WHEAT, FROM WHERE DID IT COME?

Kansas College and Career Ready Standard

HS-LS1-2: Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms. [Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neutral stimuli. An example of an interacting system could be an artery depending on the proper amount of blood within the circulatory system.] [Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.]

Subjects

Introduction to Agriculture
Life Science (Biology, Botany)
Phylogeny
Plant Science

Grade Level

9th-12th

Time Required

Three 45 minute class periods

Overview

Students will compare and contrast the different characteristics of wild and domesticated cereal grains.

Objectives

1. The student will be able to gather data pertaining to grains and their origin plants to choose what characteristics are best suited for domestication.

2. The student will be able to compare and contrast wheat, rye, and barley seeds/grains.

3. The student will be able to construct box plots of the data collected on day one and perform a statistical analysis of their data to determine significance.

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Activity 1

Materials:

- Packages of grains (seeds) [25 per package]
- *Aegilops speltoides* (goatgrass)
- *Aegilops tauschii* (Tausch's goatgrass)
- *Hordeum vulgare* (modern barley)
- *Secale cereale* (modern rye)
- *Triticum aestivum* (bread wheat)
- *Triticum turgidum* (durum wheat/pasta wheat)
- *Triticum urartu* (wild einkorn)
- Digital tare scale or triple-beam balance
- Stereoscope
- Ruler
- Images of wheat, barley, rye, and ancestral grains' vegetative portions (Note: teachers and/or students will need to gather these images from search engines and copy for classroom use.) Images of wheat, barley, rye, and ancestral grains' flowers (Note: teachers and/or students will need to gather these images from search engines and copy for classroom use.)
- Pictures of various breeds of dogs that are popular in your area (teachers and/or students will need to gather these images from search engines and copy for classroom use.)
- Phone, tablet, or similar device
- Copies of the colored background with reference circles of known size from the 1KK manual
- 1KK application found at the Google Play store or the Wheat Genetics and Germplasm Improvement website (http://www.wheatgenetics.org/download/category/21-1kk)

Background

The following web pages are recommended to those wanting more information about wheat, barley, rye, and their ancestral grains.

Discovery How Stuff Works: Wheat
Re-discovering ancient wheat varieties as functional foods--Journal of Traditional and Complementary Medicine https://www.sciencedirect.com/science/article/pii/S2225411015000401
Wheat Facts: https://www.wheatworld.org/wheat-101/wheat-facts/.
National Association of Wheat Growers
Types of Barley--Oldways Whole Grains Council
Types of Rye--Oldways Whole Grains Council

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Vocabulary

Artificial selection: The breeding of plants and animals to produce desirable traits. Organisms with the desired traits, such as size or taste, are artificially mated or cross-pollinated with organisms with similar desired traits.

Inflorescence: The complete flower head of a plant including stems, stalks, bracts, and flowers.

Natural selection: The process whereby organisms better adapted to their environment tend to survive and produce more offspring. The theory was first fully expounded by Charles Darwin and is now believed to be the main process by which evolution occurs.

Selective Pressure: The set of all the environmental factors that define whether an organism will be more or less successful at surviving and reproducing.

Preparation

The teacher will need to obtain images of several dog breeds.
Ensure that each lab group has copies of the vegetative portions and flowers of the wheat, barley, rye and ancestral grains.
Make copies of the individual student handouts.
Use the 1KK app (coming soon) to access sample data from Dr. Poland.

Dr. Jesse Poland
jpoland@ksu.edu

(Note: Stress that the seed packet needs to be weighed on a tare scale)

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Instructional Format

Start the lesson by administering the provided “Lesson Pre-test” on page 6 to the students.

Engage

Ask students to consider the following questions and write their responses in their lab notebooks or use the provided handout. Give the students approximately seven minutes to complete this.
**What is the perfect dog?*
**Describe the dog.*
**What kinds of dogs to you own?*
**Why do you like that type of breed?*
**What are some pros and cons of each breed?*
**How do breeders get the perfect dog?*

Brainstorming

Ask for several student volunteers to share their answers with the class. Then the teacher should ask the entire class: What characteristics do all these dog breeds have in common?
(Sample responses: carnivore, acute sense of smell, excellent vision, shape of skull and snout, type of canines)

What other non-domestic animals share these characteristics with dogs?
(Sample responses: wolves, coyotes, dingoes, hyenas)

What other organisms have been created for the convenience of man through artificial selection?
(Sample responses might include: strawberries, apples, cats, cattle, horses, birds, roses, tulips)

Explain that humans have not only bred animals to meet our needs, but we have also domesticated plants. Today the class will explore three domesticated grains and their possible ancestors by using samples of seeds and flour and images of these plants.

Elicit prior knowledge about grains and specifically wheat, barley, and rye from students. Students can use the KWL chart to determine what they know about grains, what they think they know about grains, and what they want to learn about grains.

Explore

Have students obtain specific grains (wheat, barley, and rye).
What are their specific characteristics, purposes, and uses?
Write student responses on the board. (Note: At this point in the lesson, students may have limited knowledge about these grains. Record all student responses and revisit those responses after the Explore portion is complete.)

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Introduce the explore portion of the lesson by displaying images of modern wheat (both bread wheat and pasta wheat), rye and barley. Students should record data using the data table provided.

Have students begin by evaluating the properties of the seed (size, hardness, color, texture and shape). Note: Wild einkorn and both goatgrasses are thought to be ancestral grains of wheat.

Students should consider the properties of the vegetative portion of the plant (leaf blade size and height) and inflorescence (size, type of potential pollinators, and blooming time) by using the images provided. Students should consider what time of year the crop will mature as well as conditions that the plants need (water, fertilizer, temperature, etc). (Note: All of these plants will have similar pollinators, in this case wind, and blooming time.)
Student groups should repeat the above procedure for the images of barley (Hordeum vulgare), rye (Secale cereale), wild einkorn (Triticum urartu), goatgrass (Aegilops speltoides), and Tausch's goatgrass (Aegilops tauschii).

Students will use the 1KK app (coming soon) and use the data sample provided.
To determine size, students should use the 1KK application by following the directions provided in the 1KK manual. Note: The app must be installed on the devices that are to be used prior to the lesson. To collect data, students should empty the contents of the entire seed packet on the colored background with reference circles that are provided in the Appendix of the 1KK manual. Next, students should capture an image. The green background should be centered in the image preview and the device should be held flat to minimize any object distortion. After zooming in on the image to determine that the image was captured correctly, the data can be exported into a sample summary. Students should record the information from the sample summary in the table provided. Students should repeat this procedure for each of the seed packets.

Conclusion

Ask students to list the similarities they saw among the grains that they viewed today. Then ask them to list the differences they saw.

See: https://youtu.be/maYrEb1ZtR8

Student Handouts:

Lesson Pre-test

Directions: Before starting this set of lessons, indicate your agreement or disagreement with each of the statements by writing an A fir agreement or D for disagreement in the Before column. At the end of these lessons, you will revisit your answers and use evidence from the lessons to refute or support your initial thoughts.

