Mass-Heater Supplemented Greenhouse Dryer for Post-Harvest Preservation in Developing Countries

Olutoye P. Akinjiola[1] & Uthamalingam (Balu) Balachandran[2]

[1] Psage Research, LLC, USA

[2] Energy Systems Division, Argonne National Laboratory, Argonne, IL, USA

Correspondence: Uthamalingam (Balu) Balachandran, Energy Systems Division, Argonne National Laboratory, Argonne, IL 60439, USA. Tel: 1-630-252-4250. E-mail: balu@anl.gov

Abstract

A mass-heater supplemented greenhouse dryer is shown to be an adaptable technology to post-harvest preservation problems in developing countries. Inadequate harvest preservation in these countries often leads to a cycle of bumper harvest and production cutbacks, famine, inability of famers to get their harvest to the market, low quality of exports, and low agro-processing. Drying is a preservation technique that is readily adaptable for developing countries, and the earliest form of this method, open air drying, is still predominant. Rigorous designs are not always possible or economical, but the greenhouse dryer will always outperform open air drying irrespective of the quality of its design. Greenhouse dryer design parameters are identified, and guidelines for optimizing performance are provided. Mass-heaters based on rocket or top-lit-up-draft heaters, fueled by agricultural wastes, are proposed as supplementary heat sources when the sun is not available at night or during cloudy periods.

Keywords: greenhouse dryer, mass-heaters, preservation methods, solar energy

1. Introduction

Agricultural products are seasonal, and it is not always possible to consume, sell, or process all products at each harvest. For food, the produce is often available in excess of local demands during harvest times but is in short supply between harvests because of inadequate preservation methods. As a consequence, famine between harvests is a common problem in developing countries.

Further evidence of poor preservation methods is the low quality of export produce from developing countries. It is a major challenge to meet the more stringent quality demands of the export market. In most of these countries, the poor transportation system creates significant delays on getting the produce to market. Such delays invariably degrade the quality of agricultural products that are not properly preserved and limit their acceptability in the export market.
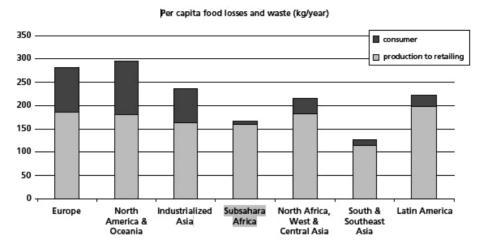
Per capita food losses and waste (kg/year)

Figure 1. Results from FAO (Gustavsson et al., 2011) study for per capita food losses in different regions

A recent study by the Food and Agricultural Organization (FAO) of the United Nations (Gustavsson et al., 2011) reported that the per capita food loss in Sub-Sahara African and South/Southeast Asia is 120-170 kg/year while the production per capita is about 460 kg/year (Figure 1). About 35% of the food production is wasted, and the bulk of this waste is between production and retailing, mainly at post-harvest. The corresponding losses per production are about twice that of industrialized countries where the per capita production of food is about 900 kg/year. The study corroborates earlier data (Aidoo, 1993) which estimated that losses in rice, maize, wheat, barley, millets, sorghum, legumes and non-grain staples, vegetables, and fruits range from 5 to 60%. To avoid spoilage and total loss, farmers in developing countries are forced to sell their produce at a very low price shortly after harvest. Such losses in one season are always followed by cutbacks in production in the next planting season. Loss-preventive cutbacks can sometimes be extreme and can lead to inadequate production in seasons that follow bumper harvests.

Any steady agro-processing rate requires some level of raw inventory as a cushion against inevitable fluctuations in raw material supplies or raw material prices or production disruptions. Hence, processing of local harvests is also low or non-existent in developing countries because the harvests cannot be adequately preserved as sources of raw materials for control of production inventory.

