13. Quality of planting materials

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INTRODUCTION

Use of high quality planting materials is critical for success in greenhouse plant production. Good propagation capacity must develop together with expanding greenhouse crop production. Some farmers grow their own transplants, while others purchase them from a specialized nursery. When and where to get planting materials must be identified before planning greenhouse production. Proximity to nurseries which might supply transplants is a factor in the site selection of greenhouse production facilities: a long distance from the supplier may preclude the purchasing of transplants. The supply of planting materials (seeds and transplants) must be precisely scheduled for each production cycle. Good coordination skills are required to effectively work with nurseries, especially commercial nurseries, as timing of production and timely delivery of transplants are critical. Whether transplants are produced in-house or purchased from commercial nurseries, care must be taken to follow good agricultural practices to avoid introducing diseases and pests to the production greenhouse through seeds and transplants.

A good transplant is usually defined by the grower's specifications. According to the grower's preferences, different management techniques may be required. For example, home gardeners may favour robust, succulent plants, while commercial farmers may select more hardened plants. No simple procedure can be followed in growing vegetable transplants, and only through experience can you begin to produce a consistent product. In general, vegetable transplants should be stocky, green and pest-free with a well-developed root system. Once transplanted, they should tolerate environmental challenges and continue growing to achieve optimum yield. Overly hardened or underfertilized transplants may not establish quickly, resulting in delayed maturity and reduced yields. Insufficiently hardened or over-fertilized plants may succumb to disease or abiotic stresses. The ideal technique for growing transplants is to raise the plant from start to finish by slow, steady, uninterrupted growth and with minimal stress. Since ideal growing conditions rarely exist, plant growth needs to be controlled through the manipulation of water, temperature and fertilizer.

SEEDS

Potential seed problems are: unexpected low germination rate, contamination with different species and introduction of seed-borne diseases. For example, bacterial canker of tomato (*Clavibacter michiganensis* subsp. *michiganensis*) is a notorious seed-borne pathogen and outbreaks occur annually in tomato production areas worldwide (ASTA, 2009). For early detection, attention must be paid to the seed source as well as to the seedlings during propagation.

Seed source

- Keep records with key information: purchase date, source (vendor name), variety name, seed lot number, seed treatments and other seed quality parameters.
- Test the germination rate before planting: it is recommended to follow the standardized protocol used by the country's organization relevant to seed quality and trade; the germination rate must be recorded and kept with the other seed-related information for potential future track-back needs.
- Use seeds from a reliable source: this is the only way to avoid unintentionally buying adulterated or "fake" seeds or improperly disinfested (therefore contaminated) seeds.
- For genetically modified organisms, follow the relevant national or international regulations.

Handling seeds

Seed storage

Understand seed type. Seeds may be classified according to their tolerance level to drying or temperature: orthodox, recalcitrant and intermediate. Most greenhouse-grown species produce orthodox seeds. However, under similar storage and harvest conditions, seeds exhibit different inherent longevities depending on the species (Walters and Towill, 2004). Relative life expectancy under favourable storage conditions for certain crop groups is: legumes (beans) 3–4 years; crucifers (broccoli, cauliflower) 4–5 years; lettuce, endive and chicory 4–5 years; spinach, beets, carrots and chard 2–3 years; cucurbits (melons, squash) 4–5 years; tomatoes 4 years; peppers 2 years; onion, parsley, parsnip and salsify 1 year. As seeds age, the germination percentage declines at varying rates depending on conditions and species. Guidelines for storage behaviour (orthodox vs recalcitrant) are presented in Table 1.

Store unused seeds following recommendations from the seed source. In general, orthodox seeds should be stored in dark, dry and low temperature environments, kept in a tight container to avoid moisture. When old seeds are used, a germination test must be performed to verify the germination rate; their viability depends on the type of crop. The rate of seed deterioration depends on the type of seed and on the storage conditions. High moisture content and high

TABLE 1

Guidelines to identify storage behaviour of seeds

Trait	Guideline	Some exceptions
Growth habit	Most herbaceous plants produce orthodox seeds.	Aquatic species
Habitat	Many aquatic species, tropical rainforest species, and temperate climax forest species produce recalcitrant seeds.	Most native Hawaiian species, temperate conifers, some maples
Water content at harvest	Most orthodox seeds naturally dry on the parent plant.	All immature seeds, Solanaceae, Cucurbitae
Seed size	Recalcitrant seeds are often large.	Some aquatic species, Rutaceae, some Rubiaceae
Desiccation sensitivity	Orthodox seeds can survive complete water loss; recalcitrant seeds cannot.	Orthodox seeds dried very slowly (for > 2 weeks) can be severely damaged

Walters and Towill, 2004

TABLE 2

Recommendations for relative humidity (RH) and moisture content, together with approximate longevity of selected species

Species	Optimum RH	Optimum moisture content of seed (g H_2O / g dw)	Time to 50% loss in viability
Lettuce (*Lactuca sativa*)	20%	0.04–0.05	>4 years at 5°C >20 years at -18°C
Onion (*Allium cepa*)	20%	0.06–0.08	>4 years at 5°C >20 years at -18°C
Sunflower (*Helianthus annuus*)	20%	0.03–0.04	>6 years at 5°C >25 years at -18°C
Pea (*Pisum sativum*)	20%	0.09–0.12	>10 years at 5°C >25 years at -18°C
Tomato (*Lycopersicon esculentum*)	20%	0.05–0.06	>12 years at 5°C >25 years at -18°C

Walters and Towill, 2004

temperature will result in a very rapid decline in visibility. Therefore, the longer the seed storage period, the more important that the seed moisture content is low, and that the temperature is also low. The optimum storage humidity conditions and moisture content of seeds of some greenhouse-grown crop species are shown in Table 2.

