Class Lesson: The Science behind Vegetable Grafting

A. Classroom Discussion and Activity

  a. Vegetable Grafting Presentation
  b. Preparation: Materials required for grafting
  c. Activity: Learn how to graft and become vegetable grafter

B. Lesson Plan: Vegetable Grafting Handout for Teachers

  a. Handout: How to Conduct a Vegetable Grafting class
  b. Handout: How to Graft Watermelon
  c. Handout: How to Graft Tomato and Eggplant
  d. Handout: Healing Grafted Plants

C. Standards connections

Big Ideas LS1 Molecules to Organisms.
LS3 Inheritance and Variation in Traits
LS4 Natural Selection (Artificial Selection) and Evolution
ESS3 Human Sustainability
ETS; Engineering

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HOW TO CONDUCT A VEGETABLE GRAFTING CLASS

Before the class activity, teachers should listen to and read the following information which is posted on the Vegetable Horticulture website at http://vegetables.wsu.edu:

1. Narrated Power Point presentations: http://vegetables.wsu.edu/graftingVegetables.html#presentations
   a. How to Graft Tomatoes and Eggplant
   b. Grafting Healing Chamber
   c. Transplanting Grafted Plants to the Field
2. Extension factsheets: http://vegetables.wsu.edu/graftingVegetables.html#information
   a. Vegetable Grafting: Eggplant and Tomato
   b. Vegetable Grafting: The Healing Chamber
   c. Vegetable Grafting: Watermelon
3. As many of the grafting articles under “Resources” as presenters have time and inclination to read: http://vegetables.wsu.edu/graftingVegetables.html#resources

This handout provides an overview of considerations, supplies, and timelines for conducting a vegetable grafting class activity. Good planning is essential when putting on a successful grafting class, and the following steps will help you increase student participation and effectiveness.

I. **Set a date and learning objectives** for the class.
   a. Locate the available venues, both classroom space and greenhouse or equivalent area for growing seedlings.
   b. Set a limit on the number of participants based on the space available and the comfort of the instructor; 10-12 participants is a good starting number; 20 participants is the maximum number for a single instructor.
   c. Set the length of the class and activity.
   d. Decide who will order and prepare materials. Develop a timeline for each task and list the person responsible for each task; check-in periodically to make sure you are on track.
   e. Decide who will do the presentation(s).

II. **Prepare written information** to prepare students for the activity.
   a. Provide a handout that includes:
      1) A list of materials and supplies that are required for the activity
      2) A reading list for students to familiarize themselves with the basic concepts of grafting before the activity.

III. **Order materials** well in advance.

a. Decide on the scion and rootstock varieties you will use. See www.vegetablegrafting.org for a list of rootstock varieties and sources.
b. **Timeline:** 4 to 6 weeks before the activity – order scion and rootstock seeds and planting supplies such as seeding trays and potting mix.
c. **Timeline:** 2 weeks at least before the activity – order all supplies that you will use for the activity and/or provide to students, and have on-hand a list of supplies (see list below, and *Grafting Workshop Supply Costs*), and a tray (optional) for setting all supplies out for each student (Figure 1).
d. Purchase supplies or boxes for healing chambers <u>if</u> plants are going to be healed (Figure 2).

Figure 1. Supplies needed for grafting include cutting tools such as razor blades, a variety of grafting clips, guide for cutting angle, spray bottles, hand sanitizer (optional), and latex gloves (optional). A tray is convenient for organizing your work area.

Figure 2. Healing chamber on left is large enough to fit 8 72-cell trays, and the clear plastic tub with lid on the right can be used as a healing chamber and is large enough to fit 2 6-packs. Place black plastic on top of the healing chamber to block light for a few days.

Supplies

1. Planting trays (72-cell works well), potting mix, seeds, 6-packs
2. Grafting clips of the appropriate sizes; need to order in advance
3. Humidity/healing chamber – plastic tub or construct appropriate size, see WSU factsheet *Vegetable Grafting: The Healing Chamber* at http://cru.cahe.wsu.edu/CEPublications/FS051E/FS051E.pdf
4. Razor blades – double-edged blades are preferred as they are very thin, economical and readily available; bend in half to break in half. Can also use single edged blades or a variety of knives
5. Disinfectant: 9 parts water plus 1part Clorox = 10% Clorox solution; or rubbing alcohol, 70% ethanol, or hand sanitizer
6. Use close-fitting latex gloves if you prefer
7. Spray bottles: 1 for disinfectant and 1 for fresh water; label each clearly
8. Guide for cutting angle (use an index card cut at a 45° angle)

IV. **Seed scion and rootstock seeds in the greenhouse** and determine proper timing for each to reach the proper size for grafting compatibility in your environment.

   a. Scion and rootstock seedlings should have 1-2 true leaves by the day of grafting (Figure 3).
   b. Seedlings are usually the right size for grafting 14-21 days after seeding, depending upon variety and your greenhouse environment; the ideal temperatures are 70/75 °F night/day.
      1) To slow down growth, if plants are getting too large too fast, reduce temperature to 65/70 °F night/day.
      2) To speed up growth, if plants do not appear to be reaching the optimal size quickly enough, increase temperature to 75/80 °F night/day.
   c. It is advisable to seed a test set of plants 6 weeks prior to the activity to determine the correct timing.

Figure 3. Tomato scion and rootstock should have 1-2 true leaves at the time of grafting.

V. **Vegetable Grafting Presentation** provides a step-by-step procedure for teaching this class. Familiarize yourself with the resource information on our website http://vegetables.wsu.edu/graftingVegetables.html:

a. Narrated Power Point presentations:
   http://vegetables.wsu.edu/graftingVegetables.html#presentations
   1) How to Graft Tomatoes and Eggplant
   2) Grafting Healing Chamber
   3) Transplanting Grafted Plants to the Field

b. Extension factsheets:
   http://vegetables.wsu.edu/graftingVegetables.html#information
   1) Vegetable Grafting: Eggplant and Tomato
   2) Vegetable Grafting: The Healing Chamber
   3) Vegetable Grafting: Watermelon

c. As many of the grafting articles under "Resources" as you have time to read:
   http://vegetables.wsu.edu/graftingVegetables.html#resources

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Science and Engineering Practice:
Obtain Combine and Communicate Information

Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source

Planning and Conducting Investigations

Select appropriate tools to collect, record, analyze, and evaluate data.