Before	After	Statement
		Scientists use tools like statistics to help verify the outcome of observational study.
		It does not matter what type of flour you use for baked goods. Any flour will work equally well.
		Gluten is unnecessary in a person’s diet.
		Wheat is a relatively new crop that occurred without much human intervention.
		Artificial selection is a tool used by humans to breed highly adapted plants and animals.
		Ancestral grains are of no use to today’s farmers.
		True science is only conducted in the laboratory.
		The wheat we use today is very similar to ancient wheat varieties.

Hybrid Dogs
*****In your opinion, what is the perfect dog?

*What kinds of dogs do you own?

*Why do you like that breed?

*What are some pros and cons of different breeds?

*How do breeders get the “perfect” dog?

Based on the class discussion, what characteristics do all these dog breeds have in common?

What other non-domestic animals share these characteristics with dogs?

What other organisms have been created for the convenience of man through artificial selection?
Why have these organisms been developed?

K What do you know about grains?	W What do you want to learn about grains?	L What did you learn about grains?

Comparisons of Various Seeds and Plants

Qualitative Data

Type of Seed	Relative Size of Seed	Color	Texture	Shape
Barley				
Rye				
Bread Wheat				
Durum Wheat				
Wild Einkorn				
Goatgrass				
Tausch's goatgrass				

Plant Structure and Inflorescence Observations

Plant	Leaf blade size	Height of Plant	Size of Inflorescence (flowering)	Blooming Time
Barley				
Rye				
Bread Wheat				
Durum Wheat				
Wild Einkorn				
Goatgrass				
Tausch's goatgrass				

Quantitative Data (using 1KK app)

Type of Seed	Total Seeds	Average Length	Length Variance	Average Width	Width Variance	Average Area	Area Variance
Barley							
Rye							
Bread Wheat							
Durum Wheat							
Wild Einkorn							
Goatgrass							
Tausch's goatgrass							

Which seeds are ancient varieties and which ones are newly evolved (modern)?

List three characteristics:

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Activity 2

Materials

- Images of wheat, barley, rye, and ancestral grains vegetative portions (students and/or teachers will need to use search engine to find these images, print, and share with class, this to avoid copyright challenges).
- Images of wheat, barley, rye, and ancestral grains' flowers (students and/or teachers will need to use search engine to find these images, print, and share with class, this to avoid copyright challenges).Pictures of various breeds of dogs that are popular in your area (students and/or teachers will need to use search engine to find these images, print, and share with class, this to avoid copyright challenges).
- Android phone, tablet, or similar deviceCopies of the colored background with reference circles of known size from the 1KK manual
- 1KK application found at the Google Play store or the Wheat Genetics and Germplasm Improvement website (http://www.wheatgenetics.org/download/category/21-1kk)
- Graph paper
- Computer
- Online one-way ANOVA calculator: http://www.physics.csbsju.edu/stats/anova.html)

Background

The following websites are recommended to those wanting more information about wheat and barley, rye, and their ancestral grains.

The story of wheat, Ears of plenty--The Economist
https://www.economist.com/special-report/2005/12/20/ears-of-plenty
Taxonomy of wheat--Kansas State University
https://www.k-state.edu/wgrc/wheat-tax.html
ANOVA: Analysis of Variance between groups--Csbsju.edu
http://www.physics.csbsju.edu/stats/anova.html
Interpreting results: One-way ANOVA--GraphPad software
https://www.graphpad.com/guides/prism/6/statistics/index.htm?stat_keyconcept_one-way_anova.htm

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Preparation

The teacher will provide copies of sample seed size data from Dr. Poland on the 1KK app (coming soon) from the previous activity.
Depending on the class's background in mathematics and statistics, the teacher may want to explain the purpose of a statistical analysis and how a null hypothesis and alternative hypothesis are determined. The teacher may also want to explain the meaning of statistical significance.

To complete the Explore portion of this lesson, students should use the 1KK app that was developed by the Wheat Genetics Resource Center.

Explain

Using the seed size data collected in the previous lesson OR sample data provided students should construct a boxplot on graph paper showing the average seed area of each species.
Students should include the standard deviation of the seed area as error bars in the box plot.
To calculate the standard deviation, students should use the square root of the variance in the sample summary. Students should then compare the boxplots of each species to determine if there is a possible difference in seed size.

Next, students should conduct an analysis of the seed area to determine if there is a statistically significant difference in seed size among the different grains measured. Using the provided handout, students should write a null hypothesis stating that there is no statistically significant difference between seed area. They should also write an alternative hypothesis stating that there is a statistically significant difference in seed area. Students should access the raw data from their 1KK data collection from Day One (or they can use the sample data provided). They should open a one-way ANOVA calculator to compare the seed areas of the grains to determine if the difference in seed area among species is statistically significant. After navigating to the one-way ANOVA calculator, students should enter the total number of groups to be analyzed as seven. Students should compare the size of the largest group by determining which group had the largest seed count. Note: If the seed count is greater than 99, they should enter 99. They should input the area for the first 100 seeds for each group. Once all of the data has been entered, they should select Calculate now. Students should then interpret the results of their statistical analysis by determining the probability of the results of this experiment, assuming the null hypothesis to be true. Note: The lower the p number, the more likely one should reject the null hypothesis A small p-value (typically ≤ 0.05) indicates strong evidence against the null hypothesis, so you reject the null hypothesis. A large p-value (> 0.05) indicates weak evidence against the null hypothesis, so you fail to reject the null hypothesis. Students should then explain why they accepted or rejected the null hypothesis based on the results of their statistical analysis and their boxplots in their lab notebooks or on the provided handout.

Student Handouts:

One-way ANOVA results for seed area

Directions: Before you begin your statistical analysis, write a null hypothesis and alternative hypothesis for seed area.

Null Hypothesis:

Alternative Hypothesis:

Probability (p-value)	Mean of Squares	*Circle one*
		Accept null hypothesis Reject null hypothesis

Explain what the results mean in the area below. Is there a difference in seed area that would not be accounted for by random error? Use examples from your statistical analysis, your boxplots and your qualitative findings from Day One to support your answer.

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Activity 3

Materials

- Bread – Wheat, rye, and barley (one slice of each per lab group)
- 1 5-lb bag of whole wheat flour (A)
- 1 5-lb bag of all-purpose flour (B)
- 1 5-lb bag of rye flour (C)
- 1 5-lb bag of barley flour (D)
- 1 5-lb bag of cake flour (E)
- 1 5-lb bag of bread flour (F)
- 1 5-lb bag of semolina flour (G)
- Tap water
- 1 container of salt
- 1 can of cooking oil spray (to spray the baking sheet)
- 1 box of food handlers gloves
- Various measuring spoons and cups
- Baking Sheets
- Digital scale
- Oven

Background

The following websites are recommended to those wanting more information about gluten.

Bread In a Bag--National Agriculture in the Classroom
https://www.agclassroom.org/teacher/matrix/resources.cfm?rid=50
Bread World--Fleischmann's
http://www.breadworld.com/education
What is Gluten?--Live Science
https://www.livescience.com/53265-what-is-gluten.html

Vocabulary

Gluten: a substance present in cereal grains, especially wheat, that is responsible for the elastic texture of dough. This structure or framework traps the carbon dioxide gas produced from yeast digesting sugar thus causing the bread to rise.

