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Solar Drying for Value Addition and to Minimize Post-harvest Losses

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Abstracts: Agriculture produce have been traditionally dried in the open sun for their consumption during off-season. Drying is essential to prevent spoilage due to micro-organisms. Drying in the open results in contamination with dust and after discoloration of the produce. Natural circulation solar dryers have been effectively used to dehydrate the farm produce. Some case studies vegetables, spices, condiments and fruit are discussed. The solar drying for value addition and proper packaging of the dried products to enhance shelflife are highlighted.

Key words: Solar drying, solar dryers, processing for drying, nutritional value of dried products, packaging.

Traditionally, drying agricultural produces in the sun is a well understood technology with little or no fuel and equipment involved. Drying removes water from the surface of the food by the combined effects of airflow, air temperature, and air humidity. The relationship between the three is important for effective drying. When the moisture content is lowered below a certain level, micro-organisms cannot grow, and the produce is preserved. According to Ofor and Ibeawuchi (2010), the aim of drying is to reduce the water content of the produce to a level insufficient for enzyme activity or the growth of microorganisms. Depending on the product, the critical level is about 10-15% moisture content, because removal of too much water may make the product become brittle and shatter easily (FAO, 1989).

In humid climates, dried products must be packaged well to prevent moisture uptake and prevent spoilage. The food problem in most developing countries worldwide is due largely to the inability to store food surpluses rather than to low production. Food crops are usually for immediate consumption unless properly stored surplus harvests result in wastage and scarcity during post harvest period. Drying is one of the methods used to preserve food products for longer periods. It has been established as the most efficient preservation technique for most tropical crops.

The Drying Process

The traditional method of drying, known as 'sun drying', involves simply laying the product in the sun on mats, roofs or drying floors and road sides. Major disadvantage of this method is contamination of the products by dust, birds and insects and therefore some percentage is usually lost or spoiled. It is labor-intensive lead to nutrient loss such as vitamin A and the method totally depends on good weather conditions. Because the energy requirements - sun and wind - are readily available in the ambient environment, little capital is required. In developing countries, this type of drying is frequently dry agricultural produce commercially. Figures 1 and 2 depict road-side drying of cassava. The cassava is normally spread in the morning and gathered at the end of the day with a broom, which may inadvertently be used at home for other domestic purposes. Contaminants like bird's droppings, twigs from plants, dust from the environment, etc., are bound to find their way into the produce. Also, sudden showers of rains adversely affect the quality of the dried product.

Recent efforts to improve on sun drying have led to solar drying, which uses the sun as the heat source and ventilation to speed up the drying time. This also reduces the risks of food spoilage or mould growth. This is more efficient method of drying that produces better quality products, but also requires initial investment.

Improving the Traditional Methods of Drying

Drying can involve (a) cereal grains and grain legumes, which are relatively dry crops, need to be dried from an initial field moisture content of about 30% at harvest to about 12% and (b) leafy green vegetables, tomatoes, fruits, fish and meat having post harvest moisture levels of about 60-80% which must be reduced in the range of

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Fig. 1. Woman spreading milled cassava on the road side.

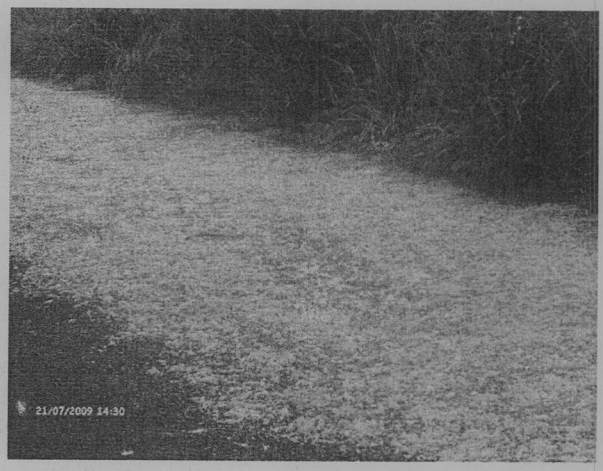

Fig. 2. Milled Cassava prone to sudden rains and contaminants in the environment.

10-25%. The ambient climatic conditions, such as relative humidity (range 30-100%); amount of sunshine (range 2-8 hours day^{-1}); available solar radiation (range 10-25 MJ m^{-2} per day); frequency and duration of rain during drying period; dust and wind etc. all affect drying rates (CSC, 1985).

