An Overview of Solar Fruit Drying: A Potential Remedy for Postharvest Losses in Nigeria

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Abstract - *Fruits consumption in Nigeria has become seasonal due to its non-availability in the off season follow-on from tremendous postharvest losses which have been on the increase as a result of the increase in the number of factors militating against it. Different methods have been employed to reduce these influencing factors by different researchers via drying. But some of the methods are expensive, such as electrical and mechanical method of drying fruits, whereas some like open sun drying of fruit tends to endanger the lives of farmers. This work overviewed solar fruit drying as a potential remedy to the high rate of postharvest losses in Nigeria. The research showed that solar dryer for drying of fruits may be capital intensive at the initial stage but highly economical in terms of energy supply. Since Nigeria is a tropical country, receives about 4.851x10^{12}kWh of energy per day from the sun, which is equivalent to 182Million tons of oil per day, solar drying go long way in remedying postharvest loss. It also indicated that solar drying is faster (2-4 days) depending on the fruits thickness and desired final required moisture content. In terms of nutritional composition, it produces better product, especially when pretreated with sulphur (best pretreatment reagent). Farmers in Nigeria should therefore maximize profit in their postharvest businesses and also maintain good quality of fruit crops via solar drying, government should in their part encourage farmers by granting access to loan for proper execution of solar project.*

Key words: Drying, Fruits, Postharvest-losses, Remedy, Solar-dryer

1. INTRODUCTION

Fruits are valuable nourishing agricultural product significantly needed by the body. But its perishability due to moisture content of the products enhances postharvest losses. To remedy the threat posed on this product, there is need to reduce it moisture content which consequentially deter the action of micro-organisms. When the moisture content of a product is reduced below a certain limit, metabolic activities ceases or limits and micro-organisms cannot survive, Such a product can then be stored [1, 2]. Beside extension of storage life, drying can also be for quality improvement, simplicity of handling, for further processing and hygiene [3].

Drying of agricultural product is therefore, focused on the reduction of moisture content for the purpose of preservation and the reduction of its weight or volume. Majority of agricultural products which are dried may be regarded as solid, porous, or coarse materials in a loose bulk state. Over the years, substantial efforts have been made to understand some of the chemical and bio-chemical changes that occur during dehydration and to develop methods for preventing undesirable quality losses resulting from the local practiced by humankind [4]. This is because drying in earlier times was done primarily in the sun (see plate1) which exposed the products to different kind of diseases.

Different technologies have been employed by industries to preserve agricultural products to avoid or reduce the risks of postharvest losses. Amongst are canning, freezing, and dehydration etc., out of the numerous preservative techniques, drying is easily accessible and preferred because of the available radiation energy. It offers an effective and practical ways of safeguarding to diminish postharvest losses and counterbalance the shortages in quantity [3]. Solar radiation in the form of solar thermal energy as an alternative source of energy for drying especially fruits and other kinds of agricultural material is the best means of dehydrating [5]. This procedure is especially applicable in the regions where the intensity of solar radiation is high and sunshine duration is long.

It is estimated that in developing countries like Nigeria, there exist significant post-harvest losses of agricultural products, especially in fruits resulting from lack or poor preservation means.

Plate 1: Maize drying in the yard [6]

1.1 Global Concern for Fruits

Fruit is one of the recommended and most important diet that every human need in every meal (one–half a plate) [7]. Fruit and vegetable consumption per capita showed an increase of 0.38% for fresh and 0.92% for vegetable from 1986 to 1995. The highest consumption of fresh fruits was recorded in china (6.4%) [8]. In Nigeria, fruit consumption fell gradually from 170g per person per day in 1992 to 167 per person per day in 2007 [9] as indicated by Fig.1 This is due to increase in population. Therefore more preservation means are needed to safeguard this fruits as they are perishable to avoid or minimize postharvest losses. Plate1 shows an open sun-drying which is the commonest method of drying adopted by most farmers because it is the only way they were cultured. This is found in most part Nigeria as the intensity of the sun is high, especially in northern part of country. This method of drying affects and increases vulnerability of the crop and fruit to other micro-diseases which peril the life of the farmers as dust and insects flies and scavenges on them. The susceptibility of fruits to all these harms is higher compared to other crops when sun-drying method is used (Plate2) due to its perishability.

