



# FEED <sup>THE</sup> FUTURE

The U.S. Government's Global Hunger & Food Security Initiative



# CHIMNEY SOLAR DRYER MANUAL

IMPROVED SOLAR DRYER FOR FRUITS AND VEGETABLES, DESIGNED BY UC DAVIS

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FEED THE FUTURE INNOVATION LAB FOR HORTICULTURE



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# HORTICULTURE INNOVATION LAB

# CHIMNEY SOLAR DRYER MANUAL

**DECEMBER 2019**

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## **COVER PHOTO:**

UC Davis student Lauren Howe, left, works with Angelos Deltsidis, international postharvest specialist for the Horticulture Innovation Lab, to roll a clear plastic cover over trays of sliced fruits and vegetables in the chimney solar dryer. Designed by UC Davis researchers working with the Horticulture Innovation Lab, the chimney solar dryer is built with low-cost materials and combines heat collection with constant airflow for efficient drying.

Except where otherwise noted: Photos by Brenda Dawson/UC Davis

Illustrations by James Thompson/UC Davis

Contributors: Angelos Deltsidis, Khush Bakht Aalia, Michael Reid, James Thompson, Elizabeth Mitcham, Britta Hansen, Mark Bell, Brenda Dawson, Archie Jarman, Lauren Howe, Michelle Boutell



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# INTRODUCTION

The UC Davis chimney solar dryer was designed to provide efficient drying even in hazy or partially cloudy conditions. Constructing the dryer is simple, and it can be built from low-cost materials found locally in markets and shops around the world. The objective of this manual is to provide the knowledge needed to build and use the chimney solar dryer, along with the basic principles of using the sun to dry fruits, vegetables and other foods. This manual will be useful for growers, farmer cooperatives, trainers, development implementers, researchers, and others.

There are two key and unique characteristics of the chimney solar dryer:

1. The chimney ensures continuous airflow above and below the product, thus increasing the speed of drying compared to other designs.
2. The dryer's large heat-collection area ensures high temperatures and rapid moisture removal.

## HOW TO USE THIS MANUAL

This manual has been divided into an introduction followed by two main sections:

### SECTION 1: HOW TO BUILD THE CHIMNEY SOLAR DRYER

### SECTION 2: DRYING FRUITS AND VEGETABLES WITH THE CHIMNEY SOLAR DRYER

## BACKGROUND

Fruits and vegetables are highly profitable commodities for both small-scale and large-scale farmers. Unfortunately, fresh produce is very perishable and postharvest losses can be quite high, especially in developing countries. The FAO (2011) estimates that roughly one-third of edible products are lost between the growing site and the consumer. In the developing world, the majority of these losses occur soon after harvest.

Many fruits and vegetables have production peaks when, for reasons such as season, weather, or planting time, high volumes of produce are harvested in a short period. During these peaks, product quality is often high, but prices are typically low because there is too much product available (see illustration). Shortly after the harvest, after the glut of produce has been sold, prices rise.

Farmers can take advantage of the higher prices by storing some of their harvest. The primary tool for storing fresh fruits and vegetables is refrigerated cold rooms, which can extend shelf life by several weeks for some crops and up to a year for others. Where cold storage is not available or economically justified, good quality excess product frequently goes to waste. Freezing and canning are common strategies for processing peak production and adding value, but may require expensive facilities, often not available to small-scale farmers.

