Application of Solar Thermal for Processing Agricultural Products in Nigeria

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Abstract
In a developing country like Nigeria, having the largest population that depends on the agriculture as the source of income to nearly 70 % of the total population, post-harvest and storage loss is a major constraint, which needs to be addressed in due diligence. Many food preservation techniques like cold storage, drying, etc., have been evolved out over the years to tackle the above losses. The major constraint is that almost all the technologies are utilizing fossil fuel resources, which are depleting very fast and wise use of these precious resources are preferred for long-term energy sustainability. Therefore, sustainable methods for food preservation are necessary. Solar drying is one of the best choices in this paper. Different models of solar dryers have been developed and good quantum of research is progressing in most of the countries to propagate the solar drying technology for value addition of agriculture products. The solar drying technology is a classical example to showcase how sun's free energy could be effectively utilized for the benefit of mankind. This paper explains the different types of dryers, different aspects of solar drying, parameters involved in the drying process and the effect of drying on nutritional value, Pre-treatment and its Influence on Nutrition Loss and Effect of Drying on Nutrients.

Keywords: *Energy sustainability · Food processing · Open sun drying · Solar drying*

Introduction
Mankind's earliest use of solar energy was probably the drying of food crops to aid their preservation. Open sun drying of fruit, vegetables, fish and meats often improved or enhanced particular flavours and textures.Becouse of those attributes many dried products remain in culinary use today, as examples, dried seaweed, sun-dried tomatoes, raisins and dried pistachio nuts. Open sun drying is displaced increasingly by glazed solar dryers that (a) enable equilibrium moisture content to be reached sooner and (b) avoid losses of the crop to rodent and insect encroachment, (c) inadequate drying and, fungal attacks. A further agricultural application, the greenhouse extended the use of solar energy from post-harvest to crop-production. Today, greenhouses are ubiquitous with a huge variety of designs providing a wide range of modified climates for plant growth. Solar energy also finds use in agriculture in solar water pumping for irrigation and in the desalination of brackish water. Solar cooking has taken the use of solar energy in the food production chain directly to the end-user. Broader industrial uses of solar

energy have also tended to be linked to food and beverage production because the temperatures required can be satisfied readily in many climates by a well-designed solar thermal system. Non-agricultural technologies such as solar furnaces have considerable potential but have had limited practical use to-date. Solar drying has been considered as one of the most promising areas for the utilization of solar energy, especially in the field of agricultural products, food stuffs, etc. The method is simple, as it does not involve any costly equipment. The product to be dried is spread under sun, and the moisture evaporates from it over a course of time. Even though the process is simple, it suffers from disadvantages such as dust contamination, insect infestation, microbial contamination and spoilage due to rains. Product dried in this way is unhygienic and sometimes unfit for human consumption (Garg and Prakash 1997). Solar drying can be most successfully employed as a cost-effective drying technique.

It has got several attractive features. For example, energy is available free of cost and can be harnessed in the site itself. Controlled drying is also possible by this method, and it enhances the quality of dried product. Solar drying systems must be properly designed in order to meet particular drying requirements of specific crops and to give satisfactory performance with respect to energy requirements.

Drying conditions for different products will be different, hence, the solar dryer should be designed for their particular requirement. A good design can help in producing high-quality products and hence bring good returns to the farmers.

Table 1: Solar dryers compared with open-air and fuel drying

Types of Drying	Merits (+) and Demerits (−) of Solar Dryers
Solar Vs Open Air	+ Superior quality dried products + Minimizes losses and contamination + Less drying area + Better preservation of nutrition and colour + Less labour intensive + Reduced drying duration and less chance of spoilage + Bring down to safe moisture level, which allows longer storage + Controlled drying − Comparatively more expensive − In some cases, food quality is not significantly improved − In some cases, market value of food will not be increased
Solar Vs Fuelled	+ Prevents fuel dependence + Operating cost is almost zero

	+ Often less expensive + Reduced environmental impact − Requires adequate solar radiation − Hot & dry climates preferred

Sources: Solar Drying—A Sustainable Way of Food Processing

Comparing Solar Drying with Other Options

When one considers solar drying, it has to be compared with other options available. In some situations open-air drying or fuelled dryers may be preferable to solar. Solar drying will only be successful if it has a clear advantage over the current practice. Table 1 lists the merits and demerits of solar drying when compared with traditional open-air drying, and then with the use of fuelled dryers (Sreekumar 201a, b; Garg and Prakash 1997). The comparison will assist in deciding among solar, open-air and fuelled dryers. The local site conditions will also play an important role in this decision. Some indicators that solar dryers may be useful in a specific location include:

- Conventional energy is unavailable or unreliable.
- Plenty of sunshine.
- Quality of open-air dried products needs improvement.
- Land is extremely scarce (making open sun drying unattractive).
- Introducing solar drying technology will not have harmful socio-economic effects.