It follows from the above that post-harvest preservation of agricultural produce must be promoted to ensure food availability, high quality of exports, and sustainable agro-processing. Options for harvest preservation include drying, canning, pickling, and refrigeration, but drying is the most appropriate and flexible technology for developing countries. Among the drying techniques, solar drying is the cheapest. Other methods such as mechanical drying (shelf dryer, spray dryer, or fluid-bed dryer) are expensive, and they require electricity or energy sources that are not available in these farming communities.

2. Availability of Solar Energy for Produce Drying

The sun radiates 1.366 kilowatts/m^2 to the earth's surface, though not all this energy is actually available at every location at all times for several reasons: clouds, inclination of the earth and its rotation, etc. To put the potential supply of energy from the sun in perspective, Knies of Desertec Foundation (Knies, 2012) claims that within six hours the deserts receive more energy from the sun than humankind consumes within a year, and that all fossil fuels (oil and gas) known and expected are equivalent to 40 weeks of the sun's radiation.

There is enough solar radiation to be tapped within each locality to meet the energy requirements of any developing country. The current limitation is the dissemination of the appropriate technology that could be used to harness solar energy even for the immediate goals of these countries. The average direct normal irradiance (DNI) for Nigeria is 5.5 kWh/m^2.day; Ghana, 5.2 kWh/m^2.day; Indonesia, 4.8 kWh/m^2.day; and Burundi, 4.5 kWh/m^2.day (Solar Electricity Handbook, 2012). In each of these countries less than 0.1% of the land area is needed to generate enough solar energy for what its projected annual energy consumption would be in 30 years (Sambo, 2008).

Solar energy offers a free energy source that could be readily harnessed with a simple technology, like the greenhouse dryer reported here, to solve the critical problem of post-harvest food preservation in developing

countries. The concept of solar drying is not new in these countries, where open air drying is the norm. In the traditional sun drying method, urban and rural farmers spread their produce to dry on a carpet or directly on pavements in open air. Not only do dust, pests, and pathogens readily infiltrate the produce, but also the process is very slow because of the low drying temperature. In addition, ambient solar drying is susceptible to a longer processing time due to rain or high relative humidity, which could result in spoilage by molds, fungi, etc. Most often the product deteriorates before drying is complete. Furthermore, open air drying is not able to dry some agricultural products to acceptable low moisture levels.

3. Greenhouse Dryer

Enhanced solar drying methods concentrate or increase the sunlight intensity on the materials to be dried. There are several variations of this technology, but the greenhouse technique is the most attractive because it is simple, cheap, and amenable for appropriate technology (Esper, 1998; Forson et al., 2007; Weiss & Buchinger, 2001; Hassanain, 2011; Almuhana, 2012; Fadhel et al., 2005). Practical greenhouses could vary from a birdcage size for subsidence farmers to the large commercial sizes used in developed countries (Figures 2 and 3). Local artisans could readily build suitable structures by adapting and replicating pilot designs.

Much of the sunlight entering a greenhouse consists of short wavelength radiation, and some light is reflected from various surfaces and then passes through the greenhouse. The materials in the greenhouse also absorb some radiation as heat, and a portion of this heat is re-emitted as longer wavelength radiation, mostly infrared. The greenhouse cover, glass or transparent film, is transparent to short wavelength but opaque to long wavelength radiation. Consequently, the greenhouse effect is caused by a fraction of the incident solar radiation being continuously trapped in an enclosed space as heat. This effect is best illustrated by a car that is parked outside during the day; the temperature inside the car is higher than the outside temperature irrespective of weather conditions.

A solar dryer of the greenhouse type is a significant development over open-air sun drying. Foremost, the greenhouse effect could heat the drying material to over $25^{\circ}C$ above ambient temperature (Esper, 1998; Forson et al., 2007; Weiss & Buchinger, 2001; Hassanain, 2011; Almuhana, 2012; Fadhel et al., 2005; Reynolds et al., 2010). At such high temperatures, drying could be ten times faster. Higher temperatures ($57°–82°C$) also destroy bacteria, fungi, eggs, and larvae. Food will be pasteurized if it is exposed to $57°C$ for 1 hour or $80°C$ for $10–15$ min (Fadhel et al., 2005). Most bacteria will be destroyed at $74°C$ and will be prevented from growing at $60°–74°C$ (Reynolds et al., 2010). Thus, compared to open-air sun drying, greenhouse drying is faster and more sanitary (Panwar et al., 2009). Furthermore, the produce inside the greenhouse can be drying while it is raining outside.