Knead: to work (dough, clay, etc.) into a uniform mixture by pressing, folding, and stretching.

Oven spring: In bread baking, the final burst of rising just after a loaf is put in the oven and before the crust hardens. The sudden increases in the volume of a dough during the first ten to twelve minutes of baking.

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Preparation

The teacher may want to pre-measure ingredients into kits to make the lesson go more smoothly. Mark the bags 1, 2, 3, 4, etc. as indicated below. For each kit you will need the following:

Bag #1: 1 cup of whole-wheat flour (labeled A)
Bag #2: 1 cup of cake flour (labeled B)
Bag #3: 1 cup of all-purpose flour (labeled C)
Bag #4: 1 cup of barley flour (labeled D)
Bag #5: 1 cup of Semolina flour (labeled E)
Bag #6: 1 cup of rye flour (labeled F)
Bag #7: 1 cup of bread flour (labeled G)

Each group should be assigned a separate type of flour, and allowed to observe the uncooked dough before it is placed in the oven. After the dough ball has cooked, each student group should be allowed to observe the cooked dough balls. If time does not allow for this to occur, the teacher may wish to make a class set of uncooked and cooked dough ball for students to observe while each individual group's dough ball bake.

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Explore

Determine the quality and quantity of gluten in various flours

Students should conduct the following procedure:
1. Use 1 c. of the type of flour assigned to your group.

2. Record its mass by using a digital scale.

3. Add ½ tsp salt and 1/3 c. cool water.

4. Mix to form a stiff dough. Form the dough into a ball.

5. Knead until the dough is smooth and elastic. This develops the gluten.

6. Knead the dough under a small stream of cool water to wash away the starch. BE CAREFUL TO RETAIN ALL THE BITS OF DOUGH. If the dough ball falls apart too much, put cool water in a bowl and knead the dough in the bowl. Be sure to change the water frequently. Continue kneading and washing until the water is clear.

7. What remains is crude gluten. Shape this into a ball.

8. Using the digital scale, measure the mass of the ball of gluten and record the results. Compare the height, mass, structure and softness of the gluten balls from each type of flour. Words to use in describing structure and softness are provided on the chart. Note: If this needs to be a two-day lab because of time restraints, stop the lab at this point. Wrap the dough balls in plastic wrap and store overnight in a refrigerator. Continue with step 9 the next day.

9. Bake the ball on an ungreased baking sheet at 450 degrees for 15 minutes. Reduce the heat to 300 degrees and bake 40 minutes longer until it is dry and crisp.
Repeat step 8.

10. Share your results on the class data table.

11. Students complete the attached handout. As part of that handout, they should analyze the data collected by the class by determining the percentage of gluten.

12. Students should divide the Mass 2 by Mass 1 and multiply by 100.

13. Students then should rank the flour types by the amount of gluten in descending order.

14. Students should complete the post-lab analysis in preparation for the class discussion.

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Conclusion

Students should rank the flours in descending order based on their percentage of gluten. As a class, discuss the purpose for each of the types of flour. Give each student a small square of wheat, barley, and rye bread. Allow students to taste the bread. Students should then write a review of each type of bread (include both positives and negatives).

Student Handouts:

Data for Gluten Ball Experiment

Flour Sample	Mass 1 (g)	Mass 2 (g)	Gluten percentage	Observations after kneading: height of ball and mass	Observations after baking: height of ball and mass	Predicted Flour Type	Actual Flour Type
A							
B							
C							
D							
E							
F							
G							

Post-lab Analysis:
Data for Gluten Ball Experiment

Define gluten:

What is the purpose of baking the gluten ball?

How is gluten developed for bread?

Based on your data and knowledge of gluten, label the flour sample (A-G) with the flour type (all-purpose, barley, bread, cake, rye, semolina, or whole wheat) in the predicted flour type column of this handout.

Note: Go check your predictions with your teacher to determine their accuracy before moving onto the next portion of this lab analysis.
How are the types of flours different? (Compare description of unbaked dough balls, calculated gluten percentage, and oven spring observations.)

Which flour contains the highest percentage of gluten?
Which flour contains the least gluten?
Explain how you determined this.

Which type of flour had the greatest “oven spring”? Explain.

What kinds of flour should be used for each of the following products?

Bread:

Pies:

Cakes:

Cookies:

Pasta:

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Sample Data Answer Sheet

Flour Sample	Mass 1 (g)	Mass 2 (g)	Gluten percentage	Observations after kneading: height of ball and mass	Observations after baking: height of ball and mass	Predicted Flour Type	Actual Flour Type
A	118.4	9.9	(9.9/118.4)= 0.083 x 100 =8.3%	Answers will vary	Answers will vary	Answers will vary	Whole wheat
B	103.7	0.2	0.19%	Answers will vary	Answers will vary	Answers will vary	Cake
C	130.5	9.9	7.5%	Answers will vary	Answers will vary	Answers will vary	All purpose
D	113.2	1.2	1.1%	Answers will vary	Answers will vary	Answers will vary	Barley
E	158.4	24.0	15.2%	Answers will vary	Answers will vary	Answers will vary	Semolina
F	106.7	6.3	6.0%	Answers will vary	Answers will vary	Answers will vary	Rye
G	151.5	17.6	11.6%	Answers will vary	Answers will vary	Answers will vary	Bread

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Activity 4

Materials:

- Images of wheat, barley, rye, and ancestral grains vegetative portions
- Images of wheat, barley, rye, and ancestral grains flowers
- Rye, Barley and Wheat flour
- Pictures of various breeds of dogs that are popular in your area
- Fertile Crescent Map

Vocabulary

Artificial selection: The breeding of plants and animals to produce desirable traits. Organisms with the desired traits, such as size or taste, are artificially mated or cross-pollinated with organisms with similar desired traits.

Natural selection: The process whereby organisms better adapted to their environment tend to survive and produce more offspring. The theory of its action was first fully expounded by Charles Darwin and is now believed to be the main process by which evolution occurs.

Selective Pressure: The set of all the environmental factors that define whether an organism will be more or less successful at surviving and reproducing

Bran: Pieces of grain husk separated from flour after milling.

Germ: A nutritious foodstuff of a dry floury consistency consisting of the extracted embryos of grains of wheat.

Endosperm: The part of a seed that acts as a food store for the developing plant embryo, usually containing starch with protein and other nutrients.

Head: A compact mass of flowers at the top of a stem

Awn: Such appendages collectively, as those forming the beard of wheat, barley, etc.

Kernel: The whole grain or seed of a cereal plant, like wheat.

Gliadin: One of two proteins that make up gluten. It gives bread the ability to rise during baking.

Glutenin: One of two proteins that make up gluten. It is responsible for the strength and elasticity of dough.

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Want to learn more?

The following websites are recommended to those wanting more information about artificial selection.

