Solar Drying Technology for Food Preservation

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Food losses in the developing world are thought to be 50% of the fruits and vegetables grown and 25% of harvested food grain (Burden, 1989). Food preservation can reduce wastage of a harvest surplus, allow storage for food shortages, and in some cases facilitate export to high-value markets. Drying is one of the oldest methods of food preservation. Drying makes produce lighter, smaller, and less likely to spoil. This paper presents the background and possibilities of solar drying, focusing on the technical needs of small farmers in the developing world. (The important social and cultural implications of introducing a new technology are not addressed here). The background section explains the moisture content of foods, how moisture is removed, and the energy required for this drying process. The "Solar Drying Essentials" section discusses drier components, the drying process, and the capabilities of solar driers. The paper concludes with a classification of drier types, some criteria for selecting a drier, and references to further information.

Background

Preserving fruits, vegetables, grains, and meat has been practiced in many parts of the world for thousands of years. Methods of preservation include: canning, freezing, pickling, curing (smoking or salting), and drying. Food spoilage is caused by the action of molds, yeasts, bacteria, and enzymes. The drying process removes enough moisture from food to greatly decrease these destructive effects.

Moisture Content. The moisture content of fresh foods ranges from 20% to 90%. Foods require different levels of dryness for safe storage, as shown in Table 1. For example: the moisture content of rice must be reduced from 24% to 14% of the total weight. Therefore, drying 1,000 kg of rice requires the removal of 100 kg of water. Safe storage generally requires reducing the moisture content to below 20% for fruits, 10% for vegetables, and 10-15% for grains. If food is properly dried, no moisture will be visible when it is cut.

Table 1: Moisture contents.

	Moisture Content (Wet Basis)	
Food	**Initial**	**Desired**
Rice	24%	14%
Maize	35%	15%
Potatoes	75%	13%
Apricots	85%	18%
Coffee	50%	11%

Moisture Absorption. The length of time required to dry food depends upon how quickly air absorbs moisture out of the food. Fast drying primarily depends upon three factors: the ***air should be warm, dry, and moving***. The dryness of air is measured in terms of *relative humidity* (RH). If air is at 100% relative humidity, it has absorbed 100% of the water it can hold at that temperature. If air has a RH near 100%, it must be heated before it will be able to absorb moisture out of food. [1, 2]

Energy Requirements. The amount of energy that must be added in order to dry produce depends on the local climate. Air drops in temperature as it absorbs moisture from food, and thus supplies some energy for drying. Therefore, if the air is warm and dry enough, food will dry slowly without additional heating from fuel or the sun. However, additional heat shortens the drying process and yields a higher quality product. Under typical conditions 100kg of maize might be dried with roughly 3kg of kerosene, or with 10kg of biomass such as wood or rice husks (Devices, 1979). Alternatively, a 6m^2 solar collector will dry the maize over three sunny days, if the relative humidity is low. The size of solar collector required for a certain size of drier depends on the ambient temperature, amount of sun, and humidity.

Solar Drying Essentials

Solar Drier Components. Solar driers may be viewed as three main components: a drying chamber in which food is dried, a solar collector that heats the air, and some type of airflow system. Figures 1 shows one type of solar drier with each of these three components labeled. The *drying chamber* protects the food from animals, insects, dust, and rain. It is often insulated (with sawdust, for example) to increase efficiency. The trays should be safe for food contact; a plastic coating is best to avoid harmful residues in food (Reynolds, 1998). A general rule of thumb is that one m^2 of tray area is needed to lay out 10kg of fresh produce (Speirs, 1986). The *solar collector* (or absorber) is often a dark colored box with a transparent cover. It raises the air temperature between 10 and 30°C above ambient. This may be separate from the drier chamber, or combined (as with direct driers). Often the bottom surface of the absorber is dark to promote solar absorption, and occasionally charred rice chaff serves this purpose. Glass is recommended for the absorber cover, although it is expensive and difficult to use. Plastic is acceptable if it is firm or supported by a rib such that it does not sag and collect water (Vanderhulst, 1990).

[1] Consider air entering a solar drier at 60% relative humidity (RH) and 20°C. Assume the air is heated to 40°C and absorbs water until it reaches 80% RH. With these conditions, air will absorb 8g of water for every m^3 circulated. (If the air were warmer or dryer, it would hold more than this). To continue the previous example, this means that removing 100 kg of water from rice will require roughly 13,000 m^3 of air to be circulated (Energy Options, 1992).