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Material and labor costs for vegetable grafting class activity

Category	Item	Cost[1]
Seeds – Tomato scions	Cherokee Purple 500 sd pk Early Girl 3 pk	9.95 9.99
Seeds – Tomato rootstock	Beaufort pk 100 sds Maxifort pk 250 sds	26.30 61.00
Seeds – Watermelon scions	Sugar Baby 1 lb (~2000 sds;1000 used for 1 class)	39.95
Seeds – Melon rootstocks	Tetsukabuto 1 lb	154.00
Seed potting soil	Sunshine #3 N&O OMRI @ $17.95 x 4	71.80
Trays	72-cell Poly-seeded (24 trays + 24 drain trays)[2] 72-cell trays cut up (16; used trays if available)	110.40
Plant ID strips, plastic	6 colors @ $2.35 per color	14.10
Razor blades, double edged	100 @ $9.62 packages (for 38 participants)	9.62
Plastic straws	200 straw pkg @ $6.95 4 colors	6.95
Grafting tubes	1.5 mm, 450 (12 x 20 participants)[3] 2.0 mm, 120 (3 x 20 participants)[4]	33.75 14.50
Grafting clips	Clear 1.5 mm 240 (6 x 20 participants)[5] Orange 2.0 mm 450 (12 x 20 participants)[6]	25.50 141.75
Ethanol sanitizer	2 bottles @ $4.00 per pint bottle	8.00
Greenhouse costs	Bench fee	16.00
TOTAL		**753.56**

[1] Prices online as of December 2017. Varieties and products listed are examples only; this listing does not constitute an endorsement, nor does it imply a recommendation over any sources not listed.
[2] Trays @ $2.95 ea.; 72-cell seeding liners @ $1.65 ea,
[3] Grafting tubes 1.5 mm, pkg of 100 @ $6.75 x 5 = $33.75
[4] Grafting tubes 2.0 mm, pkg of 100 @ $7.25 x 2 = $14.50
[5] Clear grafting clips, pkg of 100 @ $9.50 x 2 + shipping = $25.50
[6] Orange grafting clips, pkg of 200 @ $48.00 x 3 = $144.00 = shipping

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VEGETABLE GRAFTING PRESENTATION

This handout is designed to be used by presenters during the class. It is not necessary to discuss or demonstrate all grafting methods, the presenter should decide which methods to include in the class. It is good, however, for the presenter to be familiar in general with the different grafting methods in order to answer questions that may arise.

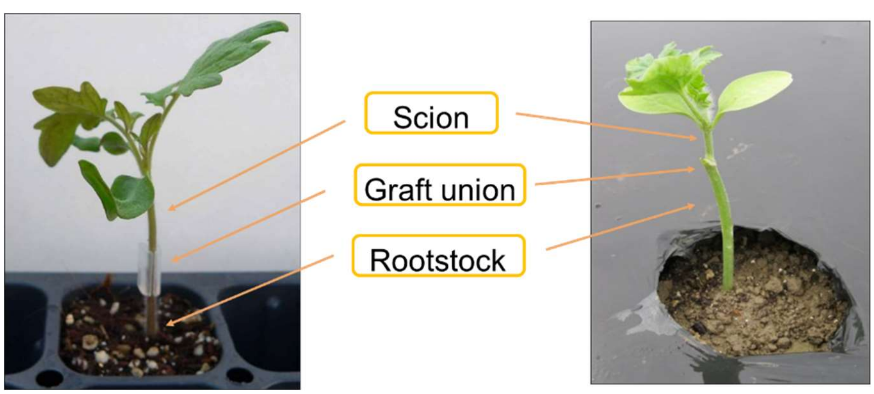
The presenter should follow the steps outlined below in the order given and should familiarize themselves with the information in advance. Be sure to do your homework – read the handouts and fact sheets and listen to the narrated PowerPoints that we have prepared regarding vegetable grafting and have posted on our website http://vegetables.wsu.edu/graftingVegetables.html. If you have any questions about procedures or vegetable grafting, contact Carol Miles at milesc@wsu.edu.

I. Introduction to Vegetable Grafting

Grafting is a technique that joins together two plants through their stem vascular tissues in order to take advantage of their combined characteristics.

Big Idea: LS1 Molecules to Organisms

Systems of specialized cells within organisms help perform essential functions of life. Any one system in an organism is made up of numerous parts. Feedback mechanisms maintain an organism's internal conditions within certain limits and mediate behaviors.



II. Brief History and Justification

A. Origin and History:

1. The earliest record of grafting is in 500 A.D., in China. Farmers grafted gourd plants to increase fruit size.
2. Grafting moved to Europe about 50 years ago, and was introduced in Canada about 30 years ago.
3. In the 1940s, tomato grafting was practiced among gardeners in the U.S. However, this practice was not widely adopted at the time.

4. Today, vegetable grafting is being adopted as a standard production practice around the world. Crops that are most commonly grafted are tomato and watermelon.

Big Idea: ESS3 Human Sustainability:
Sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources, including the development of technologies and regulations.

B. Reasons for grafting:

1. Land shortage restricts opportunities for crop rotation
2. Soil-borne diseases such as Verticillium wilt, Fusarium wilt and Root nematode can be managed by grafting
3. Rootstocks are vigorous and can take up water and nutrients more efficiently, producing healthier, more productive plants
4. Grafted plants are more tolerant of heat stress in the greenhouse as well as in very warm climates
5. Grafting can replace need for chemical pesticides for disease control, like methyl bromide in large-scale commercial production

The efficacy of grafting as a management tool for biotic and abiotic stresses depends on certain factors like the varieties used for scion and rootstock, and environmental conditions. Grafting primarily alleviates stresses mediated by the soil and does not provide resistance to foliar diseases.