Selective Breeding or Artificial Selection--University of Georgia
http://wallace.genetics.uga.edu/groups/evol3000/wiki/ce8b9/Selective_Breeding_or_Artificial_Selection.html
Understanding Evolution: Artificial selection--University of California (Berkeley)
https://evolution.berkeley.edu/evolibrary/article/evo_30
Hybridization and Introgression between Bread Wheat and Wild and Weedy Relatives in North America--Alliance of Crop, Soil, and Environmental Science Societies
https://dl.sciencesocieties.org/publications/cs/abstracts/44/4/1145?access=0&view=pdf

Preparation

The teacher will need to supply students will images of several dog breeds. They could use the same images used in this lesson series. Student groups will also need to use a search engine to find, research and copy pictures of the vegetative portions and flowers of the wheat, barley, rye and ancestral grains.

Procedure

Have students revisit their responses about their perfect dog from the beginning of this lesson series. Ask them to consider the reasoning for breeding different dogs. (Sample responses: Bigger dogs like mastiffs provide protection while smaller dogs like miniatures provide companionship.) Then direct the student discussion toward the activities conducted in class over the past several days. Ask students to relate this reasoning to why it would be important to selectively breed for larger seeds in grain crops. (Sample response: Bigger seeds will lead to more flour production.)
Discuss with students the different parts of the wheat kernel: bran, germ, and endosperm. Explain the function of each.

Students should watch Discovery Channel's How Stuff Works: Wheat. Start the video at 2:52 and end the video at 27:40. Have students complete the provided viewing guide as they watch the video (pages 24-25).

Once they have viewed the video, lead a class discussion using the viewing guide as a basis. Discuss with the students the process that takes wheat from the field to the consumer. Also, focus on the methods used by breeders and geneticists to develop new varieties of wheat. Ask students to consider why more flour is made from wheat than barley or rye. (Sample responses: Wheat seeds are larger and therefore, produce more flour.)

Procedure Continued

Also, ask them why it is important to have so many different kinds of flour. Have students review the information from the Wheat Foods Council:
https://www.uswheat.org/working-with-buyers/wheat-classes/

Ask them to consider the role of gluten in the making of different baked goods. Finally, have students consider what characteristics of wheat make it such an adaptable crop.

Students should complete the provided post-test

Conclusion

How has wheat become so adaptable to different types of stresses?

Why is that adaptability important to its success as a food crop?

Why is it important to breed new types of wheat?

Student Handouts

How Stuff Works--Wheat Viewing Guide

1. How does wheat rank worldwide as a food source?

2. In what types of environments can wheat be grown?

3. How many scientific classes of wheat are there? How many varieties are there?

4. What are the three major parts to the wheat kernel and what does each contain?

5. What are the two proteins that make gluten?

6. What is the importance of gluten in bread making?

7. What is the most ancient variety of wheat that contains the greatest concentration of gluten and is used mostly in pasta?

8. What is the best type of wheat for bread making? Why?

9. What type of wheat is best for making a cake or pastry? Why?

10. What type of wheat has the most protein?

11. What type of wheat is the most versatile? Why?

12. When do the seeds of hard red winter wheat germinate?

Student Handouts

How Stuff Works--Wheat Viewing Guide

13. What happens after planting?

14. When does hard red winter wheat sprout and grow?

15. What nutrients are found in each wheat kernel?

16. How are these nutrients made available to humans?

17. What is the difference between white flour and whole-wheat flour?

18. List the steps that bring wheat from the field as kernels to the consumer as bread.

19. What gas does the gluten protein found in flour trap as the dough rises?

20. Genetically, why is wheat considered a polyploid? What does this mean?

21. How did wheat become a polyploid?

22. Why is it important to develop new types of wheat?

23. What types of tools do scientists use to develop new types of wheat?

24. Why is it important to study all of the varieties of wheat genetically?

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How Stuff Works--Wheat Viewing Guide Answers

1. How does wheat rank worldwide as a food source?
Wheat is the third most abundant crop grown worldwide.

2. In what types of environments can wheat be grown?
Wheat can be grown at different elevations, both at sea level as well as high elevations. It is also grown at different latitudes, both at high latitudes as well as at the tropics. It can also be grown in various climates, both in areas of high rainfall as well as areas with drought-like conditions. However, it should be noted that these are all different varieties of wheat.

3. How many scientific classes of wheat are there? How many varieties are there?
There are six scientific classes of wheat and over 30,000 varieties. Each variety has specific physical characteristics, adaptability, and grain yield.

4. What are the three major parts to the wheat kernel and what do they contain?
Bran contains fiber.
Germ contains essential oils, vitamins, and minerals. Embryo; beginning of a new plant
Endosperm contains complex carbohydrates like starch and the proteins gliadin and glutenin.

5. What are the two proteins that make gluten?
The proteins that make gluten are gliadin and glutenin.

6. What is the importance of gluten in bread making?
It is a protein with elastic quality that makes wheat unique and makes bread dough stretchy enough to rise. Gluten gives structure framework or "skeleton" that traps carbon dioxide as yeast consumes the sugar this allows the bread to rise, in baked goods.

7. What is the most ancient variety of wheat that contains the greatest concentration of gluten and is used mostly in pasta?
Durum wheat

8. What is the best type of wheat for bread making? Why?
Hard red spring wheat is best because it has less gluten than durum wheat. The dough made with this type of wheat can withstand expansion and be light enough to rise.

9. What type of wheat is best for making a cake or pastry? Why?
Soft red winter wheat or soft white winter wheat because they have less gluten which makes for a softer dough.

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How Stuff Works--Wheat Viewing Guide Answers

10. What type of wheat has the most protein?
Hard white wheat has 12% protein.

11. What type of wheat is the most versatile? Why?
Hard red winter wheat is most versatile because of its gluten content. It can be used for a variety of baked goods.

12. When do the seeds of hard red winter wheat germinate?
According to the film: Although wheat kernels are planted in the fall, they do not germinate until spring.
However, in the Kansas climate most wheat planted in the fall germinates in the fall and then goes dormant during the cold winter months. When spring arrives, seedlings begin to grow at a rapid rate.

13. What happens after planting?
According to the film: Seeds go dormant during the winter.
However, in our current climate, wheat seeds sprout and small seedlings grow until colder temperatures occur. When the colder temperatures of winter arrives, wheat plants go dormant until warmer temperatures arrive.

14. When does hard red winter wheat sprout and grow?
According to the film: Seeds will sprout and grow in the spring.
However, in our current climate, seeds sprout in the fall, then they go dormant in the winter. Seedlings grow rapidly in the spring adding more leaflets or tillers as the temperature gets warmer.

15. What nutrients are found in each wheat kernel?
Each kernel has iron, thiamin, and potassium, as well, as complex carbohydrates like starch and fiber and proteins.

16. How are these nutrients made available to humans?
Kernels are milled into flour.

17. What is the difference between white flour and whole-wheat flour?
White flour contains only the endosperm, while whole-wheat flour contains all parts of the kernel (bran, endosperm, and germ).

WHEAT, FROM WHERE DID IT COME?

How Stuff Works--Wheat Viewing Guide Answers

18. List the steps that bring wheat from the field as kernels to the consumer as bread.
Wheat is grown in the field. After harvest, it is taken to the grain elevator for storage. When prices are high, wheat is sold to the mill where it is ground as flour. Flour is sold to an industrial bakery where it is made into bread. Bread goes to the store where the consumer purchases it. Flour can also be sold directly to grocery stores.