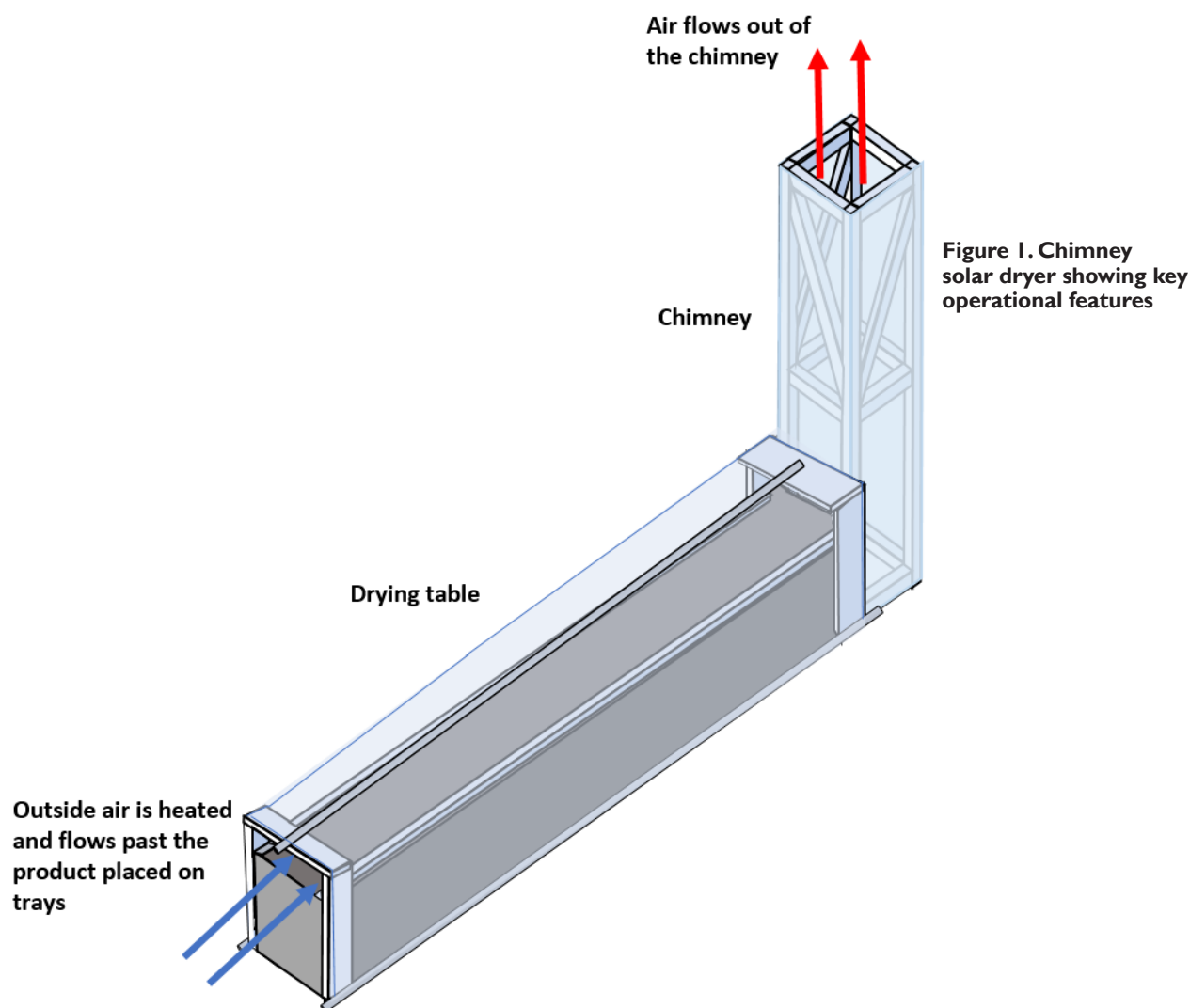


Built with widely available materials, the chimney solar dryer combines a table for drying fruits and vegetables with a chimney.



Illustration: Prices typically fall during peak supply periods and rise when supply is low.





An alternative for many crops is drying. In certain cultures, dried fruits and vegetables are a staple part of the diet, providing important nutrients in the lean season. In addition to extending the marketing season, drying reduces the volume and weight of products resulting in lower transportation and storage costs.

## WHAT IS A CHIMNEY SOLAR DRYER?

The chimney solar dryer is a solar dryer designed by UC Davis researchers with the Horticulture Innovation Lab. It is a low-cost structure that can be made from locally available materials, and that reduces drying time compared to traditional solar dryers.

### HOW DOES IT WORK?

- The dryer comprises a long table covered with black plastic or fabric that is connected to a chimney at one end (as shown in Fig. 1).
- The product is placed on mesh trays along the length of the table.
- A clear plastic sheet placed over the trays and table creates a tunnel that traps solar energy, heating the air and reducing its relative humidity. The dry, heated air accelerates moisture loss from the heated product, and the warm, moist air leaves the dryer through the chimney.
- The dryer is designed so that there is little space between the black plastic under the product trays and the clear plastic covering them. This forces the air to flow through a small cross-sectional area and generates high air speeds past the product, thereby speeding drying.



## ADVANTAGES OF THE CHIMNEY SOLAR DRYER

- Drying is fast and safe.
- The chimney solar dryer is easy to build.
- Relatively high capacity (approx. 10 kg of fresh product).
- Covered, hygienic drying protects product from contamination by dust, insects, animals, weather, etc.
- The design can be modified to suit needs of the product and the user.

The chimney solar dryer dries fresh produce more efficiently than a traditional cabinet dryer. The chimney dryer also has a larger capacity than most cabinet-style dryers. The trays can be used indefinitely, and only the clear plastic and black table covering require periodic replacement when damaged beyond repair. The design is flexible enough to accommodate a variety of products, from whole apricots, to smaller items such as sliced tomatoes or mangoes. The drying trays can be built in varying sizes depending on the product to be dried, as long as the drying table width accommodates the tray size. This type of solar dryer keeps produce off the ground and uses plastic which protects the product from rain and pests. Fast drying reduces product discoloration and improves flavor and overall visual quality. Adding value through improved solar drying is a proven way to extend the marketing period, diversify and increase income, and enter new markets.

## BUILDING THE CHIMNEY SOLAR DRYER AROUND THE WORLD

Researchers with the Horticulture Innovation Lab have already built and used chimney solar dryers with farmers in the United States, Ghana, Guinea, Kenya, Tanzania, Bangladesh, Thailand, Guatemala and Honduras. The size and materials for this low-cost structure can be modified based on local conditions and availability so long as the “Essential Features” (see How to Build page 1.2) are maintained. More chimney solar dryers using this concept and design have been built in other countries, with directions and advice from Horticulture Innovation Lab team members. We hope this manual helps make this efficient solar dryer design more widely available to users.

## BEFORE THE BUILD RESOURCES

Before starting construction on the chimney solar dryer, it is recommended that builders and users watch a 3-minute video on how to build this dryer: <http://bit.ly/chimney-dryer-video>



The Horticulture Innovation Lab team has built chimney solar dryers in several countries, including Bangladesh (top photo) and Tanzania (above). Materials and dimensions can be adjusted based on location. (Horticulture Innovation Lab photos by Britta Hansen and Angelos Deltsidis)

## SECTION I

# HOW TO BUILD A CHIMNEY SOLAR DRYER

Steps to build a chimney solar dryer using low-cost, easily available materials

## FOUR MAIN COMPONENTS OF THE CHIMNEY SOLAR DRYER

The dryer design has four elements:

1. A drying table covered with black plastic or fabric.
2. A chimney covered with clear plastic with an opening at the drying table.
3. Mesh-covered drying trays to hold the produce.
4. Clear polyethylene plastic film that covers the trays and the drying table and is sealed to the chimney.

## INSTRUCTIONS

Although this is a relatively simple structure, working with an experienced builder is recommended. Alternatively, if you do not have access to a carpenter or skilled builder, the dryer can be built with a team of 4-6 people in about half a day, with a team of 2-3 constructing the table and chimney, while 2-3 people work on the trays simultaneously.