Science and Engineering Practice: Designing Solutions to Problems
Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Big Idea: Engineering

III. Grafting methods for Solanaceae crops

A. Splice grafting. Also called Japanese tube grafting, tube method, or top grafting. Practice cutting seedlings at a 45° angle if necessary. When you first start grafting, cut one rootstock and one scion at a time. As you familiarize yourself with cutting and handling of seedlings, you can cut 3-6 and up to one flat of seedlings at a time.

1. Cut the rootstock stem at a 45° angle below the cotyledons, discard rootstock tops immediately. Cutting below the rootstock eliminates rootstock shoot growth.
2. Slip appropriate size silicon tube/clip onto the rootstock stem, placing the clip so that half extends above the cut stem. Align the clip opening so that the scion can be placed accurately onto the rootstock stem for best possible surface connections; be consistent and place the tube in the same oreintation on each stem
3. Select a scion with the same size stem as the rootstock, cut the scion stem at a 45° angle; cut above or below the cotyledon as needed to attain the same stem diameter as the rootstock.

4. Slip the scion into the silicon clip so that the cut stems are in contact with each other. Adjust the scion stem so that there is no air between it and the rootstock. Do not use excess pressure when joining the stems. An asset of the clear silicon clips is being able to see that the joined stems meet each other.
5. Mist the newly grafted seedling – mist the other grafted seedlings in the same flat but do not over mist; seedlings should not be dripping wet. Avoid getting water into the graft union.
6. Place completed tray of grafted seedlings into the healing chamber. Mist plants and chamber before closing the chamber.

B. Side or tongue-approach grafting. This method requires more steps after the initial step of grafting the two plants together. It tends to have a high success rate and require less management in the weeks after grafting.

1. Place two plants side by side in a small pot, notch the stems, and attach the plants to each other.
2. Slowly trim away roots of the scion and top leaves of the rootstock over a period of 1-2 weeks, cut the top off the rootstock and the bottom off the scion plant.
3. Requires a longer time for grafting and healing, and therefore longer time until transplanting into the field and production.
4. A healing chamber is not needed as it is not necessary to have high humidity.

C. Cleft or apical grafting. Use for older, larger diameter plants and mismatched stem diameters between scion and rootstock. This technique takes more time than splice grafting. The rootstock stem may split if the scion wedge is too wide.

1. Remove the top of the rootstock below the cotyledons and cut a 0.5 cm long vertical incision into the center of the rootstock stem.
2. Cut the scion stem below the cotyledons and cut a 0.5 cm long wedge; insert the scion into the rootstock, place a plastic clip or parafilm around the graft union to hold it tightly together.
3. A healing chamber is not needed, greenhouse conditions and reduced light will work.

IV. Grafting methods for Cucurbitaceae crops:

Practice cutting scion and rootstock seedlings, because Cucurbit grafting can be challenging. When you first start grafting, cut one rootstock and one scion at a time. As you familiarize yourself with cutting and handling of seedlings, you can cut 3-6 and up to one flat of seedlings at a time.

A. One-cotyledon grafting.

1. Rootstock seedlings should have one true leaf, and scion seedlings should have two true leaves. Cut the rootstock at a 60° angle so one cotyledon remains and one is removed.
2. Cut carefully so as to keep the remaining cotyledon firmly attached to the rootstock stem. The angled cut should also remove the apical meristem in the remaining cotyledon (these are undifferentiated cells at the base of the axillary bud).
3. Remove all of the apical meristem to prevent future shoot growth of the rootstock. To better ensure that all of the axillary bud tissue has been removed, swipe the corner of the razor blade back and forth two times over the meristem area.

4. Select a scion with the same size stem as the rootstock, cut the scion at a 60° angle below the cotyledons, where its diameter matches that of the rootstock.
5. Bring the two cut stem surfaces together, and hold them in place with a grafting clip.
6. Place a small plastic straw through the clip to provide support as needed; do not use wood/bamboo as it will mold in the healing chamber.
7. Mist the grafted plants lightly with water before placing them in the healing chamber. Avoid getting water into the graft union.

B. Hole insertion grafting.

1. Rootstock seedlings should have one small true leaf, and scion seedlings should have just the cotyledons or the first true leaf just emerging.
2. With a pointed probe, remove the true leaf, the apical meristem, and the axillary buds from the topmost growing point of the rootstock plant.
3. Remove all of the apical meristem and the axillary buds to prevent future shoot growth of the rootstock.
4. Use the probe to create a hole in the top of the rootstock where the tissue was removed; leave the probe inserted in the growing point while cutting the scion.
5. Select a scion stem with smaller diameter than the diameter of the rootstock stem so that the scion can be inserted into a hole made between the two cotyledons of the rootstock.
6. Cut the scion below the cotyledons at a 45° angle on two sides to form a wedge and insert it into the rootstock as the probe is removed.
7. Oftentimes, the scion cotyledons are positioned to avoid overlap with the rootstock cotyledons; however, this is not necessary as long as the cut surfaces are oriented so that they are in good contact.
8. Mist the grafted plants lightly with water and place in healing chamber. Avoid getting water into the graft union.

V. Grafted Plant Care – see handout *Caring for Your Grafted Tomato Plants* in this guide.

1. Transplanting grafted seedlings – do not plant the graft below the soil level or you will negate the reason for grafting.
2. Do not transplant to the field under very windy conditions. If it is necessary to transplant in these conditions, add a small stick by each plant for support. Wood stirring sticks work well for this purpose.

VI. Resource Information

On-line Fact Sheets

Vegetable Grafting: The Healing Chamber. WSU Extension Fact Sheet FS051E 3 pages. Published October 2011, reviewed July 2016.