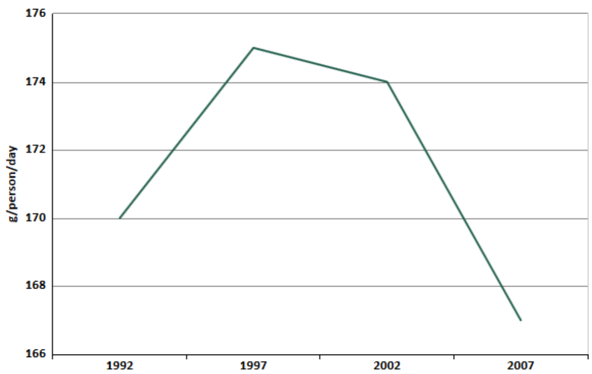
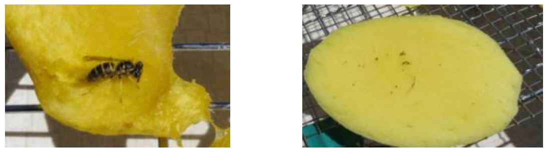


Figure 1: Fruit Consumption in Nigeria [9]

In Nigeria, fruits get spoilt very soon before they can be consumed and sold at the market and they cannot be stored for a long time, because basic storage knowledge and skills of the farmers and sellers are still poor; preservation infrastructure is expensive as power needed (electricity) is a major obstacle. The postharvest losses of fruits sometimes become an environmental problem and eventually lead to pollution. Many people are faced with malnourishment and prolonged diseases problem, while these crops being lost are important incubator of nutrients such as fiber, vitamins and minerals [10] which can rejuvenate the body cells. According to daily trust newspaper, "water melon, pineapple, pawpaw, citrus, banana, guava, mangoes, cashew are the common fruits one sees everywhere on the major highways across the country" [11]. "In spite of the high rate of production and thriving market, Nigeria spends N165billion annually to import fruit juice" [12].



(a) Wasp on an open dry mango (b) Dirt on an open dry mango

(C) House Fly on open sun-dry mango (d) Fruits stand in market

Plate2: Pictorial example of Open Sun-drying Mango Fruit [13, 14]

Generally, postharvest challenges have grown to such an extent fruits consumption in Nigeria tends to be seasonal. To overcome some of these challenges, this research paper harnessed solar fruit drying: as a remedy for post-harvest Losses in Nigeria. It mainly exposed the factors militating post-harvest losses of fruits, stated why solar drying should be more preferable to other methods of drying. It also reviewed the process involved in drying fruits using solar dryer and the considerations made and harnessed the economic importance of solar drying of fruits.

2.0 POST-HARVEST LOSSES IN FRUITS

Post-harvest losses are losses that results from agricultural produce after it have been harvested from the farm. Nearly one third of vegetable and fresh fruit are lost before it extend or get to the final consumers [15]. They are influenced by some factors like environmental circumstances such as heat or drought, mechanical damage during harvesting and handling, unsuitable postharvest sanitation, and poor cooling and environmental control [16, 17].

2.1. Major Elements of Postharvest Losses Fruit

Postharvest losses are very high in the developing world due to a number of factors, including harvesting at improper maturity, rough handling and poor packaging leading to physical damage, lack of protection from water loss leading to wilting, shrivel and loss of saleable weight, inadequate transportation to market, and lack of cooling or cold storage capabilities (largely due to unreliable electrical power supplies) [16, 18, 19]. Many researches have shown that if these aforementioned factors that governed the rate of spoilage are not controlled it will lead to postharvest losses on a large scale [15].

