Grafting Manual:
How to Produce Grafted Vegetable Plants

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Synopsis:
Minimizing the spread of diseases and utilizing proper IPM techniques are instrumental to a successful propagation system for grafted vegetables. In addition to protecting this high value crop, it is essential for propagators to minimize the spread of disease in order to maintain good relations with the market.

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USDA United States Department of Agriculture National Institute of Food and Agriculture

Minimizing the spread of plant diseases when producing grafted plants

Why is it important?

Minimizing the spread of diseases and utilizing proper IPM techniques are instrumental to a successful propagation system for grafted vegetables. When compared to nongrafted vegetable transplants, grafted ones have a higher input cost, and research has shown that the additional costs required by a propagator could range from \$0.46 to \$0.74 per plant in the case of grafted tomato (Rivard et al., 2010). Similarly, grafted plants often provide a premium price and their production has been shown to more effectively generate profit in relation to the amount of greenhouse space that they consume, compared to similar nongrafted tomato transplants (Rivard et al., 2010). Therefore, protecting the investment that they require as well as their high value in the market is critical throughout grafted plant propagation.

In addition to protecting this high value crop, it is essential for propagators to minimize the spread of disease in order to maintain good relations with the market. Grafted transplants are most typically utilized in intensive production systems like greenhouses and high tunnels, and are often used in organic and/or local production of heirloom varieties or other specialty cultivars. This results in plants that generate high "per plant" revenue and diseased or lost plants come at a very high opportunity cost to the grower. Furthermore, certain diseases such as bacterial canker for tomato, caused by *Clavibacter michiganensis spp. michiganensis* (*Cmm*), is transmittable by grafting and can lead to tremendous economic damage to greenhouse and high tunnel operations annually. Using "clean seeds and plants" is recommended for bacterial canker prevention in these production systems.

During the grafting process, the plants are subjected to several activities that significantly increase the likelihood of spreading pathogens, which could potentially lead to disease epidemics. The grafting procedure itself includes severing the stem of both the rootstock and scion, which becomes an entry point for viruses and bacteria. Grafting clips are then utilized, which could contaminate or even provide an ideal micro-environment for pathogen infection and colonization of plant tissues. Additionally, during the healing process, grafted plants are placed in a high humidity environment where typically there is low light level (Fig.1). This environment is an ideal place for fungal pathogens like *Botrytis cinerea* and others to cause rapid disease outbreaks.

Principles of plant health

When propagating grafted transplants, all steps of the production system should utilize practices that promote plant health and maximize plant quality. Transplants should be exposed to high light conditions throughout production in order to promote root growth and function (Fig 2).

Proper fertility management is also important to support healthy plant growth. Prior to grafting, transplants should be grown in a relatively low humidity environment to reduce the spread of botrytis (Fig. 3) and other diseases.

Figure 1. A batch of grafted plants in a healing chamber.

Figure 2. Use transplants that are healthy and show no evidence of nutrient stress or disease when grafting.

Similarly, circulation fans and proper greenhouse ventilation can help reduce the chances of spreading botrytis. Substrates and/or potting mixes should be selected to maximize drainage and oxygen availability to roots. Similarly, plants should not be water-logged during the growth period in order to reduce diseases caused by root rotting pathogens.

Good sanitation practices should always be used in the greenhouse environment and particularly when plants are being grafted. Conventional propagators may find value in utilizing a preventative fungicide program prior to grafting in order to reduce the incidence of botrytis amongst transplants in the healing chamber.

Identify the risk points in the system

As with any prevention program, the first step is to identify the points in the propagation system where there is risk of introducing pathogens that could lead to disease. In grafted vegetable propagation systems, there are a number of points where management practices can lead to the introduction of plant pathogens (inoculum) or help spread the disease through the grafting process or healing chamber environment.

