Cacao Grafting Using Grafting Tools

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What is grafting?

- Combining two plant parts
- **Scion**: top part of the plant (desirable for fruit production)
- **Rootstock**: bottom part of the plant (roots)

How does it work?

Why do we graft?

- Resistance to disease (Black Pod)
- Improved yield
- Architecture/Vigor
- Quality

Scion selection (look for…)

- Pencil to sharpie sized diameter (6-10mm)
- Semi-hardwood (Greenish-brown)
- Swollen buds

Scion selection (NOT)

- Thin, bent and tightly spaced nodes (a)
- Opened buds (b)

Rootstock selection

- Grown by seed
- Grafted on at 4-6 months old, typically
- Healthy and disease free

Rootstock stem-diameter needs to be the same diameter as scion or larger in diameter

Justification

- For improved production, quality and disease resistance, clonal cacao production is desirable
  - That means we need grafting
- Grafting takes skill, time, and money
- Therefore;

*The **objective** of this study was to evaluate hand-grafting and commercially available grafting tools for efficiency and successful graft union.*

Materials and Methods

Three different methods of grafting cacao (hand, bud-graft tool, v-graft tools)

- Rootstock planted February 2019
- Grafted beginning July 2019
- Results taken end of July 2019

Funding: County of Hawaii Department of Research and Development

Materials

Zep

3

More Buying Choices

$4.19 (15 new offers)

Amazon Brand - Solimo 70% Ethyl Rubbing Alcohol First Aid Antiseptic, 16 Fluid Ounces

47

$1.80 ($0.01/Fl Oz)

Hydrofarm Macore Co HGPMR1000 Plant Stake Labels, 4 x 5/8", Red

20

$34.07

Materials

Heathrow Scientific HD234526B Parafilm Moisture Proof Sealing 132mm Width x 135mm Height x 112mm Depth

16

Misc.

$39.66 ~~$43.30~~

prime Get it as soon as **Wed, Aug 7**

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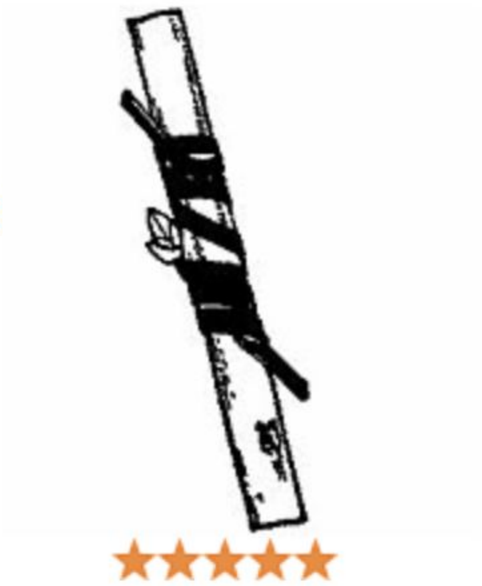

ıbber Strips for Budding and Grafting

From
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Hand-grafting

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Tina Folding Extra Heavy Grafting Knife

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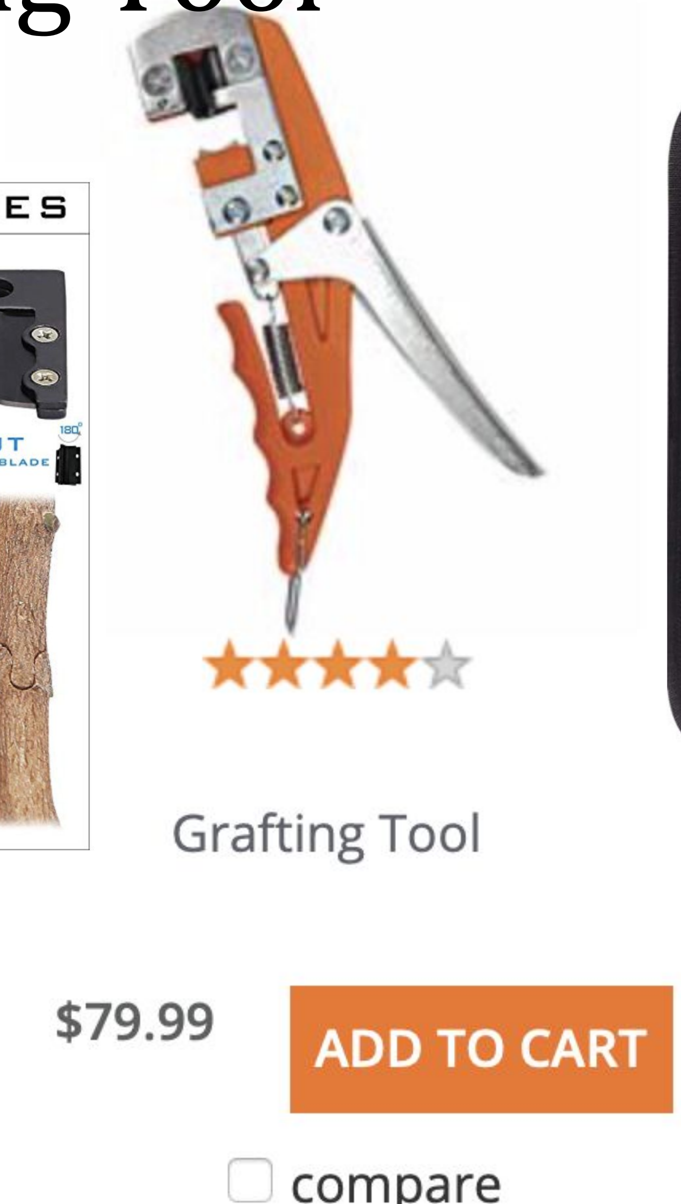
Bud-grafting Tool



V-grafting Tool (expensive)

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1

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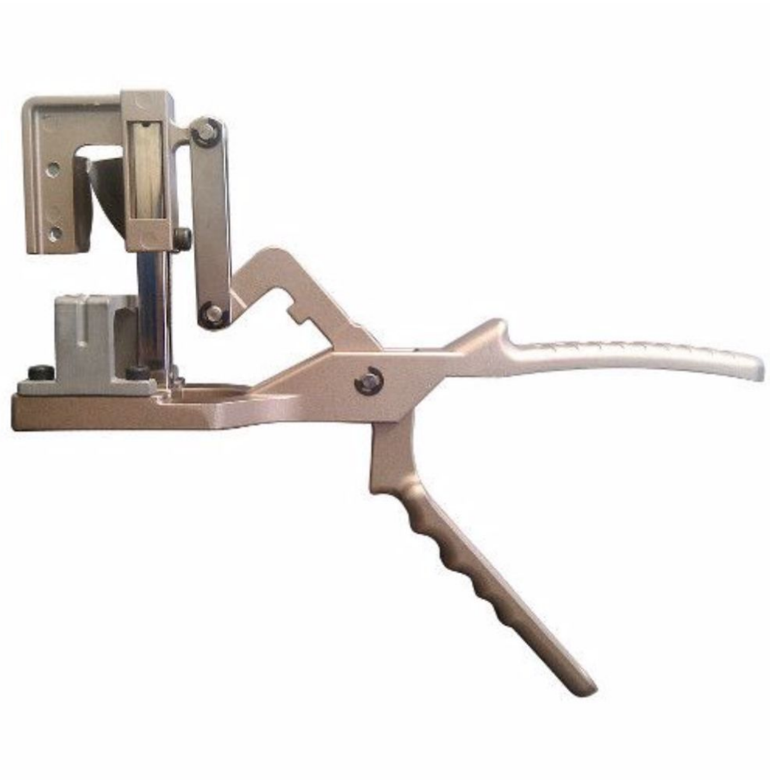
V-grafting Tool (cheap)

HOME > GROWING AND PROPAGATING > GRAFTING SUPPLIES > ZENPORT V-CUT TOP GRAFTING TOOL



Zenport V-Cut Top Grafting Tool

$64.99

In Stock

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The Zenport Top Grafting Tool is a heavy-duty device that mak
precision "V" cuts in both scions and root stocks. The two piece
match up perfectly which improves grafting success rates.

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1

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Results

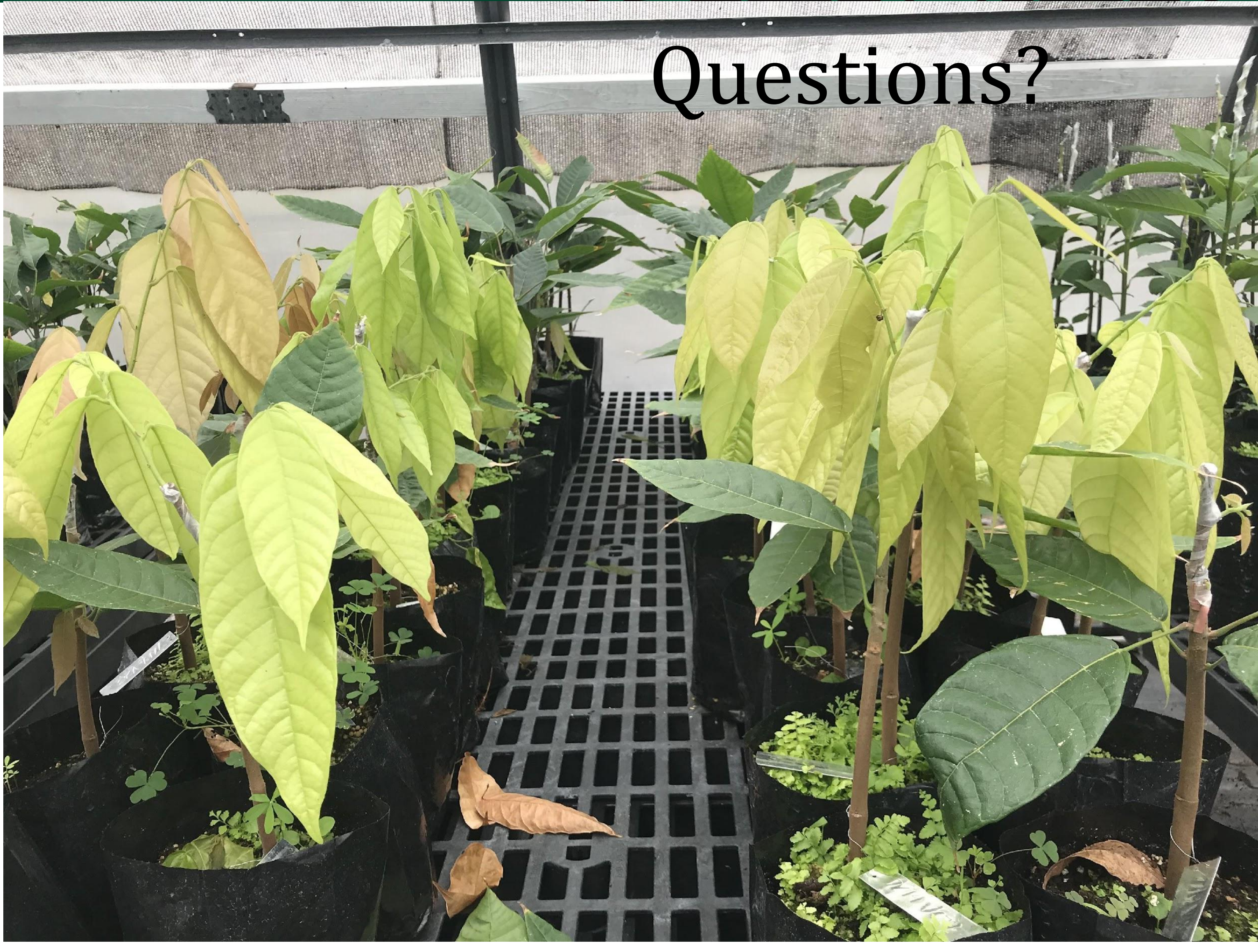
Grafting Method	# of successful grafts	% success
Hand	11/30	37%
Bud-graft tool	0/30	0%
V-graft tool	25/30	83%

Hand graft (Side Wedge)

Bud-graft tool

V-graft tool

Questions?



THANK YOU

- County of Hawaii Department of Research and Development
- Kevin Burke
- Max Breen
- Colin Hart
- Cacao Services, Inc.

The Central American Cacao Project (PCC) at CATIE (Tropical Agricultural Research and Higher Education Center) aims to increase the productivity, diversity and financial and environmental value of the cacao plantations of at least 6,000 Central American families.

Working closely with cacao farming families, the Project creates alliances with other partners in the region in order to enhance the social interactions, competitiveness and business capacity of the producers' organizations and improve the living conditions of their members.

The Project promotes efforts to increase the knowledge and skills of farming families and students at agricultural schools, technical colleges and agronomy faculties, for the sustainable production of cacao.

The Project also offers equal opportunities as well as economic, social and cultural responsibilities for men and women of all ages and from different ethnic groups in all its spheres of action.

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ISBN: 978-9977-57-534-6

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Central American Cacao Project

Grafting and other methods for the asexual Propagation of Cacao

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Eduardo Say · Olivier Deheuvels · Lauren Fins

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Tropical Agricultural Research and Higher Education Center (CATIE)
Turrialba, Costa Rica
2011

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633.7431
G737 Grafting and other methods for the asexual propagation of cacao / Eduardo Somarriba Chávez….[et al.]. – 1º ed. – Turrialba, C.R : CATIE, 2011.
15 p. : il. – (Technical series. Extension materials / CATIE ; no. 4 Eng.ed.)

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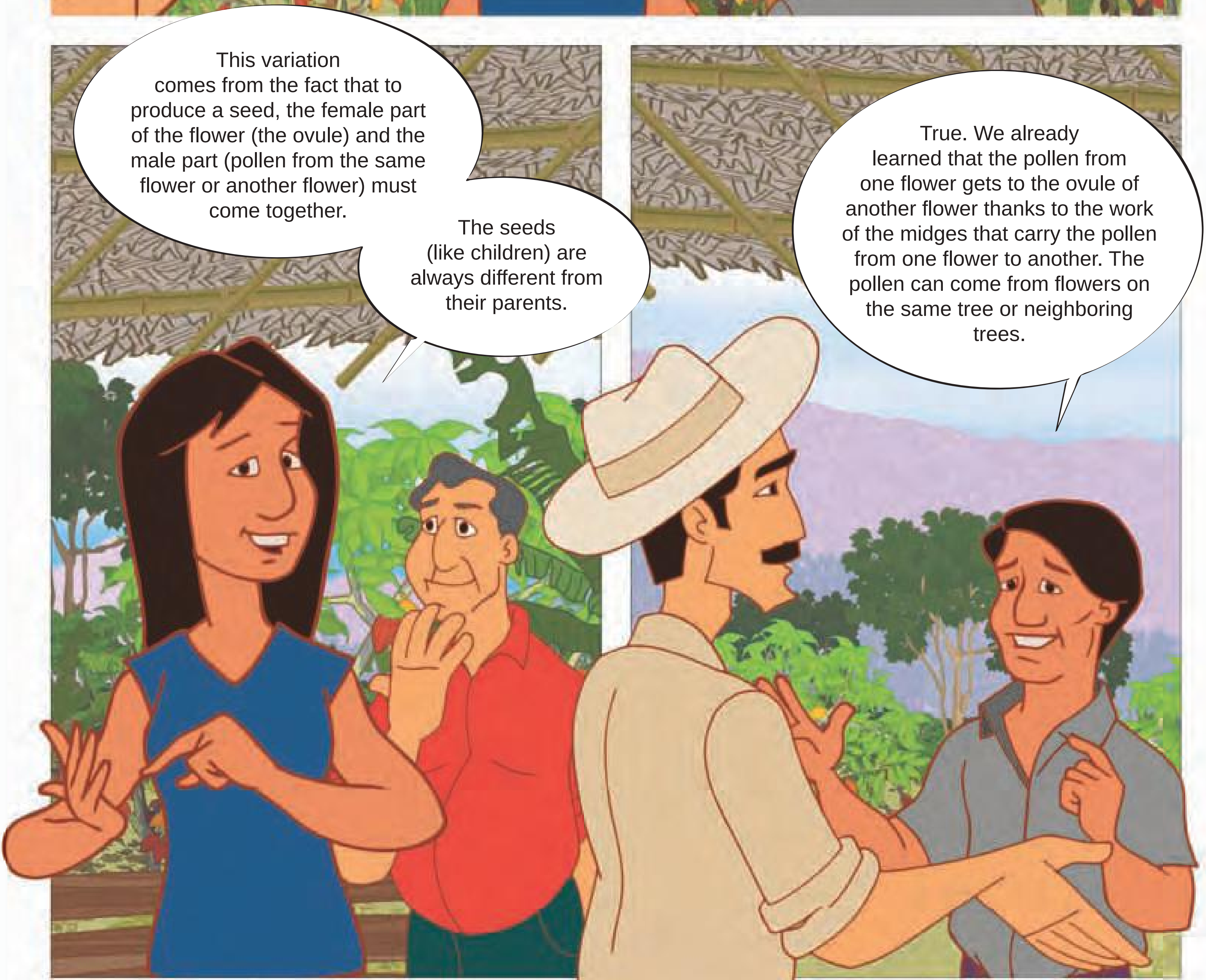
This manual was developed by CATIE's Central American Cacao Project (PCC/MAP), with funds provided by the government of Norway.


Good morning. How is everyone? Thank you for coming to visit with us this morning. I would like to introduce Gerardo, who owns this special demonstration farm where he has planted grafted cacao trees.
Good morning. It is a real pleasure for me to have you here on our farm.


Thank you, Gerardo. Friends, you remember in the last meeting we learned that sexual reproduction involves the union of male (pollen) and female (ovules) parts of cacao flowers to produce new seeds, which then grow into new plants.
However, during today's meeting, we are going to learn about other ways to produce new cacao plants. These methods are collectively known as asexual reproduction or asexual propagation.

Propagation means making more of something. For example, to propagate plants is to make more plants. Today we will learn how to propagate cacao trees by using their branches or other small pieces of the plant instead of planting their seeds.
Asexual means that new plants are generated from parts, such as leaves or branches, of already existing plants. By using asexual propagation, we can make many exact copies of the best cacao trees in our farm.
Let's get to work. Here are the topics for today's meeting. Please pass around these sheets that Filadelio and I prepared yesterday, which list the topics.
LIST OF TOPICS FOR THE MEETING
1. How does asexual propagation of cacao help us improve the farm?
2. Most common asexual propagation techniques.
A. Grafting
- Grafting with buds
- Grafting with scions
B. Rooting cuttings
C. Air layering
D. Somatic embryogenesis

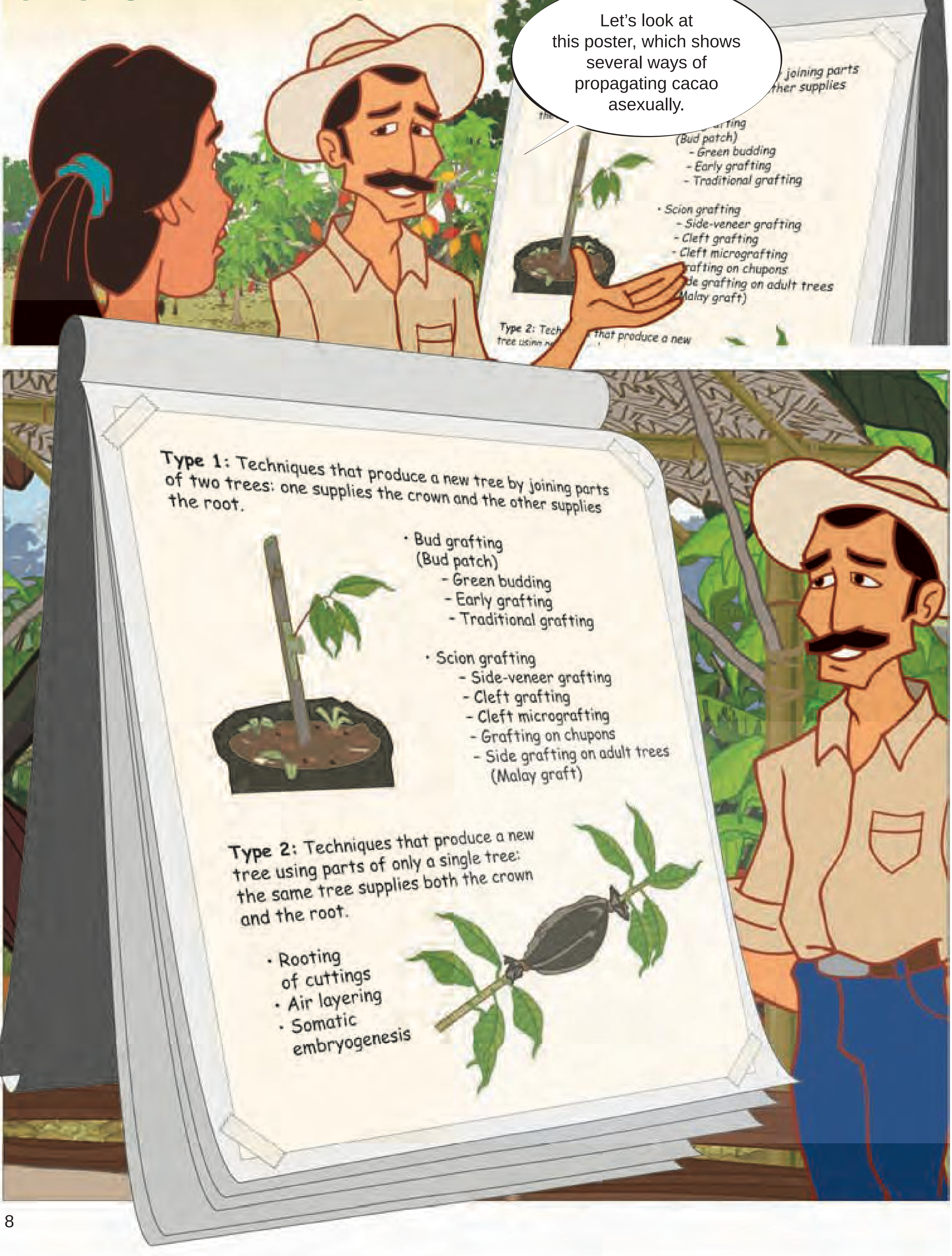
How does asexual propagation of cacao help us improve the farm?