2.2. Technologies and practices to reduce post-harvest losses

Minimization or elimination of postharvest losses from harvest to consumption depends upon the several biological, environmental aspects, which can be controlled with the use of appropriate postharvest technology. Several quality factors like nutritional value, physical appearance, and sensory characteristics affect the quantitative as well as qualitative losses of fruits [20].

There are many promising practices which range from training in improved handling and storage hygiene to the use of hermetically sealed bags and household metallic silos, and are supported by enhancing the technical capabilities of local tinsmiths in silo construction [21]. The choice of technology practice depends on circumstances, such as the scale of production, crop type, prevailing climatic conditions, and the farmers' affordability and willingness to pay (which are linked to social, cultural and economic implications of adoption [22].

Adequate management of temperature, humidity are effective methods for preventing these losses, since post-harvest food losses is complex, therefore, it requires assurance to an integrated approach, involving numerous organizations, including local communities and personnel with reliable knowledge [19]. Training of small scale processor on how to process fruits into other products can go a long way to reduce post-harvest losses [23].

2.3. Solar Fruit Drying

This is an advance way of utilizing the usual open-air sun dry method. In this method, a structure is used as a collector of the ray from sun and intensifying it to facilitate drying of the fruit. Black sheet is often used as the collector since it has the capacity to absorb heat more than any other colored material [24]. There are different types of the solar dry that have been constructed by different researchers [25-27]. Solar dryer is majorly classified into two; Passive and Active solar dryer. The both are further classified into direct, indirect and mixed-mode (hybrid) solar dryer [25, 26, 28]. Indirect type of solar dryer is often considered since it has no effect on the colour and nutrient content of the product as in the case with a direct type [29].

These aforementioned solar dyers entirely have peculiarities in terms of heat transfer mode. The heat transfer means are convection, radiation and conduction [30, 31] depending on the design.

2.3.1. Solar System Drying Time

The solar system drying time (SSDT) is affected by so many factors, especially the amount of sunlight and relative humidity of the environment, the amount of moisture in the fruit and the thickness of fruits slices [32]. So many researches shows that yield of a solar dryer product is directly related to some factor which includes the amount of moisture in the original product, temperature of the drying air, velocity of the drying air and thickness of slice [28, 32-34]. The second two factors determine the design of the drying system while the forth factor depends on the type of fruits to be dried.

Moisture Content

The knowledge of the initial moisture content of a produce is a prerequisite to further action to reducing the moisture. It also enables solar dryer operator have the insight amount of moisture required to be removed (Eqn.1) [29, 35]. This parameter is very important in the determination of the drying rate and efficiency of the solar dryer as presented by Eqn.2 [35].

$$M_R = M[\frac{Q1-Q2}{1-Q2}] \quad (1)$$

Where;

M_R = Amount of moisture to be removed

M = Dryer Capacity per batch

Q_1 = initial moisture content of the fruit

Q_2 = maximum desired final moisture content

$$R_c = \frac{M_d(Q_1 - Q_2)}{A_s * t} \quad (2)$$

Where R_c is drying rate; M_d is total weight of dried product; A_s is surface are of dried solid and Q_1 and Q_2 remain as defined in Eqn.1; and t is the drying time.

The Effect of Temperature of Drying Air

Temperature plays a major rule in the drying of fruit shown in the Fig4.1. Taking a close look at the graph, the weight of the mango decreases drastically with increase in temperature. This was carried out at constant air velocity. But in the case of solar system, the drying air temperature is highly dependent of the intensity of the sun. The Figure also shows that at 60°C, the mango lost much weight compared to 50 and 55°C [13].