19. What gas does the gluten protein found in flour trap as the dough rises?
Carbon dioxide is trapped by the gluten protein.

20. Genetically, why is wheat considered a polyploid? What does this mean?
Wheat has at least three sets of all of its chromosomes in common. Some wheat has six sets of its chromosomes in common.

21. How did wheat become a polyploid?
Wheat has naturally adapted to certain conditions over thousands of years. Humans have also used artificial selection to grow new types of wheat.

22. Why is it important to develop new types of wheat?
New types of wheat need to be developed because wheat is a major food source worldwide.

23. What types of tools do scientists use to develop new types of wheat?
Scientists use both field studies and laboratories studies to help develop new types of wheat. They select certain wheat strains because the wheat had better yields and didn't succumb to certain diseases.

Breeders select certain plants that are more tolerant to heat stress, diseases, and other stresses that wheat might encounter. These plants are crossbred using traditional methods. Breeders also want to improve productivity so that more grain is made and they also want to protect yield potential against pests and diseases. They also want to improve the quality of the flour so that it makes a good baked product. It takes at least 15 years to develop a new wheat variety using traditional methods.

Modern geneticists study ancestral species to better understand wheat's family tree. They also try to find specific genes that allow the wheat plant to thrive under high-stress climatic situations. Wheat plants are grown under controlled conditions and the yield of each plant is evaluated by measuring the mass of each seed. These plants are compared to plants grown under controlled conditions. Seed banks like the one at Kansas State University safely store 11,000 varieties of wheat and make them available for study. Included in this seed bank are 2,500 wild varieties.

WHEAT, FROM WHERE DID IT COME?

How Stuff Works--Wheat Viewing Guide Answers

24. Why is it important to study all of the varieties of wheat genetically?
Climate change causes crop stress. Crop stress can lower yield. Understanding which conditions each variety grows best allows for growers to select the best wheat variety for their environment. It takes 15 years to develop a new wheat variety. Anything that can allow for a reduction in this development time will help keep the global food supply stable.

Student Handouts:

Lesson Post-test

Directions: After completing this set of lessons, indicate your agreement or disagreement with each of the statements by writing an A for agreement or a D for disagreement in the After column. In the space under each statement, cite information from these lessons that supports or refutes your original ideas.

Before	After	Statement
		Scientists use tools like statistics to help verify the outcome of observational study.
		It does not matter what type of flour you use for baked goods. Any flour will work equally well.
		Gluten is unnecessary in a person’s diet.
		Wheat is a relatively new crop that occurred without much human intervention.
		Artificial selection is a tool used by humans to breed highly adapted plants and animals.
		Ancestral grains are of no use to today’s farmers.
		True science is only conducted in the laboratory.
		The wheat we use today is very similar to ancient wheat varieties.

WHEAT, FROM WHERE DID IT COME?

Activity 5

Materials

- Images of wheat, barley, rye, and ancestral grains' vegetative portions found by the students or teacher
- Images of wheat, barley, rye, and ancestral grains' flowers
- Guided Student Reading: Cereal Breeding Takes a Walk on the Wild Side
- Highlighters of various colors (green, yellow, pink, blue, and purple)
- Sticky notes of various colors (dark green, light green, pink, blue, yellow, and purple)

Vocabulary

Spike: An indeterminate inflorescence bearing sessile flowers on an unbranched axis.
Rachis: Main axis of a compound structure
Glume: A bract (leaf-like structure) below a spikelet in the inflorescence (flower cluster) of grasses (Poaceae).
Loci: Position of a gene on a chromosome
Phylogenomics: The intersection of the fields of evolution and genomics.
Phylogenetic tree: A branching diagram or "tree" showing the inferred evolutionary relationships among various biological species.

Want to learn more?

The following websites are recommended to those wanting more information about wheat hybridization and wheat phylogeny.

Wheat Improvement: The Truth Unveiled--The National Wheat Improvement Committee (NWIC)
https://wheat.pw.usda.gov/ggpages/Wheat__Improvement-Myth_Versus_FactFINAL.pdf
Ancient hybridizations among the ancestral genomes of bread wheat--Science
http://science.sciencemag.org/content/345/6194/1250092
Cereal breeding takes a walk on the wild side--Trends in Genetics
https://www.cell.com/trends/genetics/fulltext/S0168-9525(07)00348-4
International Wheat Genome Sequencing Consortium (www.wheatgenome.org)
International Barley Sequencing Consortium (www.barleygenome.org)
A short history of breeds-Adapa Project (https://www.adapaproject.org/doggenetics/tiki-download_file.php?fileId=68)
Where did your dog come from?-Science Magazine (http://www.sciencemag.org/news/2017/04/where-did-your-dog-come-new-tree-breeds-may-hold-answer)

WHEAT, FROM WHERE DID IT COME?

Preparation
The teacher and/or students will need to find and copy images of vegetative portions and flowers of the cereal grains and their ancestors. Each student group will also need a copy of the student handout, highlighters, and colored sticky notes.

Instructional Format
Start the lesson by administering the provided pre-test to the students.

Engage
Students will begin the lesson by taking the provided pretest for this lesson. Then students will be shown a simple phylogenetic tree of dogs and ask to describe what they see. Next, they should speculate how dogs and wolves could be related.

Explore
With partners, students will read through a modified version of the scientific review Cereal Breeding Takes a Walk on the Wild Side. Begin as an entire classroom. The teacher should project the student handout on the board. As the class popcorn reads the abstract, the teacher should model how to highlight the main ideas in the abstract.

Then as a class, look up the term germplasm and define germplasm as a crop scientist would define that term. Next have the students read for understanding with their partner. They should follow the directions outlined in the student handout.

Using a set of colored sticky notes, student pairs should prepare a set of sticky notes for each of the genomes described in the review. They should then construct a phylogenetic tree that best demonstrates the ancestral relationships seen in the Triticeae tribe.

Bring the students back together as a class. Allow student pairs to show their phylogenetic trees and explain their reasoning.

Explain
Project Figure 3 from the Cereal takes a Walk on the Wild Side. Explain scientists' reasoning for placing in the evolutionary relationships that they have based on genome constitutions. Give students time to compare their phylogenetic tree and the tree developed by professionals. Ask students to find three similarities and three differences between their tree and the tree that was developed by scientists. Also, ask them to consider why it is difficult to determine genetic relationships. Ask students to consider what other information they need in order to be successful in their construction of the tree.

WHEAT, FROM WHERE DID IT COME?

Elaborate

As a class, popcorn read about what genes have helped with domestication and how the development of new hybrid crops has helped in the understanding of tribal genetic relationships.

Finally, show students the Wheat Genomics career connection interviews on YouTube that explain how understanding the genetics of wild relatives will lead to better crop improvement.

Read more about the importance of a Seed Bank by visiting PBS News Hour: Syria pulling out of Seed Bank.

Watch this video about the importance of seed banks and their locations world-wide:
https://youtu.be/dXP2gv1Tgtg

What is a seed bank?
Where are seed banks located?
What is the advantage to having access to a seed bank?
How is K-State's seed bank unique?