[2] The term *water activity (AW)* is a measure of how likely food is to spoil. This ranges from 0.2 for cereal to near 1.0 for fresh meat. An AW of 0.65 or lower is needed for safe storage (Vargas, 1996). Several sources in the references section give detailed information concerning measuring moisture content during the drying process and achieving the desired dryness. This may be important for export to markets with strict quality standards.

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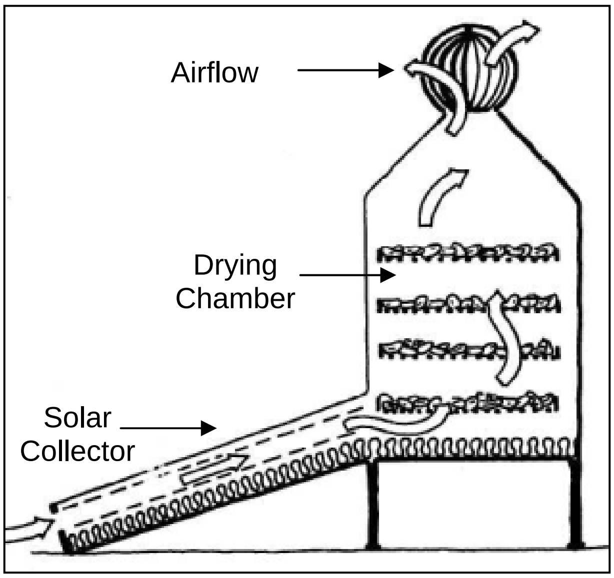

Figure 1: Solar drier components (Brace Research Inst.)

Solar driers use one of two types of *airflow systems*; natural convection utilizes the natural principle that hot air rises, and forced convection driers force air through the drying chamber with fans. The effects of natural convection may be enhanced by the addition of a chimney in which exiting air is heated even more. Additionally, prevailing winds may be taken advantage of. Natural convection driers require careful use; stacking the product too high or a lack of sun can cause air to stagnate in the drier and halt the drying process (Vanderhulst, 1990). The use of forced convection can reduce drying time by three times and decrease the required collector area by 50%. Consequently, a drier using fans may achieve the same throughput as a natural convection drier with a collector six times as large (Hislop, 1992). Fans may be powered with utility electricity if it is available, or with a solar photovoltaic cell. For comparison, one study showed that the installation of three small fans and a photovoltaic cell was equivalent to the effect of a 12m chimney (Grupp, 1995).

The Drying Process. Producing safe, high-quality dried produce requires careful procedures throughout the entire preservation process. Foods suffer only a slight reduction in nutrition and aesthetics if dried properly; however, incorrect drying can dramatically degrade food and brings the risk of food poisoning (Drying, ITDG).

A process similar to the following seven steps is usually used when drying fruits and vegetables (and fish, with some modifications):

1. Selection (fresh, undamaged produce)
2. Cleaning (washing & disinfection)
3. Preparation (peeling, slicing, etc.)
4. Pre-treatment (e.g. sulfurizing, blanching, salting)
5. Drying
6. Packaging
7. Storage or Export

Only fresh, undamaged food should be selected for drying to reduce the chances of spoilage and help insure a quality product. After selection, it is important to clean the produce. This is because drying does not always destroy microorganisms, but only inhibits their growth. Fruits, vegetables, and meats generally require a pre-treatment before drying. The quality of dried fruits and vegetables is generally improved with one or more of the following pre-treatments: anti-discoloration by coating with vitamin C, de-waxing by briefly boiling and quenching, and sulfurization by soaking or fumigating. Fish is often salted. A small amount of chemical will treat a large amount of produce, and thus the cost for these supplies is usually small. However, potential problems with availability and the complexity of the process should be considered (Rusten, 1988).The best pre-treatment procedure may be determined through a combination of experimentation and consulting literature on the subject.

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After selection, cleaning, and pre-treatment, produce is ready to place in the drier trays. Solar driers are usually designed to dry a batch every three to five days. Fast drying minimizes the chances of food spoilage. However, excessively fast drying can result in the formation of a hard, dry skin - a problem known as case hardening. Case hardened foods appear dry outside, but inside remain moist and susceptible to spoiling. It is also important not to exceed the maximum temperature recommended, which ranges from 35 to 45°C depending upon the produce. Learning to properly solar dry foods in a specific location usually requires experimentation. For strict quality control, the drying rate may be monitored and correlated to the food moisture content to help determine the proper drying parameters (Vanderhulst, 1990).