In South-eastern Nigeria, solar energy is becoming a good and alternative source of energy because of the high rate of depletion of the conventional energy sources. It is preferred to other alternative sources such as wind and shale because it is abundant, inexhaustible and non-polluting. Equally, it can be tapped at a relatively low cost and has no associated danger of fire and other hazards (Igbeka, 1986). In many parts of South-eastern Nigeria, grid connected electricity may be unavailable, unreliable or expensive. Hence, crop drying methods or systems that employ motor driven fans or electrical heating are inappropriate. This is also because the large initial and running costs of dryers powered by fuel energy present huge financial barriers, that they are rarely adopted by resource poor farmers (IDRC, 1987).

In Nigeria, the resource poor farmers produce majority of foods (Ibeawuchi, 2004). In the situations of our farmers, natural circulation solar dryer appear to be attractive as commercial proposition. Such commercial dryers have numerous advantages that include requirement of small area of land as against large expanses of land, which may be required for drying similar amount of crop in the open under the traditional systems. Also, it will yield a relatively high quality dry crop, because insects and rodents are unlikely to infest the crop during drying. The drying period is shortened compared with open-air drying and crop is protected from sudden rainfall which is common in South-eastern Nigeria.

The design and use of natural-circulating solar dryer, that is relatively low capital intensive and has low running costs, with its improved quality of dry produce enable such dryers to compete economically with traditional open-sun drying (IDRC, 1987).

Open Sun Drying

This method of sun drying has two traditional approaches and is used in passive solar crop drying in tropical countries.

- The plant bearing the grain dries, either in contact with the soil or cut down but not removed from the field or farm, thus drying takes place *in-situ*.
- The crop is placed on floors or trays, harvested exposed to solar radiation and to natural air currents. The crop should be turned occasionally to expose different parts to enhance the rate of removal of the saturated air (Fleming *et al.*, 1986).

Natural Circulation Solar-Energy Crop Dryers

In these systems, solar heated air is circulated through the crop by buoyancy forces or as a result of wind pressure, either alone or in combination. These dryers are often referred to as passive systems to distinguish them from those in which a fan forces the air through the crop. The latter can be termed active solar dryers.

Two generic types of Natural – Circulation Solar-Energy Dryers (i) distributed and (ii) integral

systems have been evolved, both of which retain many of the advantages of the traditional open sun drying (Fleming *et al.*, 1986).

Distributed System

In this system, the crop is spread on shelves in a 'hot' box and heated by circulating air that is warmed during its flow through a low pressure – drop thermosyphonic solar collector (Norton and Probert, 1984). Since the materials to be dried are not subjected to direct sun, caramelization and heat damage do not occur (IDRC, 1987).

Integral system

In the integral system of drying, the crop is placed in a drying chamber with transparent walls that allow the insulation necessary for the drying process to be transmitted. This process enhances the proper color 'ripening' of greenish fruits during dehydration, residual chlorophyll in the tissue to decompose under direct solar radiation (Fleming *et al.*, 1986). The major drawbacks of this method are the risk of overheating leading to crop damage, and the relatively slow overall drying rates achieved due to poor vapor removal. To overcome these limitations, a 'solar chimney' can be increase the buoyancy force imposed on the air stream. This according to Fleming *et al.* (1986) will help increase airflow velocity and thus, speed up moisture removal.

Preparation of Different Categories of Dried Foods

Bananas and plantain

Drying as a means of preservation is a widely used method for both unripe and ripe bananas and plantains, the end product from unripe fruit generally being chips, which are pounded into flour while the ripe fruit is make sweet meats known as banana figs which are very popular in many areas, but do not contribute very largely to a total diet (FAO, 1984). Traditionally, the fruit is sun-dried or sometimes dried in ovens or over fires; usually as slices, although banana figs are sometimes prepared from whole fruits (Goode, 1974; Mukasa and Thomas, 1970).

Cassava

The simplest method used and probably the most widespread certainly in Africa or Asia, for preparing flour from cassava is by sun-drying slices or chips of peeled roots which can then be stored as dried chips and ground into a flour when needed or stored in the form of flour (FAO, 1984). Drying generally takes 3-10 days although only 1 or 2 days is sufficient in ideal conditions and once dry, the chips can be stored for 3-6 months, the main problems being attack by moulds, predominantly *Aspergillus*, during the drying (Rawnsley, 1969); and insects (Parker *et al.*, 1981; Parker and Booth, 1979). A method for extending the storage life of chips up to 12 months and also speeding up the drying process is by parboiling them before drying, a technique often used in India and West Africa (Ingram and Humphries, 1972).