Vegetable Grafting: Watermelon. WSU Extension Fact Sheet FS100E 7 pages. Published January 2013, reviewed June 2016.

Vegetable Grafting: Eggplant and Tomato. WSU Extension Fact Sheet FS052E 4 pages. Published October 2011.

Español

Injertos Hortícolas: SandÍa. Hoja de datos de la Extensión, Universidad Estatal de Washington FS100ES. 7 páginas. Publicado enero 2014.

Injerto de Verduras: Berenjenas y Tomates. Hoja informativa de la Universided Estatal de Washington FS052ES. 4 páginas. Publicado Agosto 2013

Online Presentations
Grafting Healing Chamber. Sacha Johnson, Carol Miles, Patti Kreider, Jonathan Roozen, Jacky King and Gale Sterrett, Washington State University. How to construct and manage a healing chamber for grafted vegetables. 2011.

History of Vegetable Grafting. Sacha Johnson, Carol Miles, Patti Kreider, Jonathan Roozen, Jacky King and Gale Sterrett, Washington State University. Summary of the history of vegetable grafting. Includes first known uses of vegetable grafting and current uses. 2011.

How to Graft Tomatoes and Eggplant. Sacha Johnson, Carol Miles, Patti Kreider, Jonathan Roozen, Jacky King and Gale Sterrett, Washington State University. Highlights splice grafting for tomato and eggplant, and how to manage newly grafted plants. 2011.

Transplanting Grafted Plants to the Field. Sacha Johnson, Carol Miles, Patti Kreider, Jonathan Roozen, Jacky King and Gale Sterrett, Washington State University. Reviews procedures and considerations for transplanting grafted vegetables into the field. 2011.

Science and Engineering Practice:
Obtain Combine and Communicate Information
Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source


Activity: Learn how to graft and become vegetable grafter

- Learn how to use methods to graft tomato and watermelon
- Students will use common rootstocks for each crop and will graft 6 plants of each crop

Science and Engineering Practices: Designing and Conducting Investigations

Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled.

I. Supplies

A. Tools of the trade:

1. Planting trays (72-cell works well), potting mix, seeds, 6-packs (easy to distribute plants to students)
2. Grafting clips of the appropriate sizes; need to order in advance
3. Humidity/healing chamber – plastic tub or construct appropriate size, see WSU factsheet *Vegetable Grafting: The Healing Chamber* at http://cru.cahe.wsu.edu/CEPublications/FS051E/FS051E.pdf
4. Razor blades – double-edged blades are preferred as they are very thin, economical and readily available; bend in half to break in half. Can also use single edged blades or a variety of knives
5. Disinfectant: 9 parts water plus 1 part Clorox = 10% Clorox solution; or rubbing alcohol, 70% ethanol, or hand sanitizer
6. Use close-fitting latex gloves if you prefer
7. Spray bottles: 1 for disinfectant and 1 for fresh water; label each clearly
8. Guide for cutting angle (use an index card cut at a 45° angle)

II. Grafting Preparation Prior to Grafting - adapt to your situation and environment; the following is our successful process:

A. Choose rootstock and scions for suitability for your needs:

1. The scion and rootstock seedlings may not germinate or grow at the same rates, so it is important to conduct a preliminary test to determine their growth rates in your growing environment.

2. Perform a test to determine the growth rate of scion and rootstock varieties in your environment; there can be up to a 7-12 days difference in growth rate between scion and rootstock to reach appropriate and compatible stem diameters for grafting.
3. Seed scion in one tray and rootstock in another tray; label trays with names and dates, color code for visual recognition.
4. Seed more plants than necessary so you have a greater selection when matching stem diameters.
5. Adjust growth rates if needed: increase temperature to speed up growth and lower temperatures to slow down growth.
6. Prepare rootstock for grafting two days before graft date - place seedlings in every other cell to allow for airspace in the healing process. Sort by size for ease of selecting stem diameters for grafting.
7. Water both rootstock and scion well the night before grafting and make sure they are well drained; do not water the morning before grafting. If you water plants the day of grafting, this can cause a water bubble to form at the surface of the cut stem, and this will prevent the rootstock and scion from forming a tight union.
8. To reduce plant transpiration and trauma, graft in the morning or late afternoon in a cool place protected from the direct sunshine and to avoid drying of the cut surfaces of the seedlings.

III. Preparations on the Day of Grafting

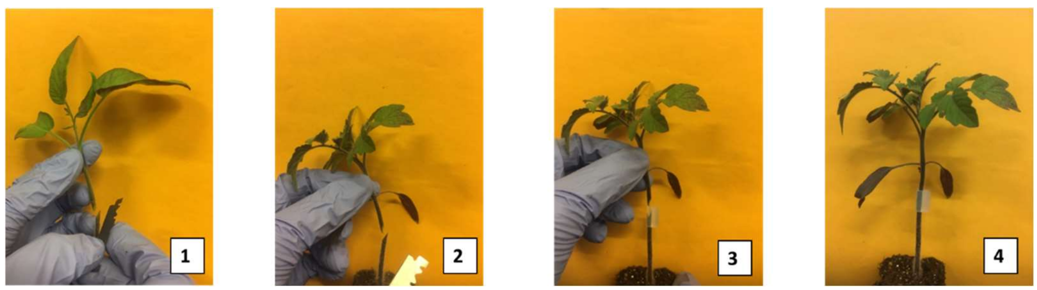
1. A clean area such as work bench, with no direct sunlight is required for grafting. If needed, place a shade cloth over your grafting space to block out direct sunlight.
2. Select a grafting space that is comfortable for your body – height of table, chair, etc.
3. Grafting is commonly done in a greenhouse, but a shaded area may be needed so that temperature is 21-23 ºC (70-73 ºF).
4. Do not graft near a fan to protect the plants from water loss and avoid disturbance to the graft union.
5. Have all your grafting supplies laid out and ready to use.
6. Fill a labeled spray bottle with disinfectant, disinfect hands and supplies.
7. Fill a spray bottle with fresh tap water.
8. Spray healing chamber with water before starting to graft, seal the chamber to retain humidity.
9. Place rootstock tray on your left and scion tray on your right; place a container on your left for discarded rootstock tops; be consistent with this arrangement to avoid confusion.
10. If using double edged razor blades, bend the blade in half to snap it; use one half of the blade for cutting the rootstock and the other half for cutting the scion. Discard the razor blade as soon as it appears dull; a sharp blade makes a clean cut.
11. It may be helpful to create a 45º or 60º angle template to become familiar with the angle cut; practice by cutting extra seedlings.
    a. Xylem tubes conduct water and water soluble nutrients from the roots up to the leaves.
    b. Phloem tubes conduct sugar compounds and hormones from the leaves down to the roots.

