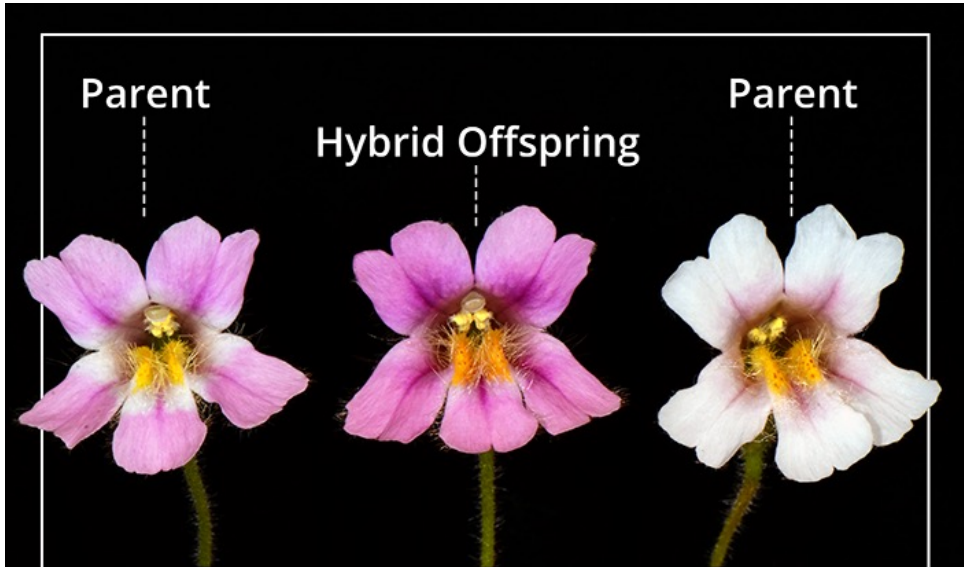
Heirlooms

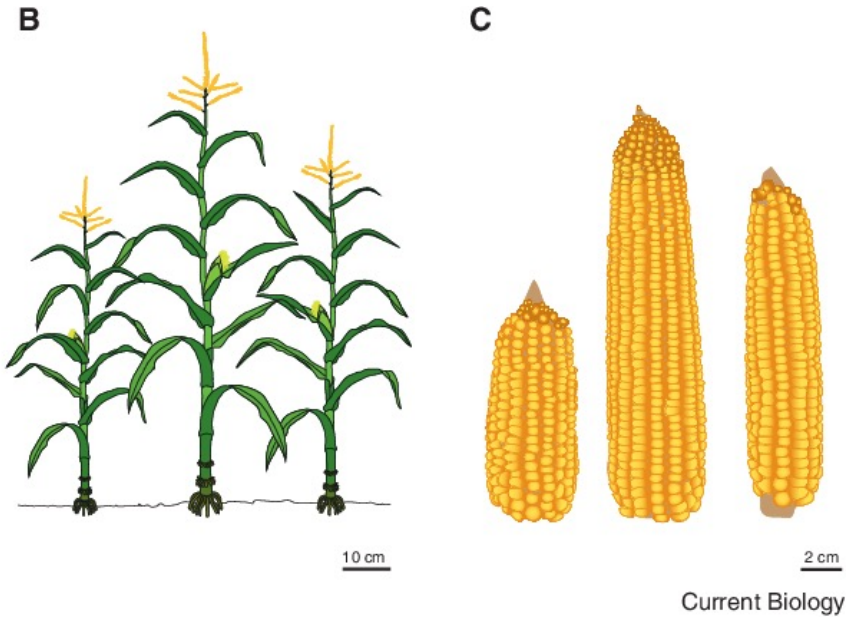
- **Heirloom** is a collective term that describes traditional plant varieties passed on in families or cultures from one generation to another
- It is used as an antonym to modern crop varieties used by large-scale farms
- In the gardening community, the term **heirloom vegetable** is usually associated with great taste and unique looks, but also with certain attributes that make such varieties commercially inviable (due to poor disease resistance, soft and easily-to-damage fruits, poor storability, uneven fruit shape and size)

Hybrid plants

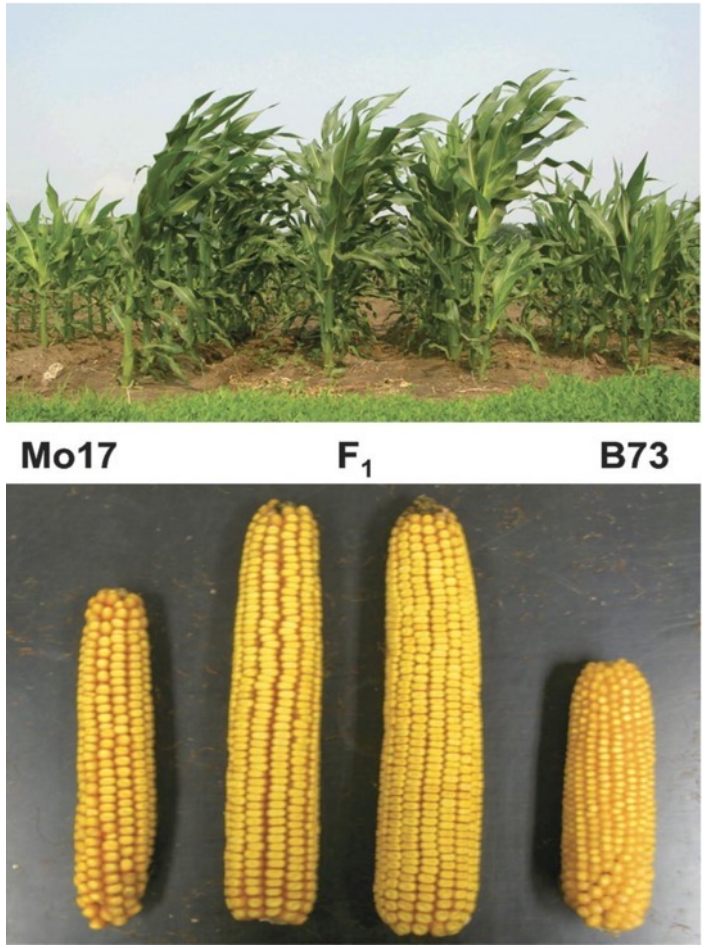
- **Hybrid** plants are typically produced via genetic crossing, i.e., by placing the pollen of one plant variety on the female reproductive structures (i.e., the pistil) of another plant variety