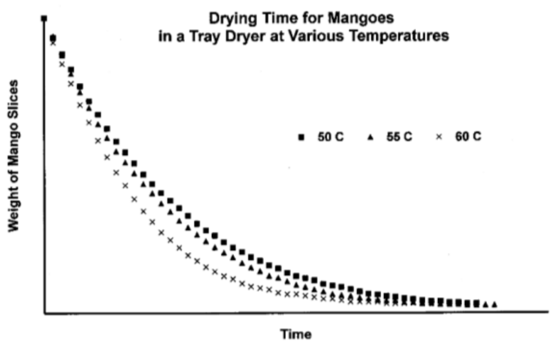


Fig2. Effect of air temperature on the drying of Mango [13]

In the crop or fruit, the temperature may range between 50-55°C to avoid or minimise it dietary loss. Though most farmers makes an indecorous assumption in regards to drying of product and drying air temperature requirement; that the higher the air temperature the better it will be drying the food materials. This result of the effect of air temperature on the fruit slices thickness was also confirmed by Humble & Reneby, [21] at 70°C and drying velocity of 3.5m s^{-1}.

The Effect of Air Velocity

In addition to the temperature of the air used for drying, the velocity, or speed, at which the air travels, is also an important factor in drying. When there is no movement of air across the surface of the fruit 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 fruits surface, especially high juicy fruit like mango [36]. 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" or moisture "pool" as indicated by (see Fig 6). Since it is between the surface of the material and the outside air, it is considered to be boundary layer [13].

Drying of product in a chamber is based on how to move away faster the stagnant boundary layer. Mercer, [13] conducted a laboratory test using different air speed to determine the effect of air velocity of the rate of drying on mango as shown in the Fig 3. Air speeds of 0.2m/s and 0.5m/s were used. An air speed of 0.2m/s allowed the mango to dry considerably well. However, when 0.5m/s speed was used, there is a noticeable improvement in how fast the drying occurred. The weight of a product decreases with increase in air flow rate because the rate of expelling evaporated moisture and replacing dry air in the cabinet is faster when there is increase in air flow [35].

This is because the faster the air flow is, it better sweeps away the stagnant boundary layer of air around the moist mango slices. Therefore when there is increase in the air velocity, it affects the drying time significantly by aiding the drying of stagnant boundary.

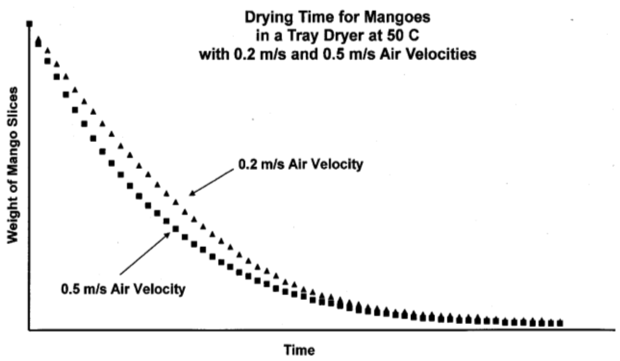


Fig.3 : The Effect of Air Velocity on Drying of Mangoes [13]

The effects of fruit slices thickness in the drying process

The slice thickness of fruit has significant effect on the drying time due it increase in the distance of the movement of the moisture from the centre of the fruit to the surface. Taking a critical look at Fig 4.3, it shows the weight margin between the slices of apple thickness on the graph lines at constant velocity of 0.5m/s [13] has significant effect on the drying process. The apple slice thickness of 0.8cm tends to dry slower at t_3 while thickness 0.6cm dries a little bit faster, taking lesser time t_2 compared to t_3. Slice thickness of 0.4cm dries faster than the other thicknesses at time t_1.