In some areas the roots may be soaked, unpeeled, for about 5 days before drying. For example, in Nigeria a flour known as lafun, an important staple foodstuff amongst the Yoruba of Western Nigeria (Oke, 1965), is prepared in this way and in Angola, bombo or makessu are dried chips prepared from soaked roots which are stored and ground into flour known as fuba (Alberto, 1958).

Yam

Yam flour is prepared by cutting the tubers into about 1 cm thick slices, peeling the slices and sun-drying them. Slices may be boiled or parboiled before sun-drying to soften the tissues giving a more palatable product. After drying the pieces are ground in mortars to give coarse flour or may be stored as pieces until needed. The main problem during storage of the pieces or flour is infestation by insects, most commonly *Araecerus fasciculatus* De G. and *Sitophilus zeamays* Mots. and rodent attack of unmilled pieces. The flour is prepared for consumption by reconstituting in boiling water to form a paste (Coursey, 1967). Dried yam slices and flour are also prepared in other parts of the world like Indonesia, Madagascar and parts of the Far East (FAO, 1984).

Spices and condiments

Spices and condiments used all over the world are usually consumed in the dried state. These may include spices like thyme, rosemary, coriander, curry, etc. In Nigeria, like in other parts of the world, spices and condiments are used in the dried state. Especially are the uses of herbs in traditional medicine. Most recipes prescribe the use of plant parts like dried leaves of *Carica papaya* L. (Paw-paw), *Ocimum viride* L. (Nchanwu in Ibo; Efirin in Yoruba) and *Musa* spp. (Plantain) in traditional formulations for the treatment of various ailments. The dried

fruits of *Xylopia aethiopica* (Dunal) A. Rich; *Piper guineense* Schum and Thonn. and *Monodora myristica* (Gaertn) Dunal. are also used for preparing meals especially for nursing mothers.

Vegetables and fruits

Blanching is a necessary step in preparing vegetables for drying. Blanching is the process of heating vegetables to a temperature high enough to destroy enzymes present in tissue. Blanching stops the enzyme action, which could cause loss of color and flavour during drying and storage. It also shortens the drying and rehydration time by relaxing the tissue walls so moisture can escape and later re-enter more rapidly. Vegetables can be water blanched or steam blanched. Water blanching usually results in a greater loss of nutrients, but it takes less time than steam blanching.

Pre-treatment of fruit

Pre-treatments prevent fruits from darkening. Many light-colored fruits, such as apples, darken rapidly when cut and exposed to air. If not pre-treated, these fruits will continue to darken after they have dried.

For long-term storage of dried fruit, sulfuring or using a sulfite dip are the best pretreatments. However, residues found in the food after either of these treatments have been found to cause asthmatic reactions in a small portion of the asthmatic population. Thus, some people may want to use the alternative shorter-term pre-treatments. If home dried foods are eaten within a short time, there may be little difference in the long- and short-term pretreatments.

Sulfuring: Sulfuring is an old method of pretreating fruits. Sublimed sulfur is ignited and burned in an enclosed box with the fruit. The sulfur fumes penetrate the fruit and act as a pre-treatment by retarding spoilage and darkening of the fruit. Fruits must be sulphured out-of-doors where there is adequate air circulation.

Sulfite dip: Sulfite dips can achieve the same long-term anti-darkening effect as sulfuring, but more quickly and easily. Either sodium bisulfite, sodium sulfite or sodium meta-bisulfite that are USP (food grade) or reagent grade (pure) can be used.

Ascorbic acid: Ascorbic acid (vitamin C) mixed with water is a safe way to prevent fruit browning. However, its protection does not last as long as sulfuring or sulfiting. Ascorbic acid is available in the powdered or tablet form, from drugstores or grocery stores. One teaspoon of powdered ascorbic acid is equivalent to 3000 mg of ascorbic acid in tablet form (i.e. Six 500 mg tablets).

Ascorbic acid mixtures: Ascorbic acid mixtures are a mixture of ascorbic acid and sugar sold for use on fresh fruits and in canning or freezing. It is more expensive than the previous method and not as effective as using pure ascorbic acid.