- The resulting hybrid offspring may display some features of both parents or show new characteristics, and may be larger and healthier than either of the parental plant varieties (this is known as **heterosis**)

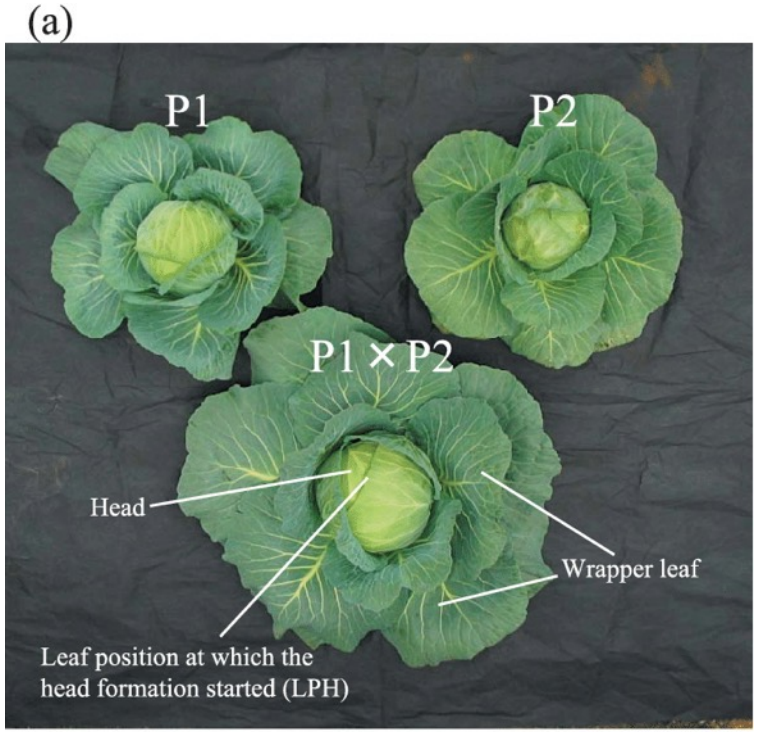


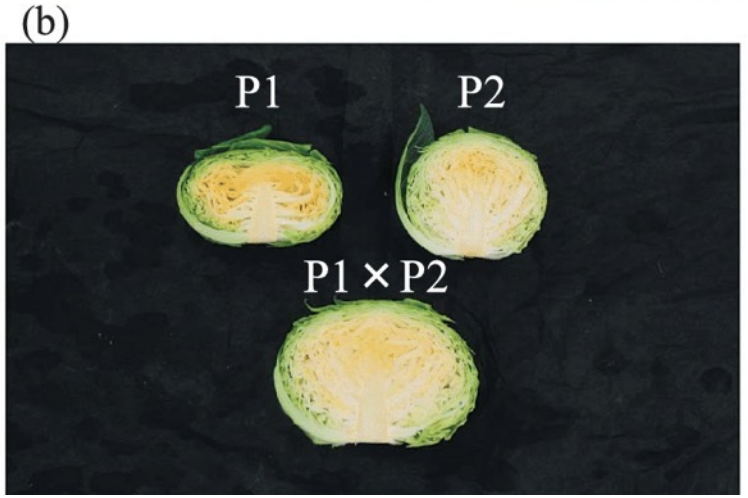


Heterosis

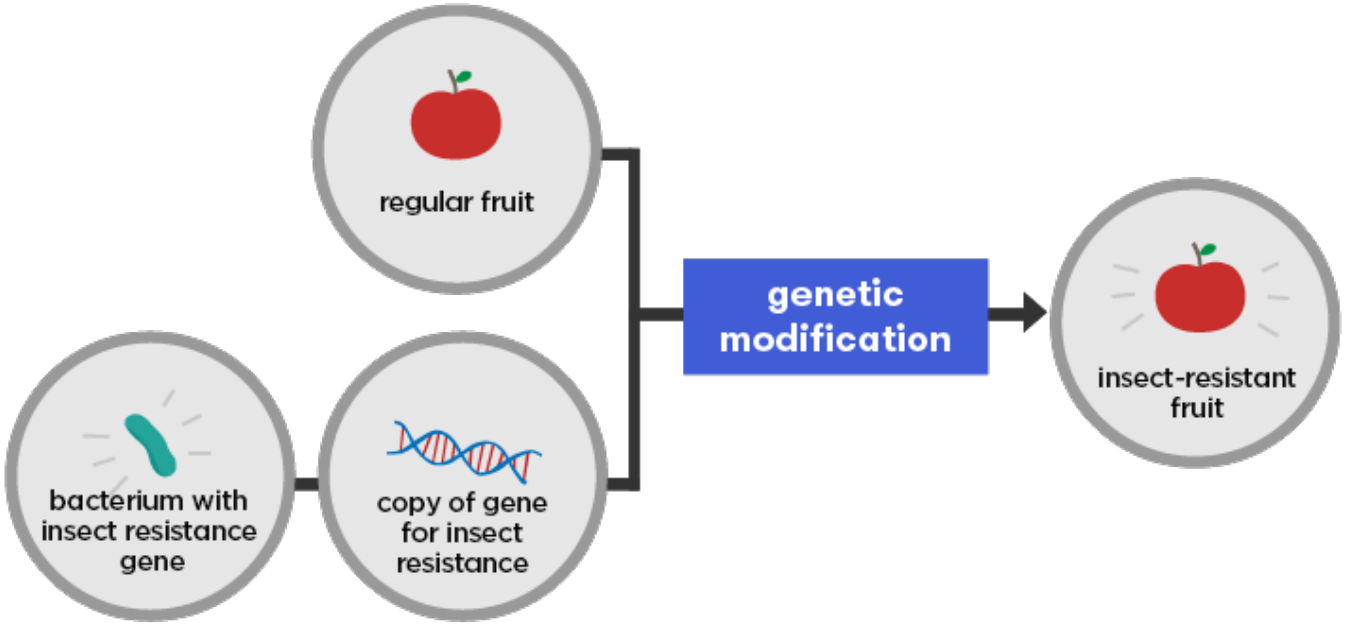


- **Heterosis** (also known as hybrid vigor) is often leveraged by seed companies that produce and sell hybrid seeds
- Hybrid plants are larger/healthier, but their progeny will not be the same as the parents (every plant will be different, and most won't be as good as the hybrid)