After drying is complete, the dried produce often requires packaging to prevent insect losses and to avoid re-gaining moisture. It should cool first, and then be packaged in sanitary conditions. Sufficient drying and airtight storage will keep produce fresh for six to twelve months (Rusten, 1988). If possible, the packaged product should be stored in a dry, dark location until use or export. If produce is to be exported, it must meet the quality standards of the target country. In some cases this will require a chemical and microbiological analysis of dried samples in a laboratory.

Food drying requires significant labor for pre-treatment (except for grains), and minimal involvement during the drying process such as shifting food to insure even drying. Solar drying equipment generally requires little maintenance.

Capabilities of Solar Driers. Solar drying can preserve a variety of fruits, vegetables, grains, and some meat. It can also be used for cash crops such as coffee, herbs, cashew, and macadamia. Solar driers exist for treating timber, although they are not discussed here. Fruits are ideal for preservation by drying since they are high in sugar and acid, which act to preserve the dried fruit. Vegetables are more challenging to preserve since they are low in sugar and acid. Drying meat requires extreme caution since it is high in protein, which invites microbial growth (Reynolds, 1998). Fish drying, for example, requires thorough cleaning of the drier after each batch. Lists are available explaining which foods are suited to drying. For example, "Apples, apricots, coconuts, dates, figs, guavas, and plums are fruits that dry quite easily, while avocados, bananas, breadfruit, and grapes are more difficult to dry. Most legumes are easily dried, as well as chilies, corn, potatoes, cassava root, onion flakes, and the leaves of various herbs and spices. On the other hand, asparagus, beets, broccoli, carrots, celery, various greens, pumpkin, squash, and tomatoes are more difficult to dry successfully" (Rusten, 1988).

Experiences in developing countries have demonstrated that simple, locally manufactured solar driers can be economical. Solar driers range in cost from a few dollars to thousands of dollars depending on size and sophistication. Table 2 gives examples of several solar driers and the possible price for local manufacture.

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Table 2: Sample prices of solar food driers w/ local manufacture (Green & Schwarz, 2001)

Solar Drier Type	Price	Drying Area	Notes
PGCP Coconut	15 US$	7 m^2	Slightly better than open-air
Kenya Black Box	400 US$	5 m^2	Much better than open-air
Hohenheim Tunnel	2000 US$	20 m^2	Professional quality

Classification and Selection of Driers

Classification of Food Driers. Drying techniques may be divided into six general categories based on the way the food is heated (summarized in **Table 3**). *Open-air*, or unimproved, solar drying takes place when food is exposed to the sun and wind by placing it in trays, on racks, or on the ground. Although the food is rarely protected from predators and weather, in some cases screens are used to keep out insects, or a clear roof is used to shed rain. *Direct sun* driers enclose food in a container with a clear lid, such that sun shines directly on the food. In addition to the direct heating of the solar radiation, the green house effect traps heat in the enclosure and raises the temperature of the air. Vent holes allow for air exchange. *Indirect sun* driers heat fresh air in a solar collector separate from the food chamber, so the food is not exposed to direct sunlight. This is of particular importance for foods which loose nutritional value when exposed to direct sunlight. *Mixed mode* driers combine the aspects of direct and indirect types; a separate collector pre-heats air and then direct sunlight adds heat to the food and air. *Hybrid* driers combine solar energy with a fossil fuel or biomass fuel such as rice husks. (It is interesting to note that a harvest of 1000 kg of rice yields 200 kg of husks, and requires burning only 25 kg of husks to be dried) (Hislop, 1992). *Fueled* driers use conventional fuels or utility supplied electricity for heat and ventilation.

Table 3: Classification of food driers.

Classification	Description
Open-Air	Food is exposed to the sun and wind by placing in trays, on racks, or on the ground. Food is rarely protected from predators and the weather.
Direct Sun	Food is enclosed in a container with a clear lid allowing sun to shine directly on the food. Vent holes allow for air circulation.
Indirect Sun	Fresh air is heated in a solar heat collector and then passed through food in the drier chamber. In this way the food is not exposed to direct sunlight.
Mixed Mode	Combines the direct and indirect types; a separate collector pre-heats air and direct sunlight ads heat to the food and air.
Hybrid	Combines solar heat with another source such as fossil fuel or biomass.
Fueled	Uses electricity or fossil fuel as a source of heat and ventilation.

Comparing Solar Drying with Other Options. A first step when considering solar drying is to compare it with other options available. In some situations open-air drying or fueled driers may be preferable to solar. If either of these is already used in a certain location, solar drying will only be successful if it has a clear advantage over the current practice. Table 4 lists the primary benefits and disadvantages of solar drying when compared with traditional open-air drying, and then with the use of fueled driers.