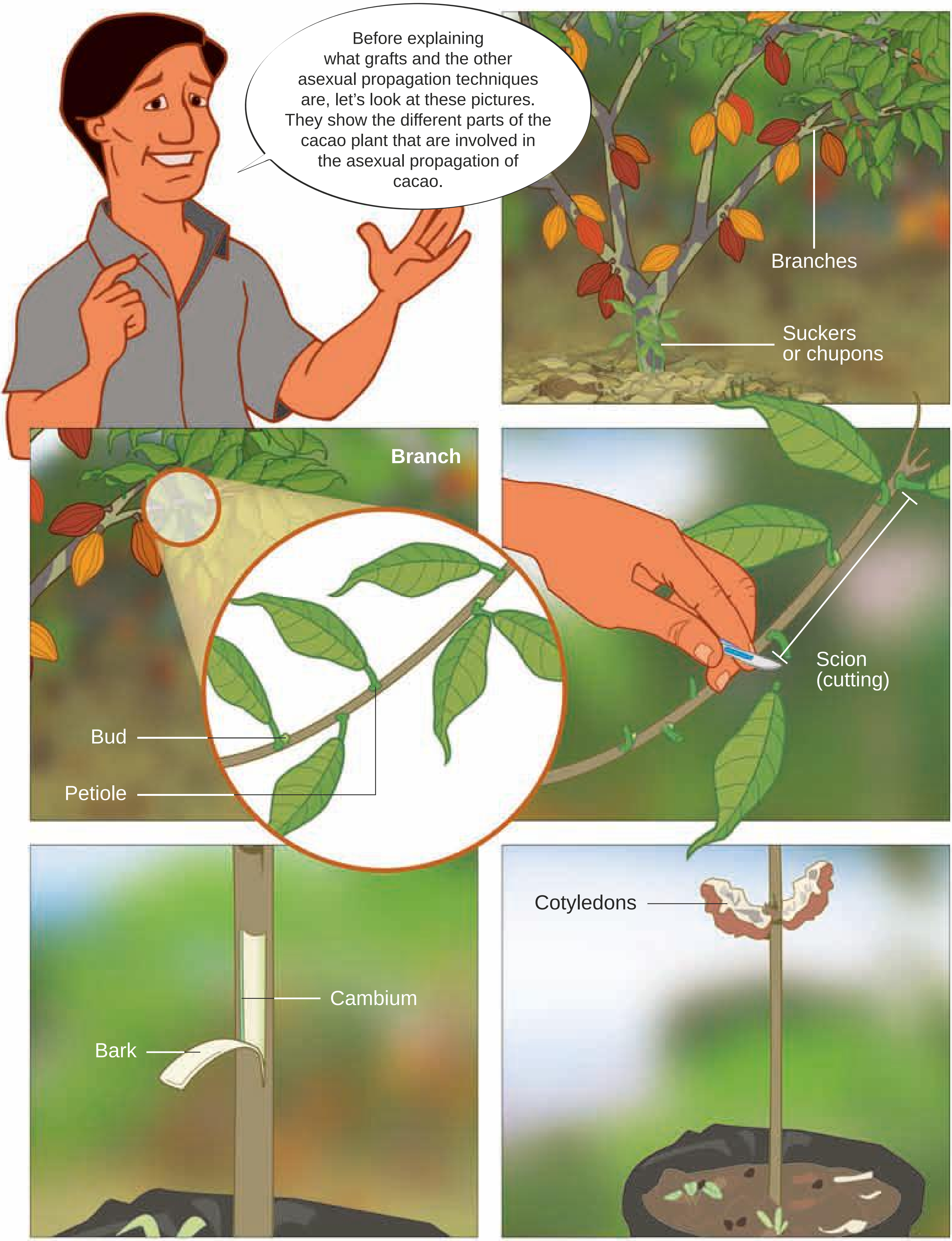


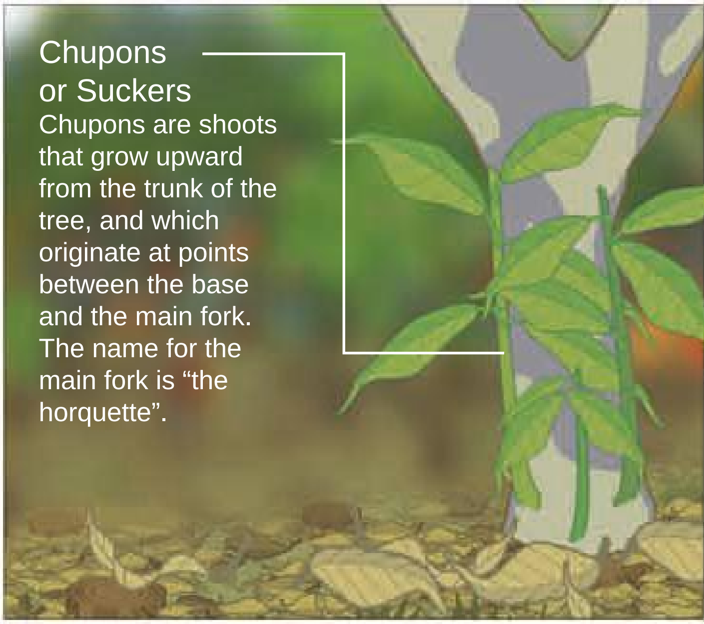

The 40 to 50 seeds found in a cacao fruit all have the same mother, but they can have the same or different fathers.
No wonder cacao plants from the same fruit may be very different from each other.
That's right. Some will be good producers, others won't; some will be tolerant to certain diseases and others won't, some will grow vigorously, while others will grow slowly, and so on.
Asexual propagation techniques were developed to take advantage of this great variability.
Once you identify your best cacao trees, you can use asexual propagation to produce exact copies of them and improve cacao yields.
These exact copies of a plant are called clones. Animals can be cloned too.
Are we going to lose our job? Aren't we going to pollinate anymore?
No, you still have a job to do! The cloned trees will also have flowers and you will need to pollinate them too. Otherwise there will be no fruits to harvest.
Happy is what I am going to be, with the feast I am going to have on the fruits from the cloned cacao trees. Yeeeha.

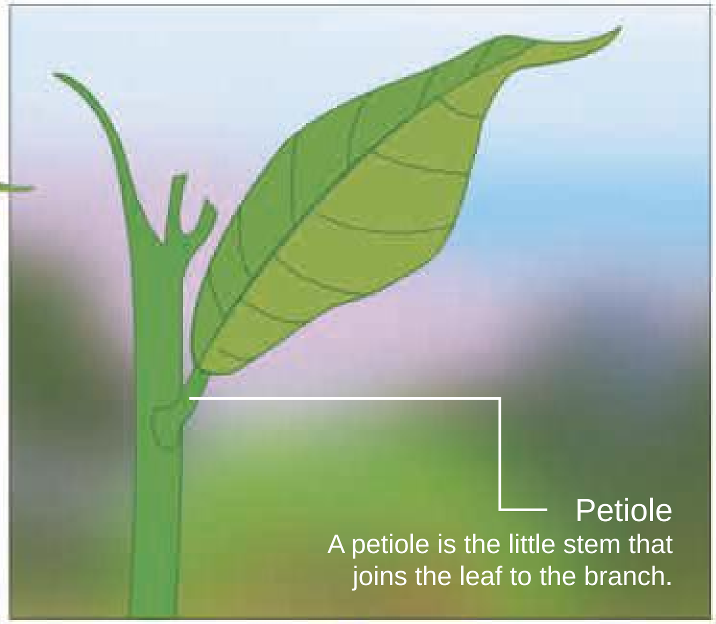

We farmers already use asexual propagation techniques, such as grafting and rooting of cuttings in other crops.
Yes, when we plant a cassava cutting or plant a banana sucker to create a new plant, we are using asexual propagation.
There are two types of asexual propagation techniques that we use with cacao. The first type consists of joining parts of two different cacao trees to form a new tree.
One tree supplies the crown and the other supplies the root. This type of asexual reproduction is called grafting.
The second type of asexual propagation uses a part of only one cacao tree, usually a small branch, to form a new cacao tree.
This branch makes its own roots, produces new shoots and leaves and becomes a whole new plant. Cacao can also be propagated in several other ways that we are going to see today.

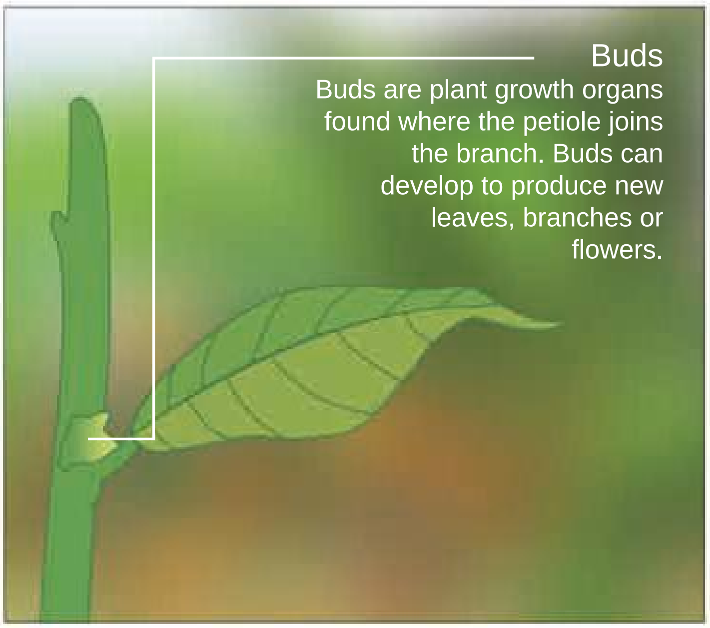
Most common asexual propagation techniques



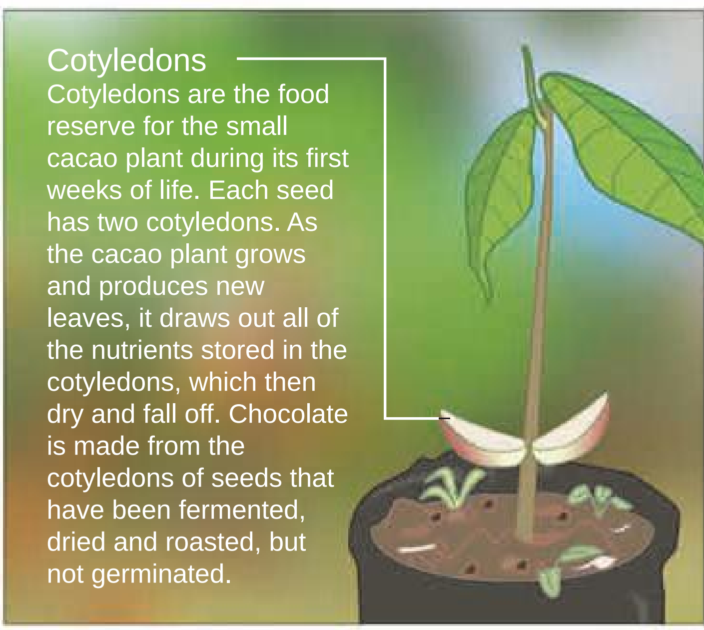

Before explaining what grafts and the other asexual propagation techniques are, let's look at these pictures. They show the different parts of the cacao plant that are involved in the asexual propagation of cacao.
Branches
Suckers or chupons
Branch
Bud
Petiole
Scion (cutting)
Cambium
Bark
Cotyledons

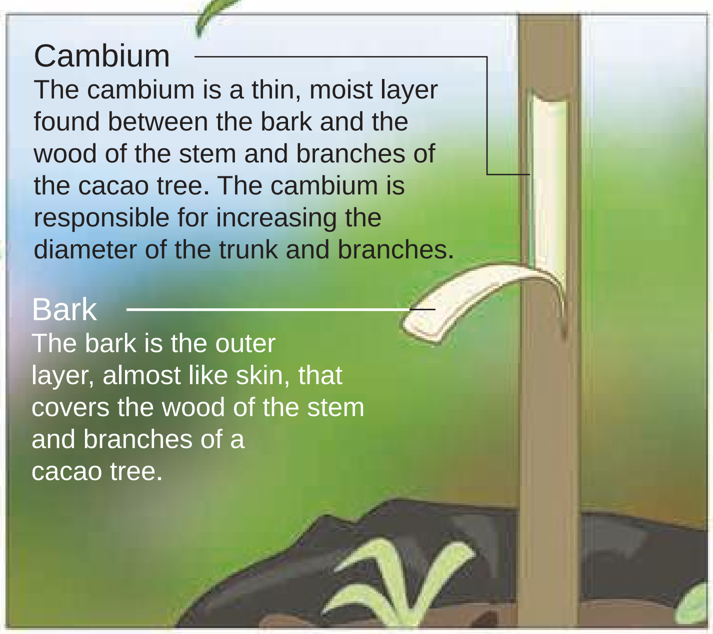

Chupons
or Suckers
Chupons are shoots that grow upward from the trunk of the tree, and which originate at points between the base and the main fork. The name for the main fork is “the horquette”.


Petiole
A petiole is the little stem that joins the leaf to the branch.


Buds
Buds are plant growth organs found where the petiole joins the branch. Buds can develop to produce new leaves, branches or flowers.


Scion
A scion is a small piece of a branch that has several leaves and buds.


Cotyledons
Cotyledons are the food reserve for the small cacao plant during its first weeks of life. Each seed has two cotyledons. As the cacao plant grows and produces new leaves, it draws out all of the nutrients stored in the cotyledons, which then dry and fall off. Chocolate is made from the cotyledons of seeds that have been fermented, dried and roasted, but not germinated.


Cambium
The cambium is a thin, moist layer found between the bark and the wood of the stem and branches of the cacao tree. The cambium is responsible for increasing the diameter of the trunk and branches.
Bark
The bark is the outer layer, almost like skin, that covers the wood of the stem and branches of a cacao tree.

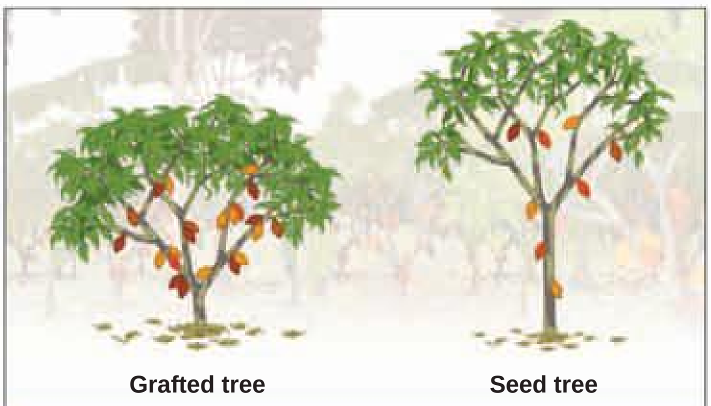
Grafting


Now that we understand the concept of asexual propagation,
let's discuss the various methods that are used to achieve our goal of making more of the best individuals. We can begin with grafting.
What does grafting entail?
Grafting consists of joining a bud or a scion of one plant to another plant, so that the union produces a new, single plant.
The plant that receives the bud or scion— and which contributes the root of the new plant—is called the rootstock, and the upper part—which will be the crown of the new plant—is called the graft.
It is possible to graft onto plants in the field or on potted seedlings in a nursery. But grafting in a nursery is recommended. Do you know why?
Yes, because that way we can use very young plants that use only a small space. This lowers the cost of labor.
Yes, that's true. And besides, in the nursery there is less of a chance for animals or bad weather to harm the plants.
Also the quantity of shade and water that they receive can be controlled.

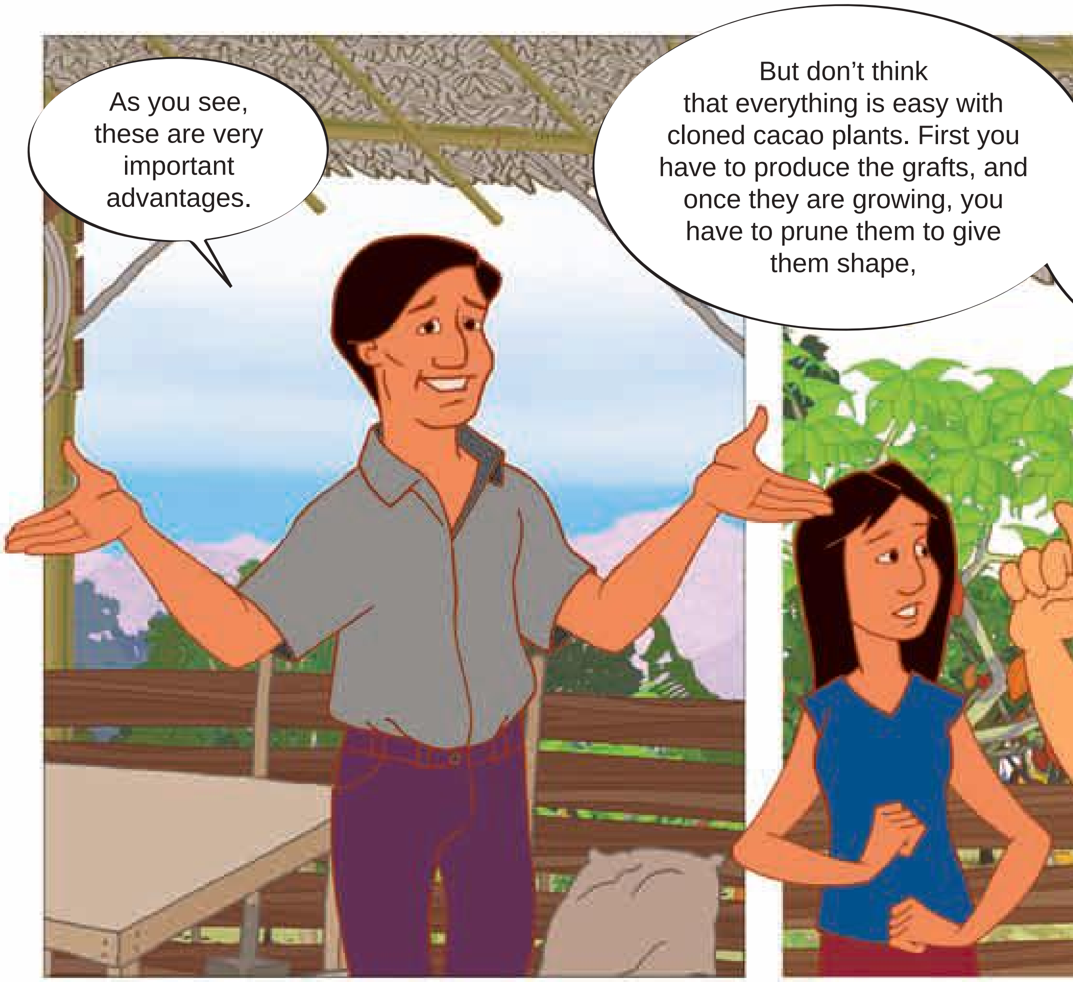
Grafted trees flower early and produce fruits at only two years of age. Trees from seed start flowering when they are three years old and start producing fruits at four years of age.

