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Tropical Fruit Tree Propagation Guide

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Several methods can be used to propagate or multiply tropical fruit trees, including 1) seed, 2) cutting, 3) micropropagation or tissue culture, 4) marcottage or air layering, and 5) grafting. Propagation by seed is regarded as the most "natural" method, but frequently the new plants are not identical to the mother plant. Thus physical and genetic variability occurs; new fruit tree varieties and cultivars are created via seedlings. However, asexual or clonal reproduction is the preferred method for establishing tropical fruit tree orchards and is typically used to multiply selected varieties and cultivars while ensuring that the genetics, physical and physiological characteristics, and fruit quality remain the same in the mother and daughter trees. Air layering, grafting, and tissue culture are the most commonly used techniques for producing clonal fruit trees.

Differences between sexually and asexually propagated fruit trees

Trees originating from seed tend to be vigorous since they are in a juvenile state and do not flower or set fruit until they reach a certain age and become mature adult trees. For some fruit trees, the juvenile period can be extensive, lasting eight to ten years or more. During this juvenile period, the plant will grow vigorously and become very large unless managed and trained with pruning. Additionally, seedling trees are naturally genetically different from their mother and siblings. As a result, seedlings will have different growth patterns and produce fruit with different- (usually inferior)-quality characteristics, making marketing difficult (Paull and Duarte 2011).

Asexually propagated trees are clones of the mother plant and bear the same type of fruit. The material used for asexual propagation is normally obtained from a plant in the adult, not the juvenile, phase. This adult material will have already fruited, so its quality can be evaluated. Trees obtained from adult plants will flower and fruit upon receiving an external flower-induction signal and do not need to pass through a juvenile phase as would a seedling. If no external stimulus is required for flowering, an asexually propagated fruit tree will flower immediately. This earlier flowering results in smaller trees, which can be desirable for ease of harvesting. In the case of grafting or budding, the existence of a graft or bud union can restrict the internal xylem and phloem transport and additionally influence tree-size reduction and precocity (Paull and Duarte 2011). Dwarfing rootstocks are often sought for species that normally grow very large. Because of early flower and fruit development, it is advisable to remove the flowers from a newly grafted tree, as the graft union cannot take the weight of the fruit.

Sexual propagation by seedlings

Many tropical fruit trees flower and fruit annually, and their seeds are often recalcitrant. "Recalcitrant" means that the seeds cannot be stored for long periods of time. Recalcitrant seeds rapidly lose their viability if allowed to dry, making seed propagation more difficult. As such, sowing must be done immediately following fruit harvest. Self-fertilization is less common in tropical fruit trees, which are mostly cross-pollinated with other varieties or pollen from male trees. Therefore, seedlings are usually very different from the mother tree, as previously mentioned. In some cases, in the absence of fertilization by pollen, fruit trees produce apomictic seeds. This situation occurs in *Garcinia* spp. (i.e., mangosteen, achachairu) and jaboticaba, where vegetative embryos are present in the seed but sexual embryos are not. In contrast, mango varieties of the Indochina–Philippine group and most citrus species have seed tissues that derive from embryos that are considered clonal and may be used in propagation (Paull and Duarte 2011), though this is not a commonly used technique in some citrus due inferior root mass.

In commercial crop production, the only seed-propagated plants that are identical to their mother plant are those that have been self-fertilized for many generations, such as rice and wheat. Fruit trees rarely have this level of in-breeding. Fruit that may be propagated by seed are usually herbaceous and short-lived crops like papaya, cocona, naranjilla, tree tomato, yellow and purple passion fruit, giant passion fruit, sweet granadilla, cape gooseberry, and some others like coconut and pejibaye palm (*Bactris gassipaes*) (Paull and Duarte 2011). Variability is very low in these crops since the best fruit are selected to obtain seed, and selected seed is very similar genetically to the mother plant. However, when they are grown in an environment different from where they were selected, seedlingscan show considerable variation, as may happen with papaya.