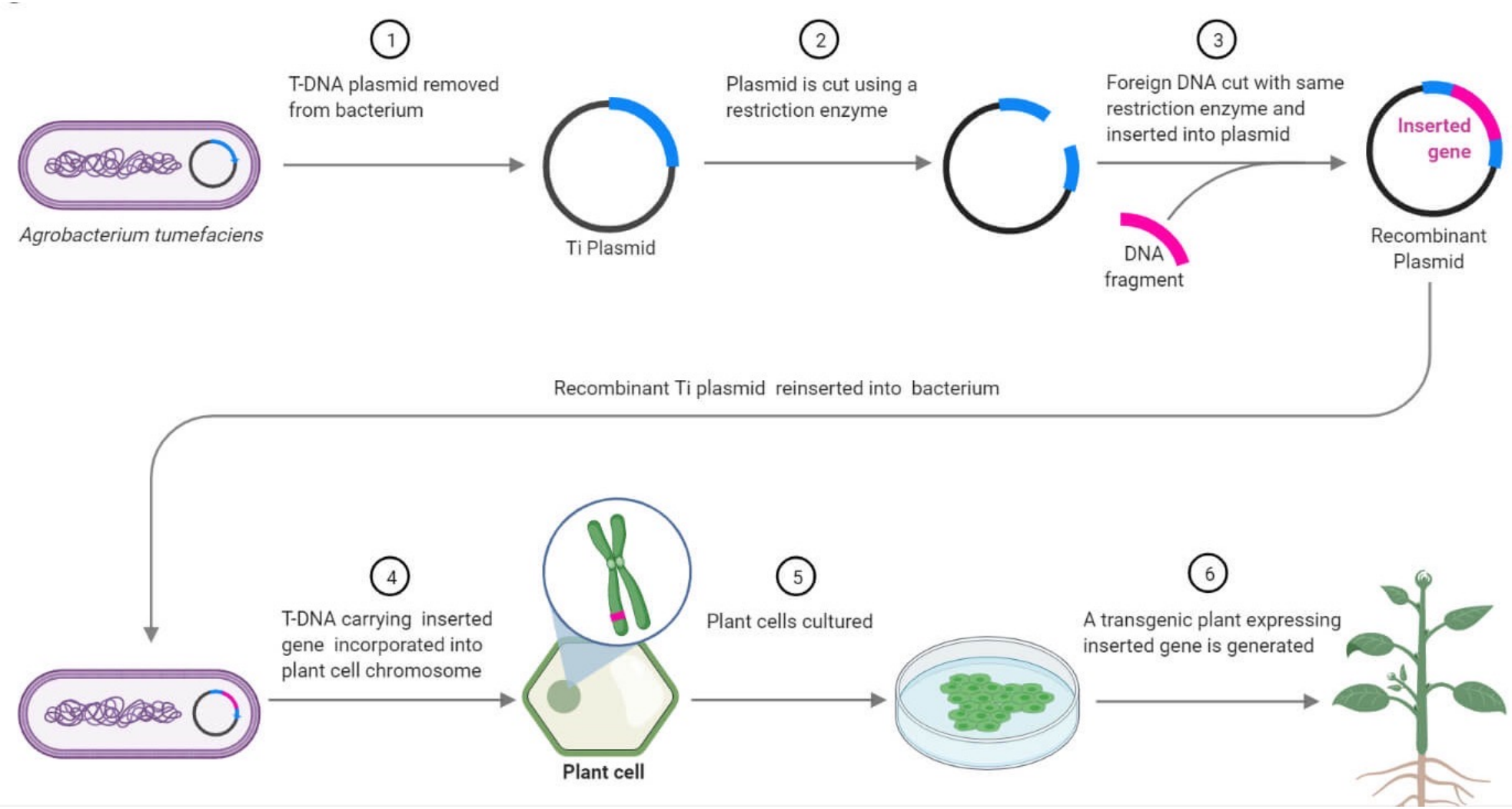


Genetic modification (GMO or transgenics)



- **Genetic modification** is the incorporation of a foreign gene, gene part, or multiple genes into the genome of a host organism (plant, animal, fungus, bacteria)
- The extra gene typically comes from another (related or unrelated) species but can also be made synthetically
- In agriculture, genetic modification is typically done with the goal to improve plant characteristics (e.g., its disease or insect resistance, color, taste, shelf life) or to simplify farming practices (e.g., to confer herbicide resistance)

In plants, GMOs are usually made using *Agrobacterium*



What GMO crops are commercially available in the US?