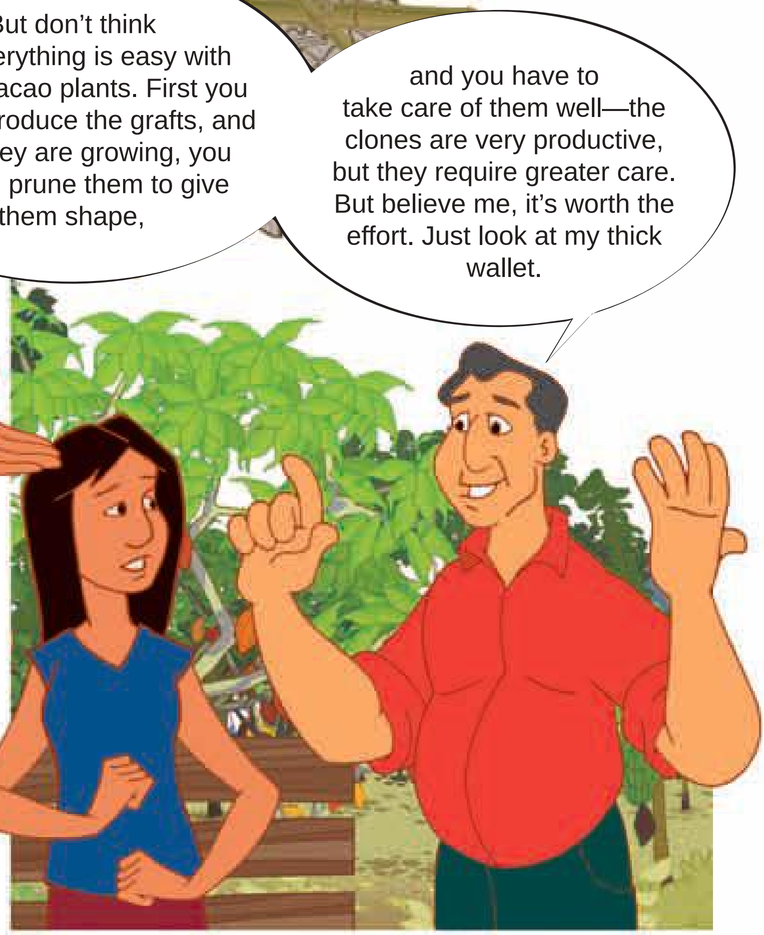
Advantages of grafted cacao plantations

I have found that my grafted cacao plot produces more fruits than the cacao plot planted from seed. This is because these grafted clones were selected for high production, disease resistance and good chocolate quality. All of my cloned trees produce quite well.



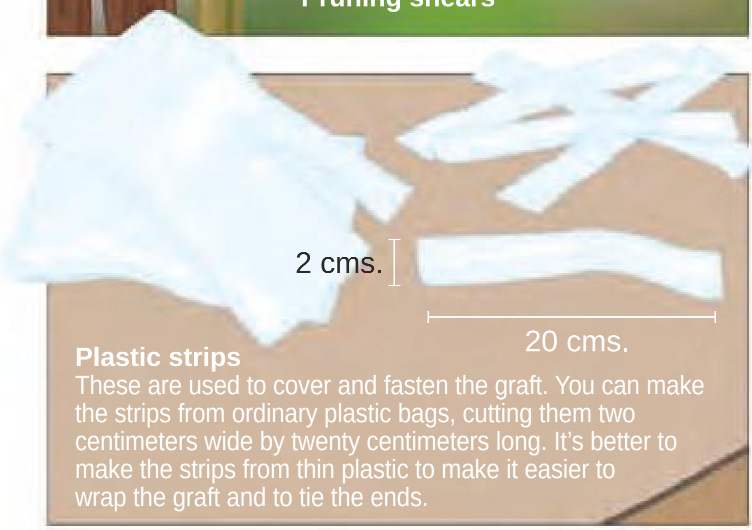
Grafted trees are smaller than trees from seed because they produce only branches and no chupons. Unlike chupons, branches grow outward rather than upward. This keeps the trees small. The small size and rounded form of the grafted trees make pruning, harvest and control of pests and diseases all much easier.


As you see, these are very important advantages.
But don't think that everything is easy with cloned cacao plants. First you have to produce the grafts, and once they are growing, you have to prune them to give them shape,

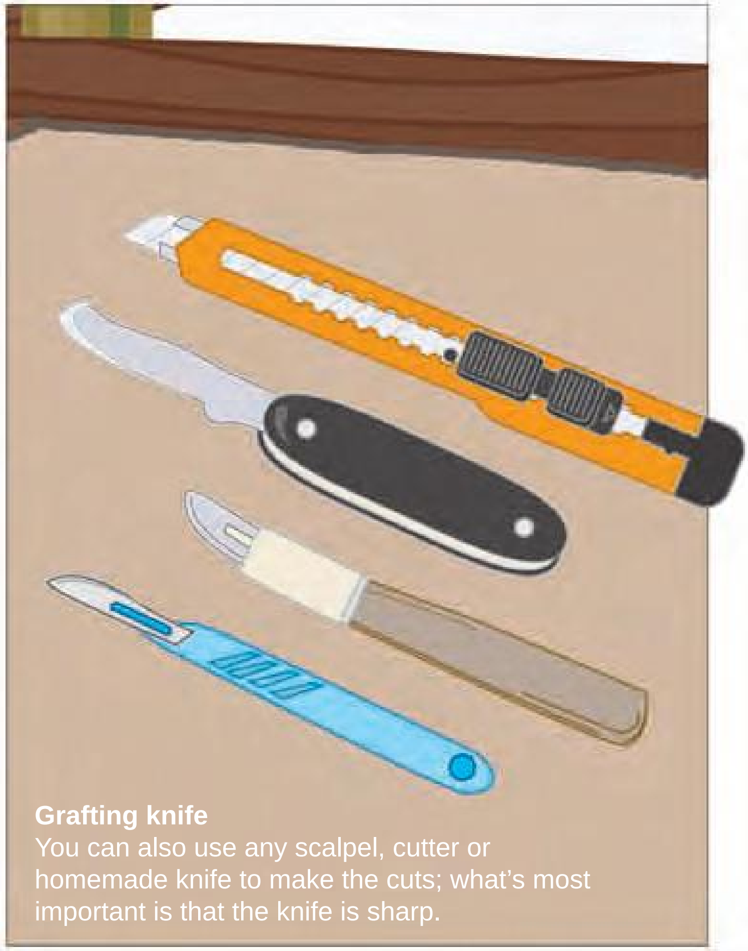

and you have to take care of them well—the clones are very productive, but they require greater care. But believe me, it's worth the effort. Just look at my thick wallet.


So what things do you need to make a grafted cacao plant?
Well, in addition to the buds or scions, and the rootstock, we also need tools and some materials—I brought them.
Let's have a look.

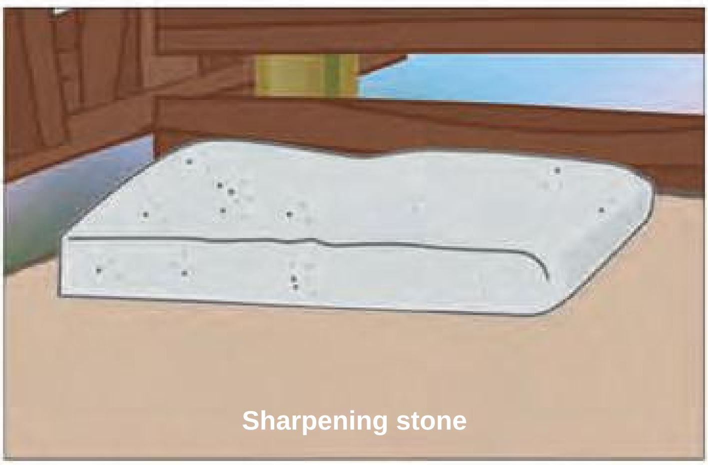
Pruning shears



Plastic strips
These are used to cover and fasten the graft. You can make the strips from ordinary plastic bags, cutting them two centimeters wide by twenty centimeters long. It's better to make the strips from thin plastic to make it easier to wrap the graft and to tie the ends.

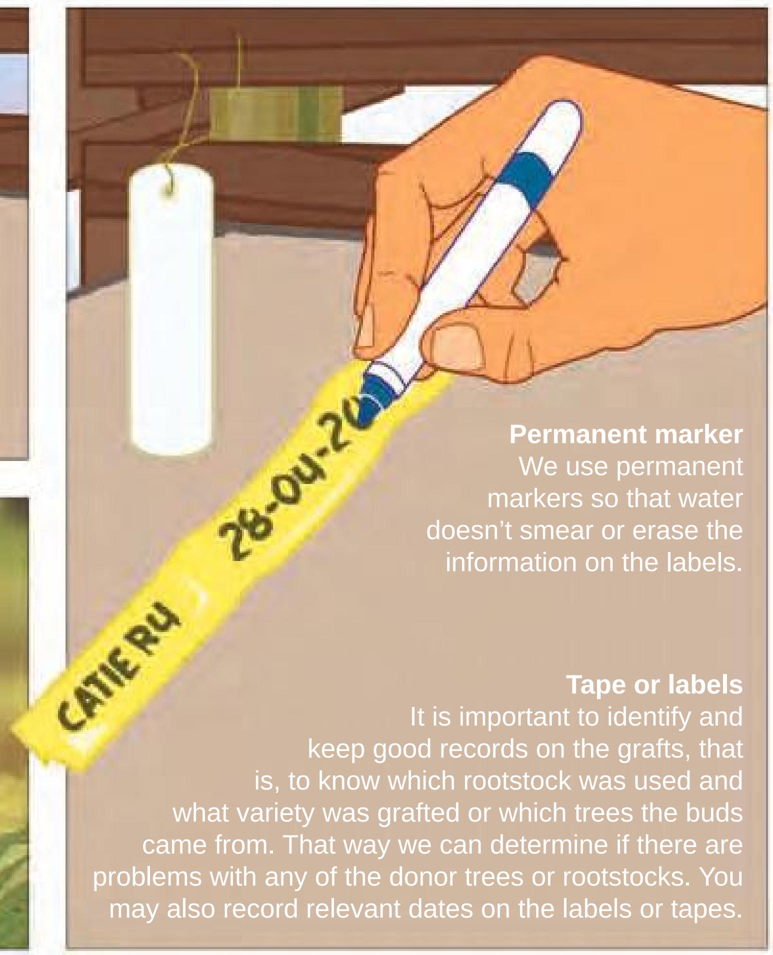


Grafting knife
You can also use any scalpel, cutter or homemade knife to make the cuts; what's most important is that the knife is sharp.



Sharpening stone

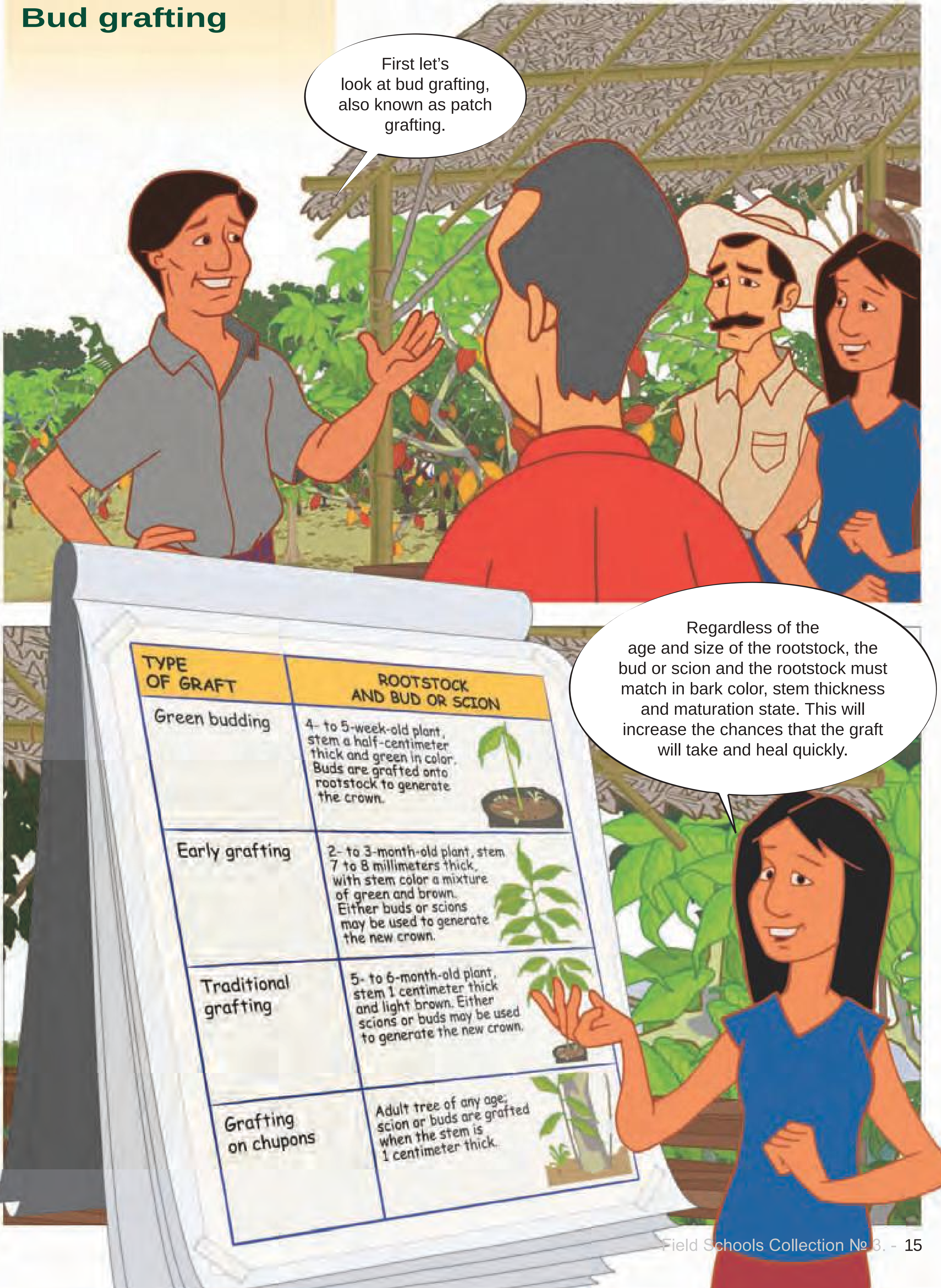
Newspaper or plantain leaves.
These are used to protect the scions and keep them moist.



Permanent marker
We use permanent markers so that water doesn't smear or erase the information on the labels.

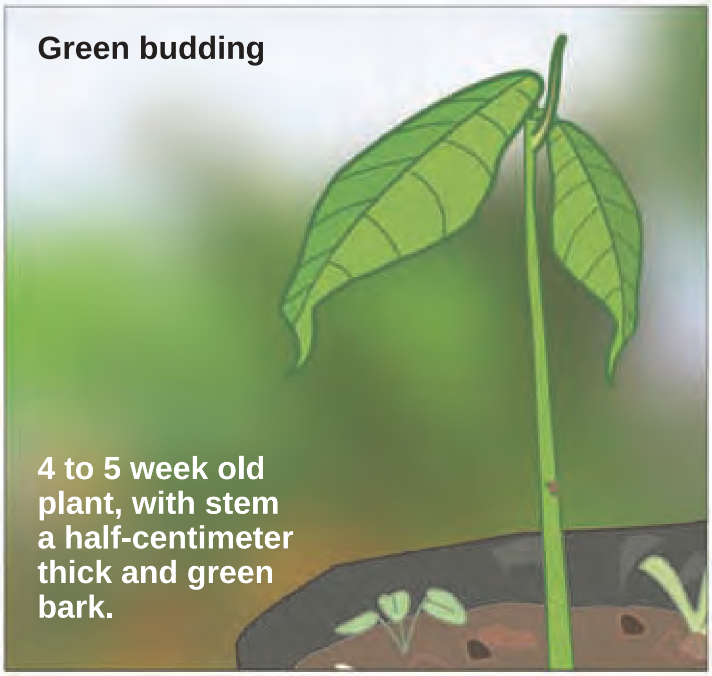
Tape or labels
It is important to identify and keep good records on the grafts, that is, to know which rootstock was used and what variety was grafted or which trees the buds came from. That way we can determine if there are problems with any of the donor trees or rootstocks. You may also record relevant dates on the labels or tapes.

