A Basic Guide to Drying Fruits and Vegetables

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1. Introduction:

One of the most serious problems facing growers of fruits and vegetables is how to prevent these products from spoiling and thereby becoming unfit for consumption. There are various methods of accomplishing this, such as canning or freezing. However, one of the most suitable methods of preserving most fruits and vegetables is through drying to remove most of the water content.

It is not possible to provide details about the drying of a wide variety of fruits or vegetables in a short guide such as this. Therefore, we will use mangoes as a specific example. While the drying of various products will vary to a certain degree, the basic principles are the same for mangoes as they would be for most other fruits or vegetables.

Mango trees grow naturally in many parts of Sub-Saharan Africa (Figure 1). Their sweet, fleshy fruit is quite nutritious and tasty. Sadly, when the mangoes ripen, they are often so plentiful that there is little or no significant commercial value to them. Since they cannot be sold, the mangoes may be left to rot where they have fallen from the trees.

Once harvested, there is a limited time during which the mangoes may be used before they begin to soften and spoil. There are a few ways in which the mangoes may be preserved for later use, including, for example, mango jams and relishes.

Figure 1: A mango tree in Southern Malawi

One very convenient way to increase the useful life of mangoes is by drying them, therefore ensuring their later availability. With proper storage and handling, dried mango slices can be enjoyed several months after fresh mangoes have disappeared from the local markets.

It is the purpose of this guide to provide some instruction for the drying of mangoes. We will attempt to cover the entire process from the selection of the fruit for drying, all the way through to the steps necessary for preparing dried mangoes for consumption. Although mangoes are discussed in detail, the principles are applicable to most fruits and vegetables.

Figure 2 shows mangoes on a tree in Northern Malawi.

Figure 2: Mangoes on the tree

2. Why Do We Dry Mangoes?

Mangoes, like most fresh fruits or vegetables, consist mostly of water. Typically, a mango may contain around 85% water.

In Figure 3, we see a mango that weighs 353 grams. Since 85% of its weight is water, there will be about 300 grams of water and only 53 grams of solid material. Of these solids, some are present in the skin or peel, as well as in the stone or pit. Both the peel and stone also contain water. Of course, neither the peel nor the stone will be eaten and will be discarded.

Figure 3: A mango weighing 353 grams

Figure 4 shows just how much water there actually is in a mango. Here, we have placed 300 grams of water in a beaker. A bit of food colouring has been added to make the water more visible in the photo. When you take time to think about it, it is rather amazing how much water is present in the foods we eat.

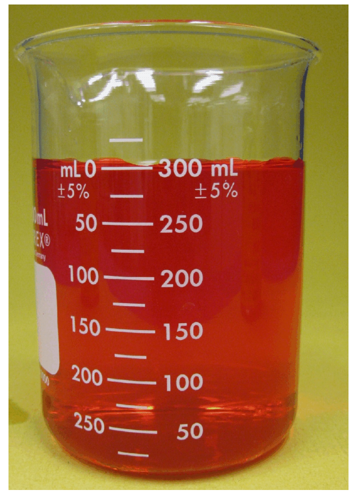

Figure 4: There are 300 grams of water in the mango shown in Figure 3

Within the ripe fleshy portion of the mango, there is a considerable amount of naturally occurring sugar. It is the sugar which gives the mango its appealing sweetness. The juice of the mango is composed of a combination of sugar dissolved in water inside the fleshy portion of the fruit. There are other compounds present which provide the distinctive flavour and aroma.

Unfortunately, the juice of the mangoes is also a convenient source of nutrients for microorganisms like molds. Once molds or other microorganisms begin to grow, they will make the flesh of the mangoes unfit for human consumption. Looking at Figure 5, we can see how unappetizing a moldy slice of mango appears. The black spots are mold colonies. Some of these have developed to the stage where they have produced a grey fuzzy covering.

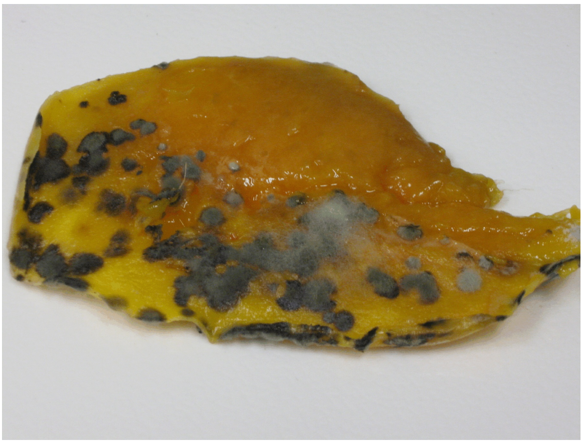

Figure 5: A moldy slice of mango

If we remove most of the water from the mangoes, there will no longer be enough moisture present to support the growth of microorganisms. As a result, the mangoes will not spoil as rapidly as they would if the water was present. This means that we will have a "shelf-stable" product that can be kept for several months without spoiling. Even though most of the water has been removed, the dried flesh of the mango will retain most of its nutritional properties.

In addition to making the mangoes last longer before they spoil, there are some additional reasons for drying them. By removing most of the water that was originally present, we are left with only the solids and a small amount of water. This makes a very large difference between the weight of the fresh mangoes and those that have been dried.

A benefit of the weight reduction is that the mangoes can be shipped at a lower cost since there is no need to transport large amounts of water. For example: 100 kg of fresh mangoes can be dried to give about 17 kg of dried mango slices. This means that we can ship only the solids portion of the mangoes and a small amount of water, thereby avoiding the expense of having to transport the added weight of the 83 kg of water that was removed.

Removing the water from mangoes causes the fleshy portion of the fruit to shrink in size. Therefore, the dried mangoes take up much less room to store or transport than fresh mangoes. Figures 6a and 6b show mango slices before and after drying. Hopefully, you can see the differences in their appearance and size.

Figure 6a: Mango slices before drying

Figure 6b: Mango slices after drying

These mangoes were dried with their peels left on as part of a drying study.

An added advantage of increasing the shelf-life of the mangoes through dehydration is that they can be shipped longer distances (possibly to foreign markets). During the considerable time it takes to reach far-off destinations, fresh mangoes could easily spoil. However, this problem can be avoided if dried mango slices are exported.

Taste and texture are two other things to consider when comparing fresh and dried mangoes. When the water is removed from the mangoes, the sugars that were dissolved in the mango juice remain in the dried mango flesh. This means that the dried mango slices will contain a high concentration of natural sugars and will have a very pleasant sweet taste and a somewhat stronger flavour than the fresh "wet" mangoes. Drying also tends to make the mango flesh take on a leathery texture which makes them a chewy snack.

We will look at how dried mangoes can be used later in this guide.

3. How Do We Dry Mangoes?

The most effective way to dry any fruits or vegetables (or even meats) is to expose them to heated air. This will remove moisture and leave behind the solids and materials which were previously dissolved in the water.

Sources of heat can include burning various fuels, or other more environmentally friendly methods such as sun-drying.

Sun-drying can be done in the open air by spreading the selected material on metal racks or mesh screens. If the air is not already saturated with moisture, the warmth of the sun and warm gentle breezes will remove moisture as the air passes across the surface of the fruits or vegetables being dried. Sun-drying can be slowed significantly if the air is humid. This reduces the "drying capacity" of the air, which is the ability of the air to remove moisture from a material.

The sun can also be used as a source of energy to heat air and dry materials that are located inside a cabinet. We refer to these enclosed devices as "solar dryers". Although the concept is fairly simple, designing an efficient and effective solar dryer is a challenge. A great deal of research has been done to improve the design and operation of solar dryers. This has made them a very attractive alternative to dryers that rely on burning fuels (wood, oil, gas, etc.) as a source of heat.