## MATERIALS

Materials needed to build the dryer include wood, clear polyethylene plastic, black plastic or fabric, and food-grade mesh. Quantities may vary depending of the size of your chimney solar dryer. Materials above are calculated based on actual dimensions. *It is suggested to buy 10 percent extra material to account for minor errors or other unforeseen issues.*



Four main components to the chimney solar dryer, clockwise from top left: a drying table, a chimney, mesh trays, and clear film to cover the drying table.



## MATERIALS NEEDED TO BUILD THE CHIMNEY SOLAR DRYER

Item description	Label in figures	Number of pieces	Size (W x H x L)
<b>Combined wood for drying table and chimney frames</b>			(total: 56.09 m)
Wood for table frame and chimney frame	A	23	3 cm x 3 cm x 54 cm
	B	4	3 cm x 3 cm x 2.8 m
	C	4	3 cm x 3 cm x 4 m
	D	8	3 cm x 3 cm x 74 cm
Diagonal stabilization boards for drying table and chimney	E	3	3 cm x 3 cm x 95 cm
	F	2	3 cm x 3 cm x 1.6 m
	G	3	3 cm x 3 cm x 1.5 m
<b>Combined wood for trays</b>			(total: 24 m)
Wood for 10 trays	H	40	2 cm x 4 cm x 60 cm
<b>Center support and lateral poles</b>			(total: 12 m)
Wood or bamboo poles	I	3	Minimum length 4 m
<b>Additional wood for support and attachment</b>			(total: 11.6 m)
Pole support	J	2	2 cm x 15 cm x 30 cm
Pole support shelves	K	2	2 cm x 15 cm x 64 cm
Wood strips	L	2	2 cm x 4 cm x 4 m
<b>Plastic covering</b>			
Clear plastic for chimney cover		1	2.2 m x 3 m
Clear plastic for drying table cover		1	4 m x 3 m
Black plastic or fabric to cover drying table front, top, and sides (thicker is better)		1	6 m x 2.7 m
<b>Food grade plastic or stainless steel mesh</b>			
Mesh for 10 trays		10	60 cm x 60 cm

In this manual, all instructions are for a 4-meter long table and a 2.8-meter tall chimney. This design uses 60 cm x 60 cm trays, because the table frame is 60 cm wide, and you can fit 5 trays (or 10 trays in stacks of 2) on a 4-meter long table.

### ESSENTIAL FEATURES

While the dryer dimensions can be changed to various sizes and preferences, several key features should **NOT** be changed:

1. The chimney and the table should be the same width.
2. The height of the chimney, as measured from the top of the table, should be 2 meters tall.
3. Seal the table to the chimney with the clear plastic covering the table, otherwise airflow above and below the product will be dramatically reduced due to air leakage.
4. Ensure a small headspace in the tunnel above the product (about 5 cm) to maintain airspeed in the tunnel.
5. For more efficient drying, avoid using milky colored polyethylene (PE) or polyvinyl chloride (PVC) plastic for covering the drying table. Thicker plastic will prevent ripping early. We recommend around 6mil or 0.15mm thick clear plastic.
6. The front of the table, below the opening to the drying tunnel, needs to be covered to prevent airflow below the top of the table versus through the drying tunnel. Do not block or impede airflow at the opening of the drying tunnel.