Conclusion:

Students should revisit the Family Tree of Dogs that they viewed at the beginning of class. They should complete the exercise **I Used to Think, but Now I Know**, so they reflect on how their thinking about how dogs and wolves relatedness may have changed in light of what they learned today about the relatedness of cereal grains.

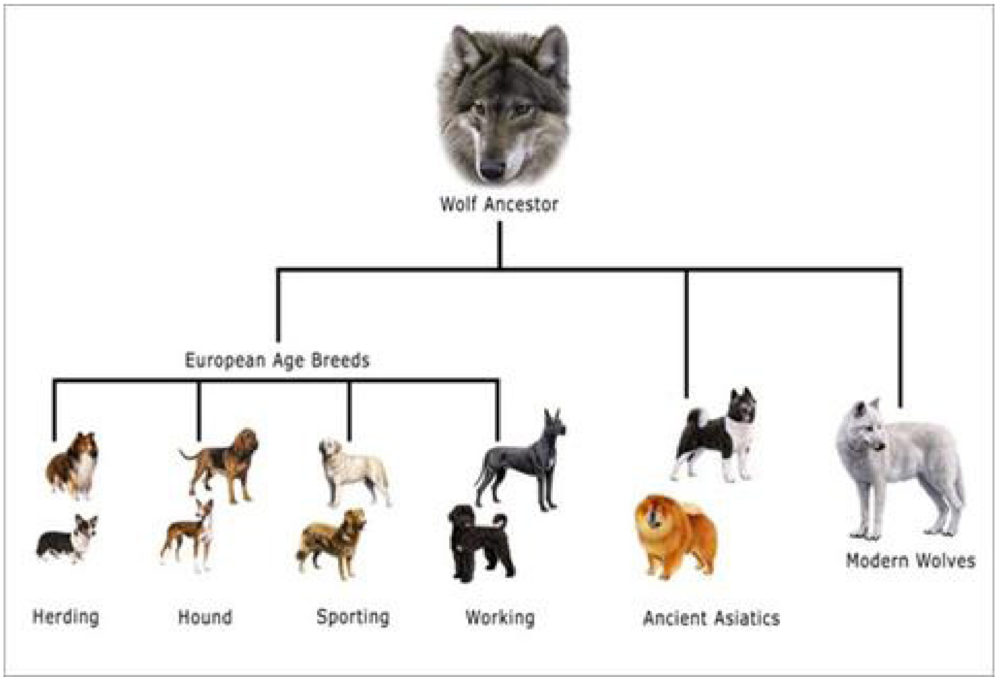
Student Handouts

Directions: Before starting this set of lessons, indicate your agreement or disagreement with each of the statements by writing an A for agreement or a D for disagreement in the Before column. At the end of these lessons, you will revisit your answers and use evidence from the lessons to refute or support your initial thoughts.

Lesson Pre-test

Before	**After**	**Statement**
		Barley, wheat, and rye show no evolutionary relationships among each other.
		Cereal crops have been improved by incorporating certain alleles of their wild relatives into their genome.
		No new types of cereal hybrids have been developed.
		Polyploidy is a problem and leads to less genetic diversity.

What do I think/What do I see?



Describe what you see in the image above.

https://sportleash.com/blogs/news/18006096-wolf-dog-hybrids-image-gallery

Speculate how you think dogs and wolves could be related. Explain your reasoning.

Student Handout:

Name __________________________ Date ________________ Period ____________________

Cereal breeding takes a walk on the wild side

Student Guided Reading Worksheet

Adapted from: Feuillet, Catherine, Peter Langridge, and Robbie Waugh. 2007. Cereal breeding takes a walk on the wild side. Trends in Genetics 24(1):24-32.

Today you will be reading the review, *Cereal Breeding Takes a Walk on the Wild Side,* written by Feuillet, Langridge, and Waugh for the scientific journal, *Trends in Genetics* in 2007. This article was written for scientists in the field to give them basic background into the history of cereal grain breeding and some challenges that scientists must solve in order to maintain high crop yield and grain quality.

Directions: First read the abstract of the paper and highlight the following:

- *Highlight the organisms being studied in green.*
- *Highlight the problem that has arisen in yellow.*
- *Highlight the solutions that scientists will use to solve the problem in pink.*
- *Highlight the end goal in blue.*
- *Highlight any unfamiliar words in purple.*

Abstract

Wheat, barley, and rye (Triticeae tribe) have limited genetic diversity. Scientists have concerns that crop yield and crop quality may be decreased in the future because environmental changes and pests. These cereal crops have been improved for over a hundred years by incorporating certain alleles of the wild relatives of wheat, barley, and rye. There are several methods that may help solve this concern. They include more easily performed gene discovery and improved technologies for breeding of plants. Scientists also need to better understand the factors that limit their ability to take advantage of the germplasm of the wild relatives of wheat, barley, and rye in order to make more genetically diverse cereal crops. Finally, new, more efficient strategies to directly use wild relative germplasm need to be developed. By using these methods, more genetically diverse cereal crops can be bred.

Questions to consider:

Look up the term **germplasm**. In your own words, explain what that term means to crop scientists.

Student Handout continued:

Directions: Now take a closer look at how we got to where we are today.

- Highlight organisms being studied in green.
- Highlight the problems that have arisen in yellow.
- Highlight the solutions that scientists will use to solve the problems in pink.
- Highlight the end goal in blue.
- Highlight any unfamiliar words in purple.
- Give each paragraph a heading that describes the main point of the paragraph.

The Foundations of Agriculture

Since the beginnings of agriculture 10,000 years ago, cereal crops have been man's main source of food. The world's first farmers domesticated many different types of cereal crops. This domestication of crops occurred because of several factors. Cereal crops had very high yields and nutritional value. They were also easy to transport and store (See Figure 1). Two members of the Triticeae tribe, wheat and barley, have been very important because they served as a primary food source, which enabled the founding of civilization and agriculture in Middle East. Show students on a map where the fertile crescent is located in the Middle East.

The Triticeae tribe is taxonomically in the Grass family. It is a unique group of plants. When considered as a group, they make up more than one third of the world's entire cereal production. Within the tribe, there are diploids (barley and rye), tetraploids (durum or pasta wheat), hexaploids (bread wheat, spelt, and Triticale), and some octoploid members. As a group, these grains are very closely related genetically. These grains can interbreed and make fertile hybrids. Most members of the tribe are in-breeders and have both male and female reproductive parts on the same plant. Rye is the exception because it has separate male and female plants. It must outbreed to make a seed.

Because of the development and application of contemporary genetic technologies, scientists know a lot about the origins of the Triticeae tribe. Over the years, because of its importance to agriculture, much of the Triticeae tribe has been interbred. This interbreeding has caused large improvement in crop yield and grain quality. Unfortunately, it has also lead to a decrease in the genetic diversity within the germplasm of the tribe. Because of this decrease in genetic diversity, scientists are concerned that continued improvement in crop yield and grain quality will not occur in the future.