Figure 2. Mango solar dryer (Weiss & Buchinger, 2001)

Figure 3. Quonset pepper solar dryer **(**Weiss & Buchinger, 2001**)**

Other forms of solar-assisted drying have been proposed (Esper, 1998; Forson et al., 2007; Weiss & Buchinger, 2001; Hassanain, 2011). In some of these methods the air is initially heated by a solar enclosure, and the resulting hot air is sent into a separate drying chamber. The greenhouse dryer has two advantages over such designs. First, it combines the heater and the dryer as a single unit. As a heater, the size and effective heat capacity of the greenhouse enclosure are larger than those of comparable indirect solar dryers. Second, the produce within the greenhouse can absorb energy directly from the sun, and this effect is very significant because the solid's heat capacity (~3 kJ/kg.^{o}C) is thrice that of air (~1.0 kJ/kg.^{o}C). The facilitation of direct solar energy absorption by the produce enables the greenhouse dryer to capture more energy than indirect solar dryers.

4. Greenhouse (GH) Designs

The greenhouse design is a very mature technology. It is mainly used to provide a warm environment for growing in the winter months and a moderate environment for growing in the hot summer months. The principles of the conventional greenhouse are the same as those of a greenhouse dryer except that the emphasis is on heat entrapment to facilitate drying.

Several parameters control the performance of greenhouse dryers, such as solar Daily Normal Irradiance (DNI), geometry, orientation, weather, heat losses, and flow of air through the greenhouse. The inherent interactions among these parameters make rigorous designs quite complex. Fortunately, the solar greenhouse is a forgiving and adjustable technology so that relatively crude designs are adequate (Rahman, 2007; Dragićević, 2011; IEA-SHC, 1998; Roberts, 2005). Various aspects of greenhouse dryer design are discussed below.

4.1 Shape

Basic greenhouse designs come in two basic shapes: quonset and gothic. The quonset structures or "hoop-houses" (Figures 3 and 4) are composed of circular arches that create a single bay and are usually covered with plastic sheeting. They are round, symmetrical, and easy to fabricate. The circular arch of the quonset can sit upon straight, rectangular sidewalls to add height and head room along the walls. The gothic frame construction is similar to that of the quonset, but it has a different shape (Figure 4, right side). The gothic shape allows more headroom at the sidewall than the basic quonset. The gothic shape also contributes to better air exchange and moisture control. The greater height of the gothic greenhouse allows for better ventilation through higher gable-end vents. Gothic type greenhouses have several advantages compared to quonset models. In many circumstances, these advantages easily offset their greater cost.

Drainage - Proper drainage is essential to allow for regular cleaning and sanitation of the greenhouse. The impermeable footprint of the greenhouse roof creates a concentration of rain water along the edges. Having a slope or shallow trench along the edges helps keep water from entering through the sides. Aligning the long axis on a very slight slope also helps with drainage and air movement.
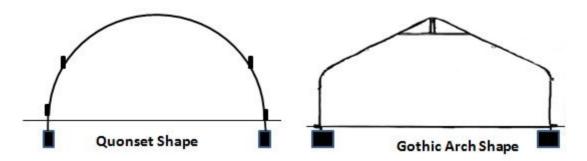
Figure 4. Basic greenhouse shapes

Shade - Shade from trees or buildings is to be avoided as much as practical. Shade on the east side of the wall delays the onset of solar radiation into the greenhouse in the morning.

Wind - Wind is the greenhouse worst enemy, and site selection should minimize exposure. In general, protected areas are better sites than exposed hilltops.