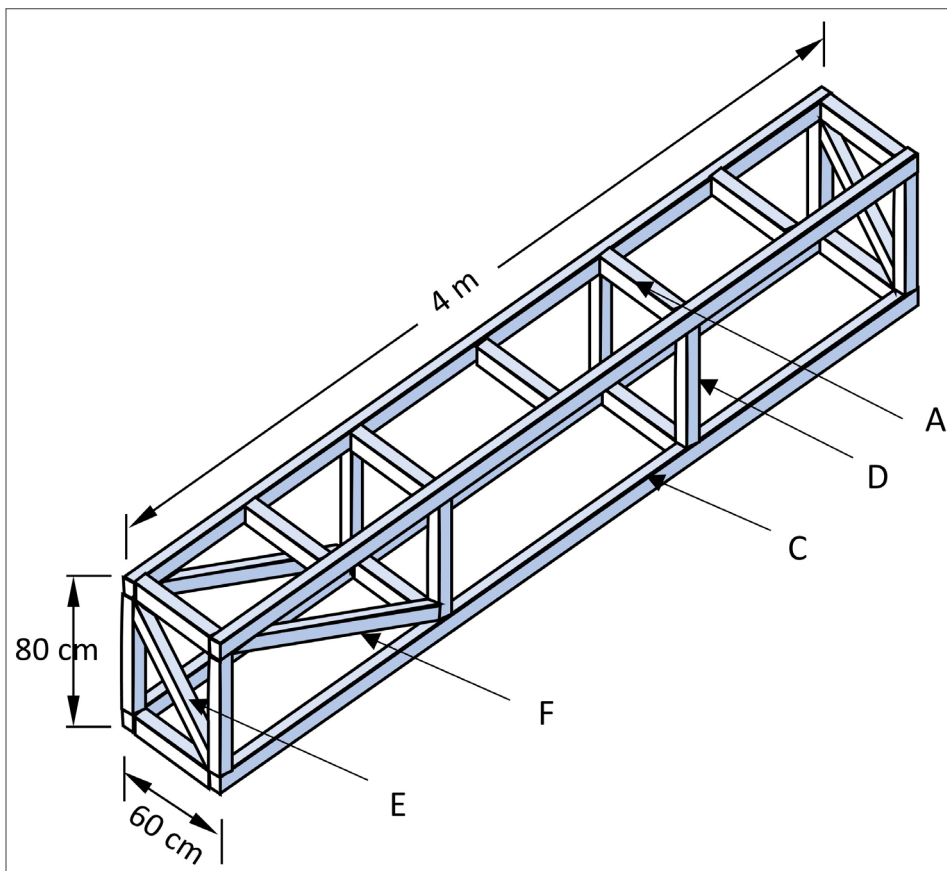


Figure 2. Wood frame for the table

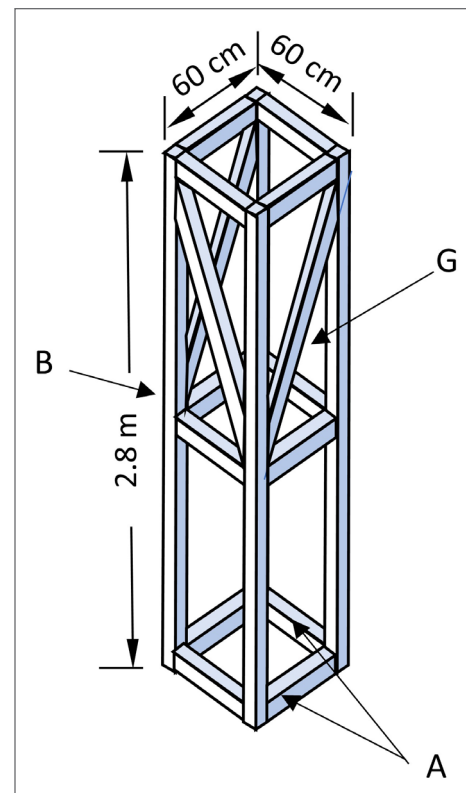


Figure 3. Wood frame for chimney

## SITE SELECTION AND DRYER ORIENTATION

A full-sized dryer, using the design in this manual will be 4 m long. You will need enough flat area with good sun exposure to take full advantage of the dryer. The opening of the dryer should always face the equator to maximize sun exposure. In the northern hemisphere, this means the opening of the dryer should face south, with the chimney in the north. In the southern hemisphere, the chimney would be in the south, with the opening of the dryer facing north. Select an area where trees do not shade the dryer. Make sure the ground is cleared of tall grasses, and the area is free from roaming animals.

## BUILD THE FRAME FOR THE TABLE

- The drying table is the core of the dryer; it holds the trays and is attached to the chimney (Fig. 2).
- The frame can be built from scratch or you can use an existing table or other similarly shaped structure.
- The table height can be adjusted according to preference and should be at a comfortable height to work on the product trays. We choose to use 80 cm for the height of the table in this manual.
- For a 4-m long dryer, the table frame will be 4 m long, 80 cm tall and 60 cm wide.
- Using the materials listed in the table, build a sturdy wood frame that can support the weight of the trays when filled with product. We like to use the 54 cm pieces (shown in Fig. 2 as A) as slats across the top to support the trays.
- Once the table frame is built, then stretch the black, non-woven fabric or plastic sheet over the top and all sides of the frame except the bottom, and secure to the frame with staples.
- Attach two narrow strips of wood to the drying table on top of the black material to hold trays above the table surface.

## BUILD THE CHIMNEY

- The chimney is made from four planks of wood (shown in Fig. 3 as B).
- Make sure that the chimney is tall enough so that it rises 2 m (200 cm) above the top of the drying table (Fig. 3). For instance, if your drying table is 80 cm tall, then your chimney height should be 2.8 m (280 cm) tall.
- The chimney must be as wide as the drying table.
- Cover the whole chimney frame in clear plastic, securing the plastic to the frame with staples, leaving the top open.