Avoid using seeds beyond the expected storage life

Seed treatment

Seed treatments vary depending on the seed company. Seed priming can improve germination and emergence, resulting in better uniformity; indeed, seeds of some species are almost always primed, as germination is poor without. Pelletizing seeds produces better uniformity and improves handling in automated seeders.

Germination

- Keep germination facilities clean and free from algae and pests.
- Select conditions optimal for the crop species, thus improving uniformity and minimizing the time, reducing the overall costs for producing transplants.
- Some species require oscillating temperature: eggplant and their rootstocks *torvum* generally germinate faster under day-night oscillating temperature conditions.
- Monitor the media (not air) temperature during germination and control it in the optimum range; evaporation from wet media can reduce the temperature to a few degrees below the air temperature.

GAPs for obtaining and handling seeds

- Keep records of key information.
- Test germination rate before planting.
- Use seeds from a reliable source.
- For genetically modified organisms, follow the relevant national or international regulations.
- Understand seed type for storage and store unused seeds following recommendations from the seed source.
- Avoid using seeds stored beyond the expected storage life.
- Work with seed companies regarding the available options on seed treatments.
- Keep germination facilities clean and free from algae and pests.
- Select germination conditions optimal for the crop species.
- Monitor the media temperature (not air temperature) during germination and control it in the optimum range.

TRANSPLANTS

For greenhouse crop production, it is recommended to use high-quality transplants with the following characteristics:

- absence of infection from diseases or pests
- ability to survive in unfavourable environments after transplanting
- good morphology suitable for planting
- well-developed root system (or higher root to shoot ratio)
- absence of visual defects such as chlorosis (yellowing) or necrosis (dead tissue)

The most important characteristic is disease-free and pest-free status (Doolan *et al.*, 1999).

Organizational separation of transplant production from final crop production is a recent worldwide trend, especially for vegetable and floriculture/ornamental crops requiring special techniques, such as grafting or vegetative propagation, and specific facilities to produce desirable transplants (Plates 1 and 2). It is cheaper to buy such transplants than to produce them in-house, considering all the specialized facilities and skill-sets required. The decision needs to be made by each individual operation, considering all the relevant issues and cost analyses.

When commercial nurseries are not available, or purchasing transplants is not economically advantageous, growers choose to produce their own transplants using their own facilities. Environmental conditions and fertilizer requirements are often specific to transplant production. Transplants are often produced by a short cycle, and growth and development are subject to weather conditions. Good production planning is necessary to coordinate with the final crop production. Records should be kept, including seeding date, variety name, substrate name, tray type, chemicals applied etc.

It is important to avoid wetting foliage. Subirrigation works better than overhead irrigation if the facility is available. If overhead irrigation is the only

Plate 1
Tomato transplants ready for shipping

Plate 2
Tomato grafting operation in Spain (Almería)

option, it is recommended to allow foliage to dry before the sun sets, as prolonged leaf wetness can lead to increased disease development (ASTA, 2009).

Inspections should be carried out to identify signs of diseases and pests. If plants exhibit signs of infection, they must be discarded or an appropriate control method applied.

Grafted seedlings

Grafting is widely applied in vegetable production. In some countries, the technology is relatively new and care must be taken to avoid failure or transmission of diseases during the grafting process.

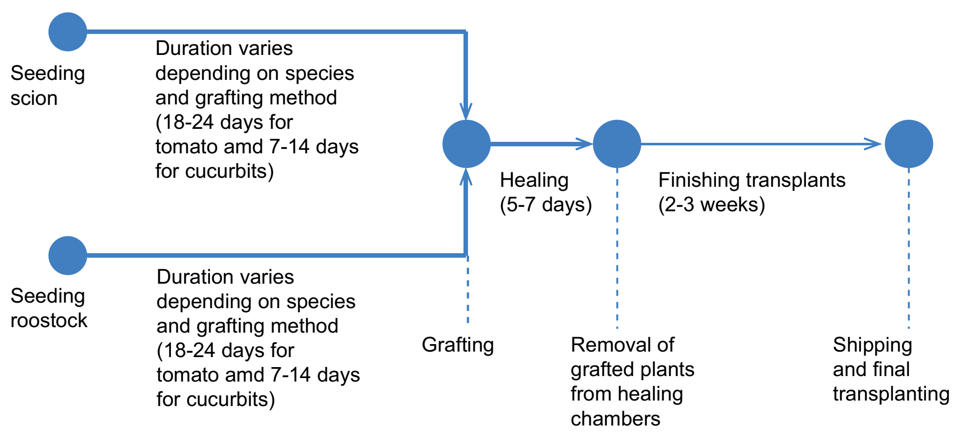
- Keep grafting tools (razorblade, grafting tubes etc.) and working area clean with regular disinfestation. According to ASTA (2009), ethanol (70–75%) and other disinfectants are suitable for disinfecting cutting tools and hands, which should then be rinsed with clean water to avoid damage to the plant from residual disinfectant. Both disinfectants and rinsing water should be changed regularly.
- Choose the rootstock on the basis of the specific problems to be solved by grafting and the grafting compatibility between scion and rootstock. Seed companies have information on expected phenotypes including disease resistance, but it is recommended to test any new scion-rootstock combination on a small scale before starting propagation on a large scale. Table 3 presents guidelines for selecting rootstocks.