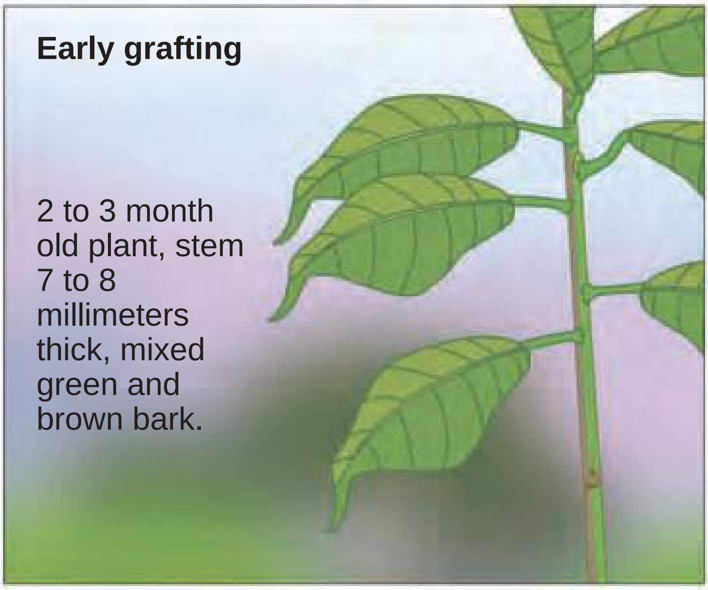
Bud grafting

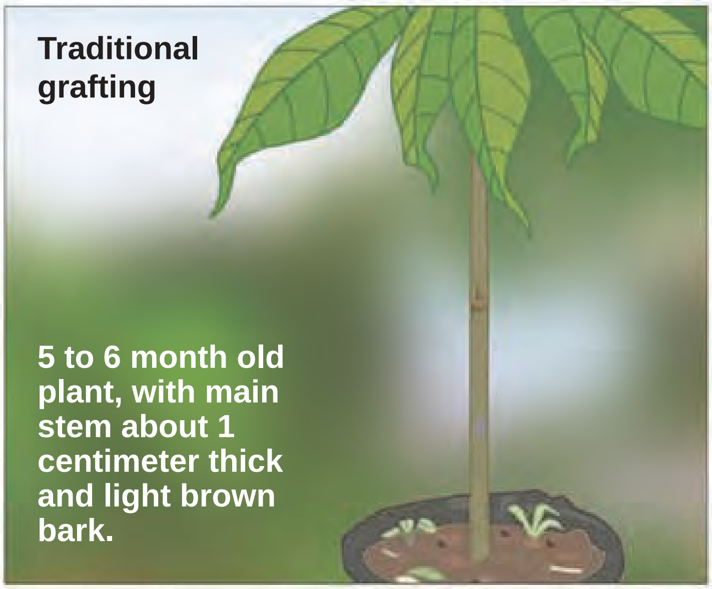


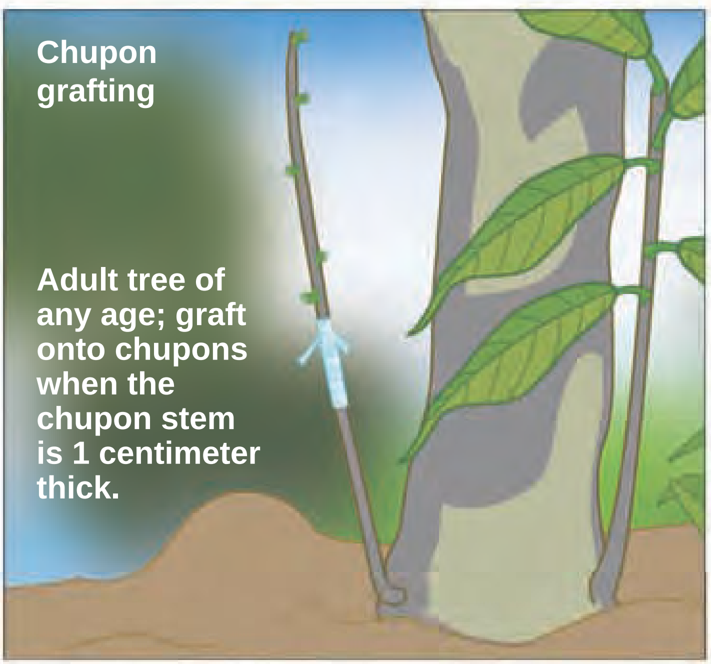
TYPE OF GRAFT	ROOTSTOCK AND BUD OR SCION
Green budding	4- to 5-week-old plant, stem a half-centimeter thick and green in color. Buds are grafted onto rootstock to generate the crown.
Early grafting	2- to 3-month-old plant, stem 7 to 8 millimeters thick, with stem color a mixture of green and brown. Either buds or scions may be used to generate the new crown.
Traditional grafting	5- to 6-month-old plant, stem 1 centimeter thick and light brown. Either scions or buds may be used to generate the new crown.
Grafting on chupons	Adult tree of any age; scion or buds are grafted when the stem is 1 centimeter thick.

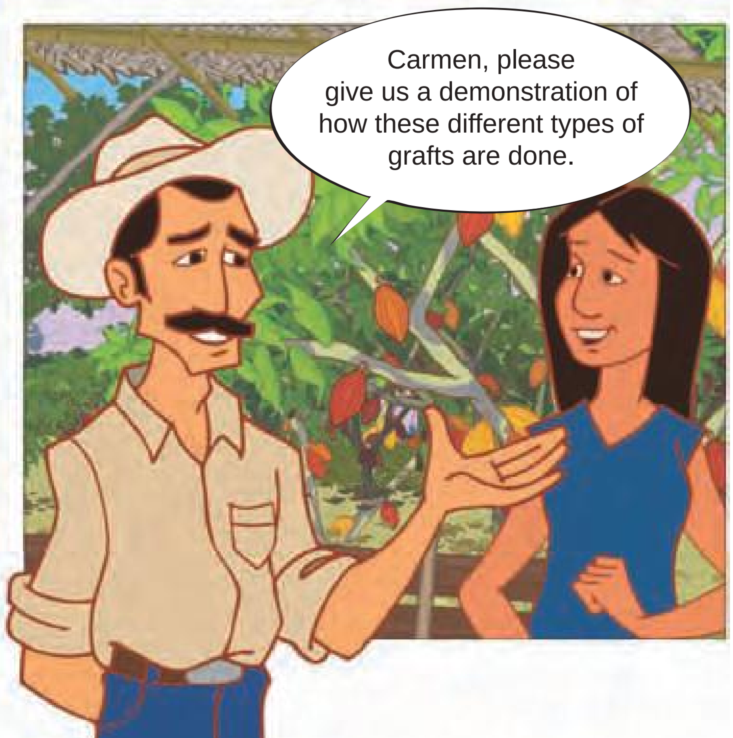

Let's look at these plants,
all of which can be used as rootstock, depending on the type of graft you need.


Green budding
4 to 5 week old plant, with stem a half-centimeter thick and green bark.

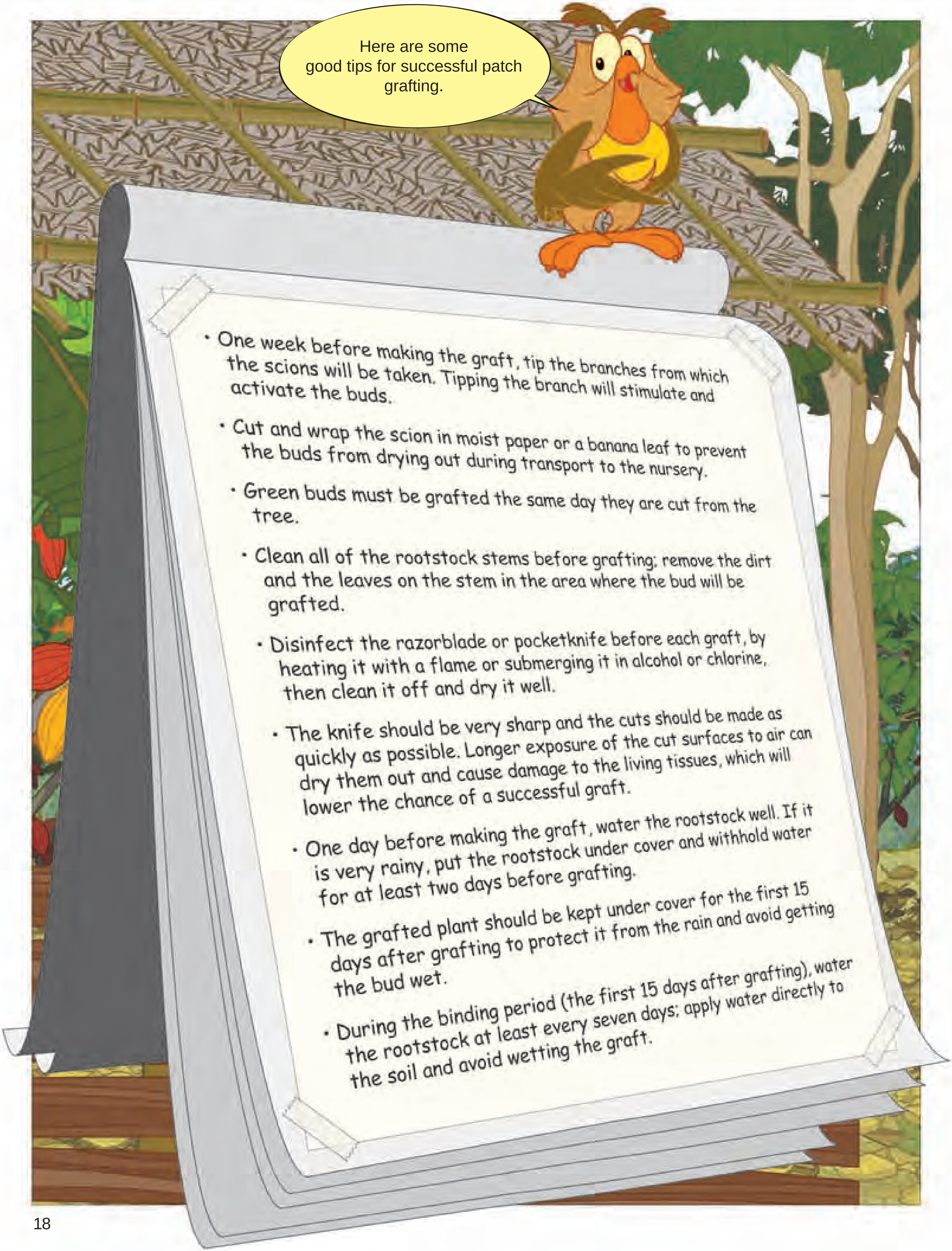

Early grafting
2 to 3 month old plant, stem 7 to 8 millimeters thick, mixed green and brown bark.


Traditional grafting
5 to 6 month old plant, with main stem about 1 centimeter thick and light brown bark.


Chupon grafting
Adult tree of any age; graft onto chupons when the chupon stem is 1 centimeter thick.

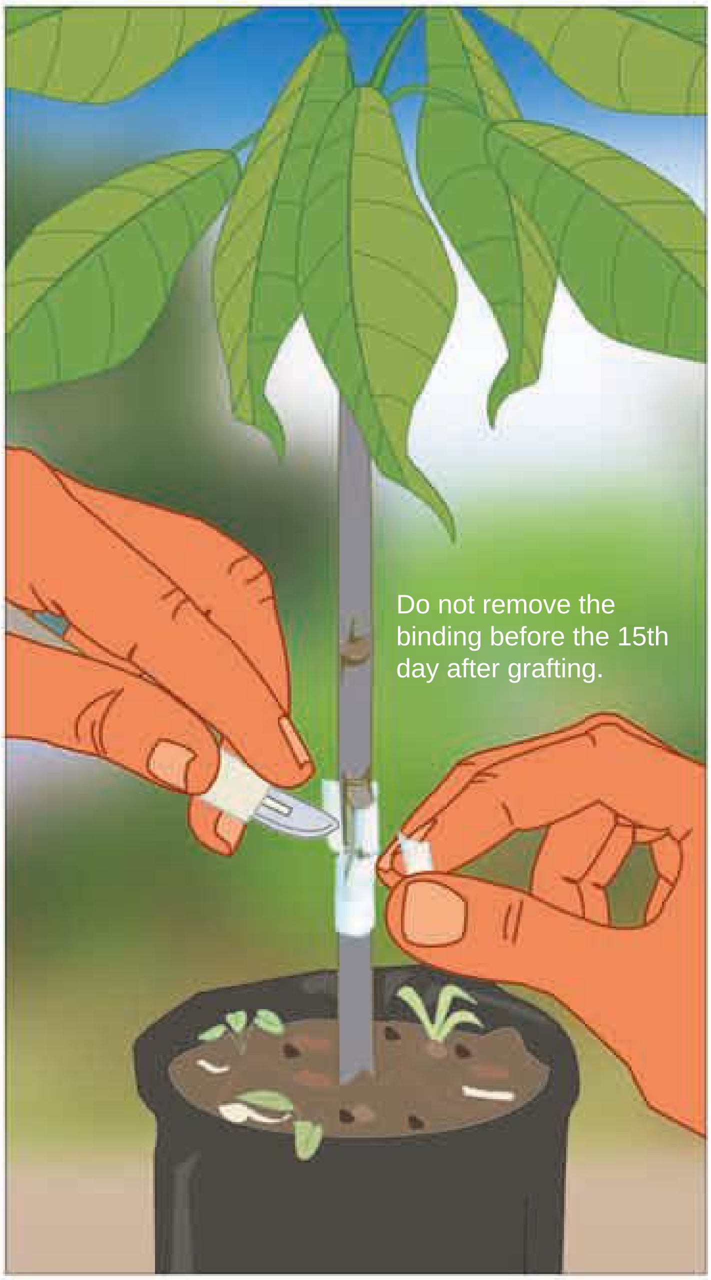

Carmen, please give us a demonstration of how these different types of grafts are done.

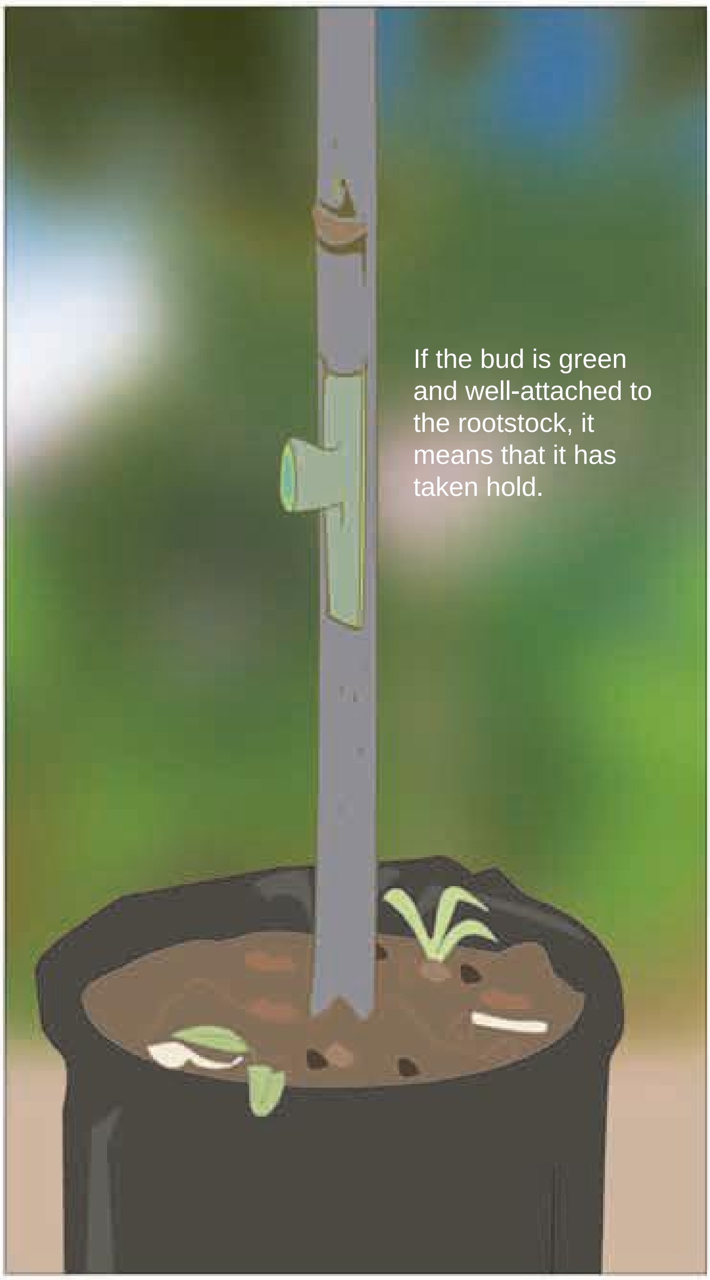

Yes, of course.
First I will demonstrate bud grafting. Watch me:
Rootstock
1. On the rootstock, just beneath the scar of a cotyledon, make two parallel vertical cuts three centimeters long and one across the top to form a small tongue with the bark.
2. From the scion, take a piece of bark, the patch, that includes one bud. This is most easily done by making two lengthwise and two crosswise cuts. Make sure the patch size and shape match the size and shape of the cut on the rootstock.
Bud
Since buds form where leaves connect to the bark, each bud patch will also include a petiole. It is important to leave a part of the petiole on the patch, so you can grab and hold the patch in place during the grafting process. The petiole will also protect the patch from the pressure of the plastic band that is wrapped tightly around the graft to hold the patch onto the rootstock.
Tongue
3. Carefully peel the tongue down without tearing the bark. Place the patch on the open face of the wood of the rootstock.
4. Cover the patch with the tongue and bind them together with a plastic strip. Begin at the top of the union and wrap the graft first in a downward direction, then upward, and then down again,
Always keep the plastic snug around the graft to ensure good contact between the patch and the rootstock. Make the knot at the bottom of the graft union to secure it and to prevent water from getting in.



- One week before making the graft, tip the branches from which the scions will be taken. Tipping the branch will stimulate and activate the buds.
- Cut and wrap the scion in moist paper or a banana leaf to prevent the buds from drying out during transport to the nursery.
- Green buds must be grafted the same day they are cut from the tree.
- Clean all of the rootstock stems before grafting; remove the dirt and the leaves on the stem in the area where the bud will be grafted.
- Disinfect the razorblade or pocketknife before each graft, by heating it with a flame or submerging it in alcohol or chlorine, then clean it off and dry it well.
- The knife should be very sharp and the cuts should be made as quickly as possible. Longer exposure of the cut surfaces to air can dry them out and cause damage to the living tissues, which will lower the chance of a successful graft.
- One day before making the graft, water the rootstock well. If it is very rainy, put the rootstock under cover and withhold water for at least two days before grafting.
- The grafted plant should be kept under cover for the first 15 days after grafting to protect it from the rain and avoid getting the bud wet.
- During the binding period (the first 15 days after grafting), water the rootstock at least every seven days; apply water directly to the soil and avoid wetting the graft.

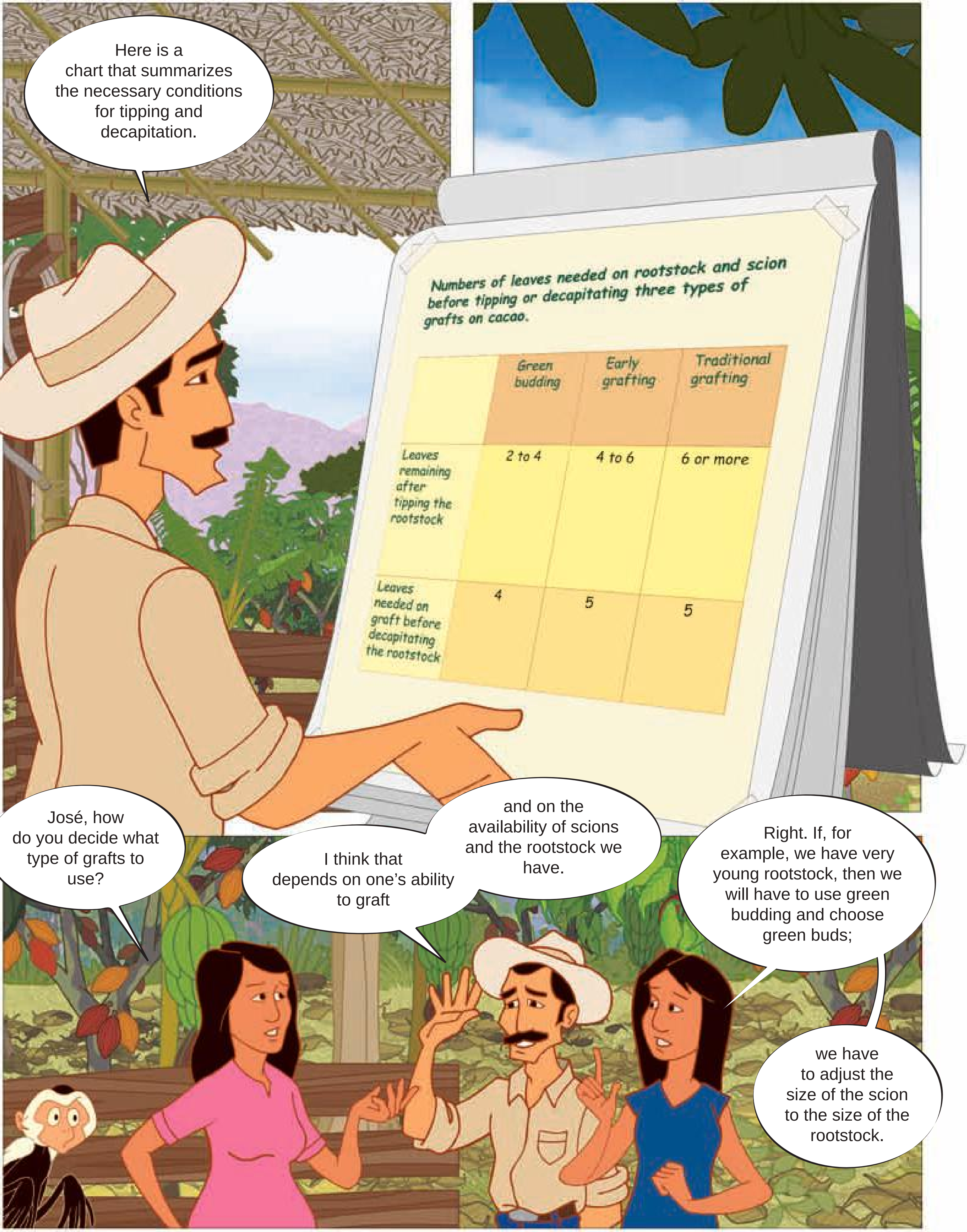

To find out whether the graft has taken, remove the binding on the 15th day after grafting and examine the bud.
If it is green and well-attached to the rootstock, it means that it has taken hold. If the bud is dry or dark brown in color, it means that the graft did not attach and has died.