Besides producing fruit trees of varied genetics and physical characteristics, some of the main benefits of growing seedlings include 1) obtaining desired rootstock material onto which the desired variety or cultivar will be budded or grafted (vegetative propagation) and 2) producing a tree with a taproot for post-planting tree stability. However, as with seed propagation, rootstock seedlings are often highly variable, and there is a preference to propagate rootstocks from cuttings or layers so that they are genetically identical.

Asexual or Vegetative Propagation

Regenerating or propagating a new plant from a piece or part of a mother plant is called clonal or vegetative propagation. Vegetative propagation began being used on woody fruit tree species after it was recognized that seeds from trees did not breed true to the mother plant. Genetic improvement and fruit tree domestication required a mastery of clonal or vegetative propagation (Zohary and Spiegel-Roy 1975, Mudge et al. 2009). Cloning developed around 3,000 to 4,000 BCE in the domestication of figs, grape, promegrate, and olive, which all rooted easily from cuttings, while date could be propagated from off-shoots (Figure 1). More difficult species such as apples, pears, and plums that do not root well from cuttings required the development of grafting. Grafting has been used for thousands of years, since about 1,000 BCE, on woody perennial tree crops to enhance yield and reduce disease (Mudge et al. 2009). Grafting possibly developed from the observation that tree limbs of the same species often fuse when they cross each other. This method of grafting, refered to as inarching or approach grafting, is still used today (Juniper and Maberly 2006). When and where the use of a detached scion was invented is not known.

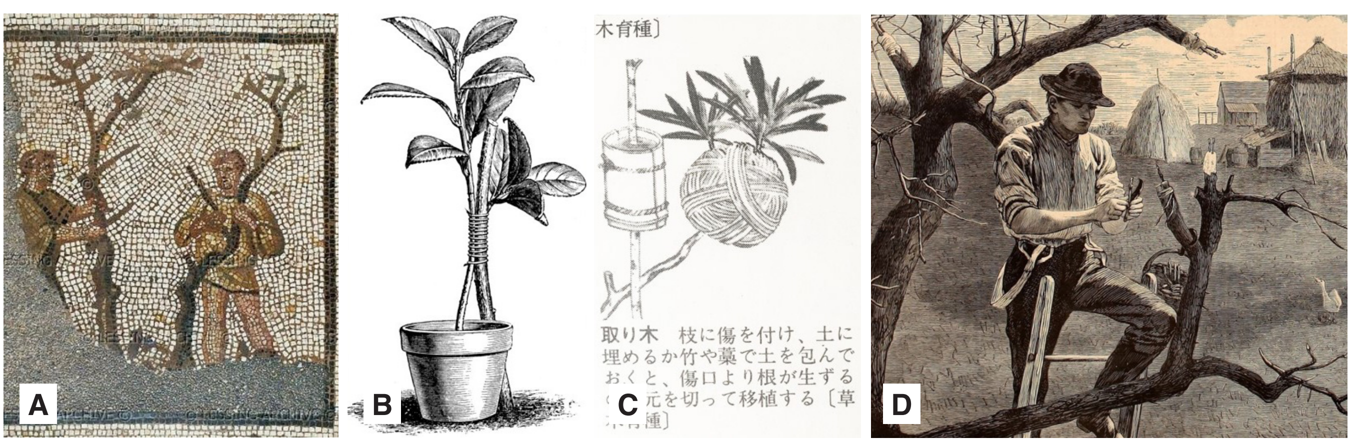

Figure 1. Propagation through ages: A. Detached-scion grafting from third-century mosaic, Vienne, France (Janick 2005); B. Approach grafting (Nickolson 1884); C. Aerial layering in Japan, early 1600s; D. *Grafting* by Winslow Homer, *Harper's Weekly*, New York 1870.