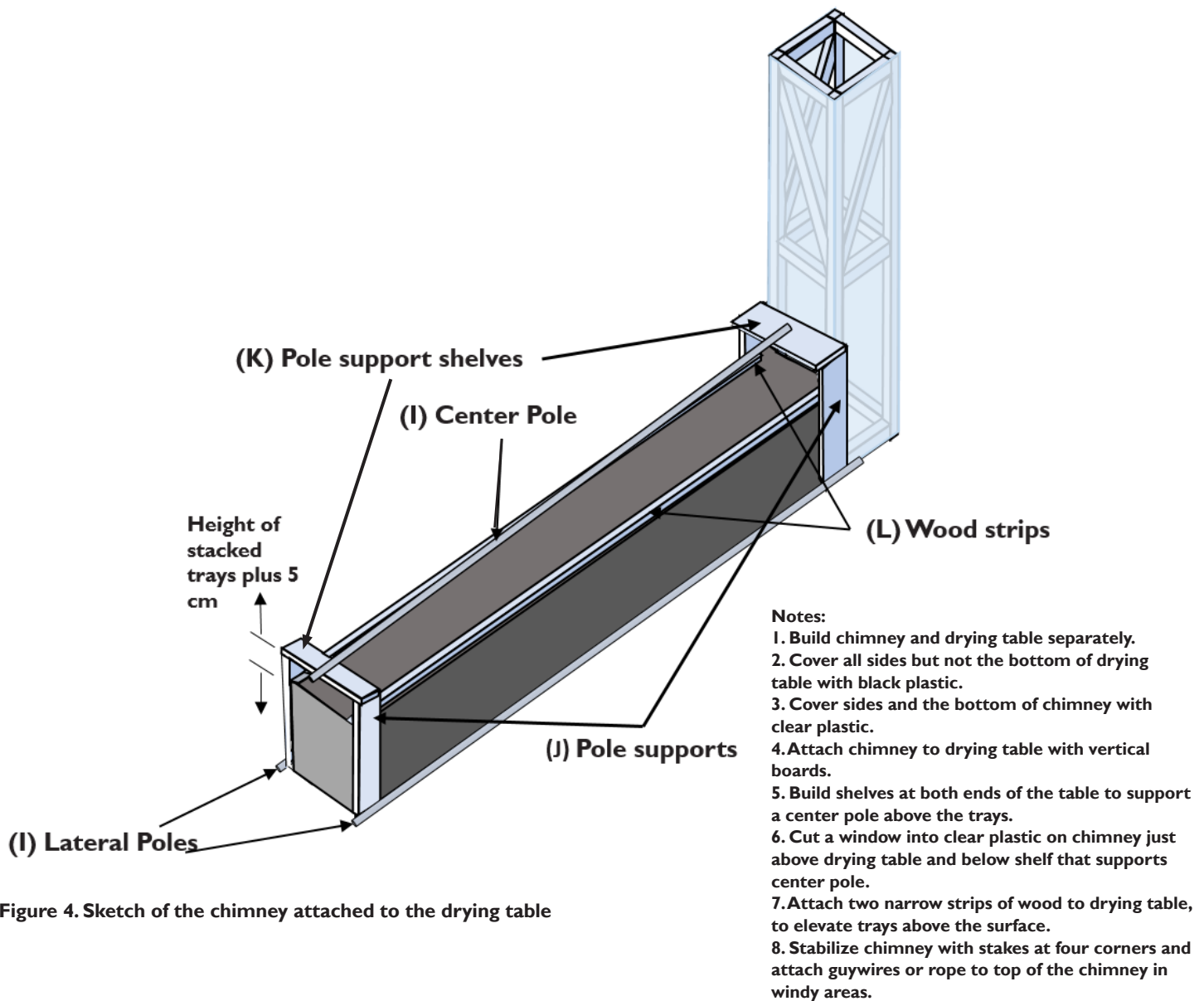


Figure 4. Sketch of the chimney attached to the drying table

## PUT THE PIECES TOGETHER

- Attach the table to the chimney with two vertical boards (shown in Fig. 4 as J) and screws. Create a shelf above the table by using these two “pole support” wood pieces (shown in Fig. 4 as J) and the two “pole support shelves” (shown in Fig. 4 as K). This should be done on both ends of the table. The height of the space under the shelves should be approximately 5 cm above the top of two stacked trays
- Cut an opening in the chimney in the shape of a rectangle, above the drying table and below the shelves, to help create a tunnel for air to flow over the product, through this opening, and out the chimney.
- Place a wood pole (shown in Fig. 4 as I) on top of the shelf as support for the clear plastic that will cover the drying table.



Build a shelf at the opening of the dryer set to be about the height of two trays stacked plus 5 cm above the table top to support the center pole over which the clear plastic will be draped.



Photos from left: Build a second shelf at the chimney end of the drying table matching the same height. Cut a rectangular window into the chimney plastic and attach the edge of the plastic to the shelf. Place bamboo or wood pole (center pole) across the top of the shelves, which will tent the plastic above the trays when in use.

## BUILD THE TRAYS

- Use the 60 cm long wood strips to make the trays (shown in Fig. 5 as H). Each tray will use 4 pieces (60 cm), one on each side.
- By joining the wood stacked as shown in Fig. 5, you will use less wood and more importantly, get good airflow.
- Pre-cut the mesh and staple it to two wood strips opposite each other, pull them apart, tightening the mesh, and secure the other two strips of wood, assuring the corners are at right angles and the overall tray is square.
- Staple along each edge to secure the mesh to the wood. Trim the edges of the mesh if needed so that edges are smooth and will not rip the plastic during use.

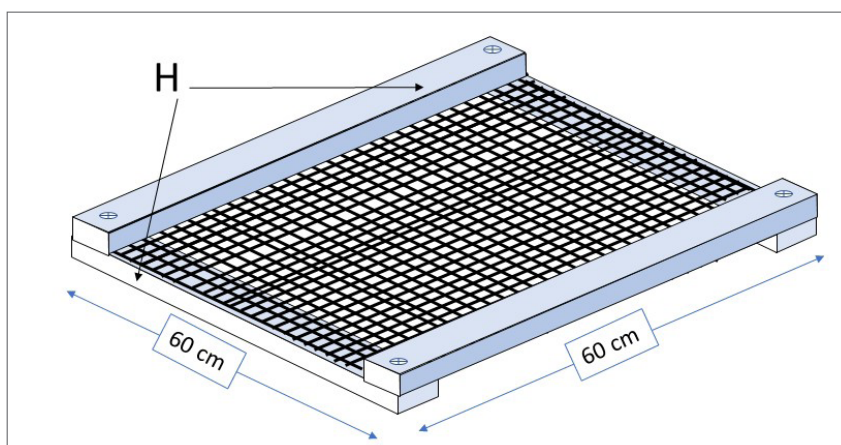
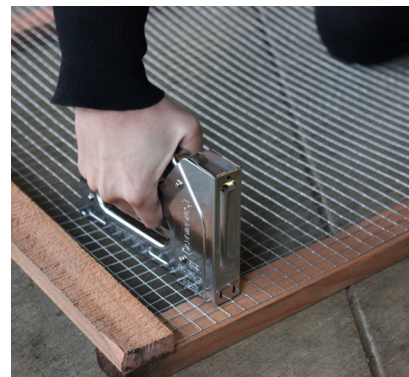
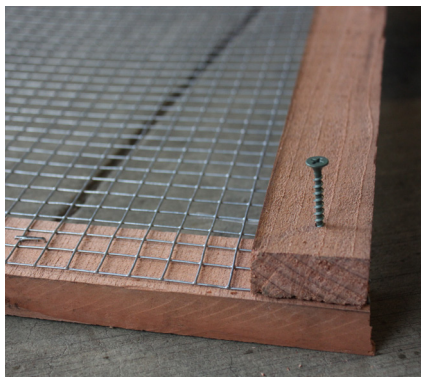


Figure 5. Drying tray

## BEFORE YOU COVER THE DRYER WITH PLASTIC

- Make sure that the desired number of trays fits on the frame; trays can be stacked one or two high.
- If the trays are stacked, make sure that the product on the bottom tray does not touch the tray above.
- Position the 4 m wood or bamboo center pole on support shelves just above the top trays to hold the plastic above the product (Fig. 6).