TABLE 3
Guidelines for selecting grafting rootstocks

Type	Resistance	Other traits
Tomato		
Interspecific hybrid (hybrid between different tomato species, e.g. 'Maxifort', *Solanum lycopersicum* x *S. habrochaitaes*)	Different for different roostock varieties but generally include *Fusarium*, *Verticillium* wilt, root knot nematodes. Some include bacterial wilt and higher race (race 3) of *Fusarium*.	Generally vigorous. Some rootstocks have chilling tolerance. However, less uniformity in plant growth at the seedling stage (germination and emergency).
Intraspecific hybrid (hybrid within the same cultivated tomato species, e.g. 'Aloha', *Solanum lycopersicum*)	Different for different rootstock varieties but generally include *Fusarium*, *Verticillium* wilt, root knot nematodes. Some include bacterial wilt and higher race (race 3) of *Fusarium*.	Very uniform growth. Less vigorous.
Cucurbits		
Interspecific hybrid squash (hybrid between different squash species, e.g. 'Tetsukabuto', *Cucurbita maxima* x *C. moschata*)	*Fusarium*. Some also have vine decline, *Verticillium* wilt and anthracnose.	Suitable for all cucurbits. Traits varied among different rootstock varieties (vigour, chilling heat or drought tolerance etc.).
Bottle gourd (*Lagenaria siceraria*)	*Fusarium*. Some also have resistance to vine decline, *Verticillium* wilt and anthracnose.	For watermelon. Chilling tolerance.
Fig leaf gourd (*Cucurbita ficifolia*)	*Fusarium*	For cucumber. Chilling tolerance.

- Select the optimum grafting method on the basis of plant performance after grafting and success rate of grafting. Tube grafting is a standard procedure for tomato and eggplant, but there are several grafting methods used for cucurbits. When considering automated grafting, it is important to take into account the advantages (e.g. lower labour input) and challenges (high capital costs and limited flexibility in terms of size of plants or trays).
- Prepare scion and rootstocks to reach optimum graftable stage at the same time. Depending on the grafting method and species to graft, grafting must be done at the optimum growth stage of scion and rootstock seedlings. Use of overgrown or too young seedlings beyond optimal ranges reduces the grafting success rate. Good propagators must pay attention to seed germination timing and growing conditions to produce scion and rootstock seedlings at an optimal stage for grafting. An example of a propagation timetable is shown in Figure 1.
- Keep healing facilities clean and free from algae and pests. Healing conditions often include high humidity (nearly 100%) and warmth (28–29 °C) with lighting, conducive to the growth of algae and fungi and the rapid spread of disease.
- Choose between two-headed and single-headed grafted seedlings. For tomato, two-headed seedlings (pinched to induce two lateral shoots) are widely used to reduce the number of plants needed per cultivation area. However, an inappropriate combination of scion and rootstock may reduce the yield when they are two-headed. A small test to determine growth and yield capacity of two-headed plants must be conducted before using them on a large scale.

FIGURE 1
Example timetable for producing grafted tomato and cucurbit seedlings



GAPs specific to the grafting of seedlings

- Keep grafting tools (razorblade, grafting tubes etc.) and working area clean.
- Proceed with the disinfection of the grafting tools between each cut with ethanol (70–75%) or other suitable disinfectants.
- Choose appropriate rootstock.
- Choose optimum grafting method.
- Prepare scion and rootstocks to reach optimum graftable stage at the same time.
- Keep healing facilities clean and free from algae and pests.
- Carefully decide whether to use two-headed or single-headed grafted seedlings.

Purchasing transplants from commercial nurseries

- Use transplants from reliable nurseries. Long-distance transportation causes deterioration of transplant quality. Select nurseries not only for their propagation skills (product quality) but also for their proximity to the production site and the transportation methods used.
- Upon receipt of transplants, inspect carefully for signs of disease or pests. On finding signs of infection of notorious diseases and pests that could spread in the greenhouse (e.g. bacterial canker or TYLCV for tomato, bacterial fruit blotch for cucurbits), discard all the transplants and disinfect any trays and bench surfaces with which they have come into contact.
- Maintain records of any products used for controlling pests and diseases during the propagation period.
- For genetically modified organisms, follow the relevant national or international regulations.
- If possible, visit the nursery during the transplant production process, check the young plants and discuss the quality with the manager.

Production scheduling

In commercial propagation, production scheduling is critical to maximize profits.

- Schedule backwards, starting from the target shipping (delivery) window determined by customers or final crop production schedule. The time required to reach the growth stage suitable for transplanting is largely dependent on the crop species, climate conditions (solar radiation, day and night air temperature, and CO_2 concentration) and growing methods (substrate, fertilizer and tray types). Experience is required to forecast transplant finishing time.
- Understand the different facility requirements for the various stages of transplant production. For standard transplants, there are several stages, such as germination, transplanting, hardening and shipping. For grafted seedlings, there may also be sorting, grafting, healing and pinching. It is first necessary

to establish how many trays (flats) one germination room can hold and how many workers are available for grafting in a given week.