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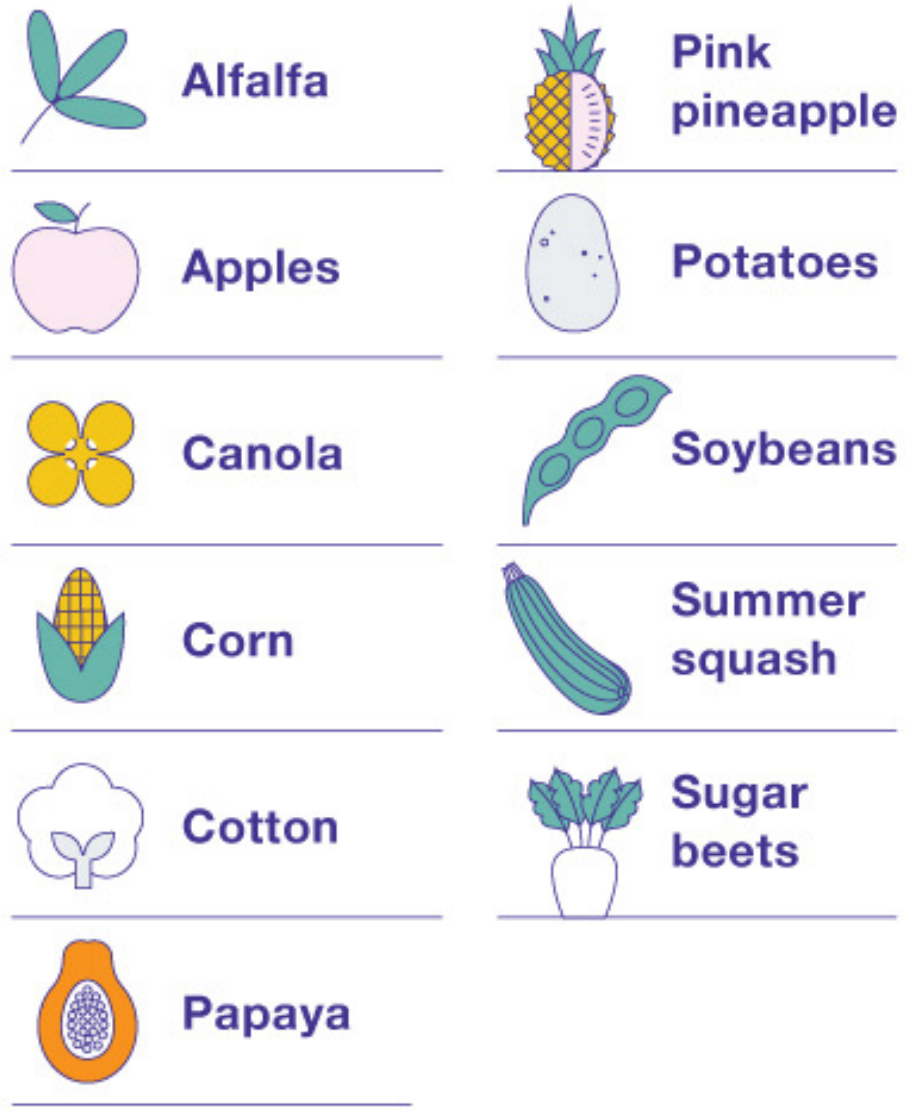
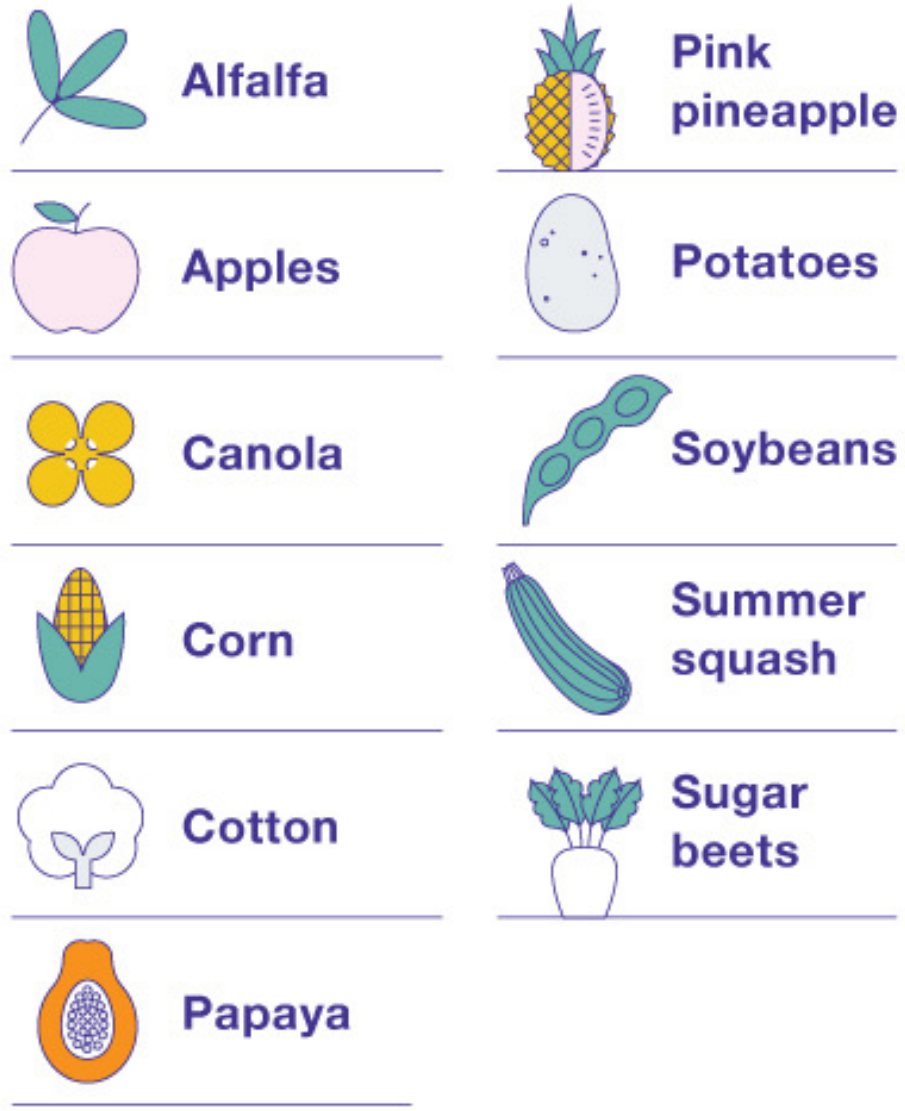


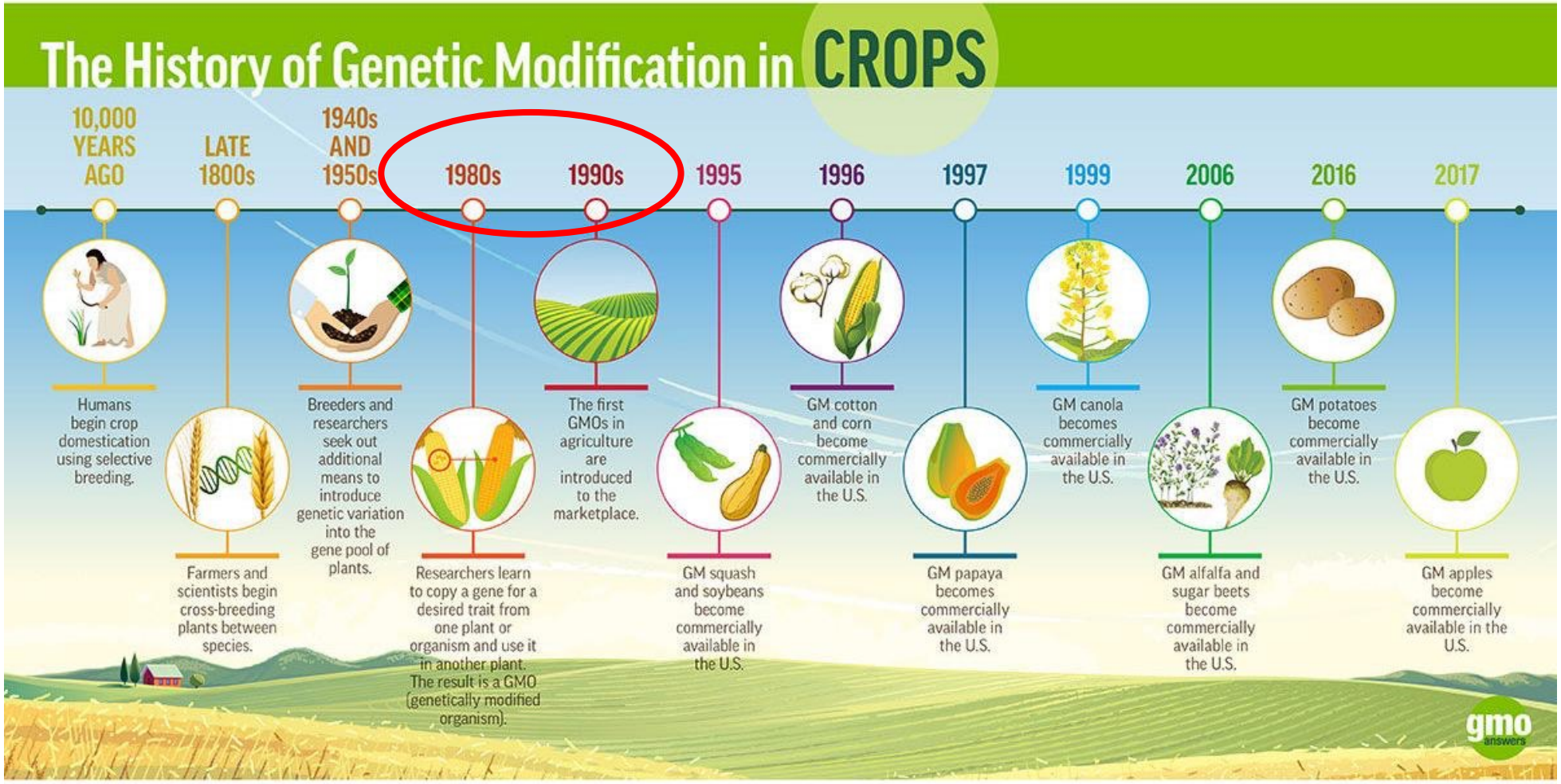
- Am I exposed to GMOs?
- Are GMOs safe?
- Can I buy seeds of GMO plants to grow in my garden?