Plants can be vegetatively propagated using many different tissues, including the roots (breadfruit), stems (guava), apices (banana), and buds (citrus). Using vegetative propagation, a large number of nursery plants with the same genetic makeup can be obtained at one time, having known tree-growth and fruit-quality characteristics. Vegetative propagation is particularly useful when seed collection is difficult; only juvenile, non-flowering trees are available; or rapid multiplication of selected high-value plants with expected inherited characters is desired (Table 1).

Cuttings

Tropical fruit tree cuttings are typically grown from plant stems and root shoots. Cuttings can be created from terminal (branch-tip) or sub-terminal (below-the-tip) parts of a shoot. Basal leaves are removed from sub-terminal cuttings. If hardwood or semi-hardwood cuttings are used, all the leaves are removed, as for *Spondias* spp. (mombin). Rooting hormones with auxin-like activity are applied to the base of the cutting as a liquid, gel, or powder, and help stimulate and accelerate rooting. The cuttings are then planted in sterile media with good drainage (i.e., vermiculite, or a mix of peat and perlite). Cuttings should not be allowed to dry or dessicate and should be grown under high humidity, such as in polyethylene chambers or a mist bed, to reduce water loss. Cuttings are used for many tropical fruits, including guava, cashew, acerola, jaboticaba, pomegranate, and passion fruit.

Tissue culture or micropropagation

This approach typically uses plant tissues from apical or axillary meristems or other parts of the plant to multiply genetically similar plant material *in vitro* or in sterile laboratory conditions. Tissue culture involves several stages: 1) initiation and establishment of sterile plant tissues, 2) dedifferentiation or replication of cells and plant tissues, 3) redifferentiation of plant tissues to generate a whole plant including roots, and 4) hardening off of plantlets outside of the lab. Seeds can also be tissue-cultured following an external sterilization process.

This approach is widely used for rapid and consistent reproduction of elite or difficult-to-propagate material. In the last thirty or forty years, this approach has been used to propagate disease-free and true-to-type plants, although genetic variations, including chimeras, can occur in these plants. Soft-tissue plants like pineapple, papaya, banana, and plantain are commercially produced by micropropagation. There has been some success with avocado, mango, *Annonas* spp., and jackfruit. The initial cost per plant is normally higher than with plants propagated using other asexual methods, but the advantage is that many plants can be generated from one mother plant.

Not all plants within a specific species can be tissue cultured. *Musa* spp. (banana), for example, has been extremely successfully propagated in this way with many varieties. However, many but not all of the Hawaiian bananas have so far eluded propagators' ability to use tissue culture.

Air-layering (marcottage)

Air-layering, or marcottage, is the most popular layering system for tropical fruit trees. In this technique, a portion of a branch relatively close to the tip and still attached to the tree is cinctured (ring-barked) to remove cambial tissue, after which it is put in contact with a moist substrate or medium (Figure 2). First the leaves are removed from a portion of a branch located about 30 to 60 cm (1' to 2') from the tip, and a 2.5–3.0 cm (1–1½") ring of bark and cambium is removed (Figure 2A). The girdled area and part of the stem with bark remaining are covered with a ball of moist sawdust or peat moss (Figure 2 B) and wrapped tightly with plastic (Figure 2C), which is tied off on both ends (Figure 2D), and then aluminum foil, to avoid moisture loss and light (Figure 2E). Sometimes auxins (hormones) are applied to the apical portion of the girdle to improve the rooting of these air-layers.

After one to three months, depending on the time of year and type of plant, when roots are visible and abundant (some turned from white to cream color), the air-layer can be harvested by cutting up to 20 cm (8") below the new rooted area. The wood below the air-layer helps to provide stability in the pot for the new, extremely sensitive roots. The wrap is removed and the root-ball is planted in a tall pot or bag with well-drained media and held under medium shade. When this new plant shows signs of new vegetative growth the bag or pot can be taken into full sun, allowed to root and grow further, and then transplanted to the field once an adequate plant size is attained.

Air-layered plants lack a tap root and can be more easily blown over by strong wind. The same problem can occur in plants propagated by cuttings. However, strong

Table 1. Propagation methods commonly used for selected tropical fruit crops (Oliver 1903, Garner and Chandri 1976, Wasielewski and Balerdi 2016, and other sources).