Size - A width-to-length ratio of 1:2 of floor area is ideal for passive solar for optimum heat gain (Edward, 1979). Narrower greenhouses will experience more heat loss than those that are wide because of their smaller ratio of perimeter to floor area. For example, a 3 ft x 17 ft greenhouse has a 40-ft linear perimeter and a 51-ft^2 area, and a 10 ft x 10 ft greenhouse also has a 40-ft linear perimeter but a 100-ft^2 floor area. The second structure has 96% more floor area and about half the ratio of perimeter (or heat loss potential) to floor area. Wider structures also tend to be taller and provide improved ventilation and interior air circulation.

It is best to load a greenhouse dryer and wait until its content is completely dried. Mixing wet and partially dried materials inside the dryer delays the drying of the latter or leads to harvest spoilage. The size of the immediate harvest and the time required to dry it determine the size of a greenhouse for a given produce. Multiple greenhouses can be built to accommodate several batches from a harvest. Only small greenhouses of the quonset type are recommended for developing countries because farm holdings are small, and in the exceptional situation of large farms, the lack of mechanized farming or mechanized harvesting limits the harvest size at any given period.

Orientation - For latitudes lower than 40°, the north-south orientation is recommended for maximum all-year sunlight into the greenhouse, but for higher altitudes, east-west is the preferred option to capture solar radiation (IEA-SHC, 1998).

4.2 Covering Material

Initially, greenhouses were constructed from glass, but the cost of glass and its breakability have shifted the construction material to transparent plastic sheet or films. Transparent film (one-sixth to one-tenth the cost of glass) is the first choice for low cost greenhouses. Greenhouse films are specialty materials that have been treated to withstand prolonged exposure to sunlight and have demonstrated long-term stability to ultraviolet radiation. There are various grades of greenhouse films. Desirable properties are long-term ultraviolet stability, high heat retention, and low vapor condensation.

4.3 Ventilation

Ventilation provides two major functions that are closely related: temperature and moisture control. Too high ventilation lowers the highest achievable temperature within the greenhouse, while too low ventilation allows high temperatures but results in poor moisture removal. An optimum ventilation rate is required to facilitate an acceptable drying rate for each batch at a temperature that will not denature or compromise the quality of the harvest.

To minimize investment, ventilation by natural convention or passive ventilation is suggested. Passive ventilation uses openings (vents), which naturally draw air through the greenhouse. The natural "chimney effect" of the convection of air through the greenhouse is based on the difference in air density (due to temperature difference) between indoor and outdoor air. The volumetric flow of air (V_{air}, m^3/h) by natural convention through the greenhouse as depicted in Figure 5 is given by (Dragićević, 2011):

$$V_{air} = A_1 A_2 \sqrt{\{(gH_s/(A_1^2 + A_2^1)\}\{(T_{GH-T_{amb}})/T_{GH}\}} \qquad (1)$$

where:

g = Gravity (m/h^2)

H_s = Stack height (m)

T_{GH} = Temperature inside the greenhouse (^{o}C)

T_{amb} = Ambient temperature (^{o}C)

A_1 = Inlet vent area (m^2)

A_2 = Stack vent area (m^2)

It follows from Equation 1 that the ventilation rate and the temperature within the greenhouse dryer can be controlled by manipulating the stack height, along with the inlet and outlet vent openings.
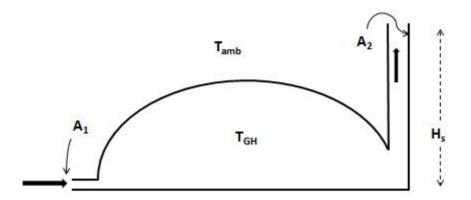

Figure 5. Illustration of Chimney Effect

The volume (V_{GH}, m^3) and surface area (S_{GH}, m^2) of the quonset greenhouse are given by:

$$V_{GH} = \pi D^2 L/8 \qquad (2)$$

$$S_{GH} = \pi D(D + 2L)/4 \qquad (3)$$

where D is the diameter of the circular section, and L is the axial length.