What GMO crops are commercially available in the US?



- Am I exposed to GMOs? Most likely yes, as corn, soybean, sugar beets and their derivatives (e.g., corn syrup or soybean oil) are components of many processed foods
- Are GMOs safe? All GMO varieties available on the market have been extensively tested by USDA and are concluded to be safe for human and animal consumption
- Can I buy seeds of GMO plants to grow in my garden? No! Only large-acreage commercial producers can by GMO seeds at the moment and need a special license

The timeline of GMOs



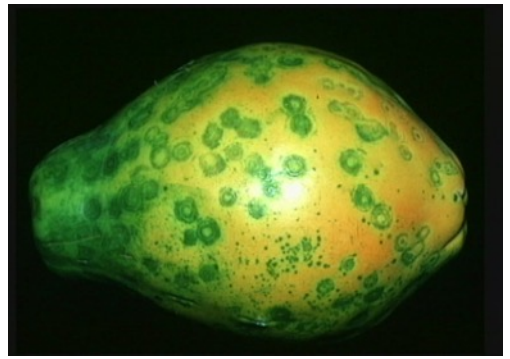
https://www.agupdate.com/illinoisfarmertoday/news/crop/outside-influences-steer-gmo-research/article_3d4827e8-b636-11ea-a15e-17bcce41b172.html

What extra genes (aka **transgenes**) do GMO crops carry?

Herbicide resistance genes (e.g., that allow GMO plants to survive Roundup treatment). This reduces both the total amount of herbicides sprayed on plants and the need to plow the fields to kill weeds, thus also reducing soil erosion.

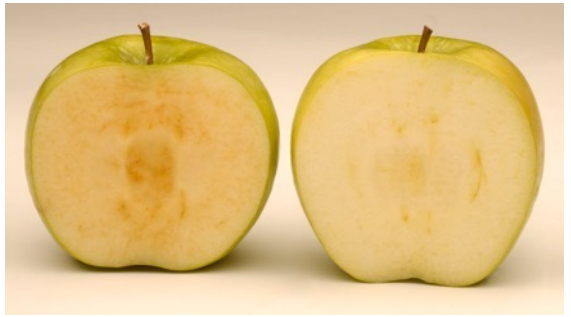
Insect resistance genes (e.g., that make the GMO plant toxic to some insects but safe for humans and beneficial insects). The gene comes from Bt bacteria (*Bacillus thuringiensis*) that are used in high quantities organic farming to control insects. GMOs eliminate the need to spray Bt on plants.

Virus resistance genes (that make GMO plants withstand ringspot virus). Most papaya grown in the US is GMO and this is what saved the Hawaiian papaya industry from going out of business



What other genetic changes do GMO crops carry?

Arctic Apples -- reduces activity of an enzyme polyphenol oxidase, resulting in less flesh browning upon fruit cutting



White Russet potato – reduces the activity of two enzymes, polyphenol oxidase, resulting in less flesh browning, and asparagine synthase, leading to less toxic acrylamide forming during frying out of amino acid asparagine