- Understand two variables: crop time and production space. Scheduling production and analysing facility use associated with transplant production can be a complicated process comprising multiple variables. To better schedule crops and turns, nursery propagators must develop their own computerized spreadsheets to better understand the facility use in any given week of the production period. This capacity is extremely important when propagation involves multiple species and different finishing timings.

Packing and transportation

- Select the packing and transportation method. Transplants are best transported when packed in trays inside cardboard boxes or on racks in trailers, but some growers prefer to receive "pull-and-pack" seedlings to reduce transportation costs. In either case, packing to accommodate rough handling is necessary, especially when a commercial freight service is employed (Plate 3).
- Avoid long distance transportation. Transplants should be transported over the shortest distance possible, to minimize costs as well as the damage associated with transportation. However, in some cases, such as grafted seedlings that are not widely available in some countries, transportation may be longer than the normal time for vegetable transplants. Normal transportation time is no longer than 10 hours.
- Select the timing of transportation to minimize environmental stress. Once scheduled, select exact timing to avoid the risk of exposing transplants to extreme heat or cold. During summer, overnight or early in the morning is preferable to midday to avoid heat stress, especially when plants are transported in a non-refrigerated truck. In contrast, midday transportation is more desirable when freezing temperatures are expected at night.
- Select the transportation route to minimize mechanical stress. Mechanical stress caused by vibration during transportation has a negative impact on the

Plate 3
Rough transportation or handling of boxes could result in tumbled seedlings during transportation

Plate 4
Ventilated truck used for transporting seedlings

transplants. It can physically damage the transplants or promote ethylene production. Ethylene accumulation can induce adverse physiological impacts such as flower abortion or leaf yellowing, especially during long distance transportation.

- Use a refrigerated trailer at a controlled selected temperature for long distance transportation. Too high temperatures can produce adverse physiological effects such as flower abortion (Kubota and Kroggel, 2006).
- Assure ventilation to avoid ethylene accumulation during transportation. Plate 4 shows a commercial nursery truck (non-refrigerated) designed for transporting transplants. This type of truck has some ventilation and is suitable for relatively short distances (no more than several hours).
- Complete necessary importation paperwork for international shipping of transplants.
- Do not transport plants if there is any sign of disease or virus infection. Introduction of viruses such as TYLCV is often associated with transportation of plant materials. Accidental introduction of infected plants following inappropriate judgment by a careless propagator could cause a catastrophic outbreak affecting the entire production region.

FACILITIES AND MATERIALS TO GROW PLANTS

The facilities and climate conditions for transplants are different from those for final crop production. Young seedlings are generally more sensitive to abiotic and biotic environmental stresses and a growing facility must be carefully selected in order to achieve optimum growing conditions. There are several production stages, and each one has specific recommendations with regard to environmental conditions, fertilization and plant maintenance methods.

Production site selection

The transplant production facility should be located at a distance from the farming area, which is a potential source of insects and diseases that can easily reach the transplant production facility. The site should be levelled and well drained with ready access to an abundant supply of quality water. The greenhouse should be positioned sufficiently far from surrounding trees or buildings so as to prevent shadows. Considerations concerning greenhouse location may be summarized as follows:

- good drainage and water supply
- sufficient distance from cultivation area
- good proximity to shipping routes
- easy access to utilities
- local zoning for land use and tax laws
- room for expansion and absence of shadows

Seedling trays

Seeds can be sown in a variety of ways (depending on their end use) in individual plant containers or plastic flats filled with various types of sterile growing media (substrates).

Plate 5
Seedling trays with various cell shapes and sizes

Choose trays or containers suitable for the production (Plate 5). Criteria include plant species, growing conditions (irrigation method), local availability and type of mechanical seeder used. There are various containers and trays:

- Individual containers may be more appropriate for foliage plants or mature seedlings (flowering stage) of vegetable species. They come in paper, plastic, clay, peat moss, Styrofoam (Plate 6) etc.
- Individual plastic containers (called net pots or web pots) are used in floating or NFT hydroponic systems, filled with coarse substrates, such as perlite, clay pellets and rockwool.
- Moulded plastic or Styrofoam "plug" or cavity (multi-celled) trays are available in various sizes containing tens to hundreds of cavities, and can be filled with growing medium or cubes for the production of multiple seedlings in each tray.

Plate 6
Tomato seedlings grown in a Styrofoam tray

Use steam or other disinfectants to sterilize reused trays. Plastic containers can be sterilized using 10 percent bleach, while Styrofoam containers and trays are steam-sterilized. In some countries in Europe, Styrofoam is recycled to be used for other purposes (Styer and Koranski, 1997). When disinfectant solution is used, soak the trays long enough to ensure efficacy; rinse containers thoroughly to avoid chemical toxicity; allow the trays to dry prior to use.

Choose tray type and size adaptable to the mechanical seeder, transplanter and other greenhouse propagation systems (benches and irrigation systems). Test candidate trays for plant performance as plant growth is affected by type of trays (cell size, volume, colour etc.).

Limit the maximum reuse of seedling trays (or plug trays) to 2–3 times. Styer and Koranski (1997) suggest that the cost of labour for washing, disinfecting, stacking and storing used trays almost equals the cost of new trays. Reuse also increases the risk of disease introduction resulting from incomplete disinfection.