In the remaining portions of this guide, we will look at various aspects of mango drying, with particular emphasis on solar drying.

4. Is Quality of the Mangoes Important?

The importance of selecting the proper starting materials for drying is often overlooked. Only the best quality fruit available should be used for drying. Any processing facility that is drying mangoes should have a set of standards in place to define the quality of their ideal starting material. Since this is very subjective, we cannot set out any actual standards here. We can, however, look at some of the basic attributes which need to be considered.

4.1 Overall appearance:

The mangoes need to pass a visual inspection before they can even be given additional consideration. They should be free from blemishes such as bruises and insect damage. They may need to be of a certain size or weight to make handling easier. Their colour may assist in determining the desired degree of ripeness. As mangoes ripen, their sweetness increases and their texture changes. Both of these are important factors that can be partially assessed by a preliminary visual inspection.

If there is any surface contamination, such as visible mold growth or bird droppings, these mangoes and those within the same group should be seriously considered for rejection. While bird droppings can be removed by washing, it should be remembered that fecal matter carries with it a variety of microorganisms that can be the cause of potential food-borne illnesses.

Figure 7 shows a mango purchased for some drying trials. It has a slightly different colour than the one shown in Figure 3, even though it is the same variety. This is due to the fact that it is slightly more ripe

Figure 7: A mango selected for drying

4.2 Feel:

The mangoes being selected may need to have a certain degree of firmness that will indicate their level of ripeness. This will help verify the initial visual inspection. Mangoes that are overly ripe, or too soft, are hard to peel and slice. Their texture may not be suitable for processing. Mangoes that are too firm may not have sufficient ripeness to have developed the correct level of sweetness. While they are easy to handle and may dry satisfactorily, the taste of the final dried product may not be as sweet as desired.

Feeling the mangoes may also let you know how juicy they are. A certain level of moisture is necessary to provide a high quality mango from the point of view of texture, flavour, and sweetness.

4.3 Aroma:

It is often possible to pick the desired starting material be examining its odour. Mangoes have a characteristic aroma that may help in assessing the quality of the starting material. In general, any fruit with an uncharacteristic or suspicious odour should be avoided, since it may be spoiled.

4.4 Source:

Mangoes for drying and other processing should be bought from trusted suppliers. The fresh mangoes entering a processing facility can bring many problems with them. As a processor, you need to know the past history of the mangoes you are using as your raw materials and will ultimately be selling to your customers.

You need to know if chemicals were used during the growth period of the mangoes. Were they sprayed with insecticides or pesticides? Were any fertilizers used, and if so, were they appropriate? What were the general conditions under which the mangoes were grown? Are there any potential health risks imposed by the growing, harvesting, or storage and handling conditions? Mangoes purchased in the market may not have a good history of how they were grown, harvested, or handled (see Figure 8).

Figure 8: We have no idea how these mangoes in the market were handled

Another very important factor is the manner in which the mangoes were obtained. Were they removed from the trees in a picking process, or were they picked up off the ground as “windfalls”? Basically, “windfalls” means that the fruit has ripened on the tree and has been knocked down by the wind. In other cases, it may simply be too heavy to be supported any longer by the stem which connects it to the tree.

Fruit that has fallen from the tree and been picked off the ground often has surface contamination. The causes of this contamination are often from being in contact with droppings of animals such as sheep, goats, or cattle that have been grazing in the areas around the trees. “Windfall” mangoes should be avoided whenever possible.

4.5 Variety:

Certain varieties of mangoes may have better properties for drying than others. Some mangoes are large and juicy with a high level of sweetness. Others may be smaller with a higher fibre content and lower sweetness level. There is also the need to understand which varieties will give you the best finished product to meet the needs of your customers. You may need to process a number of different varieties to satisfy the different preferences of the consumers.

In areas with only one variety of mango available, this factor will not be an issue.

4.6 Taste:

Since your dried mangoes will end up as a food product, it is a good idea to taste the starting material. Mangoes which are not sufficiently sweet or have an undesirable texture, or “mouth-feel”, should not be used. This is a difficult point to describe or define. However, some basic descriptions outlining examples of desirable flavour attributes can go a long way to assuring a higher quality finished product.

5. What are the Initial Preparation Steps?

Once the mangoes have been selected, the basic preparation steps can begin.

Even if the incoming mangoes have been inspected at their point of purchase, they need to be closely examined as they are coming into the processing plant facilities. This should be done before they are unloaded from the delivery vehicle. By doing this, they can be easily removed from the processing facility area if they are rejected. Had they been unloaded prior to inspection, it would be necessary to reload them onto the delivery vehicle for removal from the plant. Preliminary inspection also reduces the risks of spreading potential contaminants around the processing plant should any be found on the incoming mangoes.

All accepted fresh mangoes must be thoroughly washed before entering the main processing area. The outer peel of the mangoes can be contaminated with potentially dangerous microorganisms from a variety of sources such as birds, insects, rodents, and grazing animals (in the case of windfalls). There should be minimal delay between acceptance of the incoming mangoes and the time they go through the initial washing phase of the process. This will reduce the need to store incoming fresh mangoes before they are washed and help maintain a clean production environment.

Washing must be done with potable water. “Potable water” is water that is fit for human consumption. This will prevent the incoming fruit from being contaminated further, which would be the case if impure water was used in the washing stage.

A rinse with a chlorine solution or passage through a bath of chlorine solution would help reduce the microbial population on the surface of the mangoes. The easiest way to prepare a disinfecting solution of chlorine is by using a bleach solution. A household bleach container often has instructions on the label for preparing such a solution.

The strengths of chlorine solutions can vary depending on their application and the concentration of the initial bleach solution. A mixture of 180 mL of bleach and 4 litres of potable water may be sufficient for this application. This would need to be followed by a thorough rinse with potable water.

There is always a risk of bringing undesirable microorganisms and other contaminants into a processing facility. To minimize this risk, there needs to be a means of ensuring separation between different areas. Raw material receiving areas must be separated from the rest of the processing facility. Workers should not be allowed to travel from one area to the other without safeguards being in place to prevent contamination of one area by materials and contaminants from another area. You may want to consider the receiving area as being “dirty” and have it totally isolated from the remainder of the processing plant.

Once the mangoes have been washed, they may need to be stored for a short period of time before going on to the next processing step. This area could be considered as “clean” storage. Holding times should be minimized. The storage area must be closely monitored to ensure that the first mangoes to come into the “clean” storage area are the first ones to leave when additional fresh mangoes are brought in.

From the “clean” storage area, the washed mangoes would go to a peeling operation. Here, the outer peel of the mangoes will be removed by using a paring knife or peeling device.

Because the inner surface of the mangoes is now exposed to the workers who are doing the peeling and other steps, these workers should be wearing proper attire for the job. This would include hairnets or other suitable head covering. Where applicable, beard nets must also be worn. Coats, smocks, or similar uniform along with proper safety equipment (e.g., proper safety shoes or other footwear, gloves, knife guards, etc.) are absolutely essential. Light-coloured uniforms, especially white, are better than darker coloured uniforms for hygienic purposes since stains and spills are more easily recognized on the lighter-coloured fabric.

Your fingers are the ten most common causes of infection and food contamination

Hand-washing stations using warm potable water and equipped with soap dispensers should be within easy access of workers. Towels for hand-drying should be clean and changed regularly. In addition, there should be adequate washroom facilities which should be maintained and cleaned according to a regular schedule. Workers should never return to their work stations without having properly washed their hands.