Fruit	Scientific Name	Seed[1]	Cuttings	Air Layer	Grafting
Abiu	*Pouteria caimito*	X			XX
Avocado[2]	*Persea* spp.	X			XX
Banana	*Musa* spp.		X, Corm		
Bilimbi	*Averrhoa bilimbi*	X	X		XX
Breadfruit	*Artocarpus altilis*	~~X~~	X, Roots	X	
Cacao	*Theobroma cacao*	X	X	X	XX
Carambola/Starfruit	*Averrhoa carambola*	X	X	X	XX
Cashew	*Anacardium occidentale*	X	X		XX
Cherimoya[3]	*Annona cherimola*	X	X, Stem	X	XX
Chico/Sapodilla	*Manilkara zapota*	XX		X	X
Citrus	*Citrus* spp.	X	X	X	XX
Durian[4]	*Durio zibethinus*	X	X, Stem	X	XX
Eggfruit/Canistel	*Pouteria lucuma*	X		X	XX
Fig	*Ficus carica*	X	XX	X	X
Green Sapote	*Pouteria viridis*	X			XX
Grumichama/Brazil Cherry	*Eugenia brasiliensis*	XX	X		X
Guava	*Psidium guajava*	X	X, Stem & Root	X	XX
Jaboticaba	*Myrciaria cauliflora*	XX		X	
Jackfruit	*Artocarpus heterophyllus*	X	X, Stem	X	XX
Langsat/Lansone	*Lansium parasiticum*	X	X	XX	X
Lilikoi/Passionfruit	*Passiflora edulis*	X	X	XX	X

Notes
X = possible with some difficulty
XX = Most common method

[1] Although plant can often easily be propagated by seed, the descendant is often very different from the parent. For example, seedlings of avocados are always different than the parent, though in some cases they can be of equal quality. 'Beshore' and 'Green Gold' are seedlings of 'Sharwil'. Success rates vary greatly when methods other than seeds are used. https://hort.purdue.edu/newcrop/morton/passionfruit.html#Propagation

[2] *Annona* rootstock; although there are more than one hundred edible fruits in the Annonaceae family, the more common fruit found in Hawai'i include *Annona muricata* (soursop), *Annona glabra* L. (pond apple), *Annona cherimola* (cherimoya), *Annona reticulata* (custard apple), *Annona squamosa* (sugar apple), and *Annona squamosa* × *A. cherimola* (atemoya). The two most popular rootstocks for *Annona* in Hawai'i are pond apple and soursop.

[3] Making avocados from cuttings is difficult and needs to be done using a mist chamber. For avocado rootstock, it is advisable to use as large a seed as possible. In Hawai'i, Thompson is commonly used, although any large seed is acceptable. New patented rootstocks developed by the University of California have started to become available in Hawai'i. These include 'Dusa', 'Steddom', 'Toro Canyon', and 'Uz'i.

[4] Durian grafting is possible, though the success rate is low.

Table 1. Propagation methods commonly used for selected tropical fruit crops, cont'd. (Oliver 1903, Garner and Chandri 1976, Wasielewski and Balerdi 2016, and other sources).

Fruit	Scientific Name	Seed[1]	Cuttings	Air Layer	Grafting
Longan	*Dimocarpus longan*	X	X, Root	XX	
Loquat	*Eriobotrya japonica*	X		X	XX
Lychee	*Litchi chinensis*	X		XX	X
Mamey Sapote	*Pouteria sapota*	X		X	XX
Mango[5]	*Mangifera indica*	X	X, Stem	XX	XX
Mangosteen	*Garcinia mangostana*	X	X, Stem		X
Marang	*Artocarpus odoratissimus*	XX	X		X
Mountain Apple	*Syzygium malaccense*	XX	X	X	X
Mulberry	*Morus* spp.		XX		
Papaya	*Carica papaya*	XX	X, Stem		X
Pomegranate	*Punica granatum*	X	XX		
Pulasan	*Nephelium mutabile*	X			XX
Rambutan	*Nephelium lappaceum*	X		XX	
Rollinia	*Rollinia deliciosa*	X			XX
Soursop	*Annona muricata*	XX	X		XX
Star Apple/Caimito	*Chrysophyllum cainito*	X	X	X	XX
Surinam Cherry	*Eugenia uniflora*	X		X	X
Tamarind	*Tamarindus indica*	XX	X	X	X
Water/Wax Apple	*Syzygium samarangense*	X	XX	X	X
Wax Jambu	*Syzygium jambolana*	X	XX	X	X
White Sapote	*Casimiroa edulis*	X	X	X	XX