One essential priority for practical improvement in cereal grains is to make the gene pools of wheat and barley more diverse by adding favorable alleles, genes, or gene complexes from the wild relatives within the tribe. Scientists are currently exploring this expansion of the gene pool. They are developing large-scale genomic resources for the entire tribe by sequencing genomes for both model plants and specific crops. These resources are being used with advanced breeding strategies and deeper understanding of how crop and model plants grow and develop.

Questions to consider:
Define the following terms related to the number of chromosome pairs in an organism:
Diploid

Triploid

Tetraploid

Hexaploid

Octoploid

Directions: Next, explore how we got the wheat, barley, and rye we enjoy today.

- *Highlight the specific types of wheat in green.*
- *Underline the specific genome constitution for wheat with a green colored pencil.*
- *Highlight the specific types of barley in blue.*
- *Underline the specific genome constitution for barley with a blue colored pencil.*
- *Highlight the specific types of rye in yellow.*
- *Underline the specific genome constitution for rye with a yellow colored pencil.*
- *Highlight any unfamiliar words in purple.*
- *Give each paragraph a heading that describes the main point of the paragraph.*

Origins of wheat, barley, and rye

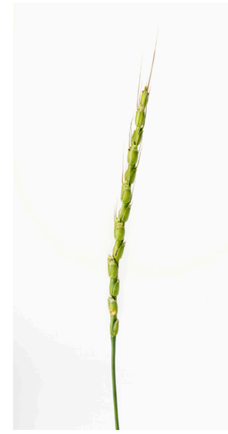
The word wheat is used to describe several related grain crops. There are two important wheat species grown today. They are bread wheat, known scientifically as Triticum aestivum and pasta wheat, known scientifically as Triticum turgidum (See Figure 2). Einkorn wheat, also known as Triticum monococcum, has great historic importance. It is not widely used in agriculture today. This is primarily due to its low yield. Einkorn was probably the first widely cultivated species of wheat. It might have been first cultivated 10,000 years ago in southeastern Turkey and was grown in the area for several thousand years. In certain mountainous regions of Turkey, Italy, and Spain, it is still grown today as animal feed. It also grows wild in the mountains surrounding the region known as the Fertile Crescent.

Figure 2

Triticum turgidum

Triticum aestivum

Triticum urartu



Aegilops tauschii

Secale cereale

Hordeum vulgare

Aegilops speltoides

In addition to einkorn wheat, other wheats and wheat relatives naturally evolved in the Middle East. These species all share the same basic set of seven chromosomes. Most of the wheats and wheat relatives are diploid. Scientists give each species a genomic constitution classification that is based on how the chromosomes pair through meiosis in diploid hybrids. Using this genomic classification as a simplified explanation of the species' genome, scientists can try to reverse engineer the origins of members of the tribe. This method is particularly helpful in determining the origin of the wheats that seem to have multiple sets of diploid chromosomes, which are also known as polyploid wheats.

The first evolutionary event that lead to the origin of polyploidy wheats was the hybridization of a diploid wheat that was closely related to wild einkorn, also known as *Tritium uratu* (genomic constitution AA) with an unknown species of goatgrass that provided the B genome. It is thought that this unknown species was closely related to the goatgrass known as *Aegilops speltoides* (genomic constitution SS). Eventually, this fertile tetraploid evolved to become emmer wheat, also known as *Tritium turgidum* (genomic constitution AABB). This process is thought to have taken over 10,000 years for domestication to occur.

Because it had the genetic resources of both goatgrass and wild einkorn, emmer wheat (*Tritium turgidum*) had a higher yield and is more adapted to a range of different environments. It had great historical importance because many subspecies were cultivated from it and grown around the world for thousands of years. Most, however, are of little economic importance today. One exception is a subspecies called pasta wheat, also known as *Tritium turgidum ssp. durum*. This type of wheat is still grown all over the world.

WHEAT, FROM WHERE DID IT COME?

Another important evolutionary event lead to the bread wheat, also known as *Triticum aestivum*. Bread wheat is thought to have arisen when a tetraploid emmer wheat that was grown in a region south of the Caspian Sea was crossed with a wild diploid species of goatgrass, known as Tausch's goatgrass (*Aegilops tauschii*). The genomic constitution for Tausch's goatgrass was DD. Normally, a genetic cross between these two species would result in a sterile hybrid. However, the doubling of chromosomes in this case produced a fertile, hexaploid species that we know today as bread wheat (genomic constitution AABBDD). It is thought that this hybridization occurred in cultivated wheat fields around 7,000 years ago. This edition of the D genome from Tausch's goatgrass (*Aegilops tauschii*) allowed bread wheat to be grown in more environments over a larger geographic area. It is hypothesized that the D genome encoded for proteins that restored the softness of the grain endosperm, which improved the bread-making properties to this new grain. In addition to a softer endosperm, bread wheat also contained proteins that trap carbon dioxide during yeast fermentation. This allowed the bread dough ball to rise and make more fluffy bread. Bread wheat is cultivated through the world and makes up 90% of all of the world wheat production today.

Barley is another of the world's oldest cereal crops. Archaeological evidence suggests it was first domesticated in the Fertile Crescent around 10,000 years ago. Barley is a more tolerant species than wheat, although it has different uses than wheat. Primarily, it is used in the making of beer and whiskey. It also has a more straightforward evolution than wheat. *Hordeum vulgare* refers to cultivated barley (genomic constitution HH). There are many different subspecies of barley that grown in the wild around the world. *Hordeum spontaneum* (wild barley, genomic constitution HH) is found throughout the Middle East and is thought to have been the parent of cultivated barley.

Rye (*Secale cereale*, genomic constitution RR) may also have originated in the Middle East. Evidence indicates that its center of diversity includes the countries of Turkey, Armenia, and Iran where it was probably first a tolerated weed. However, later it was cultivated as a crop. Both weedy rye (*Secale montanum*, genomic constitution RR) and wild rye varieties can interbreed with cultivated rye to make fertile hybrids.

A closer look at genomic constitution

Directions: Using Figure 2 and the reading, complete the graphic organizer (Table One). Determine the genome constitution and ploidy (i.e. diploid, tetraploid, or hexaploid) for each of the wheat, barley, and rye species listed. (Note: remember that two capital letters is the abbreviation for diploid).

Table One: Genomic Constitution of the Triticeae

Scientific name	**Common name**	**Genome constitution**	**Ploidy**
Triticum uratu	Wild einkorn		
Aegilops speltoides	Goatgrass		
Aegilops tauschii	Tausch's goatgrass		
Triticum monococcum	Cultivated diploid wheat or Einkorn wheat		
Triticum turgidum ssp. Dicoccoides	Emmer Wheat		
Triticum turgidum spp. Durum	Durum wheat or Pasta wheat		
Triticum aestivum	Bread wheat		
Hordeum spontaneum	Wild barley		
Hordeum vulgare	Cultivated barley		
Secale cereale	Cultivated rye		
Secale montanum	Weedy rye		
Triticale hexaploid Lart.	Triticale (wheat/rye hybrid)		

Determining how the tribe is related

Directions: Once you complete the graphic organizer, get a set of colored sticky notes from your teacher. Answer the questions on this paper (indicated by bullet points) and prepare a set of colored sticky notes for each genome.