Workers must wash their hands:

- before and after handling foods or eating
- after using the washroom facilities
- after sneezing, coughing, or blowing their nose
- after touching a cut or open sore
- after being outside or touching any unclean surfaces

Proper hand-washing procedures include:

- wetting the hands with clean warm water
- applying soap
- rubbing the hands together to create a lather which is to be spread on the front and back of the hands, between the fingers, and under the fingernails.
- lathering should continue for at least 20 seconds
- once thoroughly lathered, the hands should be rinsed with warm potable water (i.e., water that is safe for drinking).
- a clean fresh towel should be used for drying the hands (paper towels are ideal for this purpose)
- the towel should be used to turn off the water faucet and then be discarded in a proper receptacle

Hand-washing is the most effective way to stop the spread of illness and disease

During peeling, workers will be using knives or peeling devices to remove the outer peel from the mangoes. Sufficient safety training must be provided to each worker to prevent personal injuries and to impress upon them the importance of cleanliness within the processing facility.

WORKER SAFETY
IS OUR #1 CONCERN

Workers with cuts or open sores should not be allowed in the production facility where there could be a potential threat to the cleanliness of the area.

Peels from the mangoes must be removed from the area within a reasonable time period and not be allowed to accumulate. The peels may provide a risk of contamination even though they have been previously washed. Since they are biodegradable, they can be sent to a composting area. The peeled mangoes should then be sliced for drying.

Figure 9 shows peeled mangoes awaiting slicing. The slight greenish tinge is due to the fact that very little flesh was removed with the peel and that the mango may not have fully ripened.

Figure 9: Peeled mangoes

The condition of the knives and other utensils is important for worker safety. Blades should be kept sharp and free from rust, dirt, and other sources of contamination.

All surfaces should be washed with potable water and disinfected with a chlorine in water solution of suitable concentration after each production batch or shift. All equipment should be thoroughly cleaned according to appropriate standards which are beyond the scope of this guide.

6. How Should the Mangoes Be Sliced?

Mango slicing can be difficult due to the slippery nature of the mangoes and the presence of the large stone within the mango itself.

As you can see in Figure 10, mango stones tend to be flat. The ones shown in the photo were scraped to remove most of the mango flesh. They were then dried in the sun to remove the surface moisture. When dry, you can see the fibres sticking out of the stone. These will not be as noticeable when the stone is cut away from the mango flesh and it is still wet.

Figure 10: Mango stones
(side view and flat surface view)

There are numerous ways to slice a mango. The exact procedure will depend on personal preference. If you look at the shape of the mango, it is not generally round. Instead, it is somewhat flattened. You can place the peeled mango on a cutting surface so that the longer dimension is aligned vertically. This will orient the mango so that the stone is in the up-down position as well.

The mango can then be sliced vertically from the outside until the knife hits the side of the stone. Large flat slices can generally be obtained from either side of the stone, but it will not be possible to get such large slices from the mango flesh around the stone. Here, you will get much smaller slices. Procedures on how to slice the mangoes should be established to ensure that all mangoes are sliced in a uniform manner.

The slices themselves should be about 5 to 6 mm thick (approximately ¼ inch). Thickness is a very important factor in mango drying as we will see later.

The mango slices should be placed in a clean container such as a large metal bowl. The bowl needs to be covered and kept in a cool, clean area until the slices are required for drying. It is a good idea to avoid slicing the mangoes too far in advance of when they are needed. In this way, problems with sanitation can be reduced, and there is less risk of flavour changes.

7. What Happens in the Drying Process?

7.1 The Drying Mechanism:

Before we go too far into the details about drying mangoes, we need to look at how moisture is removed during a typical drying process.

Most products dry because moisture (which is really water) is removed from their surfaces. If we have a sliced mango, we can see that the surface tends to be wet - especially if the mango is ripe and juicy.

It is important that the air used for drying purposes is not overly humid, or saturated with moisture. When warm dry air is blown across the surface of the wet mango slices, it picks up some of the moisture by the process of evaporation. Evaporation is the change that occurs when water goes from being a liquid to a vapour. So, the warm air now contains water vapour and carries it out of the dryer and away from the slices of mangoes.

As more and more air blows across the surface of a mango slice, moisture from inside the mango slice comes to the surface to replace the moisture that was lost. We call this process of moisture moving from the centre of the material to the outer surface "diffusion". Moisture that has diffused to the surface is then evaporated and swept away by the moving air.

At the start of the drying process, the combination of a wet surface and additional moisture coming to the surface makes the rate at which the water is removed quite high. Figure 11 shows how the drying process occurs when the moist mango slices are first placed in the dryer. The surface is considered to be saturated with moisture which is like having a “pool” of moisture there from which evaporation can take place.

Eventually, a point will be reached where the surface no longer looks wet, since there is no visible moisture on the surface. Moisture will still be travelling from the centre of the slice to the surface, but it will be removed as soon as it gets there. As more and more moisture is removed, the rate of water removal gets slower and slower. In Figure 12, we can see that there is no pool of moisture on the surface of the mango slice. Slow diffusion of moisture to the surface has become the only way in which moisture can be removed.

There are very few things that we can do to try to speed up the drying process. We are limited by how fast the moisture can diffuse to the surface. This simply cannot be rushed. You should try to keep this description of the drying mechanism in mind whenever you are drying anything

As we shall see later, reducing the thickness of the slices is one method to decrease drying times. When the thickness is reduced, the distance moisture has to travel from the centre of the slice to the surface is also reduced.

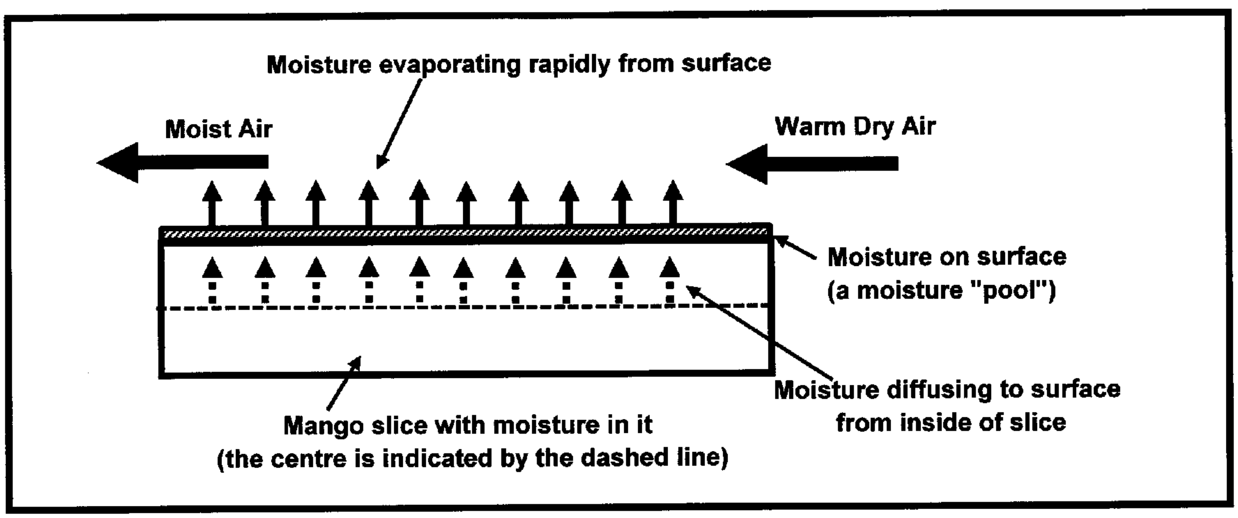

Figure 11: Moisture removal from mango slices early in the drying process

Note: A key to effective drying is to have the warm air as dry as possible.