1. ***Seedborne pathogens*** can enter the propagation system through contaminated seed

Figure 3. Fungal growth on a failed graft in the healing chamber.

material. Using certified "clean" seed that is free from *Cmm* (tomato) and *Acidovorax avenae* spp. *citrulli* is recommended. If saving seed or using seed that has not been treated, seed treatment recommendations for solanaceous (Jones et al., 2014) and cucurbit (Keinath et al., 2018) crops should be utilized.

2. ***Soil mix and substrate*** can be a source of inoculum for numerous root-rotting and damping-off pathogens. It is not recommended to use compost or any other amendment that could be a source of plant pathogens in the healing chamber. Furthermore, potting mix should promote good drainage and oxygen availability to plant roots in order to reduce microbial growth in the substrate. This is best achieved by using soilless potting media with no carbon-rich amendments added.

3. ***Plastic and containers*** are a potential source of pathogen inoculum when re-used without disinfesting properly. Due to the need to grow scion and rootstock as well as the short turnaround time for scion production, propagators may be inclined to re-use propagation and/or web trays. All plastic should be properly disinfested with a horticultural cleaner such as the ones listed in Table 1. Using new plastic for the rootstocks reduces the chance of introducing plant pathogens into the healing chamber.

4. ***The growing environment***, that is, the greenhouse itself plays a major role in disease outbreaks when growing grafted vegetable transplants. Common greenhouse diseases, such as botrytis, can become a major issue when moved into the suitable environment of the healing chamber. Propagators should utilize strict sanitation methods and other proce-

Table 1. Some Common Horticultural Disinfectants

Disinfectant	Trade Names	Exposure time	Notes:
Ammonium Chloride	Green Shield, Triathlon, Physan 20	10 minutes	Must be kept wet for 10 minutes
Chlorine Dioxide	Selectrocide	contact	Gas for cleaning GH surfaces
Ethanol	95% or 70% rubbing alcohol	contact	Do not use near open flames
Hydrogen Peroxide	Zerotol, Oxidate	contact	Does not penetrate wood well
Sodium Hypochlorite	Bleach	10 minutes	Use 10% bleach, rinse after use

(Adapted from Kleczewski and Egel, 2011) dures to reduce inoculum of *B. cinerea.* This pathogen lives on dead plant tissue so removing dead (brown) tissue from all plants within the greenhouse can reduce the presence of this pathogen. Other cultural management techniques such as proper temperature and humidity management, as well as improving air circulation are also useful strategies for reducing this disease (Pundt, 2012).

5. ***Healing chamber materials*** should be set up and clean before grafting begins. Be sure to build the chamber out of materials that are cleanable and do not support microbial survival or growth. For example, wood is not recommended for the chamber frame. Plastic lumber, polyvinylchloride (PVC) pipe, electrical conduit, and heavy-gauge metal wire are all suitable materials for a healing chamber frame (Fig 4.) and can be appropriately disinfested between uses.

Plastic that is used for the chamber covering can be re-used, but should be thoroughly cleaned between uses. Any organic matter (e.g., potting mix residue, algae, etc.) should be removed before disinfesting with one of the cleaners listed in Table 1. If using bleach or other strong cleaners, it's a good idea to rinse the plastic and other chamber materials with clean tap water in order to prevent unwanted phytotoxicity from the cleaning products.

6. ***Grafting knives and blades*** make direct contact with the severed rootstock and scion stems and subsequent graft union. This provides a perfect entry point for viruses and bacterial pathogens. Therefore, it is critical to be sure that knives and blades are cleaned properly with little chemical residue that could cause phytotoxicity to the plant. Ethyl or Isopropyl alcohol can be used to clean grafting knives, which will evaporate, leaving little to no residue (Fig. 5). In large grafting nurseries, other sanitizers such as ammonia are often used. Bleach is not recommended for cleaning grafting knives or blades, but can be used if thoroughly rinsed afterwards.

In order to reduce the spread of bacterial diseases in tomato, like *Cmm*, knives and blades should be cleaned often during the grafting process. Depending on the scale of propagation, this could be every 1-20 plants. Similarly, careful steps should be taken during grafting so that knives and blades are kept clean to reduce contamination from plant pathogens.