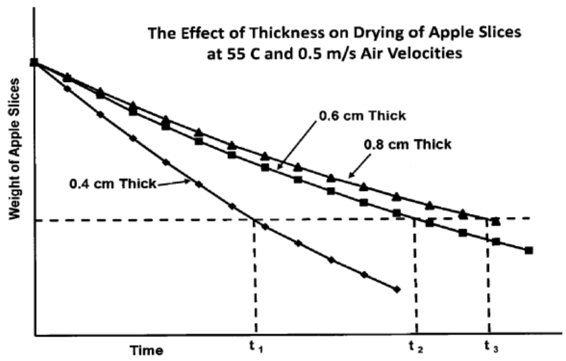


Fig. 4: Effect of Thickness on Drying of Apple Slices [37]

2.4 Basic procedures for solar drying

The quality of the dried fruit depends upon the quality of the fresh fruit used and the quality of the drying method. Good drying method can give a good quality product from good quality fresh fruit. However, good drying method cannot on its own improve poor quality fresh fruit [38]. High standards of cleanliness, quality control and care are needed at all stages from producer to consumer [39].

Factors to consider while processing and operating solar dryer include: purchase or harvest of fresh produce of good quality, careful transport and storage, proficient preparation of slices, correct loading and operation of the dryer, drying to the correct moisture content, proper packing and storage of the dried product, achieving good product quality, and efficient management of all operations [39, 40]. Fig.4. shows the procedure and care for fruit from orchard to final dried and packaged product.

Quality needs to be continually monitored by the producer as buyers are always seeking for good quality products. If fruit has been carefully selected and dried properly, then it should be possible to achieve a good quality product. In general terms, for the products to be sold as "natural", it must be pure and without added colouring agents, preservatives, sugar or other additives [41]. If products have been carefully selected and processed, then drying process start. Product should be monitored for colour, odour, flavour, size, defects, and contamination and compared with reference cards (Plate 3) [39, 41] for banana, mango and pineapple.

Ideally, all products with the following features should be rejected: poor in colour - very light or dark; have an off odour from the normal or do not taste naturally of the original fruit; improperly dried or over-dried; and mouldy, have dirt, dust, insect, dead flies or that are contaminated [39].

2.5. Preparing Fruits for Drying

2.5.1 Pre-drying Treatments

This refers to sequential activities carried out immediately after the fruits are harvested or purchased before starting the process of drying. It majorly prepares the raw product for color preservation and drying as well. The preparation includes selection of assorted fruit, washing and peeling [42]. The pre-treatment includes the following:

Selection

Fruits should be selected, that is, sorted according to size, maturity, soundness and ripe, but still firm and at the right state of maturity. Fruits with low will not give an acceptable product. Immature fruits will not give good colour and flavour. Those that are over-matured or injured fruits have the tendency to spoil before the drying process can be accomplished. Those with low qualities before drying will result to low quality product after the drying process [32, 43].