Fruit juice dip: A fruit juice that is high in vitamin C can also be used as a pretreatment, though it is not as effective as pure ascorbic acid. Juices high in vitamin C include orange, lemon, pineapple, grape and cranberry. Each juice adds its own color and flavor to the fruit.

Honey dip: Many store-bought dried fruits have been dipped in a honey solution. A similar dip can be made at home. Honey dipped fruit is much higher in calories.

Nutritional Value of Dried Foods

According to FAO (1984), the majority of studies so far undertaken in the whole field of post-harvest technology have been concerned with grains, grain legumes and other durable products which are stored dry, usually at moisture contents below around 12-14%. In these products, post-harvest deterioration is largely caused by the attack of external agents such as insects, moulds or rodents and does not arise from endogenous factors.

Unlike the grains and similar crops, the perishable staples are all of inherently high moisture content, usually over 50% and often around 60% to 70%. This governs virtually all further considerations that bear on the post-harvest technology of these staple foods, whether in traditional or in sophisticated systems. In particular, consideration of this characteristic in each individual case must influence the fundamental decision: is a particular crop product to be stored, whether it needs to be stored at all, in its natural fresh state, or is it to be processed soon after harvest into some more durable form? Processing may sometimes be necessary (e.g. with cassava and some yams) to eliminate toxicity, or to enhance the organoleptic acceptability of the food. In other circumstances, its primary function may be to render the food more easily transportable (for medium to long distance trade in food products) among subsistence societies has been much more widespread (Lathrap, 1973; Coursey, 1978).

According to Kolawole *et al.* (2009), the nutritional value of food is only minimally affected by drying. Vitamin A is retained during drying; however, because vitamin A is light sensitive, food containing it should be stored in dark places. Vitamin C is destroyed by exposure to heat, although pre-treatment of foods before drying increases the Vitamin C content (Kolawole *et al.*, 2009). Dried foods are also known to be high in fiber and carbohydrate and low in fat, making them healthy food choices. Dehydrated foods that are not completely dried are susceptible to mold. Microorganisms are effectively killed when the internal temperature of food reaches about 63°C. Reducing the moisture content to between 10 and 20% prevents bacteria, yeast, and mold from spoiling food. The flavor and most of the nutritional value is preserved and concentrated. The amount of sunlight and relative humidity determines how quickly the food dries. Some other variables include air movement, quantity and type of food (Kolawole *et al.*, 2009).

Traditional sun drying often yield poor quality, since the produce is not protected against dust, rain and wind, or even against insects, rodents, birds and domestic animals while drying. To effectively tackle these problems, the adoption and proper use of solar dryers are inevitable.

Packaging Dried Products for Value Addition

According to Fellows and Axtell (1993) good packaging serves two purposes, which are essentially technical and presentational. Technical changes in packaging aim to extend the shelf-life of the product by better protecting the food from all the hazards it will be exposed during storage, distribution and use. On the other hand, presentational aspects of packaging actually help increase sales by creating a brand image that the buyer easily recognizes.

In the packaging of dried food products, two conditions of the greatest significance are hermetic and non-hermetic closure. According to FAO (1995), cellophane paper can be used for packing of dried products, mainly for dried fruit leathers. Polyethylene sheets have a variety of uses. They are flexible, transparent and have a perfect resistance to low temperatures and impermeability to water vapor. An important advantage is that these sheets can be easily heat-sealed. It is a good packing material for primary protection of dehydrated products. If a good protection is needed

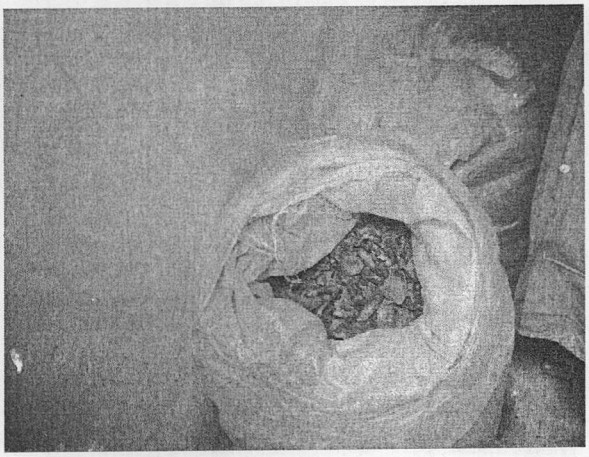

Fig. 3. Dried tomatoes packaged in jute sack (inside) and polyethylene bag (outside) in a store.

to prevent flavor and gas losses, it will be necessary to combine polyethylene with other materials.