Substrate[1]

- Select a substrate and understand its physical properties. There are various substrates available for horticultural use (e.g. sand, peat, moss, vermiculite, perlite, rockwool, rice hulls, coconut coir, compost). In general, a substrate needs to have good air porosity and water-holding capacity.
- Maintain the media pH in the optimum range (5.5–6.5 in general). Too high or too low pH can cause micronutrient deficiency or toxicity, respectively.
- Keep the initial level of EC (electrical conductivity) below 0.75 dS/cm at a 2:1 (v:v) dilution (Styer and Koranski, 1997). Some substrates have fertilizers mixed in (known as "starter charge") and the amount of starter charge needs to be taken into account in the fertilization schedule.
- Use substrate from a reliable source. Organic substrates (e.g. coconut coir) are often inconsistent in quality and vary depending on the source and origins.

Chemicals

- Ensure that any chemicals used during propagation do not violate the regulations of the country where the plants are to be grown for production.
- Use products from reliable sources.
- Follow the application instructions on the product label; some chemicals require professional certificates for applicators (workers).
- Keep records of product name, dose, application method, operator name, date and time of application etc.

Fertilizers

- Use products from a reliable source; avoid low quality fertilizers as they may contain contaminants such as heavy metal.
- Keep good records when mixing fertilizers to make up stock nutrient solution. Record fertilizer product name, salt name, weighed amount, operator name, date and time etc.
- Check EC and pH of nutrient solution regularly; EC and pH meters need to be calibrated and maintained using methods recommended by manufacturers.
- Use appropriate nitrogen source based on plant performance, pH requirement and costs. For example, use of nitrogen in nitrate form at a higher ratio tends to keep the substrate more basic.

[1] For more information concerning substrates, see chapter 11.

- Handle acid and base used for pH control cautiously with appropriate worker protection equipment (safety goggles and gloves). Store them in an appropriately designated acid cabinet.

Seeding machine and automation

Choose the seeding machine and other automation (tray filler etc.) on the basis of expected use and performance, as it could be a significant capital investment. Types of seed (size, coating and shape), trays (dimension, number of cells) and substrate need to be considered in order to select the best performing machine.

IPM facility

In order to reduce the risk of introduction into the greenhouse of insect pests or insect-transmitted viruses, it is recommended to: [2]

- use a double-door entrance;
- cover the air intake (vents) with insect screens;
- control weeds inside and outside.

IRRIGATION AND FERTIGATION

Irrigation

It is important to choose an appropriate irrigation method or system, taking account of the relative advantages and disadvantages. There are two basic irrigation systems for transplant production:

- Overhead irrigation systems are traditionally used for containerized transplants (Plate 7). However, they can contribute to pathogen attack when used in regions with high temperatures and humidity.
- Subirrigation systems (flotation or ebb and flow) are designed to flood beds with nutrient solution. In subirrigation, the water must contain disinfectants and algae growth protectants.

The advantages of subirrigation include lower pesticide, water and fertilizer use in propagation, elimination of groundwater contamination, and reduced risk of foliar and soil-borne diseases (Thomas, 1993). Also, overhead watering does not guarantee uniform waterflow throughout the medium and can induce drought stress in the roots, especially during hot seasons. Overhead

Plate 7
Overhead irrigation used for transplant production facility

[2] For the design or installation criteria and specifications of each facility, refer to chapter 15. To understand the possible impact of insect screens on greenhouse ventilation, refer to chapter 3.

irrigation enhances root growth, but it uses more fertilizer than subirrigation (Nicola and Cantliffe, 1996).

To improve fertilizer and water-use efficiency, over-irrigation should be avoided. Transplant quality tends to be low (stem extension or tender tissue) when grown under conditions of over-irrigation. It is important to water transplants thoroughly until the entire substrate is moist, and then allow the substrate water content to reduce before the next watering. When overhead irrigation is used, late afternoon watering should be avoided as the plants remain wet overnight, increasing the likelihood of disease. A too-wet substrate also increases the incidence of damping-off disease.

Fertigation

Choose the fertilizer concentration, frequency and dose according to plant growth stage and climate conditions (solar radiation and temperature, which influence transpiration demand). For example, target concentrations for fertigation in the solution for tomato seedlings are 80–100 mg/litre total nitrogen (75–100% in nitrate form), 30–50 mg/litre phosphorus, 140–180 mg/litre potassium, 100–150 mg/litre calcium and 30–60 mg/litre magnesium, in addition to other micronutrients. The pH is normally adjusted to 5.5–6.5. Seedlings grown on high rates of nitrogen fertilization are succulent and less resistant to dry weather and solar radiation, leading to a low rate of plant survival after transplanting in the open field (Rosca, 2008). Transplant quality can be improved by applying higher concentrations of fertilizer less frequently (known as "pulse feeding" – Garton *et al*., 1994), resulting in thicker stem diameters. Limiting fertilizer is also used to harden transplants before shipping or transplanting. Carefully monitor the discharge (amount and EC) to minimize pollution. Direct discharge to the ground should be avoided as it contaminates the groundwater.