Preservation Methods

Agricultural crop is perishable and it will get damaged as time passes by the attack of bacteria, fungi, etc. (Simth 2011). Preserving fruits, vegetables, grains, meat, marine products, spices, etc., has been practiced for thousands of years. Some of the food preservation methods are given below.

• Fermentation

Fermentation is the method of controlled spoilage of food stuff with micro-organisms like yeast; say milk to curd or ghee, which helps in extending the usage time. This method cannot be used for all products, but there are products which are better when fermented such as rice, chocolate and coffee.

• Curing or salting

Curing or salting is the preserving method using salt which will absorb moisture from the food materials thereby making the bacteria inhospitable. Though the bacterial activity is restricted, we need to find ways to prevent moulds. Bacon, salt pork, smoked fish, olives, pickles preserved lemons, etc., are examples of salt preserved foods.

• Freezing

Freezing is the method of keeping the products in cold storage. This method helps to store the products for months or even for years. Cold storage is not a feasible method particularly in developing countries as it is expensive.

• **Canning**
Canning is by heating and storing in containers for prolonged usage. It is expensive and also associated with risk of botulism poisoning. Botulism is a rare and potentially fatal paralytic illness caused by a toxin produced by the bacteria Clostridium botulinum.

• **Irradiation**
Irradiation is one of the latest technologies used for food preservation using controlled radiation to kill micro-organisms which can cause food spoilage. Thereby storage time can be extended provided the chemical make-up of the food is also unaltered.

• **Drying or dehydrating**
Drying or dehydration is one of the oldest methods of food preservation by removing the moisture from the food materials by open drying in the sun or by passing hot air over the products. Open drying is associated with disadvantages such as contamination, insect infestation and spoilage due to rains. Other types of drying using conventional energy sources require high capital and running cost to build and operate the facilities.

Methods of Drying

Open Sun Drying
Drying in the sun is very economical. You only have to spread the produce on a suitable surface and let it dry in the sun. Somebody has to stay at home throughout the drying period to chase off domestic animals, to remove the produce when the weather becomes too windy and dusty, or when it rains. The dried product is often of poor quality as a result of grit and dirt. The product is often unhygienic as a result of microorganisms and insects such as flies.

Solar Drying
The technology and capital required to dry fruit and vegetables by solar dryers is basic and the entire operation is not difficult. The structure can be very basic, e.g. a box frame covered with plastic sheeting. The Drying is faster because inside the dryer it is warmer than outside. Less risk of spoilage because of the speed of drying (if the drying process is slow the fruit starts to ferment and the product is spoilt).The product is protected against flies, pests, rain and dust. It is labour saving. The product can be left in the dryer overnight or during rain. The quality of the product is better in terms of nutrients, hygiene and colour (Brett *et,al*., 1996, Dormaar and Kozub.1988).

Fig 1: Pepper on solar dryer

Classification
Solar energy drying systems are broadly classified as;

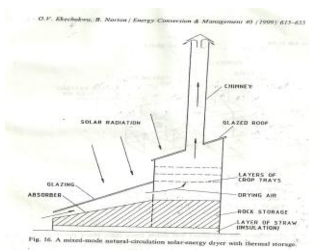
(a) Active solar energy drying systems
(b) Passive solar energy drying systems

The unit components in a drying system usually involve some or all of the following;

(a) The drying chamber,
(b) The solar air heater,
(c) Fan/pump and the ducting.