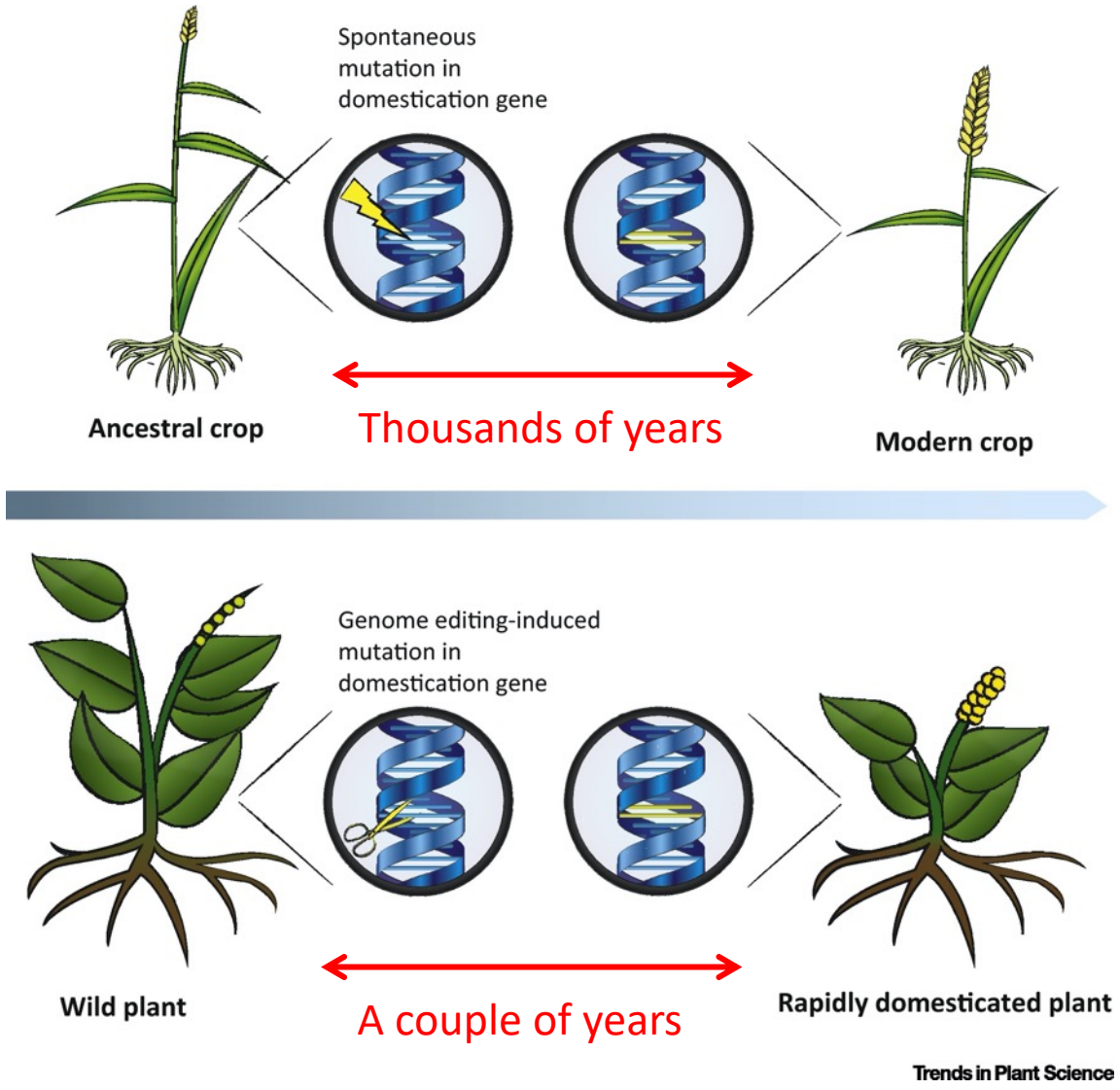
Pinkglow pineapple – reduces activity of two lycopene cyclase enzymes turning the flesh light pink

What GMOs are in development or approval/trial stages now?

- **Golden Rice** – carries two genes responsible for beta-carotene (provitamin A) biosynthesis, one from daffodils and another from soil bacteria, that aims to eliminate blindness cased by vitamin A deficiency
- **Purple tomato** – carries a snapdragon gene that activates production of beneficial purple pigments anthocyanins (powerful antioxidants that reduce inflammation, prevent cancer, and protect from type II diabetes)
- **Phytase corn** – carries an enzyme called phytase that breaks down the antinutrient phytic acid in seeds, making phosphorus more bioavailable, improving the health of corn-fed animals, reducing phosphorus content in manure, and decreasing water pollution

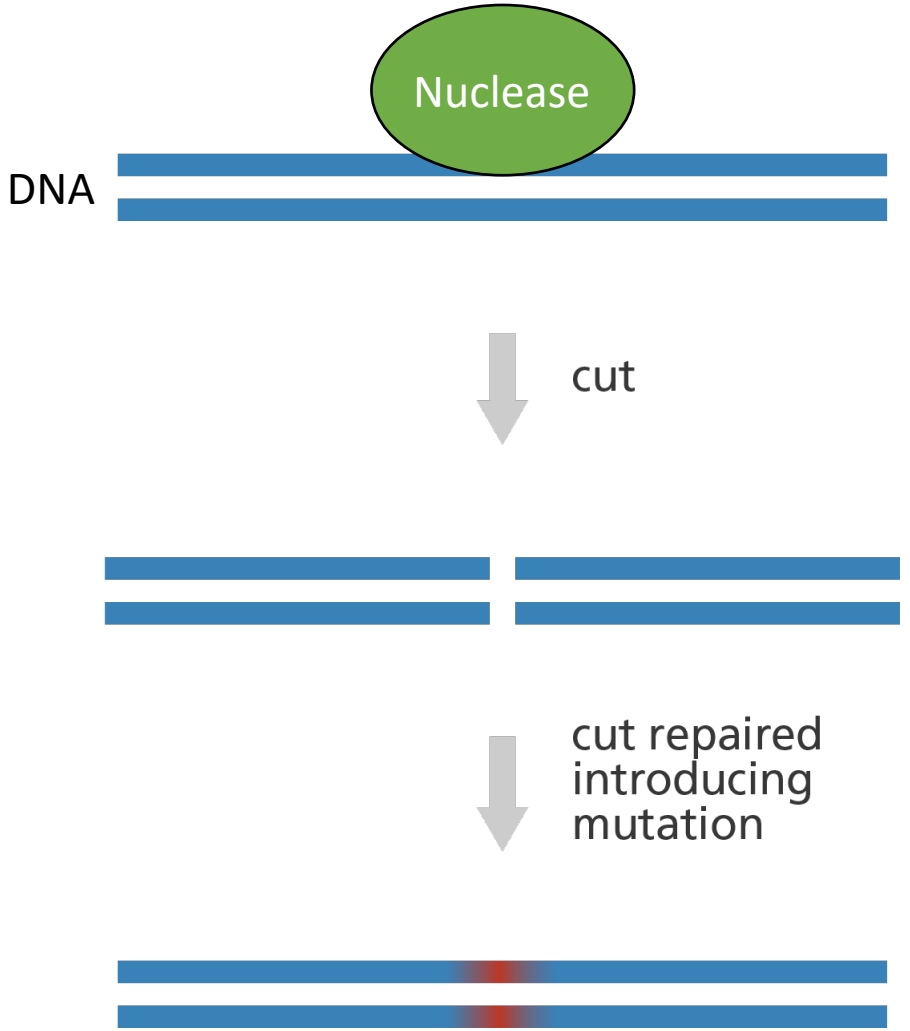
What other emergent technologies are out there?