Pre-cut the mesh. Join the wooden edges of the tray with a nail or screw. Staple the mesh to the wood sides of the tray. Trim any sharp edges of the mesh to prevent ripping the dryer's plastic during use.



## CREATING AN EFFECTIVE DRYING TUNNEL DURING OPERATION

- Drape the clear plastic over the center support pole and the table.
- After the clear plastic has been draped over the center support pole and trays of product, you need to secure the length of the plastic to the ground with two lateral poles in order to take slack out of the plastic on the sides of the drying table.
- To seal the plastic at the chimney, tuck the clear plastic tightly over the support shelf and two vertical boards (pieces J in Fig 4.) securing the table to the chimney. This prevents air from going around the drying table and not entering the chimney. To seal the plastic to the chimney end of the dryer and along the sides of the table, use any combination of the following: wrapping a bicycle tire inner tube around the shelf area; using bricks; scrap wood; tape or Velcro.



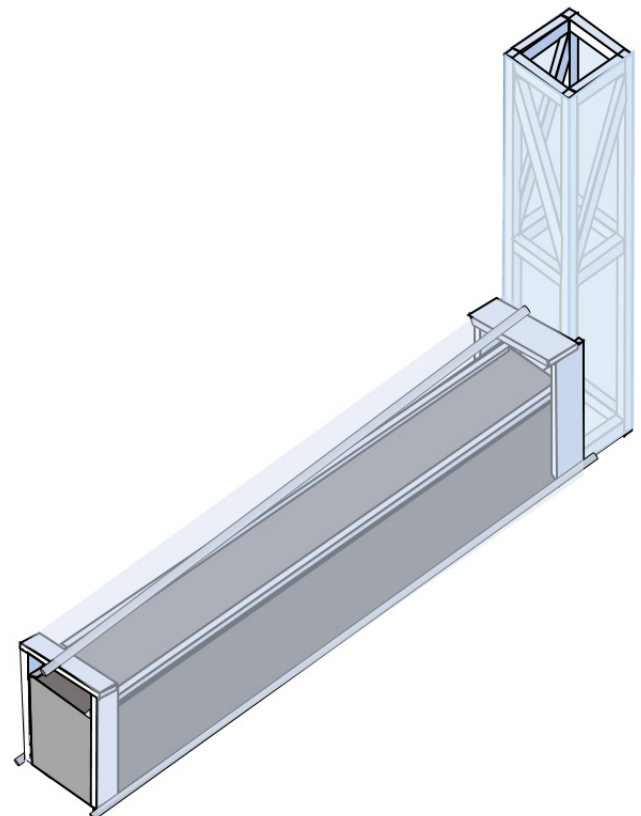
**A bicycle inner tube around the shelf is a solution for making sure the clear plastic at the chimney is tightly sealed against the sides and top of the shelf. Use bricks to secure the poles to the side and make sure there is no slack in the clear plastic cover along the table sides.**

## TIPS AND TROUBLESHOOTING

### LIMITED AIRFLOW ACROSS THE DRYING TRAYS

The height of the pole above the trays should not be more than 5 cm or it will reduce the airspeed in the tunnel. Also ensure the clear plastic is sealed tightly to the wood shelf above the opening to the chimney and sealed tightly to the drying table near the chimney. There are a few simple options to check airflow in the dryer:

- Observe the plastic around the table is slightly suctioned inwards.
- Hang small strips of tissue paper (0.5 x 7.5 cm) from the pole in the middle of the drying table. When air is flowing, these strips will move with the flowing air.
- Puff smoke into the opening of the dryer and see if the smoke goes across the product and up and out the chimney.
- “Nose check” - at the opening at the front of the table you should not notice warm air or strong smell from the product coming out of the dryer.



**Figure 6. Clear plastic wrapped around the table**

## TRAYS ORIENTED INCORRECTLY ON THE DRYING TABLE

The airflow above and below the tray is imperative; orient the trays accordingly so that edges do not block airflow. If the products on the lower tray are touching the tray above, they will block airflow and products will take longer to dry. Overloading the trays with fruits and vegetable can also slow the rate of drying.

## BLOCKAGE AT THE FRONT OF THE DRYING TABLE

Ensure that the front of the dryer is open and unobstructed (i.e. that the clear plastic on the drying table is not covering the tunnel entrance) so that air can flow into the dryer. A mesh screen can be used to cover the air inlet to keep animals out, if needed, but only do this if necessary as it may slow airflow. Insects are usually not a problem, as they are not attracted to the fruit during drying due to the airflow and resulting lack stagnant odor.



Correct tray orientation



Incorrect tray orientation

## REMOVE THE SHARP EDGES

Make sure to remove all sharp wood or metal edges on the pole support shelves and trays before putting the clear plastic over the drying table. This includes trimming down the sides of the metal mesh on the drying trays.

## WINDY CONDITIONS

Due to the chimney height, the chimney dryer can be damaged in windy conditions. To prevent the chimney dryer from tipping over or plastic being damaged, precautions should be taken.

Solutions for windy conditions while dryer is in use include:

- Use guy wires or ropes attached at the top of the chimney and staked to the ground.
- Use stakes in the ground and attach them directly against the sides of the table and chimney for bracing.

Solutions for windy conditions while dryer is not in use include:

- Remove the chimney from the table when the dryer is not in use.
- Lay the entire structure on its side.
- Store the clear plastic used for covering the table and trays indoors to prevent weather damage.

## MULTI-DAY DRYING AND STORAGE

Some products require more than one day of drying. Where possible, bring the product indoors overnight, especially in areas of high humidity, which can prevent re-wetting of the drying product in moist, night air.