Do not remove the binding before the 15th day after grafting.


If the bud is green and well-attached to the rootstock, it means that it has taken hold.


If the bud has taken hold, then we immediately tip the rootstock.
Tipping means that we cut off the tip or last shoot of the stem so that it will stop growing in length. This stimulates the growth of the bud graft.
When tipping, be sure to keep several leaves on the rootstock to support both the rootstock and the graft.
Once the bud has developed into a branch with at least four leaves, remove the top of the rootstock.
Making the cut at 10 centimeters above the graft so the scar will not damage the bud.
Also making sure to regularly remove all chupons from the rootstock because they will weaken the grafted bud. Be careful not to cut the graft by mistaking it for a chupon.

Tipping and decapitation of the rootstock


Here is a chart that summarizes the necessary conditions for tipping and decapitation.
Numbers of leaves needed on rootstock and scion before tipping or decapitating three types of grafts on cacao.
Green budding
Early grafting
Traditional grafting
Leaves remaining after tipping the rootstock
2 to 4
4 to 6
6 or more
Leaves needed on graft before decapitating the rootstock
4
5
5
José, how do you decide what type of grafts to use?
I think that depends on one's ability to graft
and on the availability of scions and the rootstock we have.
Right. If, for example, we have very young rootstock, then we will have to use green budding and choose green buds;
we have to adjust the size of the scion to the size of the rootstock.

Scion grafting

The side graft

Cleft graft


Let me show you how to do this graft.
The first step in cleft grafting is to tip a 20 centimeters tall rootstock. The next step is to make a cut about four centimeters long from the top of the tipped rootstock downward, splitting the stem approximately into halves. This is where we will place the scion, between the two halves.
4 cms.
Rootstock
2. The scion should be a small branch that includes three or four buds and it should be about the same thickness as the rootstock. At the thicker end of the rootstock we make two four-centimeter slanted cuts, one on each side, to form a wedge.
Scion
3. Insert the wedge of the scion into the cut at the top of the stem of the rootstock, making sure, as before, that the cambiums of the rootstock and scion are well-aligned.
4. Bind the graft with plastic strips, tightening it well. Once it is wrapped, place a transparent plastic bag over the graft to keep it dry and warm.
Unwrap the graft 45 days later. If the scion is alive and its buds have begun to sprout, the graft was successful. If the scion is dry, the graft did not take.

Cleft micrografting

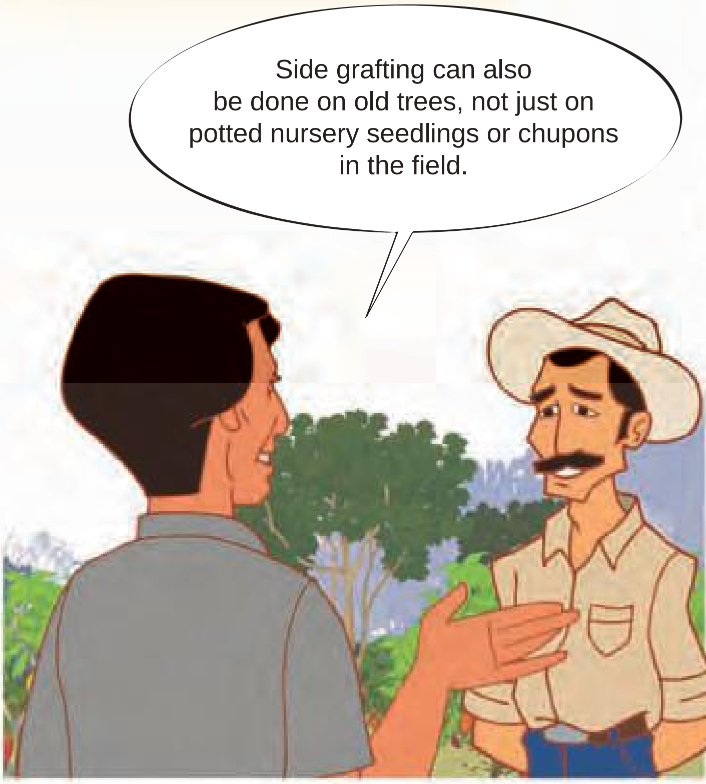

With a thin, sharp knife blade, decapitate the rootstock one centimeter above the cotyledons and then cut the stem downward,
four centimeters, splitting it into halves, with one cotyledon on each half of the stem.
Prepare a scion of the same color and thickness as the rootstock. Each scion should have three leaves. Cut the leaves with scissors, leaving only one third of each leaf.
Cut two strips from the base of the scion, one on each side, to form a thin wedge. The two cuts should be the same length as the cut on the rootstock.

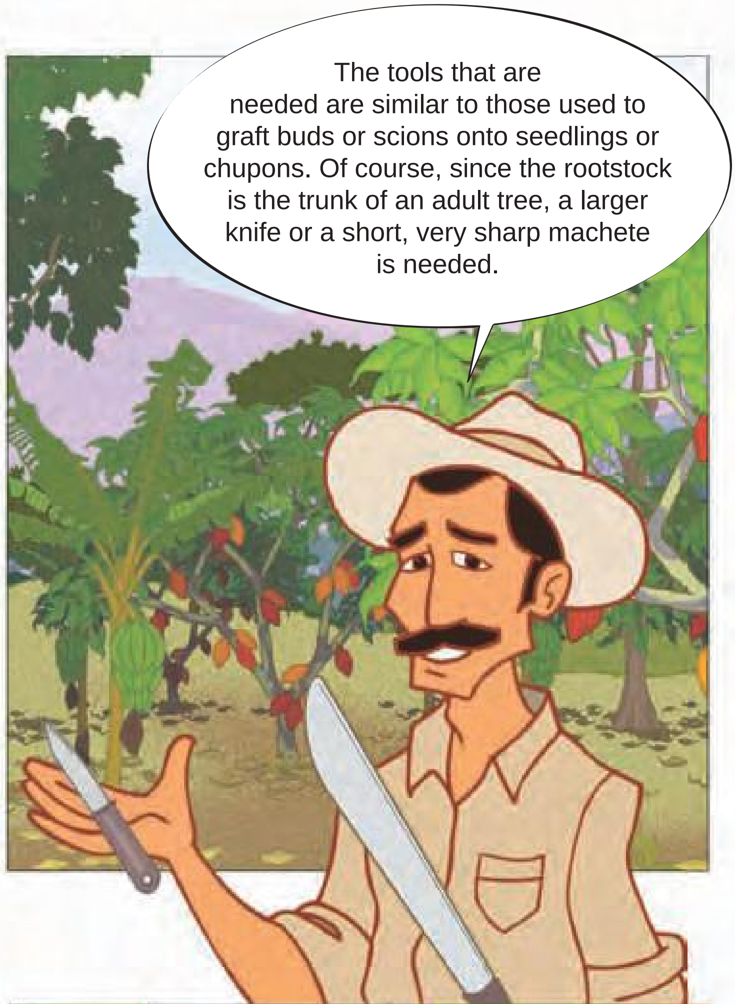

The trimmed leaves of the scion are very important
because they, together with the cotyledons, are the only ones left to feed the newly grafted plant after the leaves of the rootstock are lost through decapitation.
The next step is to put the wedge-shaped part of the scion in the cut of the rootstock, bind the graft and cover the plant with a transparent plastic bag. This prevents the graft from getting wet and keeps it in a warm and humid environment that speeds up the healing.
The bag must remain over the grafted plant for two weeks, without watering. This is why the rootstock must be watered well one day before grafting.
After removing both the bag and the binding, the grafted plant remains in the nursery for three to four months and then it is transplanted to the field.

Grafting on chupons

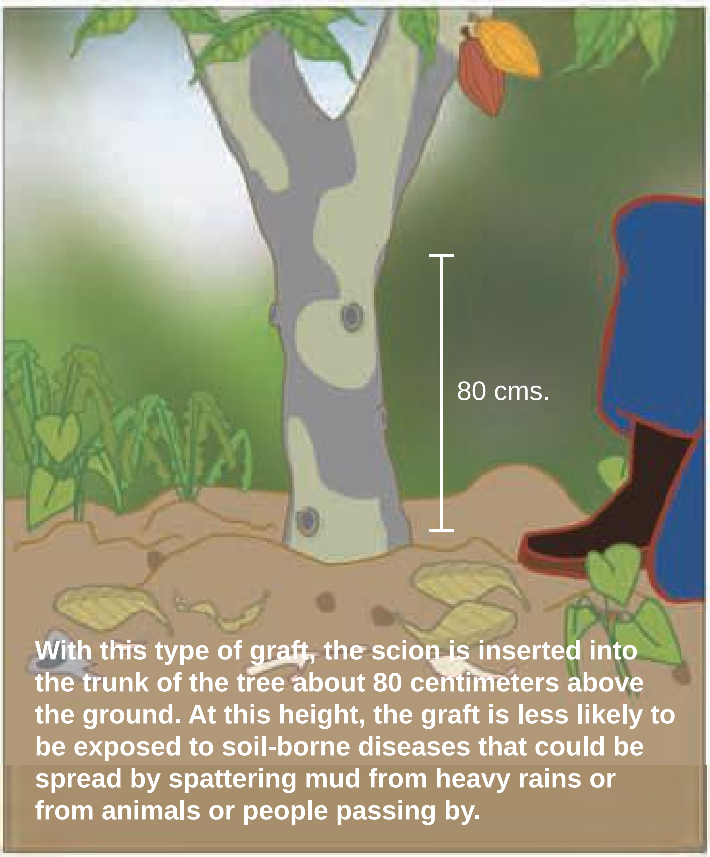

I'll be very glad to show you how to graft onto chupons.
Grafted sucker
1. The best chupons to select for grafting are those that originate closest to the ground, with stems about one centimeter thick, and that are vigorous, disease-free, and on opposite sides of the trunk. Since we will make a graft on each of these chupons, if one fails, the second one will be available in reserve.
2. Once the graft has developed and is sufficiently big, with two or more lateral branches, each having more than four leaves, we have to eliminate the original crown of the tree. But, when we cut the thick trunk, we must be very careful not to damage the graft.
3. Here is something very interesting! Chupons can also sprout their own roots and become independent from the old tree. If the chupons originate close to the ground, it is possible to stimulate the development of roots by covering their bases with soil.