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Table 5: Solar driers compared with open-air and fuel drying. (Adapted from: Hankins, 1995; Hislop, 1992; and Vargas, 1996)

Type of Drying	Benefits(+) & Disadvantages(-) of Solar Driers
Solar vs. Open-air	+ Can lead to better quality dried products, and better market prices + Reduces losses and contamination from insects, dust, and animals + Reduces land required (by roughly 1/3) + Some driers protect food from sunlight, better preserving nutrition & color + May reduce labor required + Faster drying time reduces chances of spoilage + More complete drying allows longer storage + Allows more control (sheltered from rain, for example) - More expensive, may require importing some materials - In some cases, food quality is not significantly improved - In some cases, market value of food will not be increased
Solar vs. Fueled	+ Prevents fuel dependence + Often less expensive + Reduced environmental impact (consumption of non-renewables) - Requires adequate solar radiation - Hot & dry climates preferred (usually RH below 60% needed) - Requires more time - Greater difficulty controlling process, may result in lower quality product

The above comparison will assist in deciding among solar, open-air, and fueled driers. The local site conditions will also play an important role in this decision. Some indications that solar driers may be useful in a specific location include (Speirs, 1986):

- Conventional energy is unavailable or unreliable (making fuel driers unattractive)
- Plenty of sunshine
- Dry climate (relative humidity below 60%)
- Quality of open-air dried products needs improvement
- Land is extremely scarce (making open-air drying unattractive)
- Introducing solar drying technology will not have harmful socio-economic effects

In addition to local conditions, the type of product to be dried plays a role in the decision process. For example, in some locations traditional open-air drying may be suitable for coffee, whereas fruit would largely be lost to predators. High-value cash crops often require consistent high quality without risking lost produce, and thus the use of fuel driers may be best (Drying, ITDG).

The uses of solar dried products might include: self-consumption, local sale, large markets, and export. Therefore, the potential market for solar dried foods is often another important consideration. Preservation always slightly reduces nutrition and aesthetics, and therefore dried foods are only desirable if fresh is not available (Rusten, 1988). Even where fresh is not available, consumer acceptance may be problematic if dried foods are not already on the market. Existing infrastructure may be available to facilitate marketing dried produce. The expected market price will influence how much can be invested in a drier. Unfortunately, higher quality from solar driers doesn't always bring higher market prices than open-air drying. In some cases local markets are not willing to pay extra for higher quality solar dried products (Drying, ITDG).

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In some cases a centralized operation is more economical than numerous small driers, due to economies of scale. The appropriate amount of centralization is different for simple natural convection driers than for more sophisticated forced convection driers. Natural convection may be more effective with multiple small driers rather than one large unit. This is because the construction of small driers is simpler, and independent operation allows more flexibility. However, for forced convection driers, economies of scale favor centralization to maximize use of the ventilation equipment (Spiers, 1986).

Some useful criteria for selecting a solar drier. If the use of solar driers appears favorable, the next step is to consider which type of solar drier to use. Table 6 presents four general categories of solar driers along with advantages and disadvantages of each.

Table 6: Advantages and disadvantages of the four types of solar food driers.

Classification	Advantages	Disadvantages
Direct Sun	+ least expensive + simple	- UV radiation can damage food
Indirect Sun	+ products protected from UV + less damage from temperature extremes	- more complex and expensive than direct sun
Mixed Mode	+ less damage from temperature extremes	- UV radiation can damage food - more complex and expensive than direct sun
Hybrid	+ ability to operate without sun reduces chance of food loss + allows better control of drying + fuel mode may be up to 40x faster than solar (Drying, ITDG)	- expensive - may cause fuel dependence

Choosing a solar drier is a subjective decision, and is heavily dependent upon local conditions and the product to be dried. The following aspects should be considered when selecting a drier:

- Can the drier be made from locally available materials & skills?
- What are the purchase & maintenance costs?
- What is the drying capacity?
- What range of foods can be dried?
- What is the drying time required?
- What is the quality of the dried product?
- Is the drier adaptable to local conditions?

Solar drying has the potential to improve the quality of life in some areas. The decision of whether solar, open-air, or fueled driers are best may be made according to the criteria in Table 5. If solar drying is the best option, Table 6 and the selection criteria given may be used to choose a drier. Information on drier designs and vendors is given in the reference section following. For example, the GATE Technical Information paper "Solar Drying Equipment: Notes on Three Driers" reviews three designs. Once a particular drier has been chosen, it may be purchased (if available) or constructed. Experience shows that the best configuration of a solar drier is different for each location, and therefore successful food drying usually requires a period of experimentation and adjustments at the local site (Vanderhulst, 1990).

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