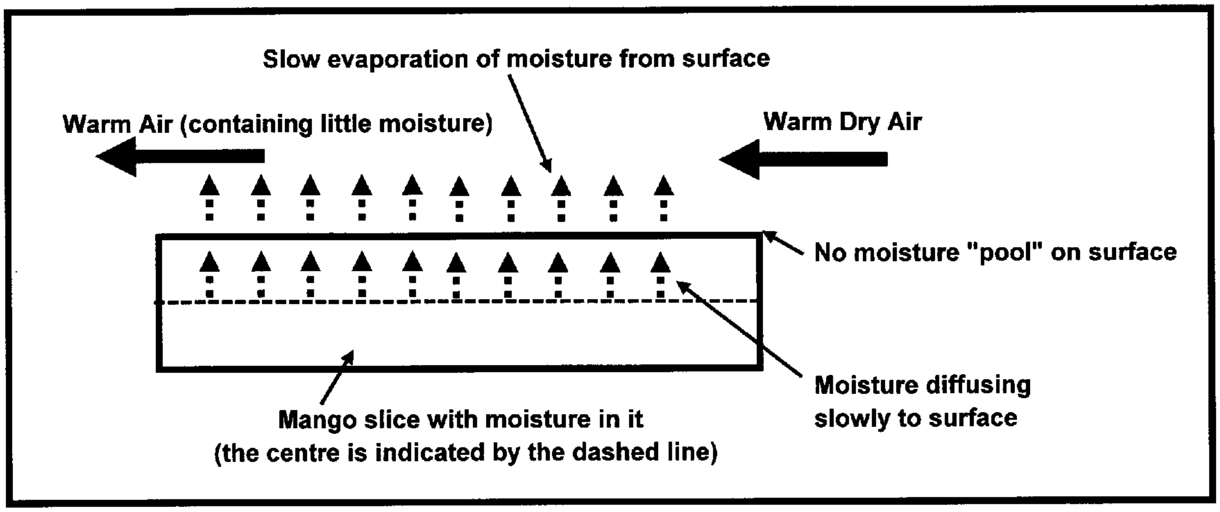

Figure 12: Moisture removal from mango slices late in the drying process

Note: The rate of drying is controlled by diffusion of moisture to the surface after the surface moisture pool has been evaporated.

7.2 Factors Affecting Drying:

There are three basic factors which have the greatest effect on mango drying. They are:

i. Temperature of the drying air
ii. Velocity of the drying air
iii. Thickness of the mango slices

The first two factors are directly linked to the design of the dryer. If the dryer happens to be a solar dryer, then weather conditions will play an important part in all of this. While it is not the purpose of this guide to teach anyone how to build a food dryer, we should look at some of the design features of dryers to understand how they function.

7.3 Basic Design of a Forced-Air Dryer:

Forced-air dryers are usually designed as a closed cabinet with a fan inside to blow air through the unit. There are many interesting designs and arrangements to suit various special drying needs. Figure 13 shows a diagram of how a typical forced air dryer may look.

Air is brought into the dryer by the fan which then blows the air across heating coils or through gas flames to warm it. Once the air is heated, it has the ability to hold more moisture than cooler air. The increased water-holding capacity of the heated air is a key factor in drying.

The heated air then travels to the drying chamber of the unit where the material to be dried is located. In most cases, moist food products are spread on wire mesh racks within the drying chamber.

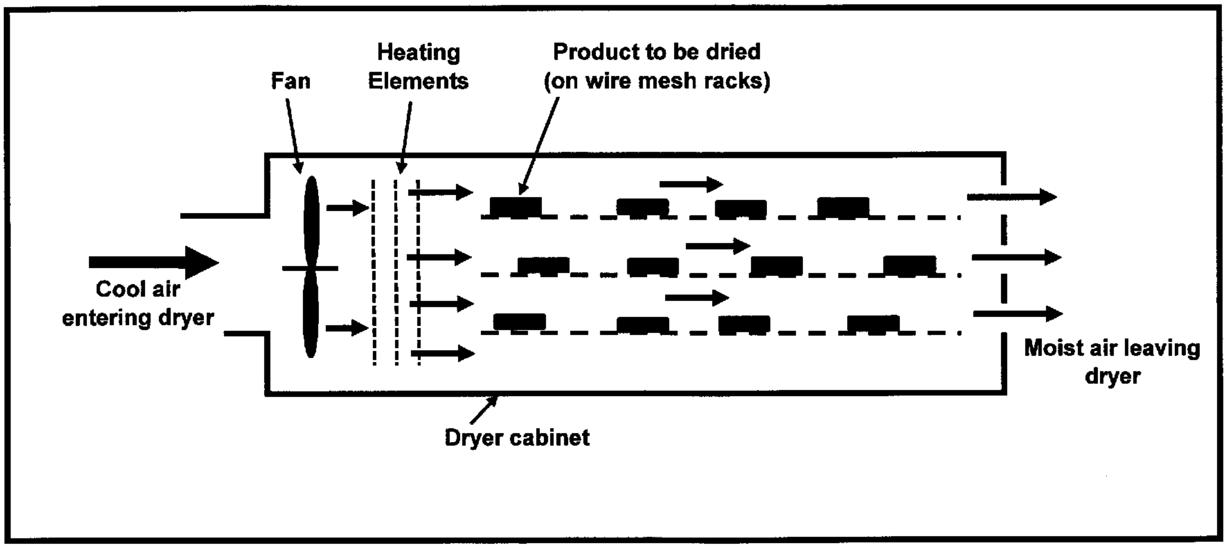

Figure 13: Diagram of a typical forced-air dryer

When the heated air passes over the moist surfaces, it picks up water through the process of evaporation. The air then carries the water away from the food and eventually out of the dryer. As the air picks up moisture, it cools and its moisture content increases. This reduces its ability to pick up additional moisture as it continues its path through the rest of the dryer.

Freshly heated air is continuously blown into the dryer, while moisture-rich air is constantly forced out of the dryer by the incoming air. With sufficient time, the moisture content of the food in the dryer will have reached its desired target level. However, it must be realized that just because the outside surface of the fruit looks and feels dry, there is still a moisture gradient in the individual pieces of fruit. That is, the outer portion is actually drier than the inner portion. In addition, because the air is flowing over the fruit, the fruit at the front of the dryer where the air enters will be dryer than the fruit at the exit where the air leaves. This is because the temperature of the air decreases as it picks up moisture. As the air passes through the dryer, it picks up more and more moisture, as well as cooling, and may become saturated to the point where it can pick up no more moisture. Many processors move the racks of fruit from the exit end of the dryer to the inlet end of the dryer part-way through the drying process to help reduce this uneven drying tendency.

When the dried food is removed from the dryer, it must be allowed to cool before it is packed for storage or for sale. This will provide time for the moisture in the fruit to equilibrate and become uniform throughout the fruit.

It is possible to control the temperature of the air in a forced-air dryer by adjusting the heater's temperature controls. The speed (or velocity) at which the air moves through the dryer can be controlled by adjusting the speed at which the fan is operating. The velocity of the air must be sufficiently high to evaporate the moisture from the surface of the food in the dryer and sweep this moisture-rich air out of the dryer. Air flows that are too low will not have the desired effect and the efficiency of the dryer will be disappointing.

It is usually best to have the air flowing across the surface of the material rather than coming in from the bottom of the dryer and travelling upwards through the material being dried. This ensures better air distribution and better exposure of the food to the drying air.

Dried product should be allowed to cool after it has been removed from the dryer. It should never be packaged while still warm. Even though it appears to be totally dry, there will still be a trace of moisture left inside. Warm products may "sweat" in the package. By this, we mean that small amounts of moisture may still leave the dried products and collect on the inside of the cool packaging material as tiny droplets of water. These water droplets can then support mold growth.

7.4 Basic Design of a Solar Dryer:

Now, let's take a quick look at solar dryers.

Solar dryers can have many different shapes, sizes, and designs - just as forced-air dryers do. The main difference between solar dryers and forced-air dryers is the source of energy for heating the air. Rather than using fuel such as natural gas or other combustible materials to provide the heat, solar dryers rely totally on heat from the sun.