Notes
X = possible with some difficulty
XX = Most common method

[5] Mango seeds can be monoembryonic or polyembryonic. Polyembryonic seedling mangoes will be the same as the parent, but it will take more years to produce fruit than from grafting. https://hort.purdue.edu/newcrop/morton/mango_ars.html#Propagation

wind is not a problem under normal field conditions and in orchards with windbreaks, though considerable losses are experienced in areas subject to cyclones and typhoons (Paull and Duarte 2011). Dwarfing and pruning techniques can aid trees to withstand strong wind by keeping them low in stature.

Grafting and budding

Grafting and budding of fruit trees require the connection of a "scion" or "bud" to a "rootstock." The scion, a piece of stem containing two to six axillary buds, or the bud, a piece of stem containing a single detached axillary bud (Figures 3A and 3B), is inserted onto the rootstock

Figure 2. Air-layering: A) Cincturing (ring-barking) by removing the bark and tissue outside the wood (phloem and cambium), leaving a gap of about 2 to 3 cm (1” to 1½”); B) wrapping the ring-barked area with moist sawdust or peat moss; C) wrapping the peat moss tightly with a plastic and tying off the end to limit water loss (D); and E) wrapping the air-layer with aluminum foil to exclude light.

Figure 3. Bud grafting: A) single bud being cut from the stem; B) axillary bud, including the cambium, showing the shape of the cut; C) “T”-shaped incision made in the rootstock, with two flaps pulled away to allow an opening to insert the bud; D) pushing the scion bud into the “T” insertion site on the rootstock; and E) wrapping the bud with plastic to hold it in place and prevent dehydration until tissue repair is completed and the bud reforms conducting tissues (xylem and phloem) with the rootstock.

(Figure 3C and 3D) and protected from desiccation with a plastic wrap (Figure 3E) until the cambiums have successfully fused. The variety or cultivar of the bud or scion will become the tree canopy from which fruit are produced.

The benefits of a rootstock may include resistance to viruses, diseases, insects, and nematodes; improved production under otherwise unfavorable conditions (i.e., saline and flooded soils), enhanced nutrient and water uptake, and the ability to control tree size. The classic example is the use of American grape vine rootstock to rescue the European grape and wine industry from the soil-borne insect grape phylloxera in the late 19th century. The interaction between rootstock, scion, growing conditions, and the environment can significantly alter crop growth and development, as well as fruit yield and quality (Table 2).

The most common methods of fruit tree grafting are cleft, splice (whip), side, and saddle grafts, while the main budding methods are “T” or shield, patch, chip, and veneer budding (Paull and Duarte 2011). In some cases, branches of different trees are brought together and bound to form a union, and this is called approach grafting. For grafting or budding to be successful, the cambium (cell-dividing) layers of both scion and rootstock must be in intimate contact to fuse and regenerate the union between all required water-conducting (xylem) and sugar-conducting (phloem) tissues.

Many tropical fruit species are or can be propagated by grafting and budding. Some species can be more difficult, requiring scion preparation or the use of a specific grafting or budding technique for best success. For example, stems that produce latex when cut can be difficult to graft or bud, as the latex prevents a direct

Table 2. Major advantages and disadvantages of grafting of fruit trees.