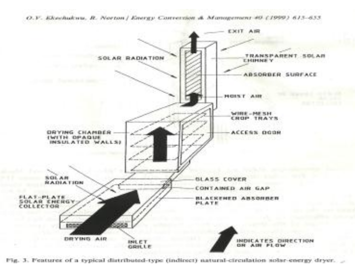
Classification
Depending on design arrangement of system components, each of the two distinct groups can further be classified as;

(a) Integral type solar
(b) Distributed type solar dryers
(c) Mixed-mode solar dryers



Source: O.V. Okechuku, NCERD

Fig 1: Mixed mode natural circulation solar energy dryer with thermal storage



Distributed type natural circulation solar energy dryer

Source: O.V. Okechuku, NCERD

Fig 3: distributed natural circulation solar energy dryer

Design Considerations (Contd)
The quantity of moisture to be removed depends on the crop and can be found from the following relationship:

Moisture content= $\{(M_w - M_d)/M_w\} x\ 100$

M_w **is mass of wet sample**

M_d **is mass of dry sample**

Design Considerations(Contd).)
Quantity of heat required to remove the water

(Q) = M × Cp × ΔT

Where;

Q is the quantity of heat required,

M is the of water

ΔT is the temperature difference dried grain and initial temperature of the dryer.

Design Considerations(Contd).
In steady state, the useful energy output (*Q_u*) of a collector of area *A_c* is the difference between the absorbed solar radiation (*S*) and the thermal loss;

$$Q_u = A_c[S - U_L(T_{pm} - T_a)]$$

The problem with this equation is the mean plate temperature (*T_{pm}*) is difficult to calculate. This equation is usually reformulated in terms of the inlet fluid temperature and a parameter called the collector heat removal factor.

The Drying Process

1) **Precautions:**

- Cleanliness and hygiene are very important in the processing of dried fruit and vegetables.
- To minimize the possibility of contamination, any person who is unwell or has infected wounds or sores, is ill with a gastric disorder or suffering from diarrhea MUST BE EXCLUDED from the processing operations.
- All cuts have to be covered with waterproof dressing
- Raw materials contaminated by moulds must not be used in processing

2) **Predrying Treatments**

- Use only ripe, good-quality fruit and vegetables.
- Select fruit and vegetables individually.
- Discard rotted, damaged or diseased fruit and vegetables.
- Remember, processing cannot improve poor-quality fruit or vegetables.

3) **Washing**

- Clean all working surfaces before handling fruit or vegetables.

- Water for cleaning must be treated with a household bleach
- Prepare the cleaning solution as follows:
    - – Pour 50 parts of clean water in a clean bucket (e.g. 20***l*)**.
    - – Add one part of any household bleach (e.g. 400 m**l**) containing chlorine
    - – For safety reasons plastic gloves should be worn when mixing the solution.
- One bucketful of the treated water (20***l***) is enough for cleaning 20 kg of fruit
- Use a fresh cleaning solution every day.
- Selected fruit and vegetables should be washed and scrubbed individually in the treated water, while plastic gloves should be worn.
- Care must be taken to avoid breaking the skin of the fruit during cleaning and thereby contaminating the flesh.
- Washed fruit and vegetables should be placed into a clean.
- Basket or bucket and taken to the peeling or blanching area.

4) Blanching

Before drying, all vegetables should be blanched in steam to halt the action of enzymes. However, blanching of fruit is optional. Steam blanching is recommended because it prevents the loss of some nutrients and the products being dried from adhering to each other. Do not under blanch, because the enzymes will not be inactivated totally and the dried vegetables will deteriorate during storage.

Procedure

- Pour several centimeters of water into a large cooking pot that has a close-fitting lid. Heat the water to boiling and place over it (high enough to keep clear of the water) a wire rack or basket holding a layer of the vegetables (not more than 5 cm deep). Cover and let the vegetables steam for half the required time, then test to make sure all pieces is reached by the steam.
- A sample from the centre of the layer should be wilted and feel soft and heated through when it has been blanched properly.
- Remove the vegetables and spread them on paper toweling or clean cloth to remove excess moisture while you steam the next load. Cover with toweling while waiting for further treatment or before taking it to the drying trays.

5) Peeling

- Hygiene is of utmost importance when peeling.
- Peeling should not take place in the area where the raw materials are washed.
- The area should be swept thoroughly and washed before handling the fruit.
- Peeling knives and working surfaces should be cleaned in fresh bleach solution before use.
- The operator should wash his/her hands and arms thoroughly with clean water and unperfumed soap.
- Clean, sharp stainless steel knives must always be used.
- Careful peeling with minimum removal of the flesh is important.
- Peelings and seeds should be disposed of as soon as possible because they attract flies and other insects.