c. Cambium cells are responsible for stem growth and make new xylem and phloem tissue.
d. All tissues must be aligned correctly for a successful graft.

12. If reusing grafting clips, wash them in warm, soapy water, sterilize them by soaking for 1 minute in a 10% bleach solution, and rinse them under tap water. Allow the clips to air-dry before reuse.

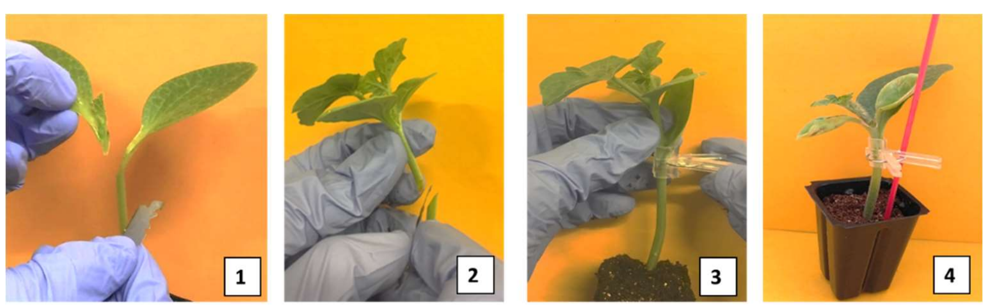
IV. Illustration of grafting methods:

A. Splice grafting:



Step 1. Cut the rootstock at 45° angle, under the cotyledon leaves
Step 2. Cut the scion at 45° angle, ensuring the diameter is the same as the rootstock
Step 3. Place a grafting clip onto the rootstock, rootstocks should occupy half the length of the clip
Step 4. Place the scion into the grafting clip

B. One cotyledon grafting method:



Step 1. Cut the rootstock at a 60° angle with one cotyledon remaining on the plant
Step 2. Cut the scion at a 60° angle below the cotyledons, where its diameter matches that of the rootstock
Step 3. Join the two cut stems together
Step 4. Secure with a grafting clip.

V. Healing Protocol

The healing chamber should be maintained at 75ºF to 85ºF with 100% humidity; the temperature inside the healing chamber is generally 10ºF higher than the temperature of the surrounding area, and if direct sunlight hits the chamber, the temperature can be even higher. Temperatures vary at night; do not let temperatures in the chamber drop below 70ºF. If temperatures go above 95ºF, seedlings can die. In the following schedule, Day 1 is the day of grafting, and all chamber openings are during the day.

Day 1. Close plastic of healing chamber; cover chamber with black fabric.
Day 2. Keep chamber closed and covered with black fabric.
Day 3. Open the chamber add water to chamber floor if needed (should be wet) close the chamber and fold the black fabric up and away from the front of the chamber.
Day 4. Open chamber for 15 minutes, wet floor of chamber if needed, reclose chamber, and fold black fabric half way up all sides of the chamber.
Day 5. Open chamber for 30 minutes, wet floor of chamber if needed, reclose chamber, and remove black fabric from sides but keep top covered.
Day 6. Open chamber for 1 hour, wet floor of chamber if needed, reclose chamber, and remove black fabric entirely.
Day 7. Open the chamber for 3 hours, wet floor of chamber if needed, reclose the chamber.
Day 8. Open chamber for 6 hours, wet floor of chamber if needed, reclose chamber
Day 9. Remove plants from the chamber and water them.

For detailed protocol for healing grafted tomato and eggplant – see *Vegetable Grafting: The Healing Chamber* at http://cru.cahe.wsu.edu/CEPublications/FS051E/FS051E.pdf
For detailed protocol for healing grafted watermelon – see *Vegetable Grafting: The Healing Chamber* at http://cru.cahe.wsu.edu/CEPublications/FS100E/FS100E.pdf

Big Idea: LS1 Homeostasis
Feedback mechanisms maintain an organism's internal conditions within certain limits and mediate behaviors.

Evaluation of Knowledge Gained

Please provide two responses for each statement: 1) in the column "BEFORE the class activity" mark the response that best represents your knowledge *now, before participating in the activity*; and 2) in the shaded section labeled "AFTER the activity", mark the response that best represents your knowledge *after your participation in the activity.*

1. I am **familiar** with the following:

BEFORE the acitivity						AFTER the activity				
Not at all				Totally		Not at all				Totally
1	2	3	4	5		1	2	3	4	5
○	○	○	○	○	The concept of vegetable grafting	○	○	○	○	○
○	○	○	○	○	History of vegetable grafting	○	○	○	○	○
○	○	○	○	○	The term "scion"	○	○	○	○	○
○	○	○	○	○	The term "rootstock"	○	○	○	○	○
○	○	○	○	○	Disease problems that can be solved by vegetable grafting	○	○	○	○	○
○	○	○	○	○	Different methods of vegetable grafting	○	○	○	○	○
○	○	○	○	○	Need for a healing chamber to heal newly grafted plants	○	○	○	○	○

2. I am **aware** of the following:

BEFORE the activity						AFTER the activity				
Not at all				Totally		Not at all				Totally
1	2	3	4	5		1	2	3	4	5
○	○	○	○	○	Ability to graft my own vegetable plants	○	○	○	○	○
○	○	○	○	○	Stem size compatibility between rootstock and scion	○	○	○	○	○
○	○	○	○	○	Correct size of plants for grafting	○	○	○	○	○
○	○	○	○	○	Temperature requirements for the healing chamber	○	○	○	○	○
○	○	○	○	○	Relative humidity requirements for the healing chamber	○	○	○	○	○

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HOW TO GRAFT WATERMELON

There are two techniques commonly used for grafting watermelon. Deciding which technique to use depends on quantity of plants to be grafted, the size of the plant material, and personal preference.