- **Genome (or gene) editing**!
- Editing involves making targeted modifications in the genome without permanently introducing foreign DNA
- Is more precise than random mutations and is viewed as an efficient, rapid way to domesticate plants



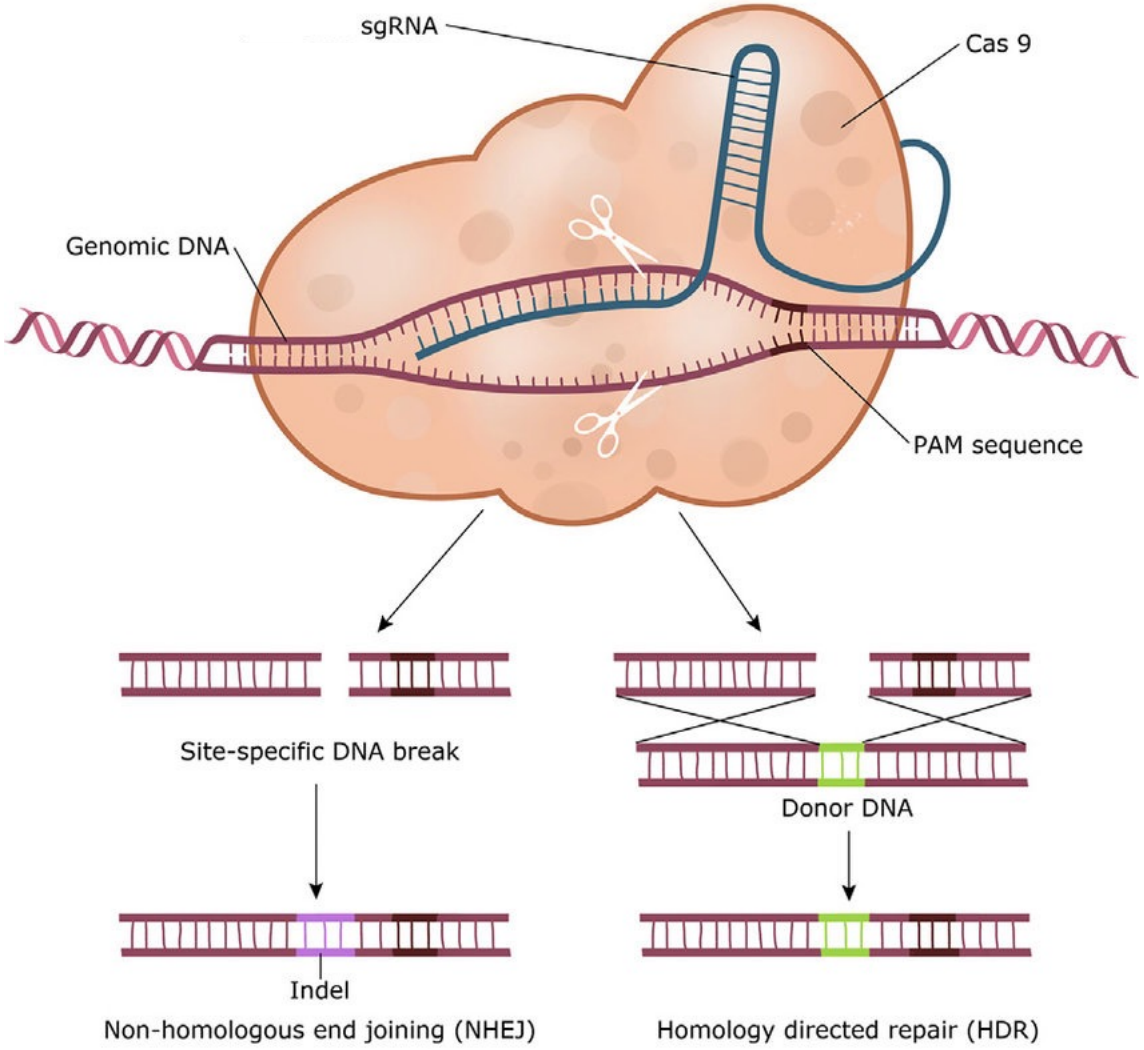
How is genome editing carried out?

- Foreign gene(s) encoding a nuclease, an enzyme that can cut DNA in a targeted manner, is/are [transiently] introduced into a host cell
- The resulting DNA break in a cell triggers DNA repair to stitch the broken ends together
- The repair process is often imprecise resulting in the incorporation of mutations



What gene editing technologies exist?

- Meganucleases
- Zinc Finger nucleases
- TALE nucleases (TALENs)
- **CRISPR/Cas editing**
  - **Cas9 protein** (makes the cut)
  - **sgRNA** (brings Cas9 to the DNA)