- Peelings can be used as animal feed or as mulch, or be buried if there is no alternate use.

6) Cutting And Slicing

Thickness of fruit pieces depends upon the kind of fruit being dried.

- Thicker slices will dry at a slower rate than thinner pieces.
- Very thin pieces tend to stick to the drying trays and will be difficult to remove.
- Thicker pieces may not dry fully and may subsequently deteriorate after packing.
- Packages of dried pieces of varying thickness appear relatively unattractive.
- Cutting knives and working surface have to be cleaned with a bleach solution before use.
- Slices should be placed in clean bowls which have been rinsed with clean water ready for loading onto the drying trays.
- Before loading the trays, these have to be brushed clean and washed.

Dryers: A basic box-type low-cost solar dryer can be constructed at home or by village artisans. It is made of wire-mesh trays in a wooden framework surrounded by a clear plastic sheet. The solar cabinet dryer type has a surface of 10 m^2 and is capable of drying 20 to 35 kg of fresh produce (depending on commodity) over a period of 3 to 4 days. Smaller portable models of the dryer can be constructed, depending on available funds for the dryer, construction and the purpose of drying (home consumption or marketing).

Tray Loading: Trays should be washed and cleaned to remove any fragments of dried fruit or contamination.

- Start to load during slicing rather than waiting until all the fruit has been sliced or cut. (This reduces the problem of sticking together in the bowls and will allow drying to start as soon as possible.)
- Lay the pieces of fruit on trays carefully and close to each other without overlapping to ensure the trays are loaded fully.
- Keep flies away and load trays quickly and continuously.

Dryer Loading

- The dryer should be positioned in a level area unobscured by trees or buildings so that it is fully exposed to the sun throughout the day
- If the wind blows predominantly in one direction for long periods the dryer should be placed end-on to the wind. This will reduce the cooling effect of the wind blowing direct into the drying cabinet, lengthening drying times. It will also reduce the possibility of dust entering the cabinet.
- Before loading, the inside of the drying cabinet should be swept clean and then wiped out with a clean, damp cloth.
- The plastic covers outside should be brushed or washed clean of dust because dirty plastic will reduce dryer performance and increase drying times.
- The doors should be closed immediately after each tray has been loaded and not left open until the next tray is fetched

Drying

- During the first few hours of drying, particularly during very hot and sunny weather, fruit may dry at such a rate that moisture condenses on the inside of the plastic covers.
- This can be avoided by opening the loading doors slightly (20 mm) to improve air circulation. The gap should, however, be covered with mosquito mesh.
- Doors should be kept open for a minimum period of time and closed again as soon as the weather becomes cloudy.
- In poor weather drying will stop. Rain will rapidly cool the dryer and this will result in a moisture
- Film on the cover because of condensation. It will be some time before the dryer functions again after the sun breaks through. Therefore, protect the dryer from rain (Aravindh, 2014a).
- Under fine and sunny conditions the fruit slices should be dry after 2 full days in the dryer. However, it is essential to test slices. If the slices are not sufficiently dry, they will become mouldy in a short time. A test for dryness is conducted for specific products.
- If the slices are not sufficiently dry, the process should be allowed to continue for 1 or 2 hours before checking again.
- The final moisture content of dried fruit should be approximately 10 % (on a wet basis).

Unloading the Dryer

- When the fruit is considered to be dry, the dryer should be unloaded as soon as possible. This must not be carried out in the early morning because dew and high humidity overnight may cause condensation of moisture onto the fruit. The best time to unload is in the afternoon on a sunny day.
- Trays should be removed from the dryer and taken to a clean and covered area for removal of the dried product.
- The operator must wash his/her hands and ideally wear clean gloves when handling the fruit.
- The dried fruit should be stored temporarily in clean dry baskets before packaging so that the product can cool down.

Packaging and Storing

Packaging should be carried out immediately after unloading and cooling because the dried slices will reabsorb moisture and be susceptible to attack by insects and other pests (Cihacek and Swan 1994).

Proper storage should take place in the absence of moisture, light and air. The use of brown paper bags folded tightly and then placed inside plastic bags is recommended.