Some solar dryers may have fans in them to assist in circulating the air, so technically they may be considered to be forced-air dryers. However, we usually class them as "solar dryers" based primarily on their source of energy rather than on how they actually function. Other solar dryers may not have fans in them and rely on the natural circulation of air.

This circulation is caused by the heated air rising up from the bottom of the dryer through the drying chamber. The air that has picked up moisture on its way through the drying chamber leaves the cabinet by means of an exhaust outlet at the top of the dryer.

A diagram of a basic solar dryer is shown in Figure 14. The surface of the black metal heat collector becomes quite warm when exposed to bright sunlight. This causes the air inside the heat collector to heat up and expand. This hot air begins to rise and travels upwards into the drying cabinet. Food to be dried is spread on wire mesh racks inside the drying cabinet. As the warm air moves across the surface of the food, it picks up moisture.

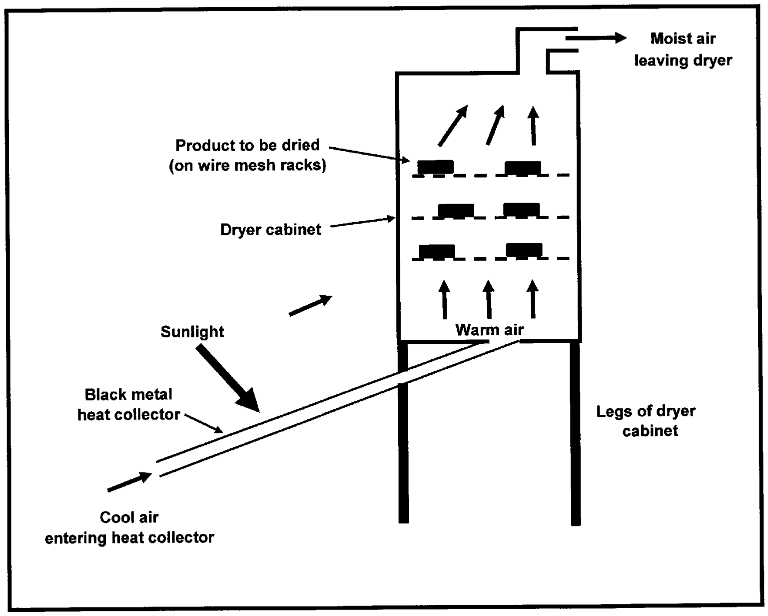

Figure 14: Diagram of a typical solar dryer

The warm moist air continues to travel upwards and leave the drying cabinet through an opening at the top, which is very much like a chimney.

While the warm air is moving upwards out of the heat collector, more cool air is drawn into the heat collector. This air is warmed up and rises into the drying cabinet. The natural circulation of the air into the bottom of the drying cabinet and out through the top will continue as long as there is enough heat to warm the incoming air.

Since sunlight is the only source of heat energy, air circulation will not proceed if there is insufficient sunlight available.

Unfortunately, the rate at which the air flows through the drying cabinet cannot be controlled without the use of fans. Solar-powered fans are a great addition to a solar dryer. By including a solar panel and battery, constant air flows can be maintained through short periods of cloudiness. You can see the solar panel and battery for a solar dryer in Figure 15.

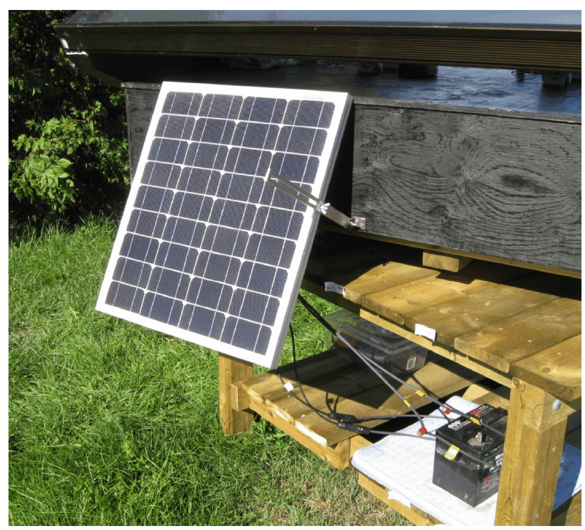

Figure 15: A solar panel and battery on a solar dryer

Figure 16 shows a solar dryer being used to dry a number of different products in Equatorial Guinea. There are no fans and the dryer relies totally on natural circulation of the air (also called "convection") to dry the food materials. The heat collector is the black metal assembly going from the lower left of the photo into the bottom of the dryer.

The drying cabinet in Figure 16 has a glass front to allow sunlight to enter. The heat of the sunlight entering the drying cabinet also assists in raising the temperature. Care must be taken in this regard, since some food products can lose a portion of their nutrients in bright sunlight.

Figure 16: A solar dryer on location in Equatorial Guinea.

Moist air will leave the drying cabinet through the white tube located at the top of the drying cabinet.

New developments in technology often bring opportunities to improve on previous designs. Figure 17 shows how the solar dryer unit in Figure 16 was modified once solar-powered fans were available to assist in moving the air. The solar-powered fans are the two circular devices near the top of the dryer.

Figure 17: A solar dryer with solar-powered fans to circulate the air

The two fans blow the moist air out of the top of the dryer which draws freshly heated air from the heat collector into the drying cabinet. This, in turn, pulls fresh cool air into the heat collector where it is warmed up.

In this new version of the dryer, the original two-piece heat collector has been replaced by a larger single heat collector. In full sunlight, the black metal surface may reach temperatures over 75°C. Air travelling through the heat collector and going into the drying cabinet can reach 50°C or more which is ideal for drying materials such as mangoes.

Recent improvements in design and available equipment have enabled additional modifications to be made to solar dyers. One significant technological advance has been in the area of solar-panels, or photo-voltaic cells, which can be used to generate electricity to power larger fans and greatly improve the efficiency of the dryer.

Figure 18 shows an example of a modern dryer with a solar panel mounted on the front and a large heat collector mounted on top of the drying cabinet. This solar panel and its battery connection were seen previously in Figure 15.

Figure 18: A modern solar dryer equipped with a solar panel to power fans

Air enters the heat collector on the right-hand side of the photo (inlet openings are not visible). It is warmed up as it travels across to the left side of the photo. Heated air leaves the heat collector and is drawn by a set of fans into the drying cabinet. The fans then blow this heated air across the surface of the food which has been sliced and placed on wire mesh racks inside the drying cabinet. This solar dryer is capable of providing temperatures of up to 60°C for drying fruits and vegetables.

In Figures 17 and 18, the solar dryers are mounted on bases which can be turned to keep the heat collectors pointing directly at the sun. This is an important feature since the sun travels across the sky from east to west throughout the course of the day.

Basically, solar drying technology is looking for any modifications that can provide uniform airflow throughout the entire drying cabinet, and give the desired temperatures for drying.

7.5 The Role of Air Temperature:

As stated at the beginning of this section, the temperature of the drying air is one of the most important factors for the drying of a food product. Mangoes are no exception.

In order to show the effects of temperature on the drying of mangoes, a forced-air dryer was used in the laboratory. Mangoes were washed, peeled, and cut into 6 mm thick slices for these tests. The sliced mangoes were then placed on a rack which was connected to a balance on top of the dryer. In this way, the weight of the mangoes could be recorded during the entire drying process without opening the dryer.