In Northern Nigeria, dried tomatoes are first packaged in jute-sack bags and then put into polyethylene bags, for transportation to destination markets in the South-eastern regions. These dried tomatoes are produced during the period of harvest (dry season) when there is an abundance of sunshine to effect sun-drying; surplus harvest almost tending towards a glut and moved to markets in Southern Nigeria during the off-season. The packaging for these dried tomatoes allows increase in moisture and therefore, the pervasion by microorganisms.

During the retail of the dried produce, they are also exposed to ambient environmental conditions, which further aggravate their poor quality (Figs. 3, 4 and 5). The dried fruits are normally soaked in fresh water for some minutes before grinding.

Solar Drying for Value Addition

In a study conducted on steam blanched and un-blanched *Gnetum africana* leaves; dried in a locally fabricated solar dryer with an average day hour temperature of 55°C and stored in different packaging materials like paper envelope, tin container, polyethylene bags and the control which were exposed to ambient temperatures, it was shown that the average moisture content was 10.16%, 11.74%, 9.88% and 14.45%, respectively, for the leaves stored in tin, paper envelope, polyethylene bags and the control at 9 WAS (weeks after storage). The polyethylene bags were felt good considering the export of rare, but highly priced vegetables like *G. africana* leaves to the

Fig. 4. Dried tomatoes exposed to ambient weather conditions in relief market, South-eastern Nigeria, during retail.

Ibos of South-eastern Nigeria in Diaspora, who use them for the preparation of soup. The method of processing is also known to affect the nutritional value of vegetables. In a study by Babalola *et al.* (2010), several vegetables were subjected to different processing methods like blanching, boiling, sun-drying, squeeze-washing, squeeze-washing with salt and squeeze-washing with boiling. Sun-drying had the least effect on vitamin C content when compared with other processing methods like blanching, boiling, sun-drying, squeeze-washing, squeeze-washing with salt and squeeze-washing with boiling. However, the mode of sun-drying, whether in a solar dryer or the conventional will also affect the overall nutritional value of the product.

Future development prospects

Awareness have to be created for the benefit and understanding of resource-poor farmers that the traditional methods involving drying in open has some hazards and thus there is a need to design and use solar dryers to improve the drying of farm and agricultural produce. According to Fabre and Mihailov (1985) the improvements will necessarily affect the traditional system, but care should be taken not to upset rural way of living, which often reflects excellent adjustment to the environment. Proposed actions for improvement of the present system include:

- Increase of horticultural production, part of which should be sundried for increasing farm income, rather than drying only the surplus produce.
- Adoptions efficient techniques which include adequate pre-treatment of raw products, improved solar dryers, improved storage and packaging; which will help reduce post harvest losses.
- Establishment of small drying enterprises or cooperatives that could produce larger and more homogenous quantities of finished products. It is expected that this move will attract middlemen who could be instrumental in the marketing of larger quantities.

These will help the resource-poor farmer improve his financial base through the retail of good quality products and also enhance his attaining international standards by the use of universally accepted drying methods for improvement of export.

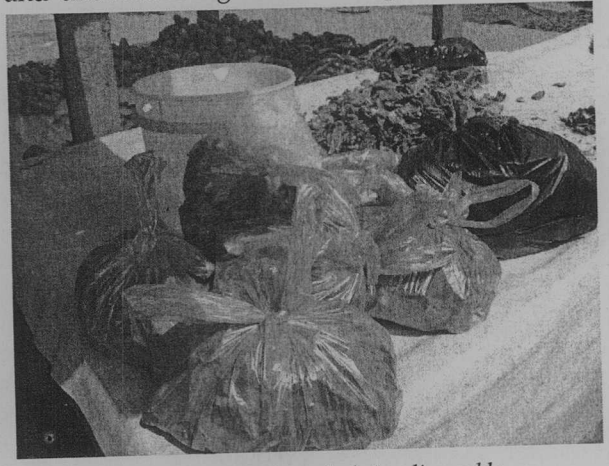

Fig. 5. Dried tomatoes packed in disposable consumer-size polyethylene bags.

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