Advantages	Disadvantages
Disease resistance/ tolerance	Additional expenses for rootstocks
Earlier flowering	Experienced labor required
Tolerance to low and high temperatures	Selection of rootstock/ scion combinations
Salt tolerance	Fruit quality lower in some combinations
Enhanced water and nutrient uptake	Higher cost
Shoot growth control	Poor rootstock/scion junction
Yield increase	Rootstock/scion incompatability

contact between the scion and rootstock. The skill and experience of the grafter plays a very important role in the success of grafting and budding each fruit tree species.

Figure 4. Mango seedling from A) monoembryonic Indian type with a single tap root; B) polyembryonic seed with multiple "apomict" embryos and seedling that are exact replicas of the female parent.

Rootstocks

Stem cuttings and air-layers yield plants that are the same genetic makeup in the shoot and root systems, though there is no taproot. Budding and grafting onto a rootstock allows for the advantage of having a root system with a taproot that is better adapted to soil conditions and weather than a scion's root system. A taproot also provides greater archorage in areas with high winds from hurricanes or cyclones. Rootstocks are normally grown from seed; it is preferable to use apomict (nucellar, somatic, polyembryony) embryos that are exact genetic replicas of the female parent regardless of the pollen source. In polyembryonic mango, often the South-East Asian types, there is one sexual embryo per seed and several somatic or nucellar ones (Figure 4). This characteristic is apparently controlled by a single gene. Apomict seeds are common in citrus, mango, and mangosteen.

Citrus has seen the greatest research effort in developing rootstocks. The rootstocks used for citrus can reduce the time before fruiting, control tree vigor, provide uniformity in trees, increase fruit yield and quality, allow wider adaptability to different soil types and weather, and heighten pest and disease resistance or tolerance. Many of these traits are achieved in other tree crops by canopy management (training, pruning, and fruit thinning). In citrus, scion compatability is also a consideration, with pummelo being frequently incompatable with other citrus species. Some citrus rootstocks are superior for some traits but inferior for other characteristics, with none being superior for all traits in all growing areas. The choice of scion–rootstock combination is dependent upon the orchard's conditions. Sour orange has been widely used as a rootstock because it imparta good yield, fruit quality, and tolerance to *Phytophthora* foot disease, but it is susceptible to *Citrus tristeza virus* (CTV) and does not grow well in heavy soils.

In Hawai'i, an important citrus rootstock consideration is resistance or tolerance to soilborne fungi (*Phytophthora* spp.) that attacks near ground level, causing foot or root rot, also known as gummosis. In situation

Table 3. Common citrus rootstocks used in Hawai'i. Citrus species are not at all well defined; many are hybrids, as they inter-breed freely, leading to confusion in descriptions and names. There are four ancestral species from which all other so-called citrus species arose by inter-breeding: citron (*C. medica*), pummelo (*C. maxima*), mandarin (*C. reticulata*), and papeda (*C. micrantha*). *Citrus jambhiri*, *C. reshui,* and *C. x webberi* are not fully accepted as species names.