- Store in small quantities to avoid large-scale contamination.
- Pack carefully to avoid crushing the vegetables.
- Glass containers are excellent, but these should be kept in a dark area.
- Each bag or glass container should be marked clearly with labels containing the date of packaging.
- The dried products must be stored in a cool, dry and clean area which is secure and protected against rodents.

Table 2: Initial and final moisture content and the maximum recommended drying temperature for different food products.

S/N	Product	Moisture content (%)		Maximum drying temperature (^{O}C)
		Initial	Final (permissible)	
1	Paddy	22–	11	50
2	Maize	24	15	60
3	Wheat	35	16	-
4	Carrots	20	5	75
5	Green	70	5	75
6	beans	70	4	55
7	Onions	80	4	55
8	Garlic	80	13	75
9	Potato	75	5	65
10	Chilly	80	15	50
11	Fish	75	24	70
12	Apples	80	15-20	70
13	Grapes	80	15	70
14	Banana	80	15	70
15	Pineapple	80	11	-
16	Coffee	50	7	75
17	Cotton	50	5	-
18	Copra	30	5	-
	Groundnut	30	9	50
19		40	18	35
	Leather	50		

Effect of Parameters on Drying

The most important parameters which determine the quality of the dried product are the mass flow rate and the temperature of the working fluid, i.e. air. Other parameters are air velocity, humidity and the required final moisture content. Effects of different parameters are discussed below (Ratti and Mujumdar 1997).

Temperature

Drying temperature is a major deciding factor, which mainly determines the quality of the dried product. High drying temperature may impair the germination capacity of seeds and also can damage the product either changing the chemical combination or smoulder the product. Lower drying temperature may lead to longer drying time which may lead microbial contamination. Recommended drying temperature with the initial and permissible moisture content for different products are shown in Table 2 above (Garg and Prakash 1997). The temperature should be maintained to the permissible level so that the drying will not damage the product.

Relative Humidity of Air

The relative humidity of air is an important factor same as that of temperature because humidity gradient between air and the product will be a major driving force in a natural convection system. Lower relative humidity of the air can increase the drying rate and will help in reducing the drying time.

Moisture Content of the Drying Product

The moisture content of the product to be dried is an important factor for determining the quality of the product and thereby the market value. Products with higher moisture content are found to have lesser drying time than those having very lesser moisture content. It is because the higher moisture content product may have better mass flow of the moisture from the interior of the product to the surface so that it is removed where the one with lower moisture content may have a thick outer skin.

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Effect of Drying on Nutritional Value

Dried products are very good source of nutrients but the dehydration process may alter the quality of the products. This can be limited by having proper pre-treatment of the materials and also by controlling the drying process. Some of the quality parameters considered are colour, visual appeal, flavour, retention of nutrients, free from contaminant, etc. These factors will decide on the market value of the product. Pre-treatments, novel drying techniques and optimized drying methods can help in producing good quality products (Sabiani ,2005).

Pre-treatment and its Influence on Nutrition Loss

Blanching and dipping in solution like sulphites are the most commonly used pretreatment methods. Steam blanching is done by direct injection of steam into the blanching chamber followed by rapid cooling. In some cases, concentrated sugar solution is used. Such pre-treatments are found to be a serious reason for nutrient loss. Reports show that there is around 80 % loss of carotene content when blanching is done. Loss of vitamins and other nutrients are also occurring due to blanching. Osmotic treatments found to have better results in retaining vitamins than other methods (Droogers and Bouma, 1996).

Effect of Drying on Nutrients

Drying temperature has got a significant role in vitamin loss. Temperature has to be maintained at the desired level to preserve nutrients in the product. Retention of nutrients was higher in shade drying and freeze-drying than other methods like oven or sun drying.

Conclusion

Solar drying is a promising technology for drying of food products for developing country like Nigeria, where solar energy is abundant. This can dramatically reduce the post-harvest food spoilage which is a major concern for the second largest populated country. Even though the drying conditions for every product are different, a dryer can be modelled in such a way that it can dry any product with good control parameters such as temperature and the mass flow rate. Case studies show some of many successful installations. From the case studies, it is very much evident that it is a proven technology and should be given wider publicity. The Energy Commission of Nigeria through its centres has created some pilot project in the country.

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