Three different temperatures were used: 50°C; 55°C; and 60°C. The speed of the air was kept constant, since we know that it can have an effect on drying and we did not want to introduce any additional factors into this set of experiments. Figure 19 shows a graph of the weight of the mango slices during the

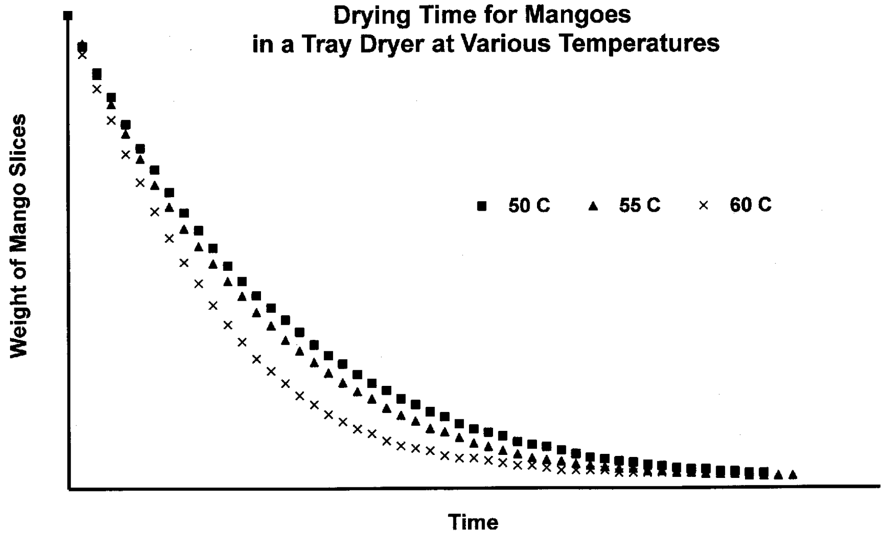

Figure 19: The effect of air temperature on the drying of mangoes

time the drying tests were run. There is a curve for each temperature.

From Figure 19, it can be seen that the weight of the mangoes decreases faster with the air temperature at 60°C than it does for 50°C or 55°C. No actual values have been placed on the graph since it is the general trend that we would like to emphasize here.

For most food products, it is best to use drying temperatures of 50°C to 55°C. The temperature should never exceed 60°C. The main reason for this is because higher temperatures can destroy nutrients within the food itself. Without these nutrients, the food loses much of its dietary importance.

Regrettably, many people think that the hotter the air, the better it will be for drying the food material. This is an incorrect assumption that can lead to some serious problems, in addition to destroying some of the nutrients contained within the food. We will discuss this in a later section under the heading of "Case Hardening".

Before leaving our discussion of the effects of temperature on the rate of drying, let's take a slightly different look at it. If we have identical weights of mangoes with identical initial moistures, we can re-draw Figure 19 with the moisture content on the vertical axis as shown in Figure 20.

In Figure 20, a horizontal dashed line has been drawn to indicate a constant wet basis moisture. At points where this line crosses the drying curves for each temperature, a dashed line has been dropped vertically. The three vertical dashed lines meet the horizontal axis for "time" at points labelled t_1, t_2, and t_3.

t_1 is the time for the sample dried at 60°C to reach a certain moisture content. It is shorter than t_2 which is the drying time at 55°C. t_3 is the time taken for drying at

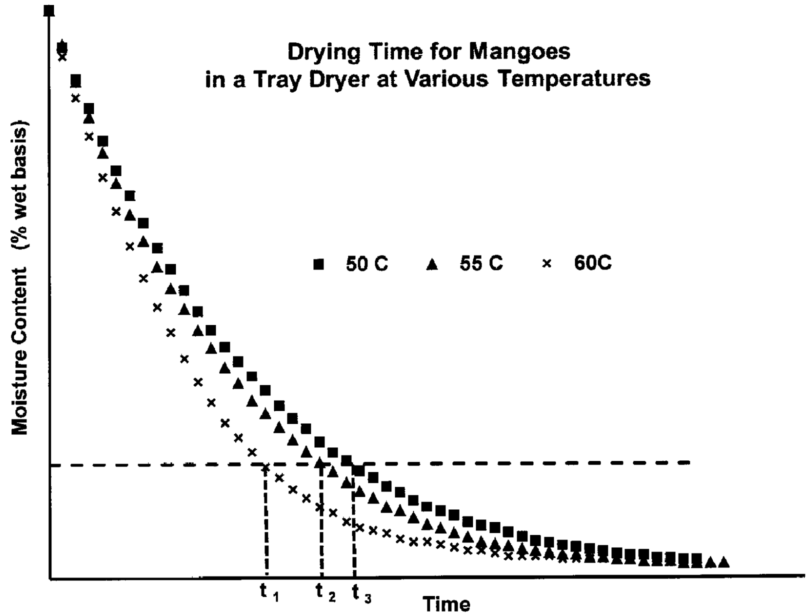

Figure 20: Times required to reach equal moisture contents at three drying temperatures

50°C, and is the longest time of the three. This clearly shows the impact of temperature on the drying of the mango slices.

7.6 The Role of Air Velocity:

In addition to the temperature of the air used for drying, the velocity, or speed, at which the air is travelling is also an important factor in drying.

When there is no movement of air across the surface of the mango slices, air at the surface becomes saturated with water. As a result, water on the surface cannot be removed. If this saturated air is displaced by fresh unsaturated air, the unsaturated air can pick up more of the moisture from the mango surface. If the air is kept moving, the drying process will continue at a satisfactory pace. In drying terminology, a layer of air clinging to the surface of a material and preventing efficient moisture removal is called a "stagnant boundary layer". It is not moving, so it is stagnant. Since it is between the surface of the material and the outside air, it is considered to be a boundary layer.

In drying studies, we are often concerned with how fast the air must be moving to sweep away the stagnant boundary layer. Tests can be done using different air speeds to determine the effects of air speed on the rate of drying.

Figure 21 gives us a look at the effects of air velocity on the drying of mango slices in a laboratory dryer. The air temperature used for drying the mango slices in Figure 21 has been kept constant at 50°C.

An air speed of 0.2 metres per second allows the mangoes to dry reasonably well. However, when the speed is increased to 0.5 m/s, there is a noticeable improvement in how fast the drying occurs. This is because the faster air flow is better at sweeping away the stagnant boundary layer of air around the moist mango slices. The air at the surface that has picked up moisture is being continuously replaced by fresh unsaturated air which is very efficient at removing moisture.

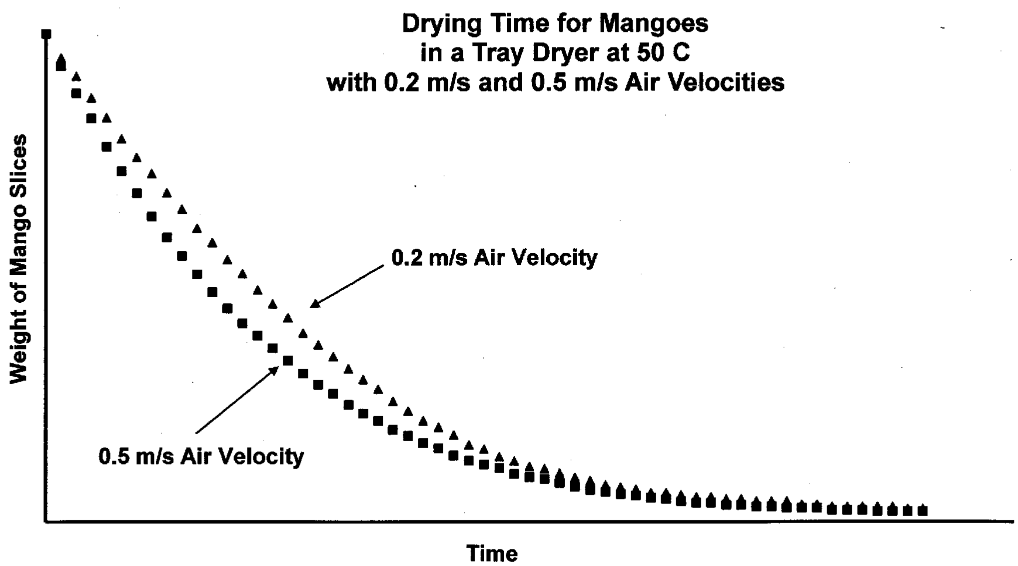

Figure 21: The effect of air velocity on the drying of mangoes (at 50°C)

7.7 The Effect of Thickness on Drying

In Figures 11 and 12, we showed how moisture travels from the centre of the mango slices to the surface where it is removed by the air passing through the dryer.