The A genome (Dark green sticky notes)

- List all of the species that have an A genome.

Now write the names of these species on separate dark green sticky notes. Be sure to include their genome constitution.

The B genome (Light green sticky notes)

- Now, list all of the species that have a B genome.

Then write the names of these species on separate light green sticky notes. Be sure to include their genome constitution.

The D genome (Pink sticky notes)

- List all of the species that have a D genome.

Then write the name of plant and its genome constitution on separate pink sticky notes.

The H genome (Blue sticky notes)

- List all of the species that have an H genome.

Then write the name of plant and its genome constitution on separate blue sticky notes.

The R genome (Yellow sticky notes)

- List all of the species that have an R genome.

Then write the name of plant and its genome constitution on separate yellow sticky notes

The S genome (Purple sticky notes)

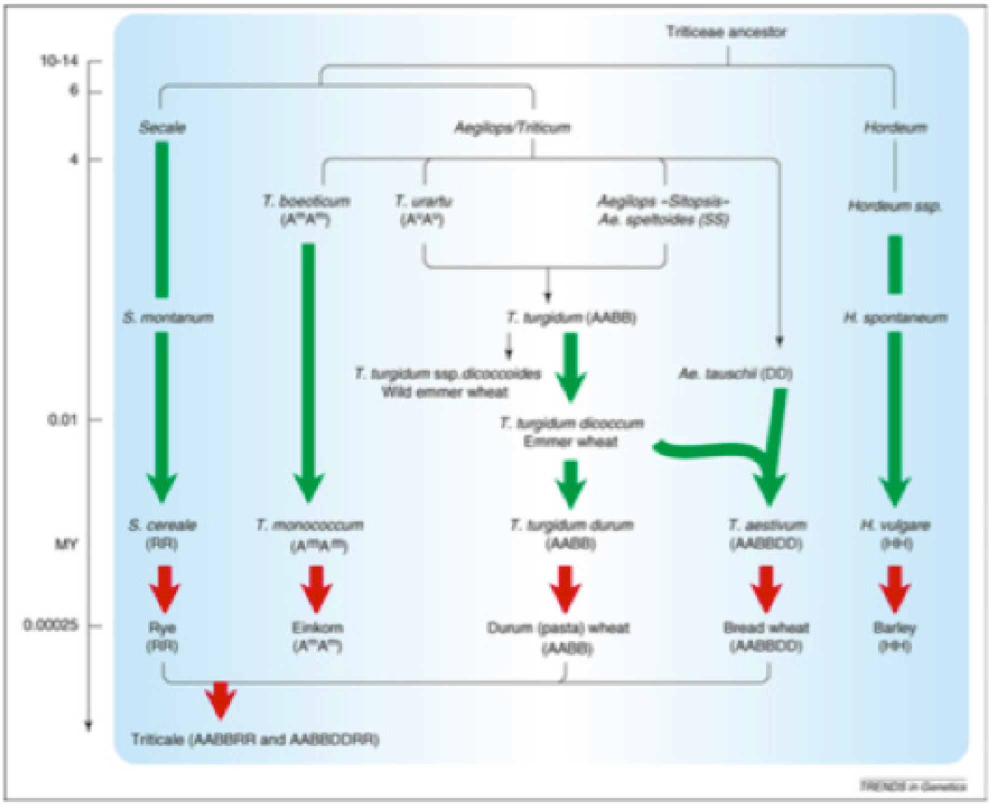
- List all of the species that have an S genome.

Then write the name of plant and its genome constitution on separate purple sticky notes.

Once all of your sticky note cards have been created, perform a card sort and arrange these sticky notes in order of complexity. List where you see overlap in the cards in the space provided below.

Construct an ancestral tree showing the genetic relationships between wheat, rye, and barley species in the space provided. Make this graphic organizer, however, your group wants.

Directions: This figure outlines how the Triticeae tribe may have arisen from a common ancestor. Compare this figure to the ancestral tree that you developed on the previous page.



The evolution of the Triticeae species from a common ancestor. The different evolutionary hybridization (black arrows), domestication (green arrows), and selection (red arrows) steps that have resulted in modern wheat, barley, and rye cultivars are described along the time scale in million years (MY). Genome constitutions are given in parentheses beside the species name.

Questions to consider

List three ways that your tree is similar to the phylogenetic tree that was developed by scientists which is shown in Figure 3.

List three ways that your tree is different.

Why is determining genetic relationships like these difficult?

What genes helped with domestication?
Wheat and barley became domesticated when plants appeared that had a grain-bearing spike. Through genetic research, scientists now know that these are caused by mutations at loci such as brittle rachis (Br), Q and Tg (Tenacious glume). The first farmers would have liked these mutant types more than their wild relatives because the mutants produced spikes that did not shatter and disperse their the seeds before harvest. They also may have had naked or hulless seeds that simplified flour milling. Scientists have recently isolated the genes underlying these traits. By using functional and phylogenomic analyses of the cloned genes, scientists will better understand how cereal grain like wheat and barley became domesticated through a process of adaptation from the wild to the human (cultivated) environment. This understanding will allow for the domestication of new plants.

New synthetic amphiploid crops
Wheat, barley and rye are all closely related and share a basic chromosome number of seven, although bread wheat is hexaploid and durum or pasta wheat is tetraploid. The close relationship between the chromosomes of these three species enables the generation of fertile amphiploid hybrids between different cultivated members of this tribe and also between the cultivated species and their wild relatives. The first hybrid between wheat and rye, 'Triticale' (Triticosecale), was made in Scotland in 1876. However, the first fertile hybrid of this cross was not produced until 1938. Triticale is mainly used as animal feed because it lacks the processing and quality characteristics of bread wheat. Tritacale's first large scale breeding began in the 1960s.

Production grew over 2 million tons in the late 1980s. In 2005, Triticale production was 13 million tons. As a new crop species, Triticale has found a strong market because of its high yield, relative to its parental species, and ability to grow in environments not suited to wheat or barley production. Although fertile hybrids between wheat and barley have also been produced, the resultant 'synthetic species', Tritordeum, has failed to find commercial acceptance.

Questions to consider:
What evidence was recently found that aided in the development of a theory of domestication of wheat and barley?

How has the development of new hybrid crops helped in the understanding of genetic relationships within the tribe?

I Used to Think, But Now I Know

In terms of wolf and dog relatedness, at the beginning of the lesson, I thought……

After completing the activity, I now understand...

Now consider how your thinking has changed after learning about how wheat, barley, and the ancestral grains are related.

The evidence that changed my thinking is...

Lesson Post-test

Directions: After completing this set of lessons, indicate your agreement or disagreement with each of the statements by writing an A for agreement or a D for disagreement in the After column. In the space under each statement, cite information from these lessons that supports or refutes your original ideas.

Before	After	Statement
		Barley, wheat, and rye show no evolutionary relationships among each other.
		Cereal crops have been improved by incorporating certain alleles of their wild relatives into their genome.
		No new types of cereal hybrids have been developed.
		Polyploidy is a problem and leads to less genetic diversity.