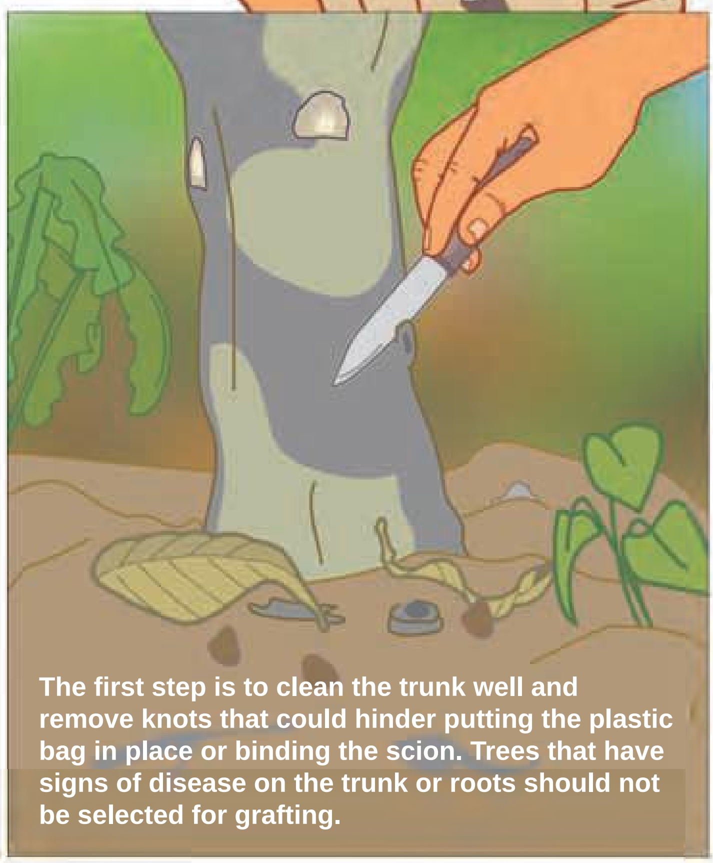
Side grafting on adult trees

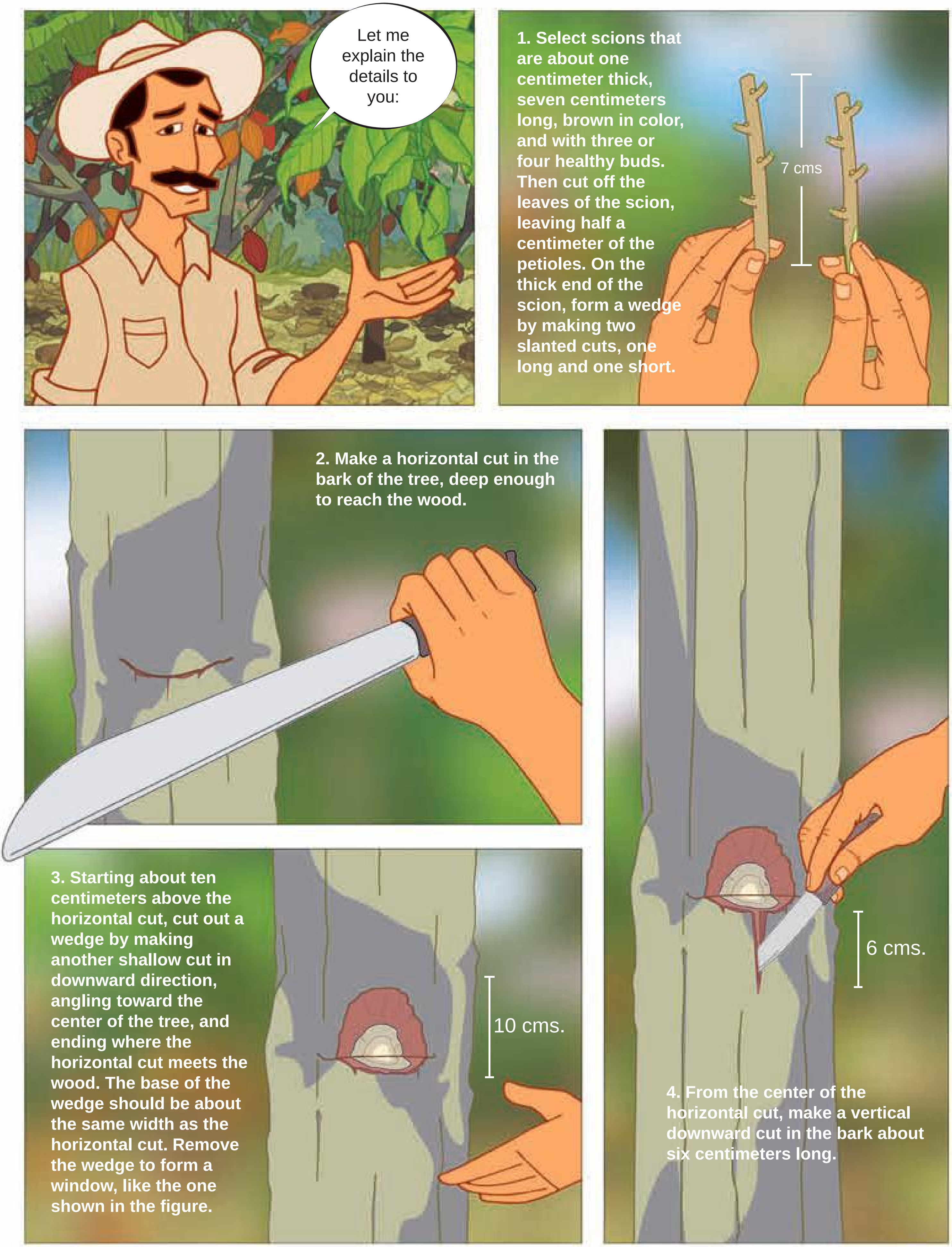




Preparation for the graft



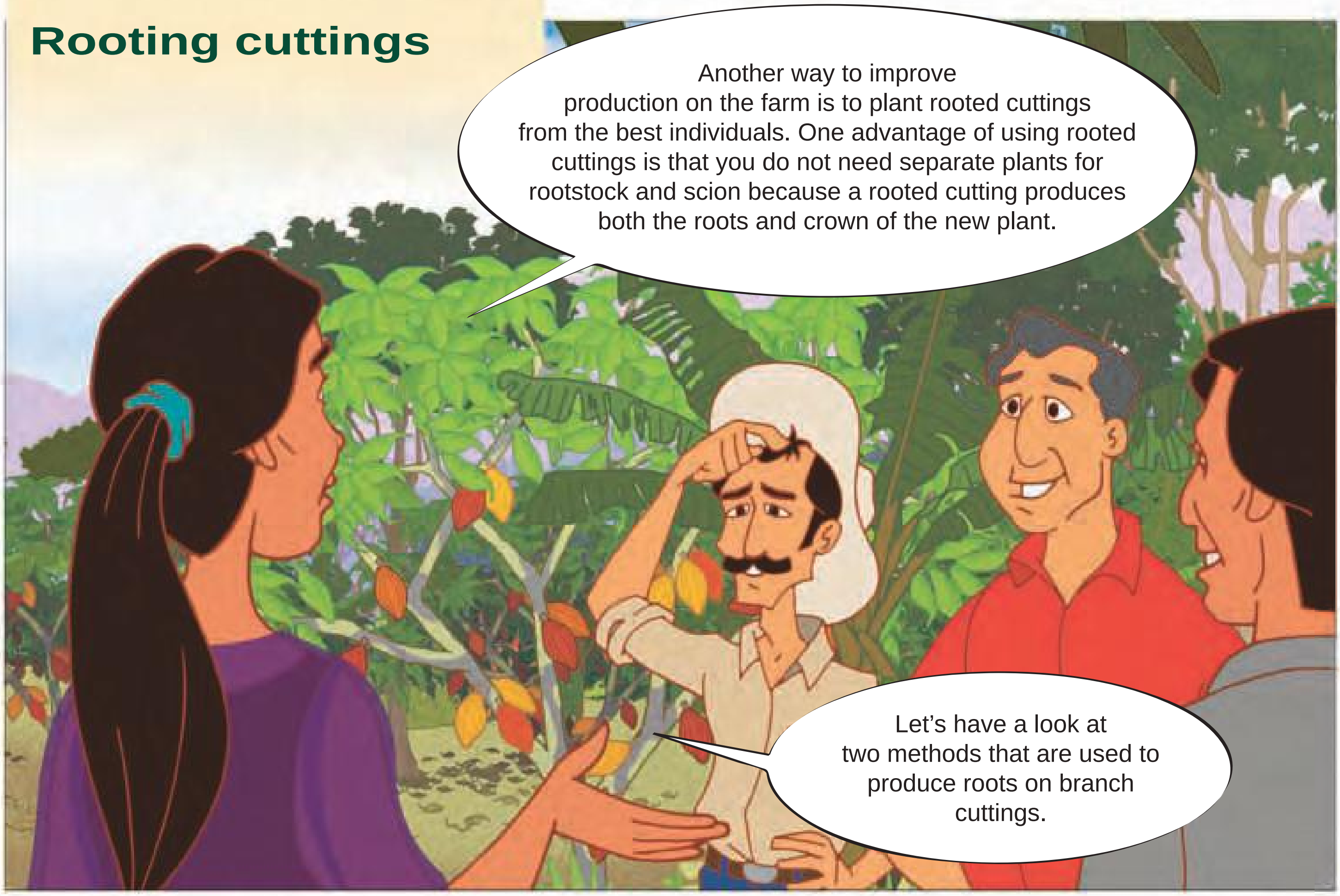


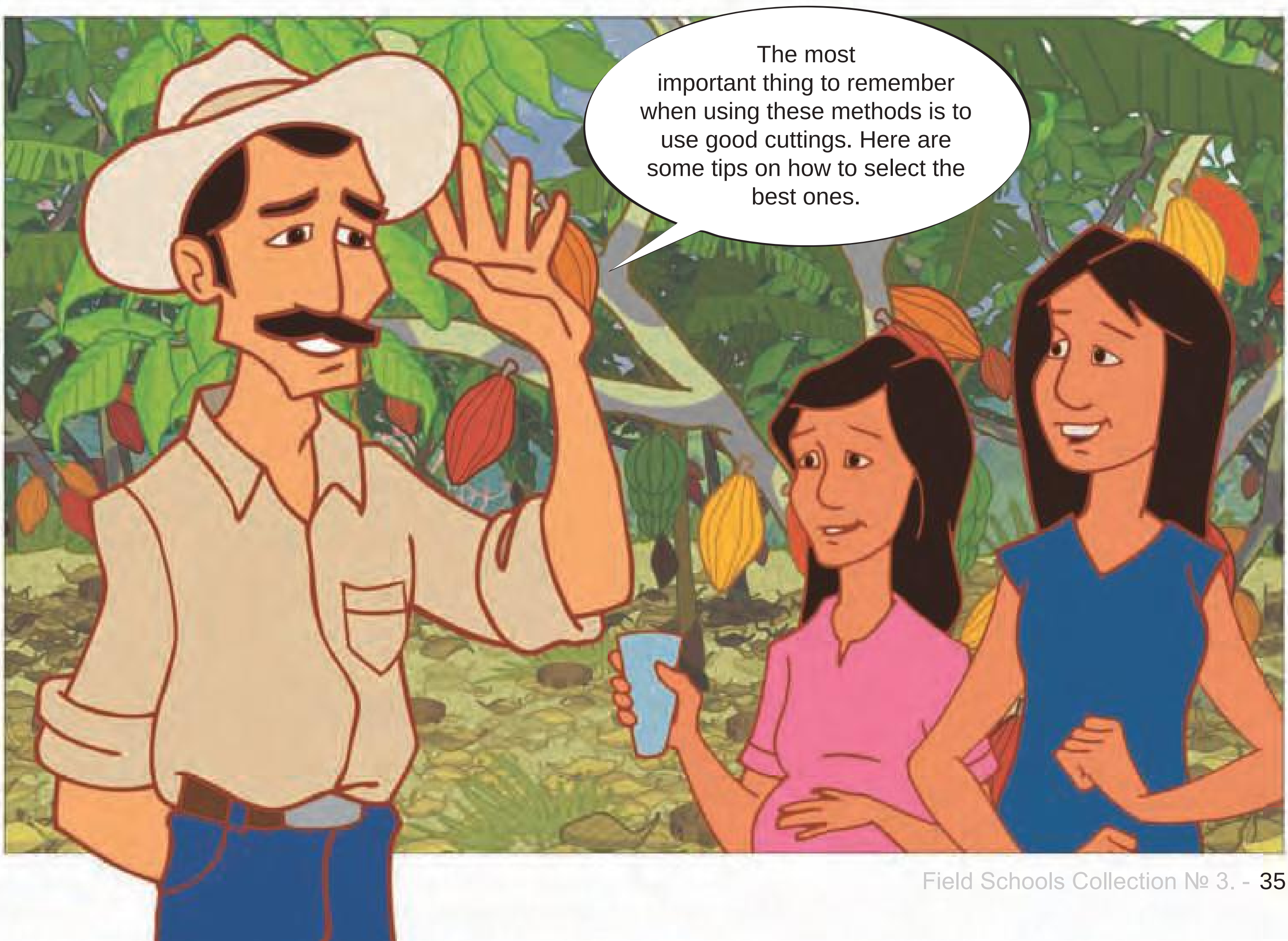

Let me explain the details to you:
1. Select scions that are about one centimeter thick, seven centimeters long, brown in color, and with three or four healthy buds. Then cut off the leaves of the scion, leaving half a centimeter of the petioles. On the thick end of the scion, form a wedge by making two slanted cuts, one long and one short.
7 cms
2. Make a horizontal cut in the bark of the tree, deep enough to reach the wood.
3. Starting about ten centimeters above the horizontal cut, cut out a wedge by making another shallow cut in downward direction, angling toward the center of the tree, and ending where the horizontal cut meets the wood. The base of the wedge should be about the same width as the horizontal cut. Remove the wedge to form a window, like the one shown in the figure.
10 cms.
4. From the center of the horizontal cut, make a vertical downward cut in the bark about six centimeters long.
6 cms.


5. Lift and separate the bark beginning at the corners of the vertical cut and insert the scion.
Cord
6. Wrap a cord around the trunk, firmly binding the scion.
Transparent plastic
7. Cover the graft with a large transparent plastic bag, tying it above and below the graft. Fold the upper end of the bag outward and downward over the upper binding so that no water can get in.
8. Twenty to thirty days later, check to see if the buds of the scion have begun to sprout and the first leaves have appeared. If so, uncover the graft and remove the plastic bag, but keep the binding on the rootstock for at least 60 more days, until the graft has two branches and several leaves and is well-attached to the trunk.
Regularly remove all chupons from the old trunk below and above the side grafting point.
9. When the crown of the graft begins to produce fruit, about 18 months after making the graft, remove the crown of the rootstock tree, cutting the trunk at about 20 centimeters above the graft. Use a slanting cut so that water does not accumulate and healing is not delayed.

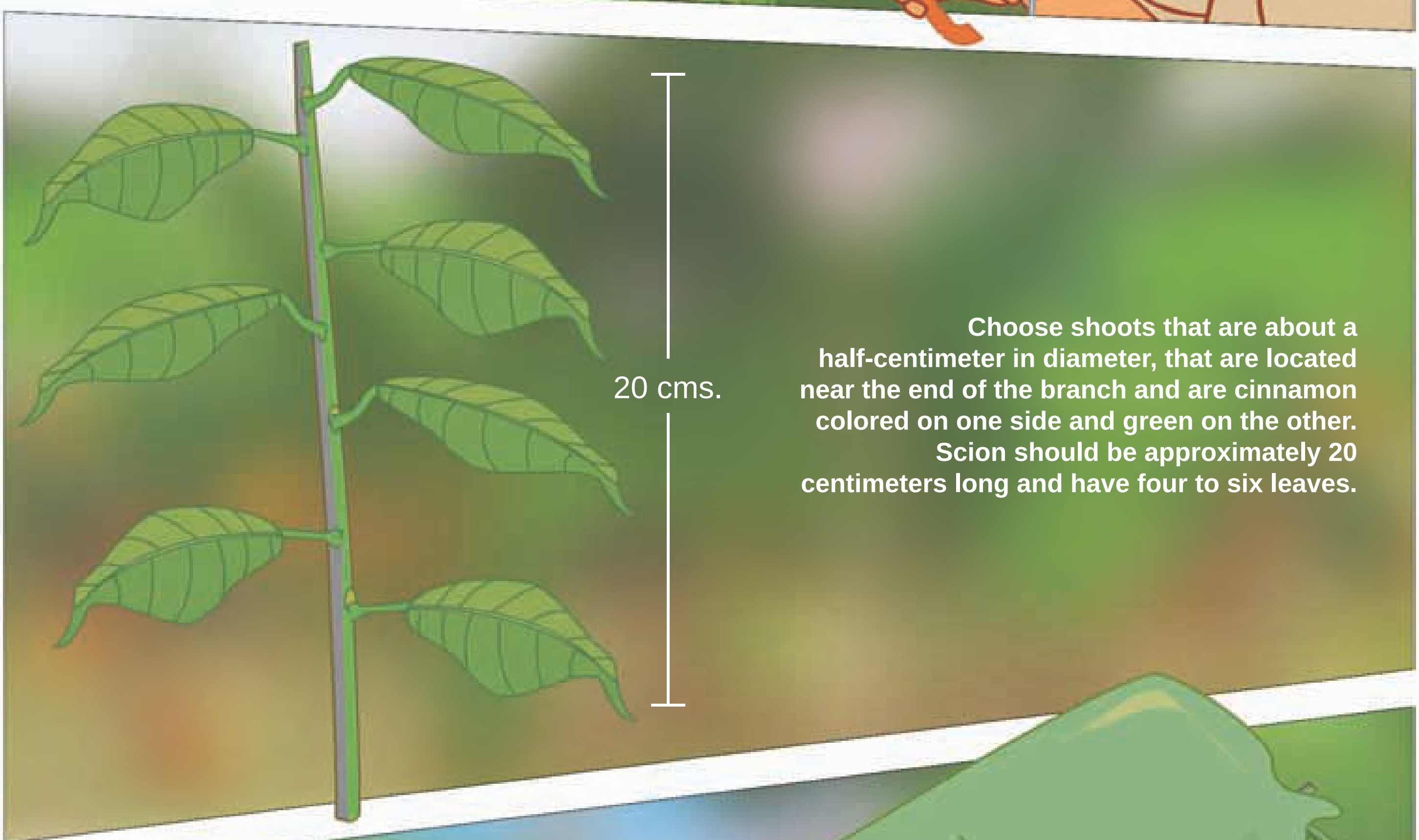

If the trunk is thick enough, two grafts can be made, one on each side of the trunk. With two grafts, the new crown can develop faster than with only one graft.
Now that we have covered all of the types of grafts, let's look at the poster to learn how the grafts take hold.
How does the graft take hold?
Inside the cacao, as in many other plants, a system of tubes carries the substances the plant needs to survive and grow, much like the veins and arteries that transport blood in animals.
There are two types of tubes: the xylem and the phloem.
Between xylem and phloem there is a moist layer called cambium.
When the roots extract water and minerals from the soil, the xylem transports these substances to the leaves and other parts of the plant. The leaves, which are like the "kitchen" of the plant, use energy from the sun to combine the water and minerals with carbon dioxide (a gas in the air), transforming them into food. The phloem then takes this food to other parts of the plant, like the roots, flowers, and branches. That's why the xylem, phloem and the cambium of the graft all have to line up well with those of the rootstock.
Only when they are properly aligned can the graft take hold, heal and function properly to provide nutrients and water to the new plant.
Xylem
Phloem

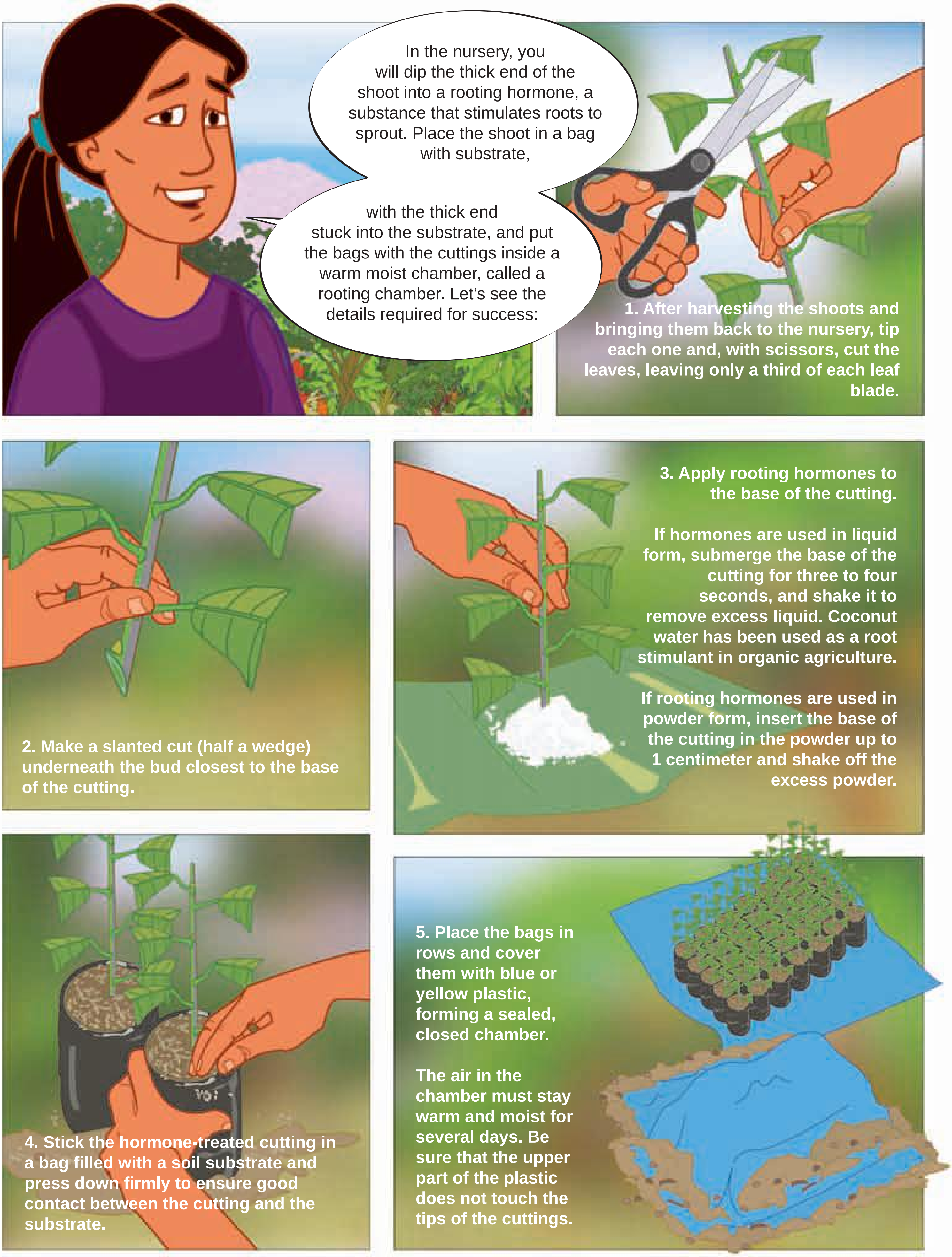
Rooting cuttings

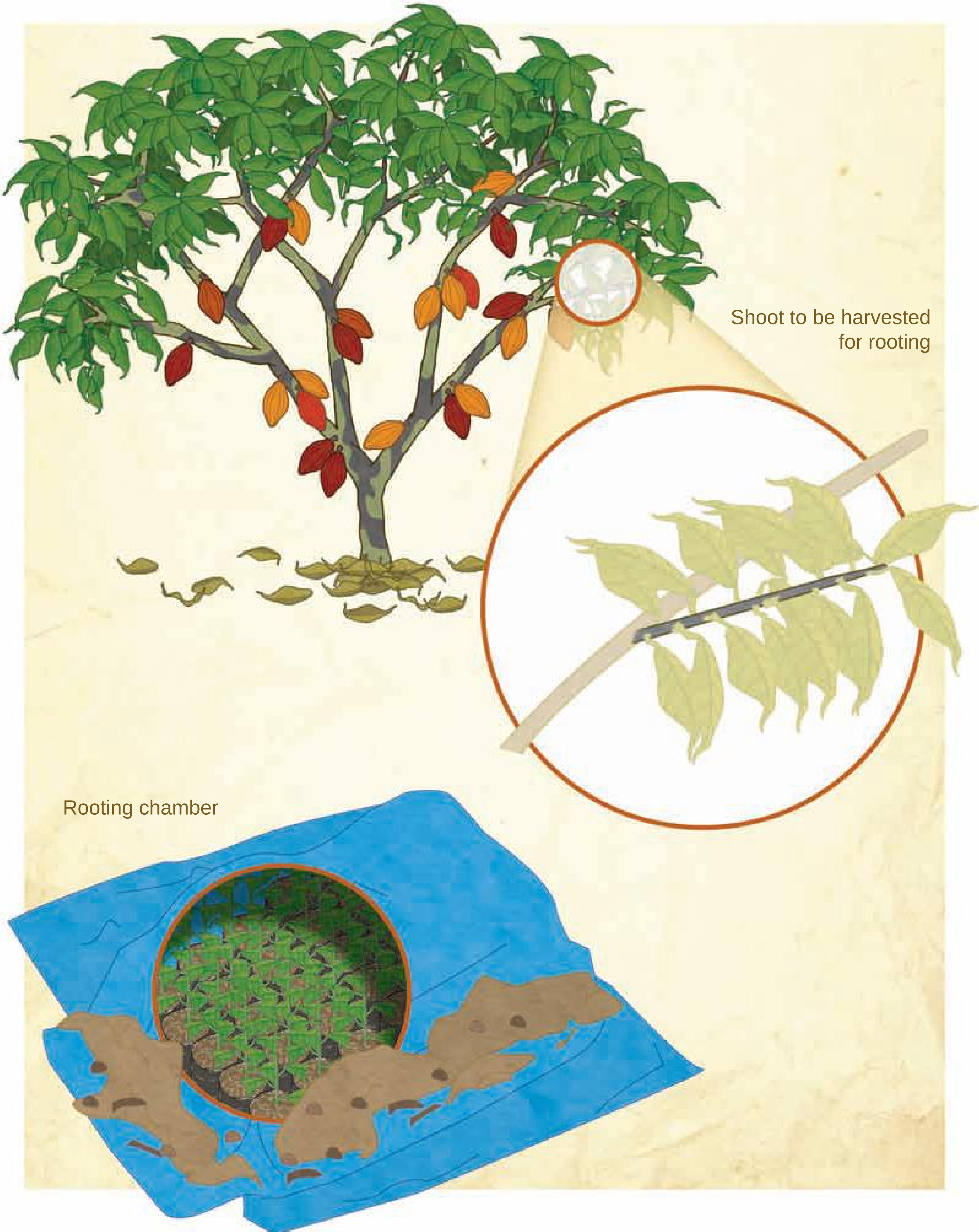




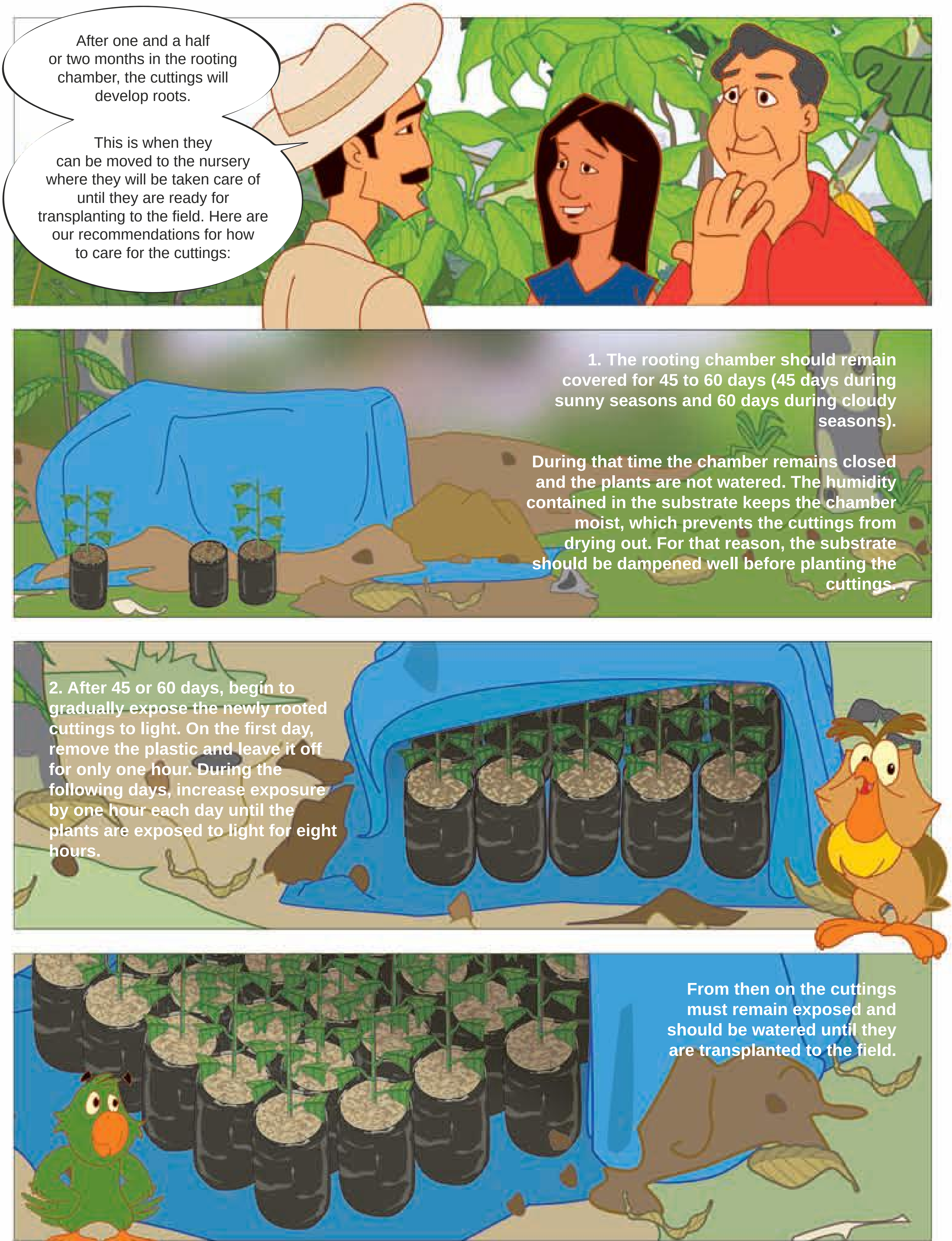
Tips for selecting and cutting branches for rooting




In the nursery, you will dip the thick end of the shoot into a rooting hormone, a substance that stimulates roots to sprout. Place the shoot in a bag with substrate,
with the thick end stuck into the substrate, and put the bags with the cuttings inside a warm moist chamber, called a rooting chamber. Let's see the details required for success:
1. After harvesting the shoots and bringing them back to the nursery, tip each one and, with scissors, cut the leaves, leaving only a third of each leaf blade.
2. Make a slanted cut (half a wedge) underneath the bud closest to the base of the cutting.
3. Apply rooting hormones to the base of the cutting.
If hormones are used in liquid form, submerge the base of the cutting for three to four seconds, and shake it to remove excess liquid. Coconut water has been used as a root stimulant in organic agriculture.
If rooting hormones are used in powder form, insert the base of the cutting in the powder up to 1 centimeter and shake off the excess powder.
4. Stick the hormone-treated cutting in a bag filled with a soil substrate and press down firmly to ensure good contact between the cutting and the substrate.
5. Place the bags in rows and cover them with blue or yellow plastic, forming a sealed, closed chamber.
The air in the chamber must stay warm and moist for several days. Be sure that the upper part of the plastic does not touch the tips of the cuttings.