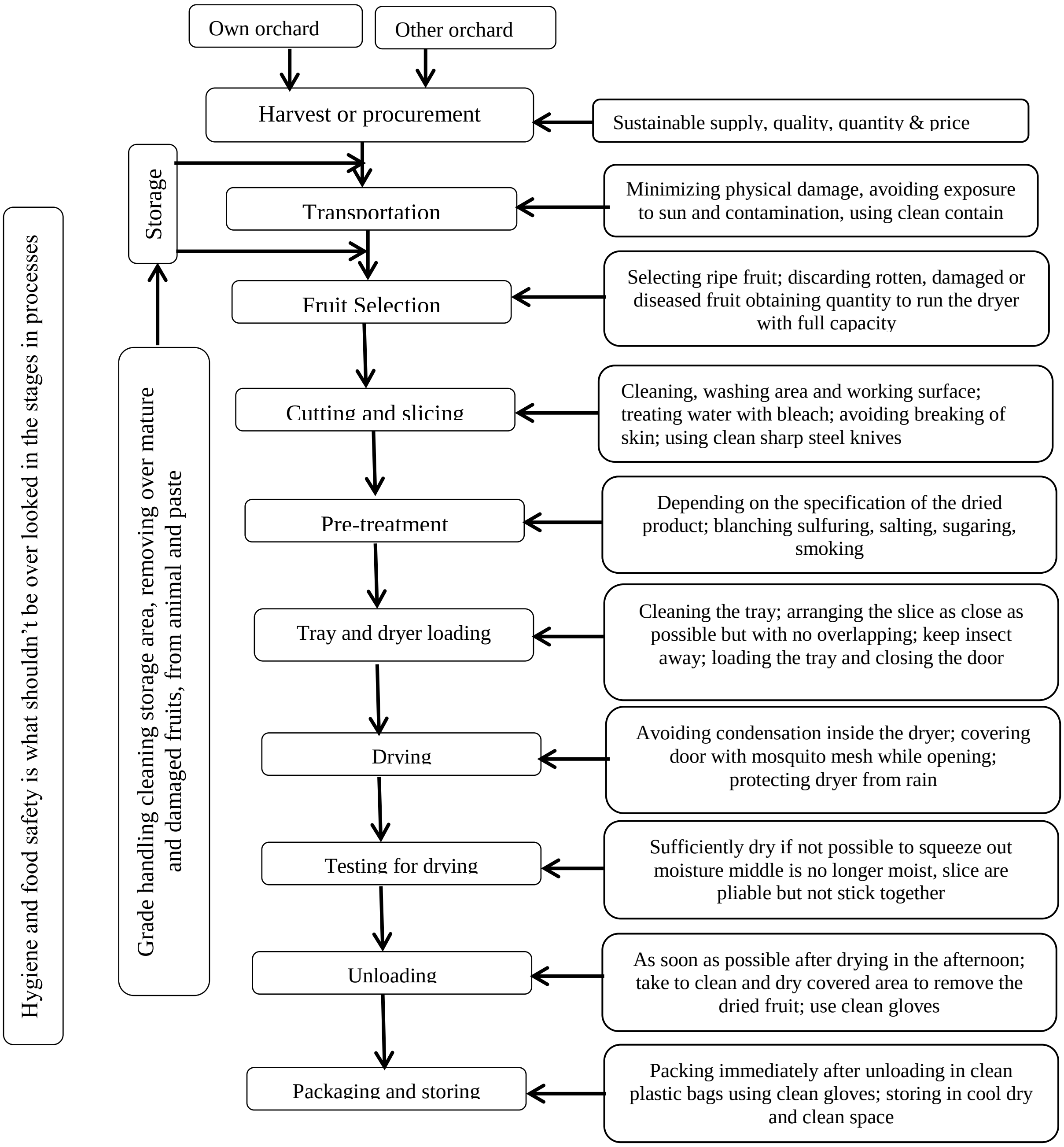


Fig.5. Basic Procedures and Cares During Solar Drying of Fruits [40]

Plate 3: Reference cards for checking dried fruit product quality [39].

(a) Unacceptable banana (too light; fruit under-ripe and starchy; cardboard-like texture) (b) Acceptable banana (good quality; no dusty appearance; pliable; chewy; natural sweet aroma); (c) Unacceptable banana (too dark and with blackening; fruit over-ripe and/or too long in the dryer); (d) Unacceptable mango (too light; under- ripe pieces showing white starchy colour); (e) Acceptable mango (good quality product with a range of rich orange colours); (f) Unacceptable mango (too dark and shriveled; fruit may have been over-ripe or dried slowly); (g) Unacceptable pineapple (compacted; packed and stored in large piles; product at the bottom becomes hard and brittle); (h) Acceptable pineapple (good quality product with a strong yellow colour; "leaf-like" appearance of pineapple; sweet aroma); (i) Unacceptable pineapple (brown colour with sour odour; soft and wet feel).

Washing

This is done to remove contaminating agents that might likely affect the colour, taste, or flavour of the fruit. If fruit is too dirty, alternatively either mild detergent of lye is used to remove contaminant [32]. Note that hygiene must be properly maintained during washing processes.

After washing, the product can be shed by hand with lye or alkali solution, with dry caustic and mild scraping, with pressure from steam, with pressurized washers, or flame peelers [43]. Not all fruits that require peeling before drying. Fruits such banana, pineapple, pear and apples are usually peeled before drying [42].