7. ***Grafting clips*** also make direct contact with the graft union so it is critical that they are cleaned and free of chemical residues. If grafting clips are being re-used, they should be cleaned thoroughly so that no organic material or potting mix is evident. Once the organic matter is removed, they can be disinfested with bleach or horticultural cleaners. Be sure to rinse grafting clips with clean tap water after disinfesting with bleach so that the plant is not exposed to harmful chemical residues. Similarly, follow the label of horticultural cleaners to reduce potential phytotoxicity from chemical residues.

Figure 4. A healing chamber made from plastic lumber, heavy-gauge wire, and poly film is cleanable with horticultural disinfestants. Use upside-down nursery trays to keep the plants out of any standing water.

Healing chamber management practices

In addition to taking steps to reduce the risk of introduction of plant pathogen inoculum, managing the healing chamber properly will help reduce the spread of disease. Unfortunately, the warm temperatures, high humidity, and low light environment that the plants require during the first 24-72 hours post-grafting is very suitable for many pathogens to cause plant diseases.

The goal of the healing chamber manager is to minimize the time that the plants are under such conditions (Fig. 6). Although high humidity (>85%) may be desired initially, research has shown that relative humidity levels in the chamber may get as low as 55-60% with little effect on graft survivability in tomato (Masterson et al., 2016). Cucurbit crops may require higher relative humidity. Similarly, light should be reintroduced as quickly as possible without causing major wilting issues. Since plant pathogens and newly-grafted plants enjoy similar environmental conditions, it's important to minimize the time that plants are exposed to very high humidity levels in the healing chamber.

Figure 5. A "painting tray" can be used to hold alcohol for sanitizing grafting knives and to keep the grafting clips clean and dry.

Proper scouting and regular inspections of the grafted plants within the healing chamber are also important for reducing the spread of disease. If plants are suspected of being diseased or a source of inoculum, they should be immediately removed from the healing chamber. At some point during the healing process, the plants may need to be watered and soil moisture should be regularly monitored throughout. When watering grafted plants, be sure to use clean tap water to prevent the introduction of plant pathogens. Do not allow roots to become water-logged as it will lead to disease or even poor graft union formation.

Although little research is currently available, there is some anecdotal evidence that wilting or other physical damage to the plants during the healing process can provide entry points for pathogens that may cause latent infections. Latent infections do not show signs or symptoms until later even though the infection was made in the healing chamber. However, oftentimes symptoms are not obvious until transplanting into the field or greenhouse for production. Careful steps should be taken to ensure that plant wilting does not occur in order to maintain the physical integrity of the scion and potentially reduce the chance of latent infections by plant pathogens.

Systems approach for grafted propagation

There is no one critical step for reducing the spread of all plant disease when propagating grafted transplants. Propagators should focus on designing propagation systems that limit the introduction of plant pathogen inoculum and minimize the environmental conditions that can lead to disease. This can be done throughout the grafted propagation process. In particular, the entire greenhouse or growing space should follow good IPM practices including detailed sanitation. Rootstock and scion seeds should be free from pathogens and all steps of the process should be performed with materials that can be cleaned and are free of potential sources of inoculum.

Careful attention should be paid to substrate, growing containers, and healing chamber materials. Similarly, all plants that are being introduced into the healing chamber should be healthy and free of disease. Finally, plants should be moved as quickly as possible through the healing process with little visible plant damage or wilt in order to reduce the risk of latent infections post-grafting. When using a systems approach, it is critical that all steps of the system are utilized in order to maximize the benefits. By preventing the entry of pathogen inoculum and minimizing the environment that is suitable for disease, propagators can effectively reduce the spread of pathogens when growing grafted transplants, which are a high-value crop with a growing market in the United States.

Figure 6. The chamber is vented for short to long periods of time in the last few days of healing to prevent too much humidity from causing disease.

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