The ventilation rate V_R is the time it takes to replenish the volume of air in the greenhouse:

$$V_R = V_{GH}/V_{air} \qquad (4)$$

The estimated volumetric flow rate of air, V_{air}, must be sufficient to remove the requisite moisture (M_w, kg) from the harvest to be dried. Each type of produce must be dried to the minimum moisture (water activity) that prevents deterioration during long-term storage. Average residual moisture of 10% is generally acceptable for most materials in short-term storage. The allowable moisture levels are lower for long-term storage. The following assumptions are made to estimate the minimum drying time of a given load of produce inside the dryer:

(1) Outlet conditions are steady (wind speed, relative humidity, and temperature).

(2) Outlet air from the dryer is saturated at 100% relative humidity (RH).

(3) Solar radiation on the greenhouse is steady.

(4) Operation is steady state where the temperature in the greenhouse is fairly constant.

The second assumption implies that the drying air removes the maximum amount of water at the exit vent; the air is saturated (100% RH) at T_{GH} with a moisture content of y_1. The value of y_1 is determined from a psychrometric chart at T_{GH}. If the inlet air is at temperature T_{amb}, relative humidity RH_{amb}, and a water vapor content of per y_0 kg/kg of air, the mass balance of water (M_W, kg/h) transport from the harvest into the ventilation air over the drying time t (h) is:

$$M_w = t(y_1 - y_0)V_{air}\rho_{air} \tag{5}$$

For a dryer with an initial loading of W (kg) of produce with initial moisture content of x_0, if dried product is to have minimum moisture of x_1 then the amount of water to be removed is:

$$M_w = W(x_1 - x_0)/((1 - x_0)) \tag{6}$$

Combining Equations 5 and 6 and rearranging yields the minimum drying time:

$$t = W(x_1 - x_0)/\{(y_1 - y_0)(1 - x_0)V_{air}\rho_{air}\} \tag{7}$$

Also from Equation 7, the minimum volumetric flow rate of passive ventilation can be estimated if the drying time within the greenhouse is set:

$$V_{air} = W(x_1 - x_0)/\{(y_1 - y_0)(1 - x_0)\rho_{air} t\} \tag{8}$$

As shown in Equations 8 and 1, the vent areas (A_1 and A_2) and the stack height (H_s) can be adjusted to provide the passive ventilation rate that is required to an initial loading of dry W (kg) of produce from a moisture of x_0 to x_1 in a given time t.

4.4 Requirements for Solar Energy Duty

The solar energy (Q_{Total}, kJ/h) absorbed by the greenhouse is consumed as:

$$Q_{Total} = \text{drying duty} + \text{heat losses} \tag{9}$$

$$Q_{Total} = \eta_{irr}\eta_{GH}Q_{DNI}S_{GH}$$

where Q_{DNI} (kJ/m^2/h) is the local average solar radiation to the greenhouse, η_{irr} is the effectiveness factor for solar radiation losses, and η_{GH} is the efficiency for the area of the greenhouse exposed to solar radiation. Q_{DNI} is derived from local average solar DNI. The drying duty includes the heat absorbed by the material to be dried, the sensible heat of moisture removed, and the latent heat required to evaporate the moisture into the drying air. Since the heat of vaporization of water (ΔH_{vap}=2260 kJ/kg) is much larger than the heat capacity of either water (4.2 kJ/kg) or the produce, the drying duty is approximated by:

$$\text{Drying Duty} \sim W\{(x_1 - x_0)/(1 - x_0)\}\Delta H_{vap} \tag{10}$$

4.5 Heat Loses

Heat losses are of major concern when the sun is not available due to clouds or night time. The extreme situation is when heat losses exceed energy input. The moisture in the greenhouse could condense on the drying material, slow down the drying process, and lead to product spoilage.