Seeding Scion and Rootstock

For a successful graft union to form, the cambium of the rootstock and scion must be well aligned and in contact with one another. The cambium is a thin layer of actively dividing cells just inside the outer surface of the stem. The scion and rootstock plants must therefore have similar stem diameters at the time of grafting.

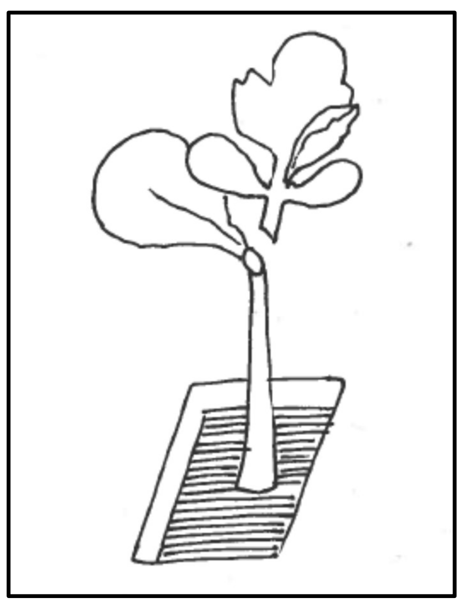
Seed both scion and rootstock varieties 14-16 days before the desired grafting date. The scion and rootstock may not germinate or grow at the same rate. Do a preliminary trial to determine the growth rates of rootstock and scion plants in your growing environment; based on results, seed them at different times for grafting.

Seed more plants than necessary, so there is a greater selection for matching stem diameters. It is rare to get 100% graft survival, so graft additional plants to account for some graft failure.

Grafting

Plants are ready for grafting when they have 1-2 true leaves. Graft when plant transpiration is lowest, such as early in the morning, to reduce water stress in the newly grafted plants.

Water both rootstock and scion plants 12-24 hours before grafting. If reusing grafting clips, make sure they have been sterilized. Razor blades must be clean, and hands sanitized with antibacterial soap or hand gel. Fill a spray bottle with tap water and mist plants frequently while grafting.



One-cotyledon grafting

Also known as the splice graft, this is the most popular method used for watermelon and melons in Korea, Europe and North America.

- Technique. Rootstock seedlings should have one true leaf, and scion seedlings should have two true leaves.
  a. Cut the rootstock at a 60° angle so one cotyledon remains and one is removed. The angled cut should also remove the apical meristem in the remaining cotyledon.

b. Cut the scion at a 60° angle below the cotyledons, where its diameter matches that of the rootstock.
c. Bring the two cut stem surfaces together, and hold them in place with a grafting clip.
d. Place a small plastic straw through the clip to provide support as needed.

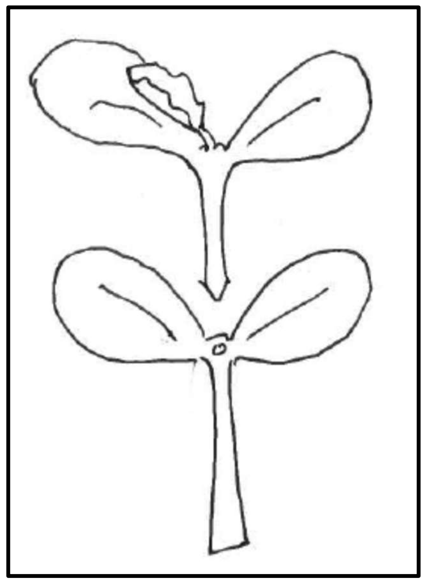
- Advantages. Due to the procedure's simplicity and speed as well as the relatively low rate of rootstock regrowth (2-3%), it has become the most commonly used manual grafting method for watermelon.

- Disadvantages. This method requires careful control of humidity, light, and temperature after grafting. High losses and possible diseases or physiological disorders may occur if the healing environment is not optimal. Some meristem tissue may remain in the rootstock, requiring removal later in the production cycle.

Hole Insertion Grafting

The most widely used method for watermelon and melon grafting in China and Japan

- Technique.
  a. Remove the true leaf, the apical meristem, and the axillary buds from the topmost growing point of the rootstock plant with a pointed probe.
  b. Use the probe to create a hole in the top of the rootstock where the tissue was removed.
  c. Cut the scion below the cotyledons at a 45° angle on two sides to form a wedge.
  d. Insert the scion into the rootstock as the probe is removed.



- Advantages. This method tends to have a high success rate with relatively minimal management during the healing period. A grafting clip is not essential, which saves time and labor involved in collecting grafting clips after healing.

- Disadvantages. Requires slightly more skill than most other grafting techniques. It may require more time to graft than some of the other grafting techniques depending on the grafter's skill and the grafting operation. Regrowth of the rootstock will occur if not all the meristem tissue has been removed.

Science and Engineering Practice: Conducting Investigations
Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.

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HOW TO GRAFT TOMATO AND EGGPLANT

The same techniques are used for to graft tomato and eggplant. For a successful graft union to form, the rootstock and scion plants must have a similar stem diameter at the time of grafting so that the cambium of the plants are well aligned and in contact with one another. The cambium is a thin layer of actively dividing cells just inside the outer surface of the stem.