GROWTH CONTROL AND HARDENING TECHNIQUES

Hardening is a crucial step in transplant production. In general, transplants should have well-balanced shoot and root development. Young seedlings growing at high planting densities may have extended stems or excessively large shoot mass relative to the roots. Spindly tender plants are more vulnerable to mechanical damage during handling and transplanting. The quality of transplants affects stand establishment after transplanting to the final production greenhouse. Hardening preconditions transplants to tolerate transplanting stress by exposing them to, for example, water stress; the practice is usually applied to transplants to be used in open-field production or to be grown in environmental conditions harsher than those they were exposed to during propagation. Excessive hardening should be avoided as it may exhaust the plant's energy reserves (Garton *et al*., 1994).

A typical hardening method involves restriction of the water supply and gradual exposure to conditions expected in the fields or greenhouse to which the plants are transplanted (light intensity, day-night temperature oscillation and relative humidity). This hardening process is performed over several days or for over a week, depending on the species and preferred nursery practice. Some vegetable seedlings (e.g. tomato) may also be hardened off with limited fertilization, as too much fertilization, especially nitrogen, tends to make seedlings soft. Some growers move the seedling trays to benches placed in open field in direct sunlight. However, it is recommended that transplants used for greenhouse production be hardened off inside the greenhouse to mitigate the risk of bringing in insect pests.

Day-night temperature difference (DIF)

Plant stem growth rates of some floricultural and vegetable species are positively correlated to the difference between day temperature (DT) and night temperature (NT), known as DIF (DIF = DT – NT) (Moe and Heins, 1990). A high DIF promotes stem elongation and the daily average temperature determines overall development rate (leaf emergence and flower initiation). Using DIF helps to keep the seedlings compact in size without using growth regulators. Keeping transplants cooler during the day than at night reduces plant height in the temperature range 10–30 °C (Wien, 1997). High temperatures during the first 3–4 hours after sunrise can cause considerable elongation in vegetable seedlings (Bodnar and Garton, 1996). This excessive elongation can be mitigated by keeping the greenhouse temperature cooler (by 4–5 °C) during morning hours than at night (Bodnar and Garton, 1996).

Irrigation deficit and water stress

When plants are subjected to mild water stress, the rate of stem elongation and leaf area expansion decreases, and carbohydrates accumulate in the leaves. Water stress therefore induces changes in plant growth that are helpful in preparing the plant for transplanting (Wien, 1997). However, as the plant transpiration rate is affected by environmental conditions, experience is required to determine irrigation timing without imposing too much water stress. A soil moisture sensor calibrated for the specific substrate offers an alternative approach.

Nutrition deficit

The growth rate of transplants can be regulated by controlling the concentration of nitrogen and other nutrients in the substrate. Reducing nutrient supply just before transplanting can slow down the growth rate during the hardening stage. As long as the transplants are not completely starved of the major nutrients by this procedure, there should be little problem with the resumption of growth after transplanting (Wien, 1997).

Shaking and brushing

Mechanical stress affects seedling growth, because it can enhance ethylene production. Brushing the tops of the transplants several times a day can have remarkable dwarfing effects (i.e. shortening stem and petioles; increasing chlorophyll content) (Wien, 1997). The effects of these mechanical perturbations vary among species and cultivars. Brushing has proved successful in solanaceous crops (including tomato, pepper and eggplant), but care should be taken with cucurbits, which are more fragile and may become damaged (Schrader, 2000).

With tomato, keeping transplant height short results in a reduction of stem elongation rate, especially important during winter, when light conditions are suboptimal (Fontana *et al*., 2003). Chemical growth regulators may not be used to control vegetable transplant height (it is necessary to check the registration status with the local authority). Therefore, mechanical conditioning is one way of controlling stem elongation in commercial greenhouse production.

Transplant age

When producing vegetable transplants, seedlings should be transplanted at the optimum age. Generally, as the age of the transplant increases, leaf number, height, leaf area and dry shoot weight of vegetable seedlings increase linearly, regardless of transplant cell volume. Avoid any delay in transplanting. Almost all vegetables may be transplanted as early seedlings with little effect on growth, but as they increase in age, this situation changes (Vavrina, 1998). Age strongly influences subsequent performance in the greenhouse. Although planting the largest seedlings possible might appear advantageous in terms of getting the crop off to a quick start, larger seedlings are also more prone to transplanting shock. In general, relatively young vegetable transplants provided with adequate growing space in the greenhouse produce the best stand and fastest crop development. The added stress associated with transplanting larger-than-optimal plants appears to substantially delay crop development.

Determine best growing practices for achieving optimum age of transplants. The optimum age depends on the crop, cell size to be used and conditions during the grow-out period. For example, 2-week-old transplants grown in the small cell volume may be the best option for muskmelon growers if their sole concern is total-season yields. However, if growers want to maximize early-season yields, then 2-week-old transplants grown in the large cell volume are the best choice (Walters *et al.*, 2005). Growers must adjust their growing practices and schedules for different crop species and cell sizes. Table 4 lists general guidelines for transplant production in various crops, planting time and cell sizes.