## ADAPTIVE DESIGNS

To overcome difficulties procuring materials, to improve dryer ergonomics, or to extend the longevity of the dryer, collaborators have introduced adaptations to the dryer design that have been recognized as effective.

- **Center pole supporting plastic is sagging or rolling around:** Build an additional pole support shelf (dimensions can match J and K in the material table) in the middle of the table to help hold up the center pole under the clear plastic covering the drying table (images A and B). Add small blocks of wood on either side of the center pole on each shelf to keep the center pole from rolling around (see image C).
- **Challenges sourcing a 4m long pole to support the plastic table cover:** One or two ropes secured at the pole support shelves (see parts labeled K in Figure 4) at each end of the table and pulled taut is an alternative means to provide sufficient support for the plastic covering the drying table.
- **Minimize readjustments to plastic covering the drying table:** Securing the plastic at the base on one of the lateral table sides of the dryer permanently and then opening only from the free side reduces the effort required to reposition the plastic after it is removed to add or remove product (image D).
- **Reduce tears in plastic:** Using irrigation drip tape along edges where plastic is secured to the wood reduces probability of tears at the contact point of the staples and the plastic (image E).
- **Moving the dryer:** Construct a “handle” by securing a wooden board on the back of the chimney (image F).



Left and top right: An additional pole support in the center of the table to reduce sagging. Bottom right: small blocks of wood on the center pole support shelves prevents pole from rolling.



Above: securing the clear plastic covering to one side can help reduce tears. Top right: drip tape placed along edges with staples reduces rips at staple points. Bottom right: a piece of wood secured at the back of the chimney can be used to help with moving the chimney solar dryer if necessary.



## SECTION 2

# DRYING FRUITS AND VEGETABLES WITH THE CHIMNEY SOLAR DRYER

Once the chimney solar dryer has been built, you are ready to use it to dry your products

## TEST THE DRYER

We recommend giving the dryer a test run to make sure all the pieces fit well together, that there are no air leaks or gaps in the plastic, and to measure the temperature (if possible) at different locations within the drying table. If the dryer is working well, strips of tissue paper hanging from the center pole under the clear plastic will flutter, the plastic over the table will be slightly concave (due to suction from the chimney), and you may see shimmering at the top of the chimney's shadow.



Load fruits and vegetables onto trays to dry. Peeling and removing pits and slicing thinly will shorten time needed to dry. Uniform slices help with even drying time.

## PREPARE PRODUCT FOR DRYING:

Produce should be clean and undamaged. Bulky products dry faster if they are cut into pieces prior to drying. It is best to begin the drying process in the morning to give the maximum drying time before sunset.

### PRODUCT SELECTION

Dry only fully ripe or even over-mature produce (freshly harvested) for best quality and flavor. Drying cannot improve poor quality produce. If you are drying multiple foods at a time, try not to mix products with very strong flavors or aromas (for example, if you dry apple and onion together, the strong smell of the onion may alter the taste and smell of the apple). In addition to large or normal-sized produce, small or “b-grade” product can be used, which can help recover otherwise lost income. You can dry partially damaged product if you can cut away the damaged portion. Avoid product that is rotting or moldy. Avoid drying produce recently sprayed with chemical pesticides.



Product will shrink as it loses moisture, so it can overlap slightly when loaded onto the trays.

### PRODUCT SIZE AND CUTTING

Thin items like herbs and leafy greens may dry in a few hours, while large products like whole apricots or whole bananas will require several days to dry. You can decrease drying time by removing pits and peeling the product though peeling may remove valuable nutrients. Cutting product into thin (6 mm) slices allows for faster water loss, reducing the amount of drying time required. Furthermore, slicing the product into uniform sizes/widths is crucial for more complete and even drying.

## FILL THE TRAYS WITH PRODUCT

Fill the trays with enough whole or sliced products to maximize the space, but the pieces should not overlap too much to ensure efficient drying. The pieces can overlap slightly because they will shrink as they lose moisture. It is a good practice to place the same product onto one tray because of similar drying time, and to utilize a separate tray for chili peppers, which can impart their spiciness to other food products. Make sure the tray is not too heavy to lift. Product cut into wedges should be positioned on the drying tray so that the peel portion of the cut product is parallel to the sides of the drying table. Product peel, or skin positioned toward the opening of the dryer can impede airflow and slow down drying.

## DRYING PRODUCT IN THE CHIMNEY SOLAR DRYER

### PREHEAT AREA

The first tray space (farthest away from the chimney) should be left empty. Leaving the first tray space empty allows the air to heat before it contacts the product.



Left: proper wedge alignment for product with a peel vs. right: overloaded tray.

### PLACING TRAYS ONTO THE DRYING TABLE

When you do not have a full drying load and are only drying a few trays of product, if you place those trays closer to the chimney-end of the drying table, they will dry faster than if you place them closer to the entrance of the drying table because the chimney end is usually the hottest part of the dryer. However, you should place trays of leafy greens or other fragile products near the opening of the dryer where temperatures are lower compared to other positions on the drying table.

### SHUFFLE TRAYS DURING DRYING

Move the trays according to the thickness and water content of the product to different locations within the dryer. Temperatures are generally higher closer to the chimney, therefore shuffling the trays to different positions (front to back, top to bottom) ensures more uniform drying. Generally, thicker and moister products require more time and thus more shifts in position compared to leafy greens and other similar products. It is advised that you shuffle the trays 2 to 3 times during the drying process. Move the trays closest to the chimney to the opening of the dryer and the trays from the opening next to the chimney. Switch the bottom tray with top tray if trays are stacked.



A chimney solar dryer ready for drying fruits and vegetables. Leave the first tray space (left side of photo) empty as a “preheat area.”