Seed both scion and rootstock varieties 14-21 days before the desired grafting date. The scion and rootstock may not germinate or grow at the same rate. Do a preliminary trial to determine the growth rates of rootstock and scion plants in your growing environment; based on results, seed them at different times for grafting.

Seed more plants than necessary, so there is a greater selection for matching stem diameters. It is rare to get 100% graft survival, so graft additional plants to account for some graft failure.

Grafting

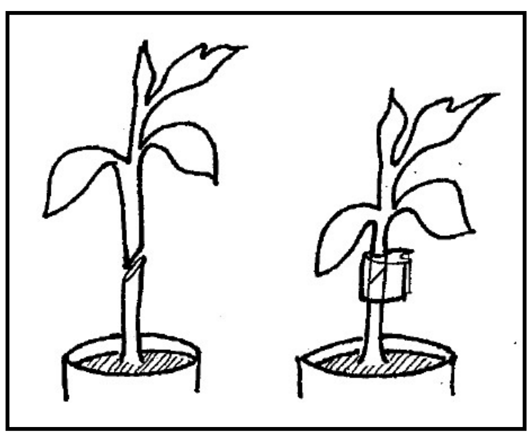
Plants are ready for grafting when they have 1-2 true leaves. Graft when plant transpiration is lowest, such as early in the morning, to reduce water stress in the newly grafted plants.

Water both rootstock and scion plants 12-24 hours before grafting. If reusing grafting clips, make sure they have been sterilized. Razor blades must be clean, and hands sanitized with antibacterial soap or hand gel. Fill a spray bottle with tap water and mist plants frequently while grafting.

Splice Grafting

The **splice grafting technique**, also known as top grafting, tube grafting and slant-cut grafting, is the most commonly used grafting method because it has a high success rate (95%), is relatively simple, and can be used to graft a large number of plants in a short amount of time.

- Technique.
  a. Cut the rootstock stem at a 45° angle below the cotyledons to prevent rootstock regrowth. Discard rootstock tops immediately.
  b. Select a scion with a stem diameter that matches the rootstock stem diameter, and cut at a 45° angle either above or below the cotyledons; choose the scion stem location that best matches the rootstock diameter.
  c. Slip a silicone grafting clip onto the rootstock.
  d. Slip the scion into grafting slip such that cut surfaces of both stems are in close contact and



air is not trapped between them. If the cut surface of the scion or the rootstock dries out, the graft will fail.

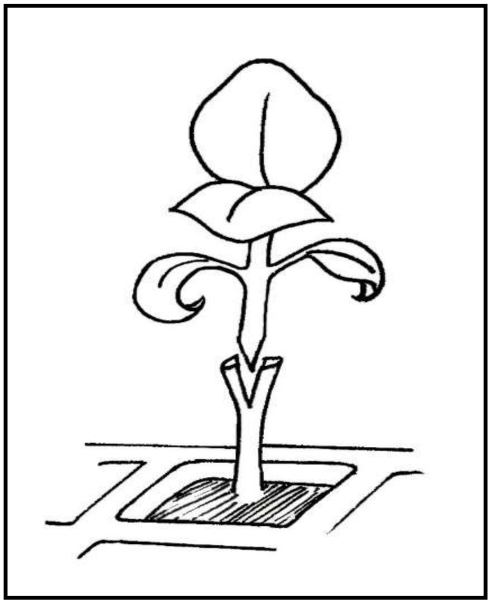
e. Once you are comfortable with the grafting process, you can cut multiple rootstocks and scions at once to speed up the process.

- Advantages. Easy technique to learn, and a fast way to graft large quantities of plants.

- Disadvantages. Grafting clips are required to hold scion and rootstock in close contact. A healing chamber is needed to provide high humidity.

Cleft Grafting

The **cleft grafting technique**, also known as apical grafting or wedge grafting, is used for solanaceous crops. This technique is used when plants are too large for splice grafting, and to utilize plants that otherwise might be thrown away.



- Technique.
  a. Cut straight across the top of the rootstock below the cotyledons.
  b. Cut a 0.5 cm long vertical incision into the center of the rootstock stem.
  c. Cut the scion stem below the cotyledons and cut a 0.5 cm long wedge.
  d. Insert the scion into the rootstock, place a plastic clip or parafilm around the graft union to hold it tightly together.

- Advantages. The cleft cut holds the scion more tightly than splice grafting, so it is possible to use parafilm rather than grafting clips to secure the graft union.

- Disadvantages. This technique takes more time than splice grafting. The rootstock stem may split if the scion wedge is too wide.

Big Idea: Engineering Design: Optimizing Solutions

Optimizing the design solution involves a process in which solutions are systematically tested and refined and the final design is improved by trading off less important features for those that are more important.

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HEALING GRAFTED PLANTS

Big Idea: LS1 Homeostasis

Feedback mechanisms maintain an organism's internal conditions within certain limits and mediate behaviors.

CROSSCUTTING CONCEPT: STABILITY AND CHANGE

science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems over very short or very long periods of time. They see some changes are irreversible, and negative feedback can stabilize a system, while positive feedback can destabilize it. They recognize systems can be designed for greater or lesser stability

Immediately after grafting, place plants in a healing chamber. Plants will remain in the chamber for 9 days, and then placed on the greenhouse bench for 5 days to acclimatize. Although vascular connection is established between scion and rootstock at approximately 7 days after grafting, it takes at least 14 days after grafting for the graft union to fully heal.

Healing Chamber

A healing chamber is a covered structure that allows grafted plants to heal by maximizing humidity, reducing light, and minimizing water loss from the scion (the top portion of the grafted plant). Healing chambers can range in size depending on the number of grafted plants you have. The height of the healing chamber should be 1–3 feet, and provide about 6–8 inches of air space between the top of the plants and the top of the chamber.