There is no single definition of the best seedling age or the most appropriate phenological stage of transplant age. In general, northern countries use older and further developed seedlings, as follows (OMAF, 2007):

- Tomatoes: first flowers showing
- Cucumbers: 4–5 true leaves visible
- Peppers: flower at first branching level opening

TABLE 4
Scheduling transplants of various cell sizes, for several vegetable crops

Crop	Tray size [a]	Transplant age and production details
Early-market tomatoes	24, 38, 50	Usually seeded in 288s or 406s and transplanted to large tray at first true leaf; aim for approx. 8-week-old field-ready plants
Mid-season to late tomatoes	128–288	Direct-seed in tray; plants should be 6–7 weeks old for mid-to-late May plantings, 5 weeks old for June plantings
Early peppers	50 or 72	Transplant seedlings or direct-seed in tray; aim for 8–9-week-old field-ready plants
Mid-season to late peppers	128–200	Direct-seed in tray; aim for 7–8-week-old field-ready plants
Early cole crops	72 or 98	Direct-seed in tray; aim for 5–6-week-old field-ready plants
Mid-season to late cole crops	128–200	Direct-seed in tray; aim for 4–5-week-old field-ready plants
Cucumbers, melons, squash	24–128	Direct-seed in tray; aim for 3–4-week-old plant for 24 or 38 trays, 2–3-week-old plant for smaller cells (128 trays)
Spanish onion	200 or 288	Direct-seed in tray; seedlings should be clipped several times to produce a stocky transplant; aim for 8–10-week-old plants

[a] Standard cell tray size: 540 x 280 mm.
Bodnar and Garton, 1996

In other countries, tomato seedlings 3–5 weeks old and not yet flowering (Peet and Welles, 2005) are considered ideal, while seedlings over 5 weeks old are less desirable (Zeidan, 2005). While modern cultivars, improved production systems and technical expertise may produce high yields regardless of transplant age, relatively young transplants are still preferred for commercial production under Mediterranean conditions because older seedlings are more costly to produce and difficult to handle.

PHYSIOLOGICAL DISORDERS

Nutrient deficiency and toxicity

- Optimize fertilization programme based on the plant's needs. Different species require different fertilization. Some commercial substrates for transplant production contain a starter charge of fertilizers, in which case no fertilization is required for the first few days. For nitrogen, many plant species perform better when both ammonium nitrogen and nitrate nitrogen are used. However, an excessively high rate of ammonium nitrogen may cause toxicity to the plants; furthermore, the form of nitrogen also affects the pH in the substrate (nitrate makes it more basic and ammonium more acidic). An example of phosphorus deficiency in tomato plants is shown in Plate 8.

Plate 8
Typical symptom of phosphorus deficiency in tomato – seedlings develop purple pigments (anthocyanins)

- Maintain adequate pH in the substrate to avoid nutrient deficiency and toxicity. Generally, a pH of 5.5–6.5 is considered optimum for many plant species: a too high pH can lead to iron deficiency inducing pale green newly emerged leaves; too low can cause micronutrient toxicity (e.g. boron). Some substrates (e.g. peat moss) are acidic and others (e.g. vermiculite) basic. The amount of bicarbonate ions determines the water alkalinity and influences the buffer capacity of the nutrient solution in the substrate.
- Use fertilizers from a reliable source to avoid contamination (heavy metals etc.).
- Analyse the water quality and design the fertilization programme accordingly. Water quality may change over time (seasons or years), and periodical analysis in a reliable laboratory is therefore recommended. Excessive amounts of sodium, soluble salts or bicarbonates can become problematic and growers may want to consider another water source or different water treatment.

Pests and diseases

Good agricultural practices relevant to plant propagation are described below.

- Inspect planting materials regularly. Early detection is critical to control biological problems and minimize damage. Propagation is usually conducted in short cycles, but because of the high density, pests and diseases spread very rapidly. Once any symptom is found, minimize access to the affected area and notify workers of the outbreak as soon as possible.
- Be familiar with the symptoms of commonly occurring pests and diseases to identify problems at an early stage and minimize plant loss.
- Apply appropriate control methods (chemical or biological) in consultation with a local extension agent or advisor.
- Do not apply foliar fungicides in high temperatures as foliage may get injured.

Disorders caused by growing environments

Pay attention to light contamination from neighbouring greenhouses and buildings at night. Street lights and worker's lights sometimes influence plant morphology and flowering. Be familiar with toxicity symptoms of air contaminants. Incomplete combustion of gases causes air pollution that can harm humans as well as plants. The concentrations that negatively affect plants vary according to whether exposure is short term or long term. Young transplants are especially tender and sensitive to by-products of incomplete combustion (Bodnar and Garton, 1996), and tomato is particularly sensitive to ethylene exposure. Problems are often associated with the first use of heating systems in the winter and they disappear as heating demand becomes less.

TRACEABILITY

Record key information for each lot of planting materials (seeds and transplants) including material information (source, type), dates, facility used, environmental data and workers' names. Consider the introduction of a tracing technology (e.g. barcodes or RFID – radio frequency identification), to identify each lot or tray of transplants (especially if a large number are grown under various schedules in the same facility) and to record the relevant production-related information. The successful introduction and use of such a system significantly reduces errors in boxing and shipping.