Heat loss determination is imperative, particularly when the amount of supplementary heat for the greenhouse needs to be estimated. The heat losses from a greenhouse dryer depend upon the exposed surface area of the greenhouse, the temperature difference between the greenhouse and the ambient air, local wind speed, and the thermal properties of the glazing or covering material. Heat losses to the ground are not considered because they are usually negligible relative to losses to the atmosphere. Heat loss can be mathematically expressed as

$$\text{Heat losses } (Q_{Loss}) = \text{Conduction } (Q_c) + \text{Air Infiltration } (Q_{Inf}) + \text{Radiation } (Q_r) \tag{11}$$

$$Q_c = U S_{GH} (T_{GH} - T_{amb})$$

$$Q_{Inf} = \rho_{air}V_{air,Inf} C_{p,air}(T_{GH} - T_{amb})$$

$$Q_r = \epsilon \tau \sigma S_{GH}(T_{GH}^4 - T_{sky}^4)$$

$$T_{sky} = 0.0552 T_{amb}^{1.5}$$

where:

Q_{Loss} = Heat loss (kJ/h)

$V_{air,Inf}$ = Average volume rate of infiltration air (m^3/h)

$C_{p,air}$ = Average heat capacity of infiltration air (kJ/kg.K)

U = Heat transfer coefficient in kJ/h per m^2 of surface per °C of temperature difference

ϵ = Emittance factor

σ = Stefan-Boltzmann constant (kJ/h.m^2.K^4)

τ = Transmissivity coefficient at long wavelength radiation (~0.7)

The value of U varies from 6.1 to 10.2 kJ/m^2.h.^{o}C for double-glazed greenhouses, and for single layer glass houses it is between 14.7 and 20.4 kJ/m^2.h.^{o}C (Roberts, 2005). The air infiltration heat loss (Q_{Inf}) is the energy for raising the temperature of the draft of air from ambient to its exit temperature. Q_{Inf} is maximum when all vents are fully open and minimum when all the vents are closed.

It is necessary to supplement the energy into the greenhouse when solar energy is inadequate: at night or during cloudy periods and during any period when heat losses exceed solar energy input. Two methods are often used. The first method is to store excess heat when the sun is available and release it at night or during cloudy periods. The second method is to use an external heating source. A combination of both methods could also be used.

4.6 Heat Storage

Heat storage options in greenhouses varies from the application of low temperature phase change materials (PCMs) (waxes, calcium chloride hexahydrate, and sodium sulfate decahydrate) to rocks and water. PCMs are expensive and may not be available in developing countries. Water is preferable because it has a higher energy storage (1288 kJ/m^3.^{o}C) capacity than rocks (715 kJ/m^3.^{o}C). For most solar greenhouse dryers, 6 to 12 liter containers of water per square meter of glazing are probably adequate. A collection of smaller containers, such as milk jugs or glass bottles, are more effective than aggregates of 200 liter drums in providing heat storage. The smaller containers have a higher ratio of heat capacity per surface area, resulting in more rapid absorption of heat when the sun does shine.

4.7 Supplementary Heat

The minimum external heat requirement is when supplementary heat is set to offset heat losses; during this period the drying process is suspended and vapor condensation inside the greenhouse is to be prevented. In this case, heat storage devices could be used. Larger supplementary sources would be needed to overcome heat losses and to provide any drying, which is energy intensive. The volume of water storage required to sustain drying is prohibitive since the heat capacity of water (4.12 kJ/kg.^{o}C) is very low compared to the energy required for drying or the latent heat of water evaporation (2257 kJ/kg). An external heat source is the most feasible option for supplementary heat for the greenhouse if drying is to be sustained when sunlight is not available.

Top-lit-up-draft (TLUD) and rocket mass heaters (Roth, 2011, Anderson, 2011) are natural fits for supplementary heat sources for greenhouse dryers. These heaters can be fuelled to provide adequate supplementary heat by agricultural residues such as corn cobs, corn stalks, cassava stalk, rice husks, and kernel shells. These heaters are based on the use of TLUD and rocket stoves. Wood usage in these gasifying stoves has been reported to be less than 50% of those used in conventional wood stoves. The flue gases of these stoves could be used to directly heat the greenhouse, provide heat for the storage devices, or heat the drying air (Panwar et al., 2009).