### PLASTIC COVER AND AIRFLOW

The clear plastic that covers the trays should not touch the fresh product; this may cause product damage or incomplete drying. The plastic should be as taut as possible, creating a tent over the product and trays. Make sure that there is plenty of airflow through the dryer, especially above and below the product. Remember, ambient air enters, quickly warms up and dries the product. Warm, humid air exits through the chimney.

## CONDITIONS THAT AFFECT DRYER PERFORMANCE

### AIR TEMPERATURE

High air temperature speeds drying. However, air temperature must not get too hot or it could damage the product. Excessively hot air results from too little airflow. Make sure the tunnel openings at the front of the drying table and the chimney are not obstructed. The clear plastic cover should not touch product.

If the inside of the dryer gets too hot and is damaging products, either orient the chimney solar dryer so the opening of the drying table faces windward, allowing a higher amount of cooler air to flow above and below the drying product, or consider drying during relatively cooler periods of the day. Leafy greens, herbs, and other fragile products require frequent monitoring during drying due to their rapid water loss and potential for being burned or damaged. Do not slice or shred the leafy greens into pieces small enough that they will fall through the mesh of the drying trays once they become dried. It is not recommended to dry herbs in the chimney dryer in extremely hot conditions.

If the temperatures become too cold in the dryer and thus products are not drying quickly enough, they may spoil. Low temperatures could occur if the dryer is in the shade and not receiving enough sunlight, or if outside ambient temperatures are very low. Maximum air temperature during drying of most fruits and vegetables should be in the range of 60 – 65°C (140 – 150°F). Cabbage and onions should not be dried at temperatures above 57°C (135°F). Grains and most nuts should not be dried above 54°C (130°F) with the exception of walnuts that should not be dried above 43°C (110°F). Air temperatures above these recommendations cause quality loss, such as darker color or decreased storage life. Test products in the dryer to be sure of the conditions required for best quality. Operators should try to regularly monitor air temperature in the drying area. An inexpensive dial thermometer works well for this purpose.

### SOLAR RADIATION

Direct radiation on the top trays will result in faster drying than product on the lower trays. More uniform drying can be achieved by rotating tray positions 2-3 times during the drying process. Rotating trays is also beneficial because exposure to direct solar radiation may cause bleaching and this light color may or may not be desirable by consumers. Product on the top tray may be exposed to excessive heating, which can cause quality loss. In addition to shuffling trays, the top trays can be covered with a light colored fabric, which should not touch the product and can be layered underneath the plastic or above the trays on top of the plastic to partially shade sensitive products.

### AIR SPEED

Faster airflow increases the rate of moisture loss from the product and speeds drying. Make sure the air tunnel entrance is not blocked or covered in any way. A few centimeters of headspace over the product is enough to provide for the free flow of air and allow for air to heat up. If the plastic covering is too high above the trays, air speed will be slowed and drying times will increase.

### HUMIDITY

When the relative humidity of the ambient air is low, drying speeds are faster. Heating of the air from solar radiation further reduces its relative humidity. Even in locations with high ambient relative humidity, the dryer heats the air enough to produce the low relative humidity levels required for rapid drying.

### AMOUNT OF PRODUCT ON TRAYS

Adding more product (by weight) to the trays increases the overall amount of product dried per drying cycle; however, it also increases the length of the drying cycle. Users should experiment with the product load to determine what works best under their conditions. Light tray loadings associated with drying of flowers, herbs or products weighing less than 2.5 kg/m<sup>2</sup> (0.5 lbs. /ft<sup>2</sup>) will dry in less than one day. The dryer has been modified by some users to dry grapes in bunches, producing equivalent tray loadings of more than 50 kg/m<sup>2</sup> (10 lbs. per ft<sup>2</sup>). In preliminary experiments, complete drying was achieved in about 5 to 7 days.



## STACKED TRAYS

The dryer can be used with two trays stacked on top of each other. Because air temperatures are higher at the top of the drying table, the top trays will dry faster than the lower trays. Rotating trays may also reduce bleaching, an effect of direct solar radiation that may not be desirable. Bleaching may also be reduced by covering the top trays with a light shade cloth.

## ADVERSE WEATHER CONDITIONS

The dryer works in cloudy to sunny conditions, and even occasional rain showers are not a problem. However, drying should not be attempted during periods of continuous rain or heavy clouds.

## STORING DRIED PRODUCT

Properly dried fruits and vegetables can be stored for several months to a year. Dried products should be stored in a cool, dry and dark area. After drying, the product should be allowed to cool a short time and then packed into dry, airtight containers or sealed plastic bags. Do not be afraid to pack the dried product tightly together. Storing at cool temperatures increases storage life of dried products.

## HOW DRY IS DRY ENOUGH?

Crops must be sufficiently dried to be safely stored. Vegetables are sufficiently dried when they are hard and brittle or tough and leathery, depending on the vegetable. Sufficiently dried beans, corn and peas are hard and can shatter. Dried leafy, thin vegetables should be brittle, and larger chunks or slices of vegetables should be leathery. Sufficiently dried fruit will still be pliable, but not sticky or tacky. Dried berries should rattle when shaken in a container.

However, the best method for accurately determining safe product dryness for storage is to measure the relative humidity of the air in the dried product storage container. Mold will not grow when equilibrium relative humidity in the air around the sealed product is lower than 65 percent. One inexpensive method for measuring equilibrium relative humidity is to use a **DryCard™** indicator (more information at <https://horticulture.ucdavis.edu/drycard>).

The moisture content of fresh produce at harvest ranges from 20 to 95 percent depending on the product. High sugar content fruit should be dried to approximately 20 percent moisture content. Dried leafy or thin vegetables should contain about 10 percent moisture



**DryCard™** dryness indicator. Pink is not sufficiently dry, purple or blue is sufficiently dry.

# ADDITIONAL RESOURCES

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