Rootstock	Phytophthora	Tristeza	Tree Size	Graft Scion	Notes
Rough lemon, Jambhiri *Citrus jambhiri*	Susceptible	Tolerant	Large		Vigorous growth and large root mass. Often the grafts die off in times of drought, leaving the lemon to grow into large, thorny trees with abundant fruit. Susceptible to poorly drained conditions. Suitable for a wide range soil pH. Numerous hybrids available.
Cleopatra mandarin *Citris reshui* Hort. ex. Tam	Tolerant	Tolerant	intermediate	Tangerine Grapefruit Orange	Late bearing; can produce high yields of slightly smaller fruit. Drought tolerant, grows well sandy and heavy soils.
Heen naran, *Citrus reticulata* Blanco	Resistant	Tolerant	Dwarf	Tangerine Orange Grapefruit Lime Pummelo	Seedy type of tangerine that was thought to be good for Hawai'i; naturally dwarfing and grows well on a'a lava soils. The tree never performed as expected in Hawai'i but can be found as the root stock for some citrus imports.
Kalpi, *Citrus* subgroup *Papeda* x *webberi* Citrus hybrid	Resistant	Tolerant	intermediate	Grapefruit Lime Fingerlime Pummelo Lemon	Small lemon hybrid from the Philippines; brought to Hawai'i as a rootstock, like the jambiri. Related to I'chang papeada and Japanese yuzu and worth growing for its own value.
Rangpur/Kona lime, *Citrus limon* (L.) Osbeck	Susceptible	Tolerant	Large	Tangerine Orange	Often called local lemon or lime, looks like a tangerine. When the graft dies off the vigorous lime takes over. Adapted to a range of soil types; good fruit quality, early fruiting.
Trifoliate, *Poncirus trifoliata*	Tolerant	Tolerant	Dwarf	Orange Kumquat	Most popular rootstock; most new citrus brought into Hawai'i are on different types of this rootstock. Hybrids include 'Flying Dragon', 'Volkamer', 'Troyer', 'Carrizo', C-35, Rich 16-6, and 'Macrophylla'. Adapted to cool conditions and heavy and acid soils.
Sunki, *Citrus reticulata* Blanco (*Citrus sunki* (Hayata) Hort. ex. Tanaka	Tolerant	Tolerant	Intermediate	Tangerine Orange	Sunki is a seedy type of tangerine that was thought to be good for Hawai'i because of its virus resistance; naturally dwarfing. The tree never performed as expected in Hawai'i but can be found as the root stock for some citrus imports.
Shikuwasa, *Citrus reticulata* Blanco (*Citrus depressa* Hayata)	Susceptible	Tolerant	Intermediate	Lime Lemon Calamondin	Native to Okinawa and Southern Kyushu, the tree is rare in Hawai'i but becoming increasingly popular on Maui for its lemon/lime flavor. Popular juice-drink fruit in Japan.

Figure 5. Simple wedge grafts (A and D) can be used on older rootstocks or to completely change the variety being grown on older large trees. Single (B) or multiple (F) scions can be grafted on the same rootstock. The procedures are similar to those described in Figure 3 for bud grafting. The wedge-shaped scion is inserted into a slit at the top of the rootstock or old tree that has topped. The wedge grafts are then wrapped in plastic film to prevent the graft drying out while the new graft union is formed.

where *Phytophthora* is a problem or where there is heavy soil or high rainfall and humidity, grafts should be done 30 to 45 cm (12" to 18") above the ground. Resistance to CTV is also required, as the virus is widespread in Hawai‘i. Common rootstocks that have been evaluated in Hawai‘i are outlined in Table 3.

Top-working of older fruit trees is common in Hawai‘i when there is a desire to change the variety or cultivar in an orchard without replanting or to bring trees down to a more manageable height (Figure 5). Growers may top-work avocado and citrus. This can be done with a simple wedge graft (Figure 5A and 5D) of a scion or scions onto an existing tree trunk that has been topped and is completely devoid of vegetative growth, or onto shoots arising from the stump. Often, the large, established root mass is beneficial to a healthy tree.

Some growers use grafting and budding to create trees with multiple varieties or cultivars on a single rootstock, whereby providing varied fruit production and the ability to grow different fruit in minimal space.

Natural propagative structures

Some plants naturally produce structures such as suckers to continue production after the mother plant has fruited, though this is not common for perennial fruit trees. In Hawai‘i these structures are often referred to as “keiki.” As with bananas and plantains, suckers arise from the base or corm of the mother plant. These suckers can be transplanted whole or with most of the pseudostem (fleshy trunk) removed, so long as the corm remains and roots can develop from it. Pineapple suckers arise either on top of the fruit (crown), at the base of the fruit (slips), or at the base of the plant (basal or stem suckers). In fresh fruit production often the crown is sold with the fruit and is the preferred propagation material, followed by slips. Slips may not be produced year-round nor by some clonal selections.

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