GAPs for growing and handling transplants (1)

- Keep records of key information (seeding date, variety name, substrate name, tray type, chemicals applied etc.).
- Choose the appropriate irrigation method/system and carefully manage the irrigation to keep the substrate uniformly wet while avoiding over-irrigation
- Avoid wetting foliage as much as possible.
- Inspect carefully to identify signs of diseases and pests.
- Understand and practise hardening methods.
- Avoid delay in transplanting.
- Optimize fertilization programme based on the plant's needs.
- Inspect planting materials regularly.
- Apply appropriate control methods (chemical or biological).
- Do not apply foliar fungicides in high temperature conditions.
- Be familiar with toxicity symptoms of air contaminants.
- Consider introducing tracing technologies (e.g. barcodes or RFID).
- Maintain records of any products used for controlling pests and diseases during the propagation period.
- Schedule transplant production backwards, starting from the target shipping (delivery) window.
- Understand the different facility requirements for different stages of transplant production.
- Select optimum packing and transportation methods.
- Avoid long distance transportation and select transportation route to minimize mechanical stress.
- Select transportation timing to minimize environmental stress.
- Use refrigerated trailer at a selected temperature for long distance transportation.
- Assure ventilation to avoid ethylene accumulation during transportation.
- Complete necessary importation paperwork for international shipments of transplants.
- If there is any sign of disease or virus infection, DO NOT transport plants.

ORGANIC TRANSPLANT PRODUCTION

Record-keeping

Record-keeping and certification are required for all organic producers selling products labelled "certified organic" (Santos, 2007). Production of organic transplants involves more than using organic fertilizers and substrates or avoiding the use of non-approved pesticides. Regulations extend to greenhouse building materials and phytosanitation methods. In an organic nursery, the use of chemical-synthetic products for substrates and plant protection is not allowed; appropriate cultural techniques and inputs must be adopted to obtain well-established seedlings (Nicola *et al*., 2011). Root zone management is necessary for the main inputs in the organic nursery: containers, substrates and fertilizers (all organic farming certified).

Containers and substrates

For organic nurseries, biodegradable containers composed of biodegradable polymers are commercially available (Nicola *et al*., 2010). Organic commercial substrates are composed of peat and other products allowed in organic farming regulations. Peat can be completely substituted using a substrate composed of citrus residues mixed with coconut coir (Possanzini, 2006). New organic substrates that are possible alternatives to peat include: rice hulls or rice chaff (a by-product of rice processing), and *Posidonia oceanica* (L.) Delile (an abundant sea plant) (Sambo and Santamaria, 2009).

Organic farming regulations list the permitted fertilizers (guano, manure, potash, seaweed etc.) (Nicola *et al*., 2010); most certified organic fertilizers can be used for post-transplant or mature crop production, since they are generally applied in the soil months before being absorbed by the plant during crop development. The problem of using plant- or animal-based fertilizers is finding horticultural and animal residues originating from organic farming. To improve the uptake of organically based soil nutrition, techniques related to mychorrization could be adopted: through pre-inoculation, the young seedlings benefit from enhanced availability of nutrients, especially those coming from an organic matrix (Conversa *et al*., 2009).

GAPs specific to organic transplant production

- Keep records of key information.
- Be familiar with materials (trays and substrates) allowed for organic production.

SEEDLING MYCORRHIZATION

Mycorrhization establishes symbiosis between plants and fungi. It can improve not only the growth of seedlings but also their physiological status by enhancing the photosynthetic capacity, and increasing the uptake of water and nutrients and their accumulation in the seedling tissues (Rincón *et al*., 2005). Environmental conditions characterized by the Mediterranean climate include prolonged dry periods with high temperatures and rain concentrated in a few months. These climatic conditions limit the activity of natural fungal inoculums of soils by reducing the optimal time for fungal spore germination and mycelial growth, thus minimizing the opportunities for root colonization by native fungi. Under these circumstances, controlled nursery inoculation with suitable mycorrhizal fungi can be an advantage for the successful establishment of transplants in Mediterranean regions. Furthermore, water quality in many areas of the region is low due to high salinity: the advantages of mycorrhization include enhancing salinity tolerance (Ruta *et al*., 2009), enhancing overall plant growth (Conversa *et al*., 2009), improving product quality (Tiradani and Gianinazzi, 2009; Kappor *et al*., 2004) and enhancing plant resistance to *Fusarium* and *Phytophthora* (Tiradani and Gianinazzi, 2009).

QUALITY OF PLANTING MATERIALS

Access to high quality planting material is essential for successful greenhouse vegetable crop production. GAPs relative to seeds and transplants are generally classified as follows:

- Prevention of introduction or spread of disease
- Production of high quality seedlings
- Minimization of environmental pollution

GAPs for growing and handling transplants (2)

- Select types of tray/container suitable for the production.
- Use steam or other disinfectants to sterilize reused trays.
- When disinfectant solution is used, soak the trays long enough to ensure efficacy.
- Choose tray type and size adaptable to the mechanical seeder, transplanter, and other greenhouse propagation systems (benches and irrigation systems).
- Limit reuse of seedling trays (or plug trays) to 2–3 times.
- Select substrate and understand its physical properties.
- Keep the media pH and EC for optimum range.
- Use substrate from a reliable source.
- Make sure that the chemicals used during propagation do not violate the country’s regulations where the plants are grown for production.

GAPs for growing and handling transplants (2, cont'd))

- Use products from a reliable source.
- Follow chemical application instructions on product label; keep records of product use.
- Check regularly EC and pH of nutrient solution.
- Use appropriate nitrogen source, based on plant performance, pH requirement and costs.
- Handle acid and base used for pH control cautiously with appropriate worker protection equipment.
- Choose the seeding machine and other automation (tray filler etc.) on the basis of expected use and performance.
- Choose fertilizer concentration, frequency and dose according to plant growth stage and climate conditions.
- Carefully monitor the discharge (amount and EC) to minimize pollution.
- Analyse water quality and design fertilization programme accordingly.

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