The important thing to recognize here is that as the slice of mango gets thicker, the distance from the centre of the slice to the surface increases. When the distance increases, the time it takes for the water to travel from the centre to the surface also increases. This means that it will take longer for the product to dry.

Figure 22 shows the effects that the thickness has on the drying of apple slices. This graph has been included since similar tests have not been done in our lab for mangoes. However, the same trends as shown for apples have been observed for other fruits and vegetables studied in this manner.

As can be seen, the 0.8 cm thick slices dry more slowly than the thinner slices. This is because water at the centre of the slice has further to diffuse and reach the surface in the thicker slices than it does in the thinner slices.

t_1 is the time required for 0.4 cm thick slices of mangoes to reach a certain moisture content. It is noticeably shorter than the times taken to dry 0.6 cm thick slices (t_2), and 0.8 cm thick slices (t_3), to the same moisture content.

In most mango drying work, a thickness of 0.5 to 0.6 cm (approximately ¼ inch) is used. It is a convenient thickness to visualize when slicing the mangoes, and it makes the slices easy to handle without tearing or ripping them. They are also thin enough to dry reasonably quickly and the final dried product is not excessively thick.

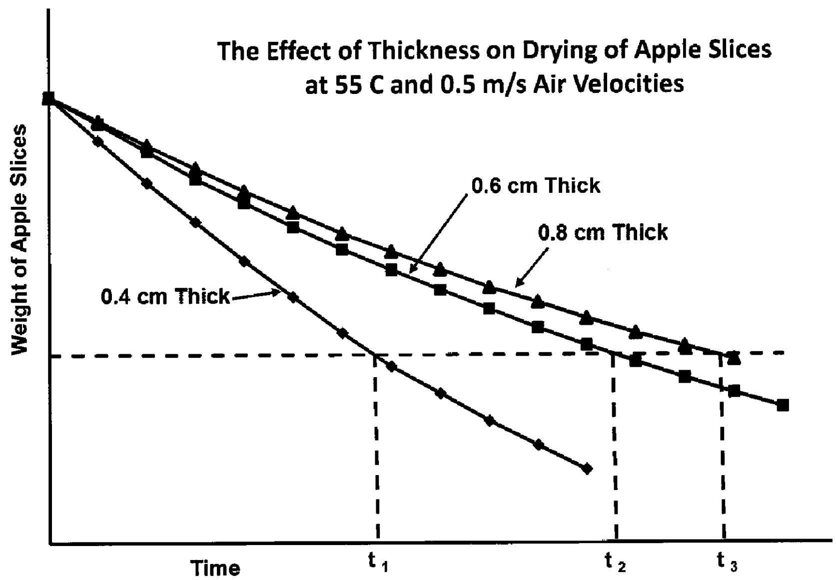

Figure 22: The effect of thickness on the drying of apple slices

7.8 Case Hardening

Care must be taken in the way information is interpreted when dealing with food drying.

In Figure 19, we saw the effects of temperature on the drying of mango slices. However, this graph can be misleading if the overall effects of temperature are not fully understood.

Some dryer operators may look at graphs like that shown in Figure 19 and concluded that if 60°C is a fast temperature at which to dry food quickly, then 80°C will be faster and better, which in turn means that they can dry more product in a day. When they try to dry foods like mangoes at 80°C and find that the drying actually takes longer, they are left wondering what went wrong.

This is where we also need to recall how the drying process takes place in a mango slice. You may recall from Figures 11 and 12 that moisture is removed from the surface of the mango slice first. Moisture that is still inside the mango slice then needs to diffuse to the surface where it will eventually be removed by the warm air passing through the dryer.

As moisture is removed from fruits or vegetables, their cellular structure begins to collapse and the cells become smaller. The result of this is the shrinking of the product as it dries.

At 80°C, moisture is removed quite rapidly from the surface of the mangoes. It may be removed so fast that the hot air starts to make a hard thick layer on the outside of the mango slices due to the collapsing of cells at the surface. This layer is much like a skin that can trap moisture inside the mango slices. It severely reduces the efficiency of the drying process and may prevent this trapped moisture from leaving the mango slices. We call the development of the skin-like shell of hard material on the outside of the product “case hardening”.

Once this outer shell has formed, there is little that can be done to dry the product in a controlled manner. An additional problem is that many dryer operators look at the case hardened mango slices and think that they are dry. When they feel them and bend them, the slices actually appear dry enough to remove from the dryer and be packaged for sale.

After packaging, moisture at the centre of the mango slices may begin to travel very slowly through the thick layer of collapsed cells at the surface of the slice. It then goes into the air inside the package where it condenses on the cooler packaging surfaces to form water droplets. These water droplets are now available to support mold growth on the mango slices. Of course, any mold growth will make the product un-saleable and unfit for eating.

Figures 23 and 24 illustrate how case hardening occurs.

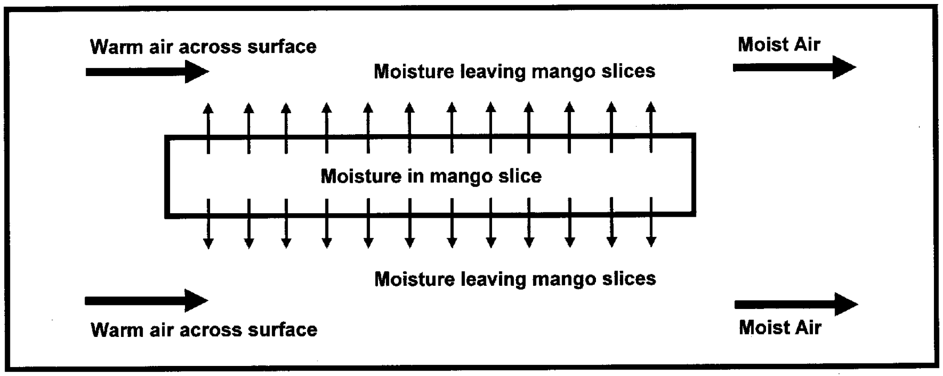

Figure 23: Drying of mango slices with warm air

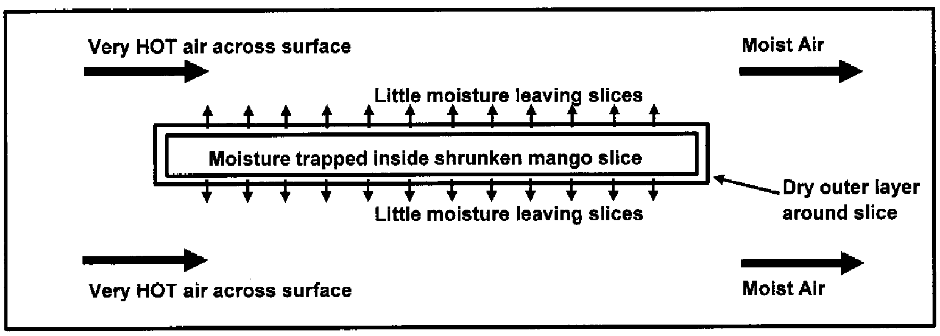

Figure 24: Excessively hot air being used to dry mango slices.

Note the dry outer layer around the slice and its shrunken size

8. How Do Drying Methods Compare?

There are numerous ways of drying mangoes and other fruits or vegetables with similar moisture contents.