The principle of the TLUD mass heater is illustrated in Figure 6. It is a micro-wood gasifier where the biomass fuel is ignited at the top of the column. The primary combustion air, which is drawn upward from the bottom by natural or forced draft, allows only a partial combustion of the wood gases that are created in the process. The hot pyrolytic wood gases move into the secondary combustion zone, where additional air is provided and the combined gases are burnt to give a very clean flame.

The rocket mass heater is an innovative and efficient space heating system developed from the rocket stove, and it is similar in principle to the TLUD. Wood is fed into a heavily insulated combustion chamber, where the hot gases enter an equally insulated secondary combustion chamber, the exhaust then passes along a duct embedded within the thermal mass to be heated. The key to the efficient biomass-to-energy conversion of the rocket stove is the insulated combustion zones that promote efficient high-temperature burn and thereby create the high draft (the rocket principle) to push exhaust gases though the rest of the system.

The amount of wood/biomass for supplementary heat fuel can be estimated whether the energy is needed to offset heat losses or to sustain drying when sunlight is not available. Heat losses are estimated from Equation 11, and the energy required for drying is given by Equation 9. The heating value of wood is about 1,232 kJ/kg (Seifert, 2009), and the efficiency of the TLUD or rocket mass heater could be as high as 35% or more than double that of traditional wood stoves (Panwar et al., 2009).
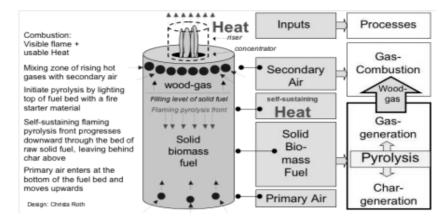
Figure 6. Top-Lit-Up-Draft Bio-Mass Stove (Roth, 2011)

5. Pretreatment

Pretreatment of some produce by drying is often recommended to save vitamin content, set the color, hasten drying by relaxing the tissues, or facilitate reconstitution. Blanching, sulfuring, and dipping them in solution of ascorbic acid or citric acid are some of the pretreatment methods. The type of produce and its end use determine the most appropriate method.

6. Conclusion

Inadequate harvest preservation in developing countries can lead to a cycle of bumper harvest and production cutbacks, famine, inability of famers to get their harvests to market, poor export quality, and low agro-processing. Traditional open air drying, the norm in these countries, is slow and inefficient. A mass-heater supplemented greenhouse dryer is an adaptable technology for post-harvest preservation in developing countries. Design parameters are identified, and guidelines for estimating them for optimum performance are provided. Rigorous designs are not always possible or economical, but the greenhouse dryer will always outperform open air drying irrespective of the quality of its design.

Acknowledgment

References

Aidoo, K. E. (1993). Post-harvest storage and preservation of tropical crops. *International Biodeterioration & Biodegradation, 32*(1-3), 161-173. http://dx.doi.org/10.1016/0964-8305(93)90048-7

Almuhanna, A. E. (2012). Utilization of a solar greenhouse as a solar dryer for drying dates under the climatic conditions of the eastern province of Saudi Arabia. *Journal of Agricultural Science, 4*(3), 237-242. http://dx.doi.org/10.5539/jas.v4n3p237

Anderson, P. S. (2010). *Top lit up draft gasification (TLUD) stoves in 2011 - Within a classification of stoves.* Presentation at ETHOS Conference, Seattle-Kirkland, WA, USA.

Dragićević, S. M. (2011). Determining the optimum orientation of a greenhouse on the basis of the total solar radiation availability. *Thermal Science, 15*(1), 215-221. http://dx:10.2298/TSCI100220057D

Edward, M. (1979). *The Passive Solar Energy Book: A Complete Guide to Passive Solar Home.* Greenhouse and Building Design, Rodale Press.