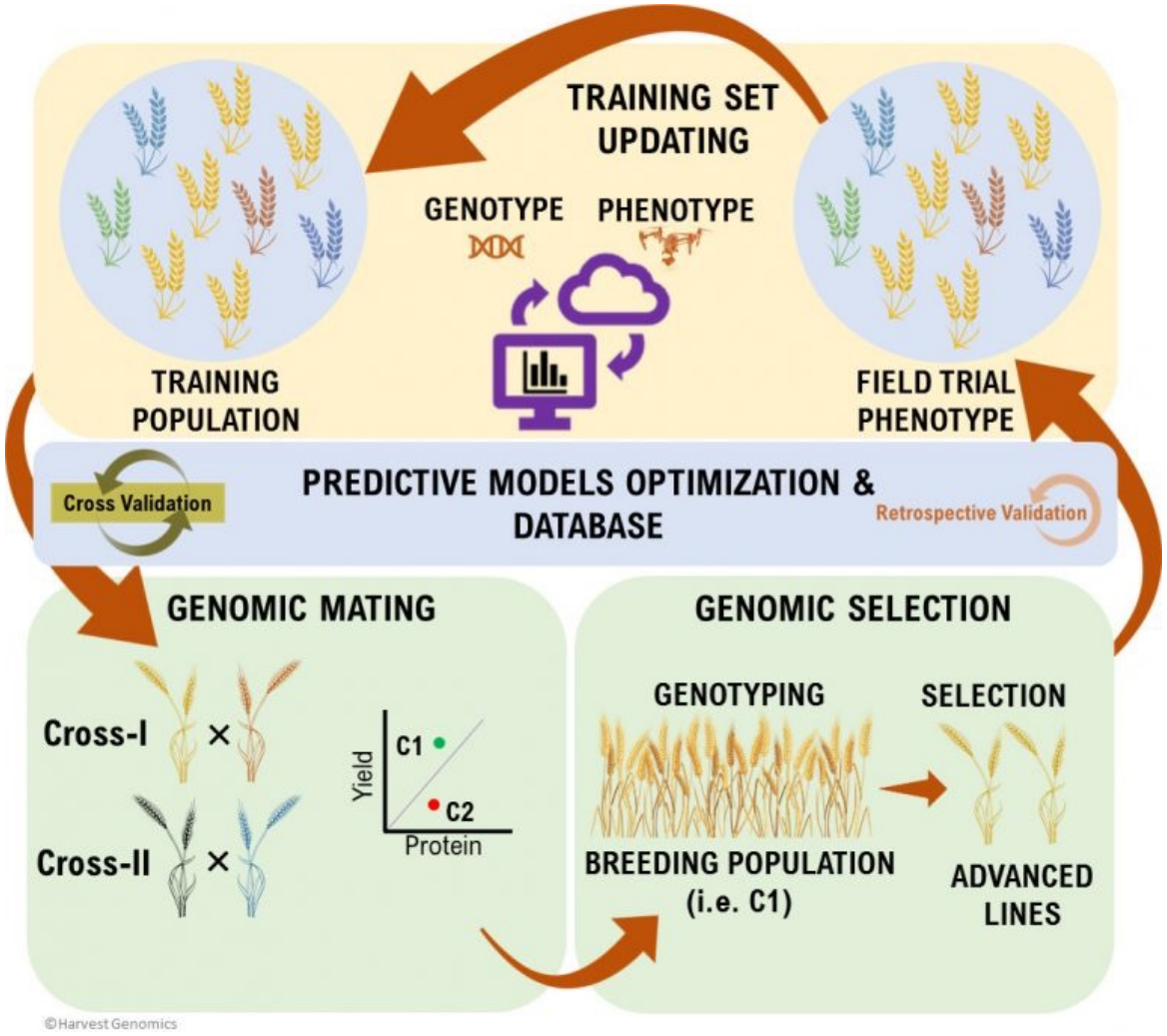
Genome edited (GE) crops

- GE crops do not carry foreign DNA (the editing machinery is no longer there!) and are thus different from GMO (aka transgenic) crops that harbor non-native DNA
- Plant varieties developed via genome editing are exempt from USDA GMO regulations, as long as the genetic changes GE plants carry could be made via conventional breeding
- Several GE crops (soybean, canola, rice, maize, mushroom and camelina) have already entered the markets and many more are in development
- A local startup RTP company, Pairwise, has recently released Conscious Greens (leafy mustard with spiciness edited out)
- A Japanese company, Sanatech Seeds, made GABA-reach GE tomatoes (GABA helps brain function)

What other emergent technologies are out there?

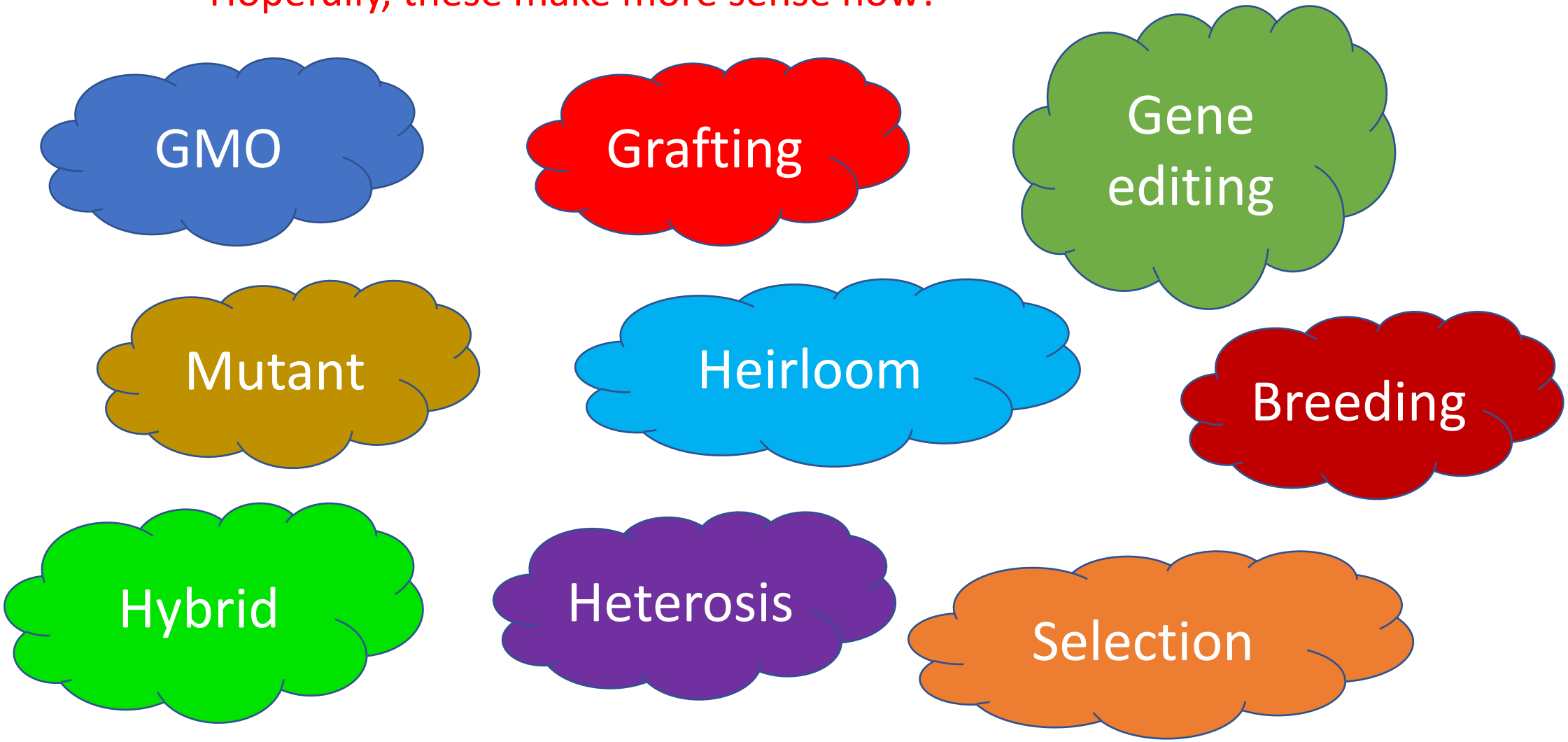
- Computational biology, bioinformatics, and machine learning enable integration of genetic (DNA sequence) and phenotypic (cultivar performance in the field) data to speed up breeding

- This is known as **genomic selection** where specific individuals to be crossed are computationally chosen based on their DNA that is predictive of plant performance in the field



These are some of the concepts we talked about today

Hopefully, these make more sense now!



Let’s revisit the grocery store’s produce section

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Questions?