In some areas, mango slices may simply be put out in the sun to dry in the open air as shown in Figure 25.

Figure 25: Open-air drying of mango slices

This may be satisfactory in cases where the mangoes are for the personal use of whomever is drying them. However, it is definitely not appropriate from a food safety point-of-view, especially if you want to sell the dried product.

In the following photographs, we can see some of the problems associated with the open-air drying of mango slices.

Dirt can easily be blown onto the surface of the mangoes (Figure 26).

Figure 26: Dirt on a mango slice drying in the open air

In other cases, there can be unwanted visitors landing on the food. This would include insects like wasps (Figure 27) or houseflies (Figure 28).

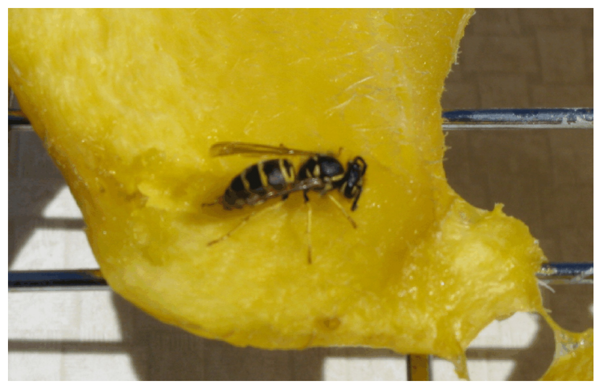

Figure 27: Wasp on a mango slice

Figure 28: Housefly on a mango slice

Undesirable pests also include crawling insects such as ants (Figure 29), roaches, beetles, and others.

Figure 29: Ant on a mango slice

Drying products inside a cabinet such as a solar dryer or a forced-air dryer protects the product from many of these problems. It also protects the product from contaminants in the air and the highly undesirable effects of birds and their droppings.

In addition, drying with an actual dryer gives more control over the drying process than can be obtained with open-air drying. Unfortunately, solar drying is limited to sunny weather with sufficient heat and low humidity to drive the drying process. Forced-air drying allows for a higher degree of controlled drying and permits around-the-clock drying which is not limited by the amount of available sunlight. Temperatures and air velocities are among the controllable factors with forced-air drying.

Whatever drying method is selected, it is important to understand the drying process and to take every precaution to make a product that is of the highest possible quality and that is safe for human consumption.

9. What Do We Need to Remember for Mango Drying?

When drying any fruits or vegetables it is important to prepare a standardized set of procedures so that everyone operating the equipment will be using the same approach and methods. Failure to do this can result in non-uniform products from batch to batch and from one process operator to another.

All personnel must be thoroughly trained in the operation of the process. This includes the actual drying of a product, as well as maintenance and cleaning of the equipment.

One very important aspect that is often overlooked is familiarization of workers with “cause and effect” relationships. Basically, this means that everyone working on the process must know the consequences of any actions taken to adjust the process, or the effects that any changes to the process may have on the final product.

As an example, operators must understand that thicker slices of product will take longer to dry than thinner slices due to diffusional limitations within the product. They also must understand that they cannot simply increase the temperature of the air going into the dryer to compensate for the thicker slices. If they do take this action, they will end up with a thickly case hardened product that will not be acceptable for sale, and will ultimately spoil during storage due to the entrapped water.

Once a detailed set of operating instructions has been developed and the operators have been thoroughly trained, there is still a need to monitor their performance. This can generally be done by regularly testing products through quality control checks and periodic refresher training courses for the process operators.

Every aspect of the process must be monitored. Accurate records need to be kept and retained for future reference. Each batch of product will need a unique reference or “lot” number to identify it in case problems are identified at a later date. This lot number must appear on packages of finished product that are offered for sale and must match the lot numbers on the records. In this way, it will be possible to match actual product with records taken during the time it was produced. “Traceability”, as it is called, is essential in any commercial processing operation.

To keep accurate records, it is necessary to design data sheets that operators can use to collect information during the processing of each product batch. All critical operating parameters must be recorded. These would include such things as the temperature of the air entering the dryer, the temperature inside the dryer, and a host of other observations.

Training manuals and “trouble-shooting” guides are also important resources in a production environment. If a situation presents itself during a production run and the operator is unsure of how to cope with it, a trouble-shooting manual can offer some assistance. It could take the form of a list of problems which might be encountered, accompanied by a number of potential remedial actions for dealing with them.

There will be a need to have standardized assessments of the acceptability of raw materials. What constitutes a “quality” mango versus an unacceptable mango that should be rejected rather than used? Providing a quality check-list will go a long way to ensuring that sub-standard raw materials are not used for drying purposes.

Overall, high standards for all aspects of production, packaging, storage, and distribution must never be compromised. Failure to follow procedures at any stage of the processing chain must never be tolerated.

10. How Do We Use Dried Mango Slices?

Whatever fruits or vegetables are dried, their characteristics will be substantially changed compared to their undried starting form.

Let’s consider tomatoes as an example. Fresh tomatoes contain up to 95% moisture by weight which makes them quite soft and juicy. Dried tomatoes contain only 10% moisture, and tend to be dark in colour and somewhat leathery. As a result, dried tomatoes cannot be used in fresh salads or other similar applications which require these attributes of fresh tomatoes. However, dried tomatoes are ideal for soups or stews where they can be heated in water to rehydrate them and increase their moisture content. Since moisture is needed to rehydrate the dried tomatoes, it is necessary to add additional water to the soup or stew to compensate for the required extra moisture.

Teaching consumers the way in which to use dried products can be a challenge.

Providing instructions in the form of sample recipes for such things as chutneys can go a long way towards this goal. Recipes can be incorporated into the packaging or labels on the finished product. Demonstrations at a local level or instructions given in newspapers and radio announcements can be effective in familiarizing consumers with how to use dried products, as well.

When providing instructions on the use of dried fruits or vegetables, do not forget that they may be consumed in their dried form as snacks. Consumers may not be familiar with this application, so they may need to be urged to expand their eating habits to discover the appeal of such things as dried mangoes, which are sweet, chewy snacks.

Since dried fruits have most of the water removed, the natural sugars which they contain become concentrated after they have been dried. This means that 100 grams of dried fruit such as mangoes will contain more sugar than 100 grams of fresh mango slices. This also means that 100 grams of dried mangoes will contain more calories than 100 grams of fresh mangoes. Consumers need to be made aware of this fact in such a way that they do not view it as a negative attribute of dried mangoes. Dried mangoes are also less filling than the equivalent weight of fresh mangoes so their intake needs to be monitored. For this reason, the inclusion of recommended serving sizes on package labels would be appropriate.

11. Summary Comments

We sincerely hope that this brief guide will provide assistance to drying fruits and vegetables. Drying is an extremely versatile approach to preserving food products.

Please keep in mind that whatever products are being dried, it is important to understand every aspect of the process from the selection of raw materials right through to distribution of the finished product to the consumer.

12. Sources of Information

The following two book chapters are available on-line:

Donald G. Mercer, "Solar Drying in Developing Nations: Possibilities and Pitfalls", Chapter 4, in "Using Food Science and Technology to Improve Nutrition and Promote National Development", G.L. Robertson and J.R. Lupien, editors. Published by The International Union of Food Science and Technology, 2008. ISBN 978-0-9810247-0-7

Donald G. Mercer and Robert Myhara, "Improving the Operation of a Commercial Mango Dryer", Chapter 6, in "Using Food Science and Technology to Improve Nutrition and Promote National Development", G.L. Robertson and J.R. Lupien, editors. Published by The International Union of Food Science and Technology, 2008. ISBN 978-0-9810247-0-7

In addition, there are numerous other internet resources available on the topic of food dehydration and drying.