Ekechukwu, O. V. (1999). Review of solar-energy drying systems II: An overview of solar drying technology. *Energy Conversion & Management, 40*, 615-655. http://dx.doi.org/10.1016/S0196-8904(98)00093-4

Esper, A., & Mühlbauer, W. (1998). Solar drying - An effective means of food preservation. *Renewable Energy Efficiency, Policy and the Environment, 15*(1-4), 95-100. http://dx.doi.org/10.1016/S0960-1481(98)00143-8

Fadhel, A., Koolo, S., FarHat, A., & Bellghith, A. (2005). A study of the solar drying of grapes by three different processes. *Desalination, 185*, 535-541. http://dx.doi.org/10.1016/j.desal.2005.05.012

Fath, H. E. S. (1992). Development of a natural draft solar fan for ventilation of greenhouses in hot climates. *International Journal of Solar Energy, 13*(4), 237-248. http://dx.doi.org/10.1080/01425919208909788

Forson, F. K., Nazha, M. A. A., Akuffo, F. O., & Rajakaruna, H. (2007). Design of mixed-mode natural convection solar crop dryers: Application of principles and rules of thumb. *Renewable Energy, 32*, 2306-2319. http://dx.doi.org/10.1016/j.renene.2006.12.003

Greeley, M. (1986). Food, technology and employment: The farm-level post-harvest system in developing countries. *Journal of Agricultural Economics, 37*(3), 333-347. http://dx.doi.org/10.1111/j.1477-9552.1986.tb01602.x

Gustavsson, J., Cederberg, C., Sonesson U., Otterdijk, R., & Meybeck, A. (2011). *Global food losses and food waste: Extent, causes and prevention*. Food and Agriculture Organization of the United Nations, Rome.

Hassanain, A. A. (2011). Drying sage (Salvia officinalis L.) in passive solar dryers. *Research Agricultural Engineering, 50*(1), 19-29.

International Energy Agency Solar Heating and Cooling Program (IEA-SHC), Solar Air Systems. (1998). Retrieved from http://www.iea-shc.org

Knies, G. (2012). DESERTEC Foundation, Ferdinandstr, Hamburg, Germany. Retrieved from www.desertec.org

Koyuncu, T. (2006). An Investigation on the performance improvement of greenhouse-type agricultural dryers, *Renewable Energy, 31*(7), 1055-1071. http://dx.doi.org/10.1016/j.renene.2005.05.014.

Panwar, N. L., Kurchania, A. K., & Rathore, N. S. (2009). Mitigation of greenhouse gases by adoption of improved biomass cook stoves. *Mitigation and Adaptation Strategies for Global Change, 14*(6), 569-578. http://dx.doi.org/10.1007/s11027-009-9184-7

Rahman, S. (2007). *Handbook of Food Preservation*. CRC Press. http://dx.doi.org/10.1201/9781420017373

Reynolds, E., Schuler, G., Hurst, W., & Tybo, P. T. (2010). *Preventing food poisoning and food infection*. University of Georgia Cooperative Extension Bulletin 901.

Roberts, W. J. (2005). *Environmental Control of Greenhouses*. Publication of Center for Controlled Environment Agriculture, Cook College, Rutgers University.

Roth, C. (2011). *Micro-gasification: Cooking with Gas from Biomass*. HERA – GIZ Manual Micro-gasification, Version 1.0.

Sambo, S. (2008). Electricity demand from customers of INGA hydropower projects: The case of Nigeria, WEC Workshop on Financing INGA Hydropower Projects, April 20-21, 2008, London, U.K. Retrieved from http://www.ffydd.org/documents/abubakar_sambo_final.pdf

Seifert, R. D. (2009). *Heating Value of Fuels*. University of Alaska Fairbanks Cooperative Extension Service, EEM-04253.

Solar Electricity Handbook. (2012). Greenstream Publishing, Warwickshire, United Kingdom.

Weiss, W., & Buchinger, J. (2001). *Solar Drying*. Institute for Sustainable Technologies, Austria. Retrieved from www.aee-intec.at