If you have more than 2 seedling flats of grafted plants, an economical healing chamber can be made out of PVC pipe and covered with clear plastic. If you have a very small number of plants, a medium or large sized clear plastic container with a lid can make an ideal healing chamber (Figure 1). Cover the top of the chamber with black plastic, shadecloth, cardboard or any other solid material to block light and reduce photosynthesis, which causes plants to transpire and lose water. For more information on how to construct a healing chamber, see *Vegetable Grafting: The Healing Chamber* at http://cru.cahe.wsu.edu/CEPublications/FS051E/FS051E.pdf.

Figure 1. Healing chamber made of PVC pipe and clear plastic with a top layer of shadecloth, and a healing chamber made from a clear plastic tub inverted so the lid is at the bottom.

Healing the Grafted Plants

The healing chamber should be maintained at 95–100% humidity for all crops. The temperature in the chamber should be 75°F for watermelon and 75°F to 80°F for tomato and eggplant. Be aware that the temperature inside the healing chamber is generally 5°F higher than the temperature of the surrounding area; and if direct sunlight hits the chamber, the temperature can be even higher. Temperatures vary at night; do not let temperatures in the chamber drop below 70°F. If temperatures go above 90°F, seedlings can die.

It is necessary to maintain the humidity and temperature during the healing period, especially during the first 48-72 hours after grafting. After the critical 72 hours, gradual reduce the humidity and increase the amount of light to complete graft healing and prevent disease.

A few hours before grafting, spray the inner surfaces of the healing chamber with water and add a thin layer of water to the chamber floor to raise the relative humidity to about 95% within the chamber. Mist the newly grafted plants before placing them in the chamber, avoid over-misting the plants.

The following schedule lists the steps to take each day of the healing process. Day 1 is the day of grafting, and all chamber openings are during the day. This healing schedule is based on our greenhouse grafting environment. Your greenhouse or grafting environment may be different (higher or lower humidity and temperature), and so you may need to adjust the exposure times. Misting and watering plants during healing is a judgement call, and you will need to determine how much water is needed to keep plants at 100% humidity but not overly wet. You may need to adjust the exposure times for grafted plants so they are not stressed when introducing them back into the greenhouse environment. The key is to slowly acclimatize the grafted plants without causing permanent wilting which will lead to plant death.

Day 1. Close plastic of healing chamber; cover chamber with black fabric.
Day 2. Keep chamber closed and covered with black fabric.
Day 3. Open the chamber add water to chamber floor if needed (should be wet) close the chamber, and fold the black fabric up and away from the front of the chamber.

Day 4. Open chamber for 15 minutes, wet floor of chamber if needed, reclose chamber, and fold black fabric half way up all sides of the chamber.
Day 5. Open chamber for 30 minutes, wet floor of chamber if needed, reclose chamber, and remove black fabric from sides but keep top covered.
Day 6. Open chamber for 1 hour, wet floor of chamber if needed, reclose chamber, and remove black fabric entirely.
Day 7. Open the chamber for 3 hours, wet floor of chamber if needed, reclose the chamber.
Day 8. Open chamber for 6 hours, wet floor of chamber if needed, reclose chamber
Day 9. Remove plants from the chamber and water them.

For detailed protocol for healing grafted tomato and eggplant – see *Vegetable Grafting: The Healing Chamber* at http://cru.cahe.wsu.edu/CEPublications/FS051E/FS051E.pdf
For detailed protocol for healing grafted watermelon – see *Vegetable Grafting: The Healing Chamber* at http://cru.cahe.wsu.edu/CEPublications/FS100E/FS100E.pdf

Acclimatizing Grafted Plants
After removing plants from the healing chamber, allow them to rest in the greenhouse for 5 days, and then move them outside for 3 days, so they can harden off before transplanting. Adjust this schedule as needed if plants appear stressed when they are introduced into each new environment. Keep the grafted plants in a warm, sunny location. Water transplants lightly every day or as needed to keep soil moist but not saturated. If plants wilt, mist the leaves and water lightly 2-3 times per day. Apply a low rate of water-soluble fertilizer once per week. If the grafted plants cannot be transplanted within 1-2 weeks, consider repotting them into larger 4 inch or 1 gallon pots.

Transplanting

Place the plant in the transplant hole so that the graft union is at least 1 inch above the soil surface (Figure 2). If the graft union is buried, the scion will root into the soil, and any advantages provided by the rootstock, such as resistance to soil-borne diseases, will be lost. Leave the clips on to provide extra support, especially in windy conditions. Do not place grafted transplants into the field under very windy conditions. Grafting clips generally do not fall off the stem as the stem increases in diameter, so be sure to remove them 1-2 weeks after transplanting.

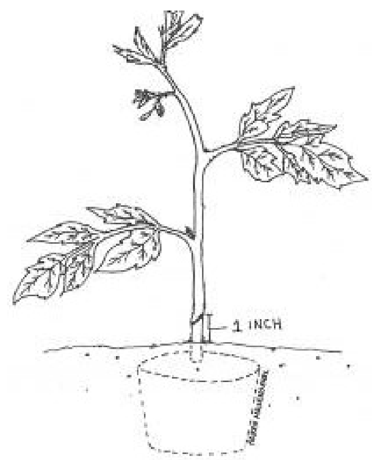

Figure 2. Place grafted plant in transplant hole such that the graft union is at least 1 inch above the soil surface.

Resource Information

WSU web page: Grafting Vegetables http://vegetables.wsu.edu/graftingVegetables.html

Vegetable Grafting: Eggplant and Tomato, Sacha Johnson, Carol Miles, and Patti Kreider. http://cru.cahe.wsu.edu/CEPublications/FS052E/FS052E.pdf

Vegetable Grafting: Watermelon, Carol Miles, Lynette Hesnault, Sacha Johnson, Patti Kreider, and Sahar Dabirian. http://cru.cahe.wsu.edu/CEPublications/FS100E/FS100E.pdf

Vegetable Grafting: The Healing Chamber, Sacha Johnson, Carol Miles, Patti Kreider, and Jonathan Roozen. http://cru.cahe.wsu.edu/CEPublications/FS051E/FS051E.pdf