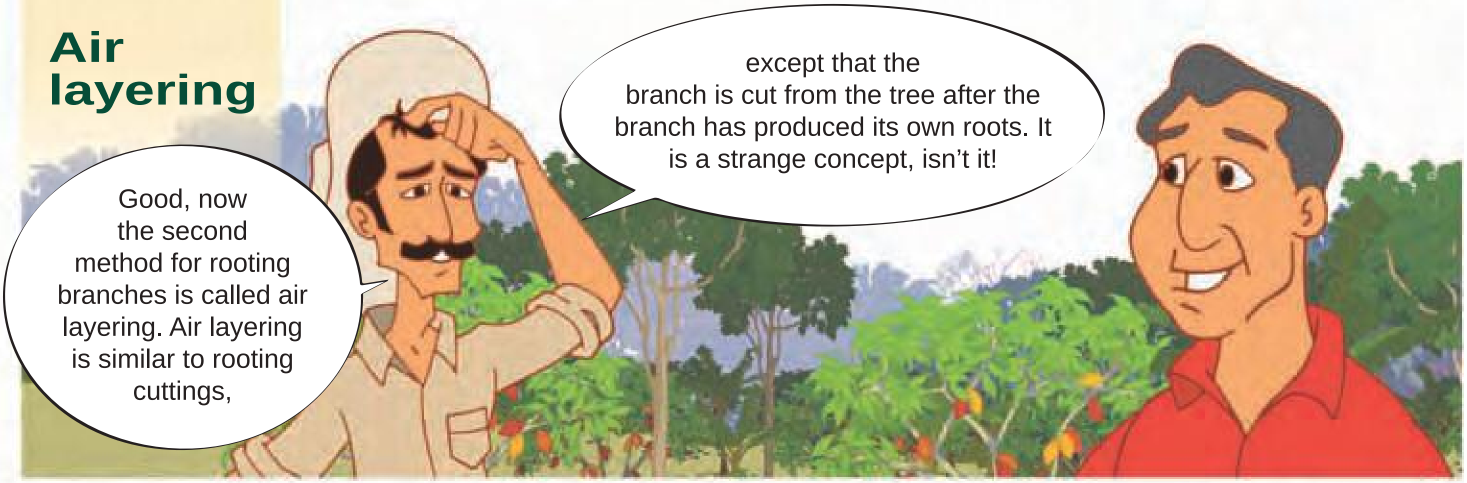


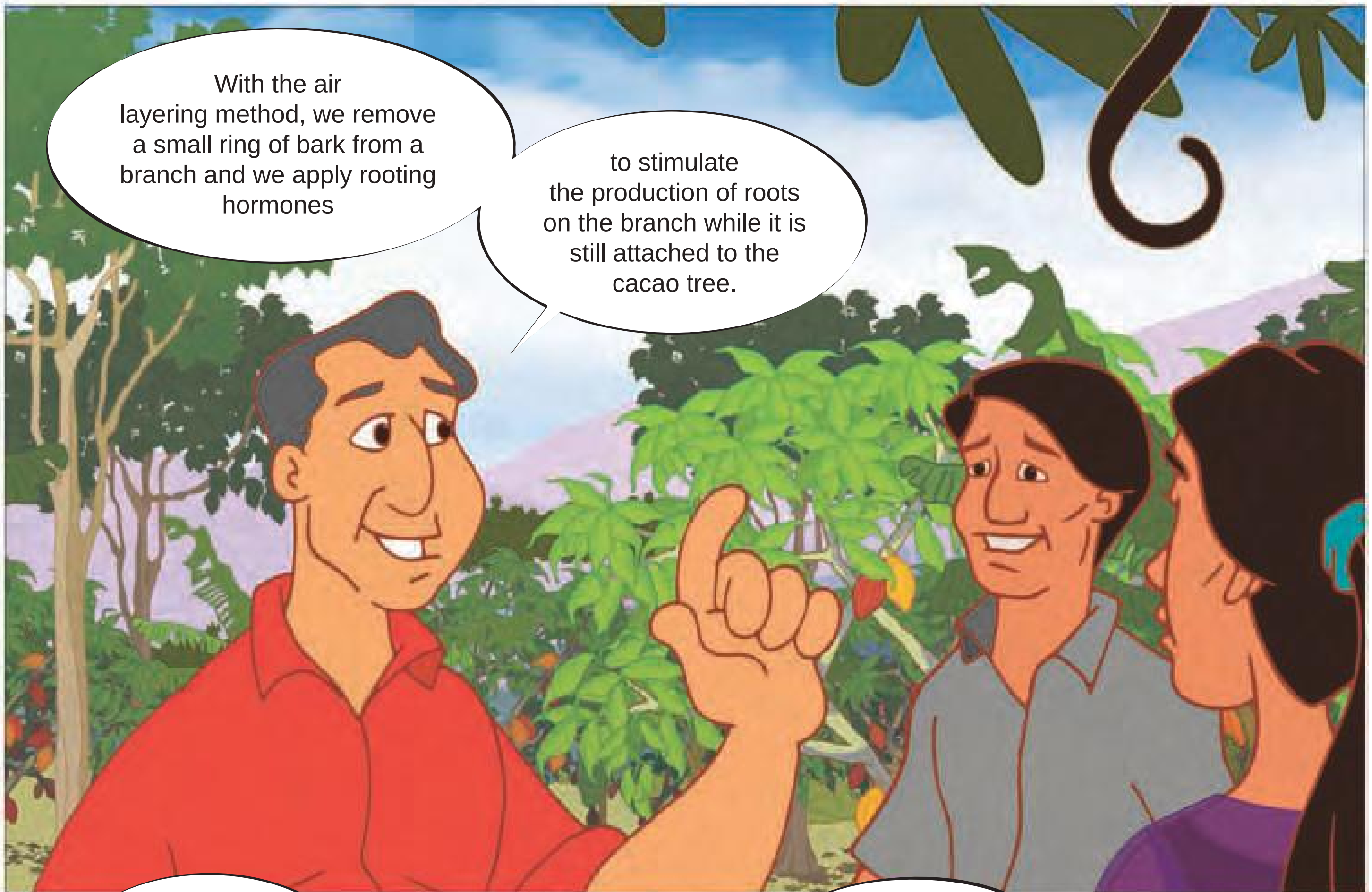
Cuttings stuck in substrate in a rooting chamber

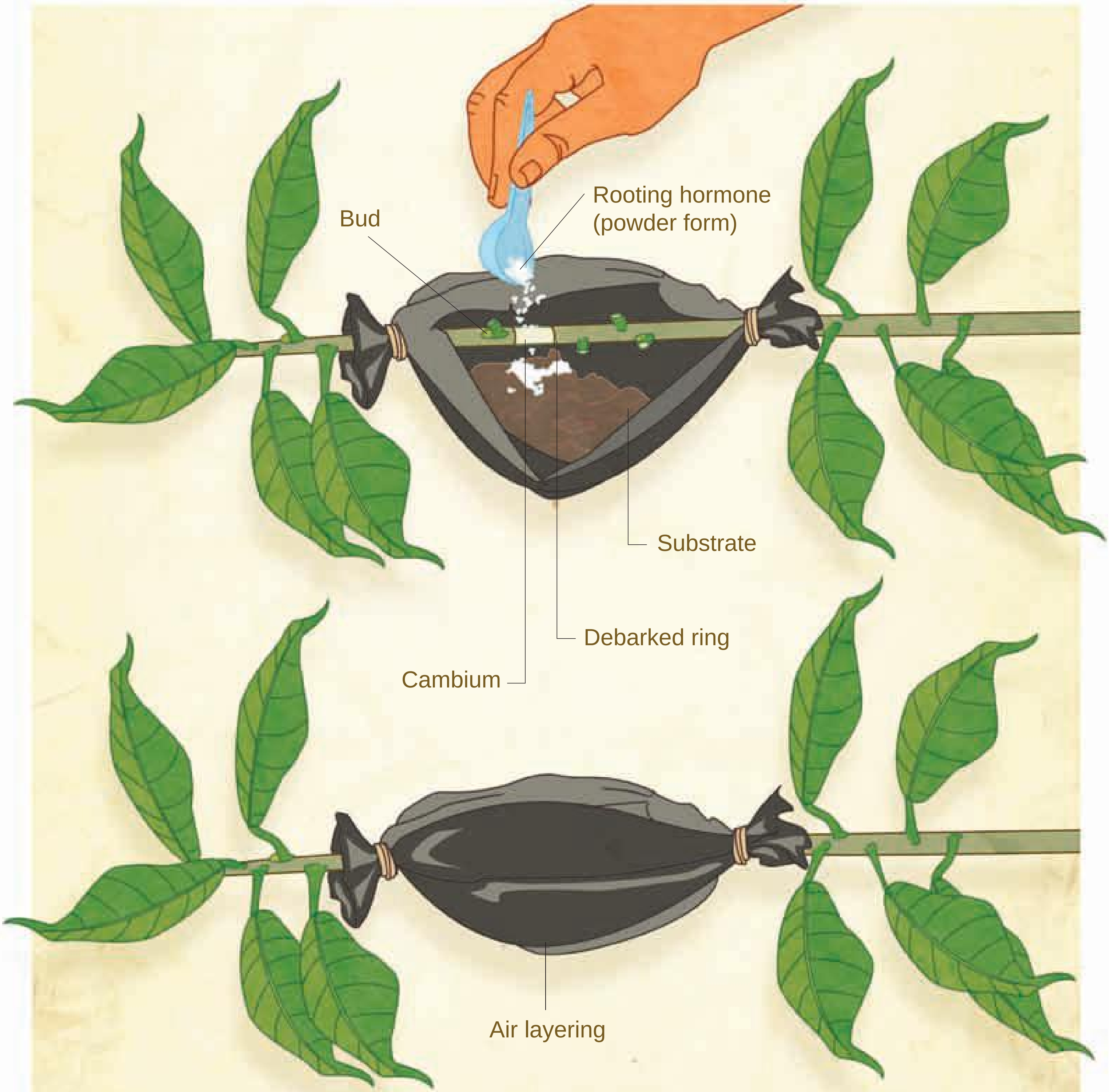


After one and a half or two months in the rooting chamber, the cuttings will develop roots.
This is when they can be moved to the nursery where they will be taken care of until they are ready for transplanting to the field. Here are our recommendations for how to care for the cuttings:
1. The rooting chamber should remain covered for 45 to 60 days (45 days during sunny seasons and 60 days during cloudy seasons).
During that time the chamber remains closed and the plants are not watered. The humidity contained in the substrate keeps the chamber moist, which prevents the cuttings from drying out. For that reason, the substrate should be dampened well before planting the cuttings.
2. After 45 or 60 days, begin to gradually expose the newly rooted cuttings to light. On the first day, remove the plastic and leave it off for only one hour. During the following days, increase exposure by one hour each day until the plants are exposed to light for eight hours.
From then on the cuttings must remain exposed and should be watered until they are transplanted to the field.

Air layering







1. First choose a healthy branch, one to two centimeters thick, with all its leaves.
2. Ring the branch, which means cut and remove a ring of bark, about one and a half centimeters wide, exposing the wood of the branch.
3. Apply rooting hormones to the ringed area, wrap the ring with moist substrate and cover it with black plastic tied on both ends.
4. Leave the cover in place for 30 to 40 days, until roots sprout.
5. Once it has produced roots, cut the branch 15 centimeters below the ring and plant the cutting in a bag with substrate, being careful not to damage the delicate roots.
6. Care for the plant in the nursery until it produces new leaves.
7. Transplant to the field.

Air Layering

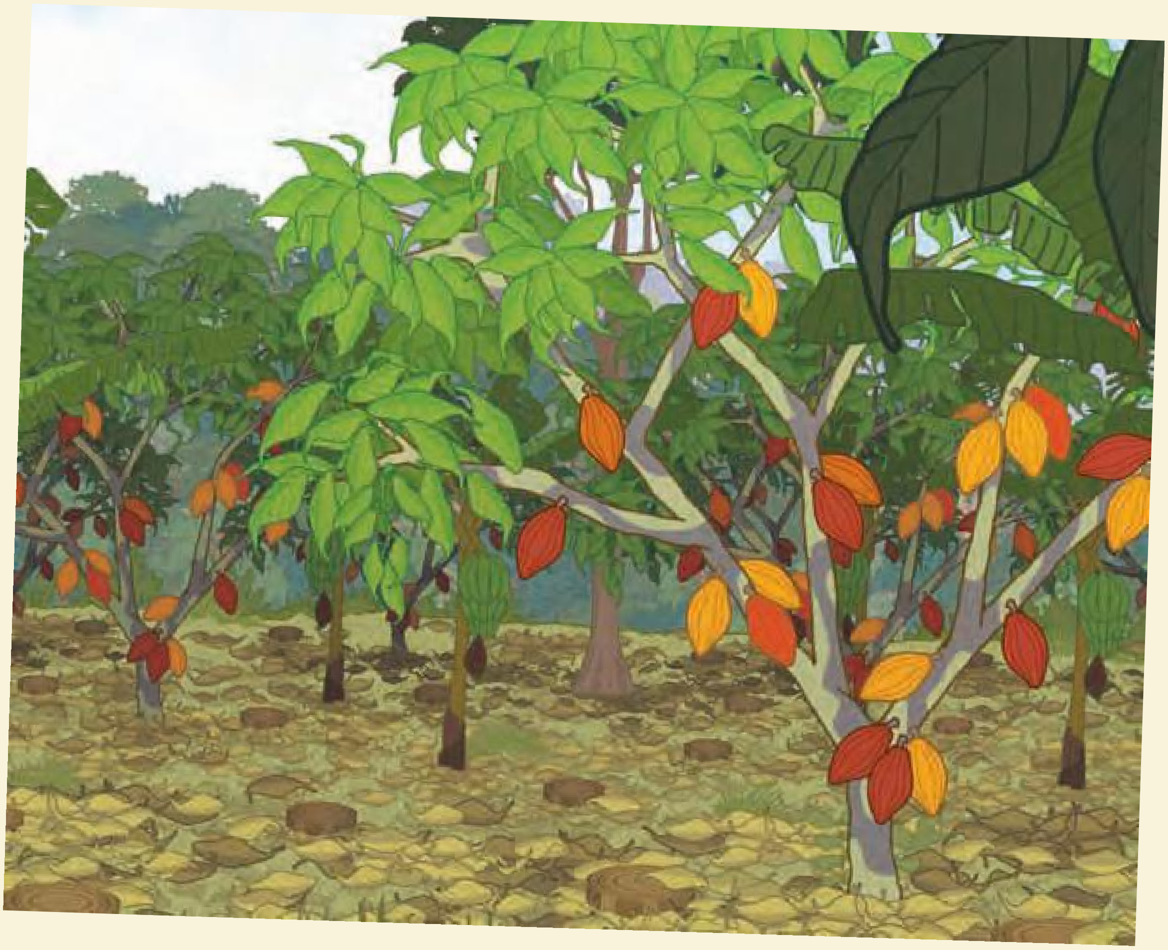

Here is another tip. The plastic that covers the debarked ring must be black so light won't penetrate to the area where the new roots are going to form. Roots don't like light.
As you can see, with air layering, there is no need for a rooting chamber.
OK, friends. Can you explain the advantages and the disadvantages of using either rooted cuttings or rooted branches from air layering?
Well, one advantage of both methods is that you don't need separate rootstocks. In order to have rootstocks, you have to get the seeds,
plant them and take care of the plants until it they are ready to graft. And all of that must be done in a nursery, which costs money.
That's true, but on the other hand, since air layering is done in the field, it's not a practical method for rooting a lot of branches because you would spend so much time going from one tree to the next.
But isn't that what life is about, spending time going from one tree to another, eating, without getting tired, and having fun?
Besides that, in the field you can't control rain or drought and they affect the rooting efficiency and development of roots from the branches.

When should plants be taken to the field?

Type of propagation	Time needed to grow the rootstock (months)	Time in nursery after grafting or rooting (months)	Total time before planting in field (months)
Green budding	1	3	4
Early bud grafting	3 weeks	3	almost 4 motns
Traditional bud grafting	6	3	9
Cleft micro-grafting	3 weeks	4	almost 5 months
Rooting cuttings	Doesn't use rootstock	4 to 6	4 to 6
Air layering	Doesn't use rootstock	3	3


Before our meeting ends, and to be well-informed, we want to mention a modern, asexual propagation method called somatic embryogenesis.
This method usually involves cutting very small pieces of cacao flowers and using growth stimulators –similar to rooting hormones- in the laboratory, to make them sprout roots and leaves.
When these small pieces of the cacao plant begin to sprout their first roots and leaves, they resemble embryos. The term embryogenesis means “creation of embryos.” Somatic means that the little pieces come from the body of the plant.
I am really interested in this topic of romantic embeddedness.
Don’t mix things up, and pay attention!
Since you can cut thousands of pieces from a donor plant, you can produce thousands and thousands of identical plants from a single individual cacao tree. Isn’t that interesting?
Okay, good. So now, to finish our meeting, let’s look at the following two charts, which have information on clonal gardens and the selection of elite cacao trees in a farm.

What is a clonal garden of cacao?



A clonal garden of cacao is a parcel of land planted with different clones of cacao trees, all selected for their desirable traits, for example, high yield, good quality chocolate or tolerance to diseases.