The following key points should be noted on peeling operations [32]; removal of damaged parts and maintain appropriate hygienic practices.

Cutting and Slicing

The fruits are cut into the appropriate shape or form depending on the types of fruit to be dried. Though some fruits may not follow through this process, e.g. corn and cherries [42]. The following will have to be considered during cutting and slicing to obtain proper and unquestionable results; ensure the cutting thickness depending on the type of fruit are the same to avoid variation in drying time resulting from slice thickness as shown in plate 3 [32]. The materials and the surface that will be used for cutting and slicing have to be kept clean or bleached [43] to cripple the action of contaminating organisms

Plate 4: Thickness of Sliced Pineapple (Daller, 2013)

Colour Preservation

The final step in the pre-dehydration treatment is color preservation. This is done to preserve the colour of the fruits after moisture have been reduced. There are different methods of pretreatment of fruits such as sulfuring, sulphite solutions (sodium bisulfite, sodium sulfite, or sodium metasulfite) obtained at wine making supplies are sold, Ascorbic acid or other treatment like saline dip honey dip, honey lemon dip and ho syrup [41]

But majority of fruits are treated with sulfur dioxide (SO_2) for its antioxidant and preservative effects [44] and also to halt the action of enzymes, preserve colour and flavor, ensure more even drying and minimize nutrient loss [41] as presented in plate 4. In a nutshell, it has the advantage of producing excellent quality. When this action of the enzyme is not distorted, browning of fruits occur consequentially making it to look unattractive. Plate 4 indicates cherry raisins treated with three different methods. 4a maintained it original colour signifying that it is a method preferable compared to the other two.

Sulphur treated grapes

Ethyloleate treated grapes

Boiled and cold treated grapes

Plate 5: Different Pretreatments of Raisins Grapes [2]

2.5.2 Loading and unloading of Tray

Appropriate loading of the tray has tremendous positive effect on the dryer efficiency. To maximise utility, the tray should be well loaded with some clearance. A minimum about 10% of the space on the mesh should be open, creating gap between slices as shown in Plate 6 to allow free flow of drying air. Before doing this, the trays should be brushed and washed clean to remove any previous fruit pieces [32, 43]. Instead of waiting for the slice to be much, begin loading as the fruit is being sliced. This is done to reduces the problem of the pieces sticking together in the whatever type container it is been kept and will enable the drying process start as shortly as possible [2, 32, 43].

Plate 6: Arrangement of Sliced Fruit on the Perforated Tray [32]

When fruit is considered to be dried, remove the tray and take it to clean environment and ensure proper hygiene is observed [13, 43]. Store the product in a temporary clean basket. Uploading should not be done early in the morning because dew and high humidity might have caused condensation [43].

2.5.3 The Drying Mechanism for Solar Fruit Dryer

This is similar to that of open sun air drying warm air blow on the exposed or other forced air drying mechanism where warm or hot air is blown across the dying chamber [43]. The mechanism is as shown in the Fig. 6. As more air blows across the surface of a fruit slice, moisture from inside the fruits slice comes to the surface to replace the moisture that was lost. This process of moisture moving from the center of the material to the outer surface is known as "diffusion" [45]. Moisture that has diffused to the surface is then evaporated and swept away by the moving air. Fig. 6 also shows that the moisture that is diffused from the center of the slice forms a pool at the surface. As hot air is blown across the surface, the moisture is being lost, and it continuous like that until the required moisture volume of the product is attained.