The main purpose of a clonal garden is to produce scions with buds for grafting or cuttings for rooting. Clones intended for seed production for rootstock are also planted in clonal gardens.

Good rootstock should be resistant to soil-borne diseases that attack roots and their roots should grow vigorously.

What are superior cacao trees?

Farmers and cacao agronomists select individual cacao trees that regularly produce superior yields, are resistant to diseases, produce large seeds and good-quality chocolate, or which have other desirable traits, such as tolerance to drought.

Once the farmer spots a likely superior cacao tree, he or she should mark it and monitor its yield, growth, and other traits for at least two years.

Some cacao trees that appear to be superior at first are not truly superior, because their high production is due to their privileged location near sources of water or they happen to have been planted in a location with high fertility soils, at the edge of the plantation without competition with neighbor trees, or with unusually favorable light regimes.


Well, we are at the end or today's meeting. Now all we have to do is put these asexual propagation methods into practice in our farms.
All members of the family should do this. In each cacao family there is at least one expert in asexual propagation of cacao just waiting to be discovered!
The recipe is simple: practice, practice, and practice.

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Plant Disease
May 2015
PD-108

Black Pod Rot of Cacao Caused by *Phytophthora palmivora*

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Introduction

Cacao is the most economically important species in the genus *Theobroma* (Acebo-Guerrero 2012). It is an upright evergreen tree that can grow to 15 m but is usually kept below 5 m for ease of harvesting. The tree has a polymorphic habit: the seedling grows 1 to 2 m in height as a single stem and then separates into the jorquette, a whorl comprised of 3 to 5 branches. Two to three years after planting, flowers begin to grow from pads or cushions beneath the bark. Under optimal conditions these pads will continue to produce flowers for 60 to 100 years. In Hawaiʻi, less than 1% of the flowers set fruit (Bittenbender 2011). Pollination of cacao requires a pollinator; in Hawaiʻi, pollination is by midges (Bittenbender 2011). Some self-incompatible varieties of cacao require cross-pollination, while others are fully self-compatible. The cacao fruit, better known as a pod, is cut from the tree without damaging the flower pad below the surface. Damaged flower pads will no longer bear fruit. The pods are harvested for the seeds, known as beans, inside the pod. Each pod contains about 30 to 60 beans, which are covered with white mucilage that is high in sugar content. Pods are picked at maturity for their primary use, the production of chocolate. Cacao can be grown only within the tropical belt (Acebo-Guerrero 2012). The largest cacao-producing region is the Ivory Coast on the west coast of Africa, where 68% of the world's cacao is harvested. The Amazon Basin is believed to be the origin of *Theobroma cacao* but makes up only a portion of the 15% of world production from the Americas (World Cocoa Foundation 2014).

Figure 1. Incipient infections (arrows) occurring on a ripe cacao pod caused by *Phytophthora palmivora*.

Cacao in Hawaiʻi

Hawaiʻi is the only state in the United States where cacao can be commercially grown. It was introduced in the mid-19th century but is newly commercialized and is gaining a foothold throughout the Islands. Cacao was grown on approximately 28 acres in 2013. An additional 18 acres have been planted since then but are not yet in production. A majority of these plantings, 35 acres, are on Oʻahu, with 68 additional acres expected by the end of 2018 (Bittenbender 2013). However, Hawaiʻi doesn't produce enough dry bean weight commercially to compete with other cacao-growing regions of the world. The University of Hawaiʻi and the United States Department of Agriculture (USDA) are

Figure 2. Unripe cacao pod showing signs of black pod rot caused by *Phytophthora palmivora*.

Figure 3. Unripe cacao pod showing increased signs of black pod rot caused by *Phytophthora palmivora*.

Figure 4. Severely infected cacao pod covered with the white sporangia of *Phytophthora palmivora*. This pod is in the beginning stage of becoming mummified.

currently testing new cacao varieties. They are evaluating specific genotypes for high bean quality, increased yield per acre, and resistance to diseases and pathogens such as *Phytophthora palmivora*, a devastating fungus-like pathogen that is already established in the state. This paper discusses *P. palmivora*, the cause of black pod rot, and other methods of combatting black pod rot in Hawai‘i in addition to resistance.

Environmental Factors and Cacao

Cacao can grow in soils ranging from acidic to slightly alkaline, with a pH of 6.5 optimal for nutrient uptake by the trees. In high-rainfall areas, increased soil moisture can increase the potential for black pod rot.

The Pathogen

Black pod rot of cacao is caused by a pathogen in the genus *Phytophthora*, literally translated as the “plant destroyer.” This is the same genus responsible for the Irish potato famine of 1845–1852. These pathogens were originally classified as fungi but have since been reclassified into the kingdom Stramenopila. There are more than 80 species of *Phytophthora* that cause plant diseases, of which several, including *P. palmivora*, *P. megakarya*, *P. citrophora*, and *P. capsici*, are responsible for black pod rot of cacao. *Phytophthora* spp. are responsible for pod loss of 20 to 30% of the total cacao crop annually, though some plantations have lost up to 90% of their pods due to the disease. Cankers caused by the pathogen may kill up to 10% of all trees each year (Acebo-Guerrero 2012). In Hawai‘i, it is *P. palmivora* that causes the disease. This species attacks over 150 host plant species in the tropics, although strains *of P. palmivora* may infect only one or several host plants.

Morphology and Life Cycle of *P. palmivora*

P. palmivora has four types of spores that may directly or indirectly cause infection: sporangia, zoospores, oospores, and chlamydospores. Sporangia are produced on infected fruit, leaves, stems, or roots. They can germinate directly on the plant surface or in the soil and are capable of producing zoospores. Zoospores can swim in soil water or in water on a plant surface until they find entry into the plant. When the two mating types of zoospore,

Figure 5. A cacao pod consumed by *Phytophthora palmivora*. Note the infected bean mass.

A1 and A2, are present, oospores are formed. This sexual cycle can produce genetic variations with the possibility of overcoming host resistance. Fortunately, the two mating types are not usually found together. Chlamydospores are produced asexually and can survive for months in soil or dead plant material in the absence of their host. The spores germinate when host plants are again present under favorable weather conditions.

Symptom Development

Symptoms of pod rot of cacao caused by *P. palmivora* appear below. Note that these symptoms may be confused with Cherelle wilt, an unrelated, physiological disease in which no specific plant pathogen is involved.

- **Brownish spots on fruit**. When cacao is infected by *P. palmivora,* the pathogen penetrates the waxy cuticle and attacks the epidermis. A small brownish spot appears at the point of infection (Figure 1). Such infections can begin at the stem- or blossom-ends of fruits.
- **Spread of infection and symptoms on fruit**. Infection spreads rapidly across the outer surface, covering the entire pod in a few days (Figures 2 and 3). Infected areas turn from brown to black and, if conditions are favorable, clusters of white sporangia appear on outer surfaces of the pod (Figures 3 and 4).
- **Infection of cocoa beans**. As visible symptoms progress, the pathogen moves deeper into the pod, infecting and destroying the beans (Figure 5). Infected beans quickly deteriorate and rot, rendering the pod useless. The pods then dry up and mummify on the tree, becoming a major source of inoculum to nearby pods, leaves, and stems.
- **Cankers**. Cankers can form under the bark of infected stems and branches. There may be a dark spot on the bark that oozes reddish fluid. The canker can continue to expand until it girdles and kills the branch. Dead and dying leaves are sometimes the first indication of branch dieback. The leaves die because the branch they are on is killed; the pathogen does not directly infect and kill the leaves.

Disease Management

- **Site selection**. A site with relatively low rainfall and good drainage is recommended. High rainfall will increase the spread of *P. palmivora* within the canopy. A well-drained soil will reduce the amount of inoculum in and on the soil.
- **Quarantine**. Avoid transporting soils or plants from areas where the disease occurs into clean areas. Seedlings acquired from outside of Hawai‘i should be exchanged through an intermediate quarantine facility. Contact USDA or the local Extension agency for assistance.
- **Resistance**. Generally, varieties with fruit that have a thicker cuticle are more resistant to black pod rot. Resistant varieties have been identified, but further research is needed to determine if these varieties can withstand the *Phytophthora* species present in Hawai‘i.
- **Removal**. Infected pods should be removed from the area and destroyed. A single infected pod has the potential to release 4 million sporangia.
- **Spacing and pruning**. Trees should be spaced and pruned to allow for increased airflow in and around the orchard. This will reduce the relative humidity and further reduce spread of the disease.
- **Mulch**. Leaf mulch on the ground will reduce the amount of splashing water when it rains. It will also increase the biodiversity of soil microorganisms. However, leaf mulch may result in increased relative humidity in the canopy, which favors infection and disease development.
- **Fungicide**. Although chemical control is an option, it may not be cost effective, depending on the size of the operation and environmental conditions. Below is a list of registered products for cacao pod rot control in the state of Hawai‘i at the time of publication of

Figure 6 (top). Early symptoms of a branch canker caused by *Phytophthora palmivora*. Figure 7 (middle). Branch canker with the bark removed to show the extent of infection. (Note: this is the same branch as in the previous photo. It indicates that internal damage can be more severe than it appears on the surface. Figure 8 (above). Branches killed by cankers. Dead leaves often remain attached after death of the branch. Photos by Fred Brooks.

this paper. Verify with the pesticide label that the product is registered for application to cacao. Follow all label directions and warnings for a safe and proper application of the product.

- GWN-4620 copper fungicide/bactericide
- LPI Chesson fungicide
- AmeriCop 40 DF
- Nu-Cop XLR
- Nu-Cop 3l HB
- Basic copper 50 HB
- Copper hydroxide 10% liquid
- Copper hydroxide 20% DF
- Basic copper 53
- COC WP
- Blue Shield 40 DF
- Cuproquim Nu-Cop 40 DF
- Champ® WG
- Champ® Formula 2 flowable
- Champ® 30 DP
- MasterCop
- Magna-Bon Bahama Klear
- Cuprofix® Ultra 40 Disperss
- Fungi-Phite®
- Fungi-Phite® DF
- Kentan® DF
- Badge® SC
- Badge® x2
- Siscop 60 SC
- DelCup L
- CuH_2O
- Dupont™ Kocide® 3000
- Kocide® 4.5 LF
- Kocide® DF

Acknowledgements

The authors thank Fred Brooks and H.C. Bittenbender for their thoughtful reviews of this manuscript. Dr. Brooks also provided some photographs for this publication.

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TARS Series of Cacao Germplasm Selections

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Additional index words. Theobroma cacao, pod index, flavor

Cacao (*Theobroma cacao* L.) is an important component of small farming systems in the tropics. It adapts to a wide range of soils and climatic conditions, grows well under minimum tillage, adapts to temporary intercropping, has cash crop value in local and export markets, and pods are harvested year-round, providing a steady source of income.

World average cacao yield is low and was 522 kg·ha^{-1} in 2005 (Food and Agriculture Organization, 2007). In a commercial production system, it is highly recommended that cacao be propagated through the use of controlled-pollinated seed obtained from crosses of two or more productive parental clones (Batista, 1981; Wood and Lass, 1985). The use of this so-called "hybrid seed" is considered the simplest and cheapest method of cacao propagation and may offer the opportunity to assemble into a single tree useful traits from distant parents (Enriquez and Paredes, 1985; Enriquez and Soria, 1984; Willson, 1999). Other proponents also consider the use of controlled-pollinated seed as the most useful means of increasing cacao production (Hunter, 1990). In most cases, however, the data available to support the high yielding assumption attributed to controlled-pollinated seed is based only on the production obtained from a few unique segregating 'F_1' trees. Additionally, the yield data needed from long-term experiments to validate this assumption are not available. Lockwood et al. (2007) observed that the optimal strategy for clone selection is by family selection followed by evaluation of large numbers of clones drawn from superior families. There is a need to identify clones with high yield potential for use by growers or in breeding programs (Warren, 1993). In this report, we describe the release of nine cacao clones selected for high yield during 4 years of production.

Received for publication 17 Dec. 2008. Accepted for publication 9 Mar. 2009.
We thank Mr. Edward S. Seguine, Vice President, Research and Development/Quality Assurance, Guittard Chocolate Company, for the organoleptic evaluations of cacao samples.
This manuscript is dedicated to the memory of Nicolas Diaz, former Agricultural Science Research Technician, outstanding employee, and excellent human being.
Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement of the U.S. Department of Agriculture.
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Origin

In a multisite (Corozal, Gurabo, Yabucoa) experiment in Puerto Rico, Irizarry and Rivera (1998) studied the yield potential of 1320 trees representing five interclonal cacao full-sib families (UF-668 × Pound-7, IMC-67 × UF-613, EET-400 × SCA-12, SCA-6 × EET-62, and IMC-67 × SCA-12) over a period of 8 years (1986 to 1993) of production at two locations and 4 years (1986 to 1989) at a third location (Table 1). Trees were ≈4 years old when first harvested. All parental clones used in the generation of the full-sib families belong to various populations of the Forastero cacao group (Motamayor et al., 2008). The controlled-pollinated seed from these families was introduced from the Cacao Improvement Program at the 'Centro Agronómico Tropical de Investigación y Enseñanza' (CATIE), Turrialba, Costa Rica. The self-compatible parental clones possessed various levels of resistance against important cacao diseases (International Cocoa Germplasm Database, 2008) such as black pod disease (*Phytophthora* spp.), witches broom (*Moniliophthora perniciosa*), and vascular streak dieback (*Oncobasidium theobromae*) and were of frequent use in breeding programs at CATIE. Consequently, resultant seedlings were expected to have superior combining ability for higher yield and resistance to diseases. Single tree harvests were made throughout the experiments. The authors concluded that only ≈3% of the progeny in each family accounted for ≈60% of the total family yield. In a second experiment, Irizarry and Goenaga (2000) grafted scionwood from the 40 highest-yielding trees obtained from these families at the three locations above onto an open-pollinated rootstock (EET-400) with resistance to ceratocystis wilt (*Ceratocystis fimbriata*) and evaluated these clonal selections under full sunlight and intensive management at Corozal, Puerto Rico, during 4 years of production. Grafting plays an important role in the preservation of desirable genetic traits observed in cacao clonal selections and in maintaining homogeneity of the propagating materials (Paulin et al., 2007; Ramadasan and Ahmed, 1984). In addition to the 40 clones, five of the eight parental clones, UF-668, Pound-7, EET-400, SCA-12, and IMC-67, representing the original families (Irizarry and Rivera, 1998), were also grafted onto the same rootstock for comparison. Grafted clones were arranged in a randomized complete block design with six replications, each containing two experimental trees per treatment and evaluated during 4 years of production, 1994 to 1997, when trees were 3 to 6 years old. Organoleptic evaluation of 65% cacao-containing chocolate samples from the highest yielding clones was conducted at Guittard Chocolate Company, Burlingame, CA, using the protocol of the CFC/ICCO/INIAP Flavor Project (Sukha et al., 2008).

Performance

Of the 40 clones selected for final evaluation, only nine demonstrated superior yield when compared with either the combined mean of the five parental clones or the mean of their highest yielding parent (Table 2). For this reason, any potential negative effect of the rootstock on yield appeared negligible for these nine clones. These clones yielded an average of 2170 kg·ha^{-1} of dry beans per year during their first 4 years of full production and there were no significant yield differences among them. Clones TARS-1, TARS-9, TARS-23, and TARS-34 had lower pod index values than other clones (Table 2). A low pod index is normally associated with good bean size and a reduction in harvesting costs. None of the clones selected from families IMC-67 × SCA-12 and IMC-67 × UF-613 yielded more than the combined mean of the five parental clones or the individual mean of parents IMC-67 and

Table 1. Soil and weather characteristics at three cacao test sites in Puerto Rico.

	Location		
Site characteristics	Corozal	Gurabo	Yabucoa
Soil order	Ultisol	Inceptisol	Entisol
pH in water	5.3	6.5	4.6
CEC (cmol (+)·kg^{-1})	10.9	33.50	3.8
Elevation (m)	200	50	10
Rainfall (mm)	1,840	1,700	2,274
Class A pan evaporation	1,410	1,678	1,796
Temperature maximum (°C)	19.2	20.2	21.4
Temperature minimum (°C)	30.0	31.6	30.2

CEC = cation exchange capacity.

Table 2. Yield comparison of nine superior cacao clones and of five of their corresponding parental clones grown under full sunlight and intensive management in Puerto Rico during a 4-year harvesting period, 1994 to 1997.

TARS clone number	Family pedigree or parental clone	Mean dry bean wt per year (kg/tree)	Dry bean wt per year (kg/ha)	Pod index[z]
14	SCA-6 × EET-62	1.60 a[y]	2,400.0 a	36.6 c
31	SCA-6 × EET-62	1.54 a	2,310.0 a	43.3 b
34	UF-668 × Pound-7	1.48 a	2,220.0 a	25.0 ef
23	UF-668 × Pound-7	1.45 a	2,175.0 a	24.5 ef
27	EET-400 × SCA-12	1.43 a	2,145.0 a	39.7 bc
30	SCA-6 × EET-62	1.43 a	2,145.0 a	40.4 bc
9	EET-400 × SCA-12	1.38 a	2,070.0 a	28.7 de
15	SCA-6 × EET-62	1.36 a	2,040.0 a	41.2 bc
1	UF-668 × Pound-7	1.35 a	2,025.0 a	25.4 ef
	UF-668	0.94 b	1,410.0 b	22.0 f
	SCA-12	0.85 bc	1,275.0 bc	31.0 d
	Pound-7	0.79 bc	1,185.0 bc	31.3 d
	EET-400	0.57 c	855.0 c	50.3 a
	IMC-67	0.52 c	780.0 c	23.6 f
	Mean of parental clones	0.73	1,095.0	31.6

[z]Total number of pods required to produce 1 kg of dried beans.
[y]Means within a column followed by the same letter do not differ significantly with a Waller–Duncan *t* test at the 0.01 *P* level.

Table 3. Chocolate flavor profiles of nine cacao clones selected for high yield in Puerto Rico during a 4-year harvesting period, 1994 to 1997.

Clone	Flavor profile of 65% chocolate
TARS-1	A very complex nut character comes through, more like chestnuts roasting with a blend of some hazelnut skins
TARS-9	Gorgeous color; very smooth in flavor profile; very mild chocolate notes up front with low overall bitterness and a distinct nut character that persists; aftertaste has a residual nut/nut skins note; really good chocolate
TARS-14	Good base chocolate notes with a deep woody source; slight earthy, woodsy, and mushroom notes; overall flavor comes off as quite good, very complex and very dark
TARS-15	Very dark color; early mild astringency with an interesting wood resin/floral note that comes through nicely; the late taste has an aldehyde, fruit character that is quite interesting; the continuing aftertaste of the chocolate is very notable; complex floral/mild fruit note
TARS-23	Rich, smooth chocolate profile up front with lots of deeper, mild dark wood notes; really good overall flavor profile; the aftertaste is really a good chocolate
TARS-27	Smoother flavor profile from the beginning with some very mild floral notes and some mild chocolate cocoa; some mild spice notes along with slight flowers; the color is also a very attractive brown, lighter brown hue
TARS-30	More of a woody late floral taste; astringency comes back at the aftertaste
TARS-31	Interesting fruit tartness along with some astringency and a complex mildly floral with tropical fruit notes
TARS-34	Mild chocolate note with some mild fruit character; more of a fleshy yellow fruit flavor and some mild brightness; acceptable flavor

SCA-12 (data not shown). A description of organoleptic characteristics of the nine high-yielding clones demonstrated wide diversity in flavor characteristics among clones (Table 3).

Availability

In 2002, scionwood of these nine clones was grafted onto Amelonado rootstock and trees have been established at the USDA-ARS cacao germplasm collection in Mayaguez, Puerto Rico. Scionwood and seed samples of these clones are now available for research purposes, including development and commercialization of new cultivars. A limited quantity of scionwood and seed may be obtained by writing to orders @ars-grin.gov or to the curator at brian.irish @ars.usda.gov. It is requested that appropriate recognition be made to the source if this germplasm contributes to the development of a new breeding line or cultivar.

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