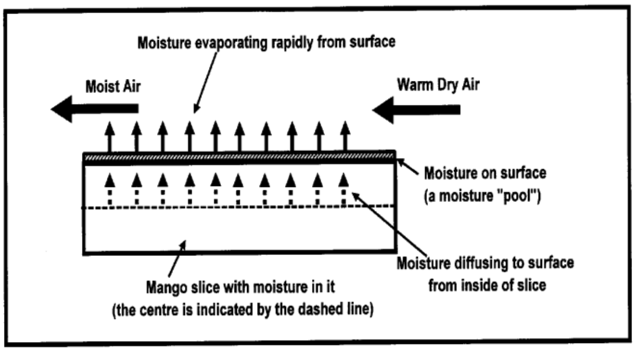


Fig. 6: Moisture removal from mango slices early in the drying process [13]

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. The surface is considered to be saturated with moisture which is like having a "pool" of moisture there from which evaporation can take place [46]

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 center 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 Fig. 7, 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 [47]

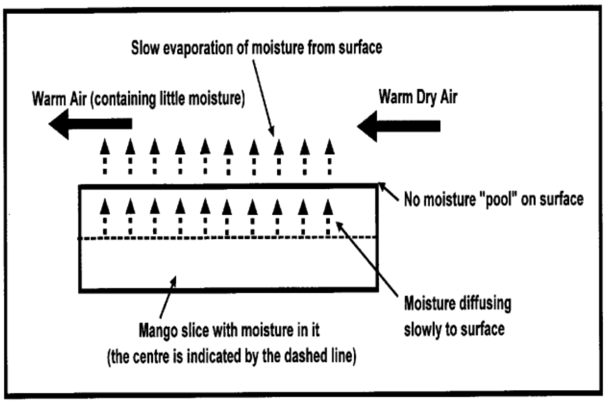


Fig.7: Moisture removal from mango slices late in the drying process [13]

3.0 ECONOMIC IMPORTANCE OF SOLAR FRUIT DRYING

Financial implication cannot be eschewed in solar fruit drying; especially initial cost, yet the economics importance cannot be underestimated in the tropical countries like Nigeria and other parts of the world. With population estimate at 191.8million and a growth rate of 54.8% in the past seven years, Nigeria is set to dislodge the United States (U.S.) as the world third largest country population by 2050 [48]. This increase in population consequentially demands an increase in food production [49]. But fruits most of which are perishable materials is among the world class required food for man [50]. If solar dried, it can stand taste of time in storage, for further processing and can be exported with east without any huge threat of postharvest loss.

In every industrial processing, dehydration is one major activity that requires much energy [2], and it requires approximately 2.4MJ to evaporate a litre of water and to dehydrate a metric ton of most fruits in conventional dehydrator to reduce moisture content for long term storage; it is approximately 100 litres of oil [50], but with the fruit solar dryer design, 20MJm^{-1} can be harnessed per day global solar radiation incident on the horizontal surface [28] free of charge. Nigeria which is located in the tropical zone of the world approximately receives about 4.851x10^{12}kWh of energy every day from the sun rays [51]. This is equivalent to about 182 million tons of oil equivalent per day and is about 4000 time the production based on energy unit [46]. If this solar energy is properly harnessed for the purpose of drying fruit and other agricultural material, the problem of postharvest losses can be minimized to the nearest zero level.

Many researches have shown that solar drying is time saving and drying period for highly moisture-content products lies between 2-4 days depending on the thickness and desired final moisture content required by the farmer [17, 28, 32, 45].

4. CONCLUSION/RECOMMENDATION

Solar drying of fruits is nutritionally practicable and has effects on the nutrient content of fruits (protein, ash, fat, crude fiber and cellulose and vitamin C). From all sense of belongings, solar drying has been observed to produce relatively better product in terms of nutrient composition compared to sun drying. Drying has also been observed to be faster with the use of the solar dryer. Therefore, solar dryer is recommended for drying of fruits like mango, apple, grapes etc. for off season purpose and export without recording tremendous losses as has always been the case in Nigeria fruits market. Farmers who therefore engage in exportation and importation of fruit should always solar dry the product before export to minimize huge record of post-harvest losses (PHL) and maximize profit in their business and also maintain the quality of the product.

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