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Review Paper

Solar drying of fruits and windows of opportunities in Ethiopia

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Fruits are essential food items as they play a vital role in the diet of humans. Fresh fruits are highly perishable and bulky commodities because they contain high moisture. Hence, their transportation to distant places is costly and their condition on arrival in the importing country may be less than satisfactory. Postharvest loss of fruits in Ethiopia is very high. This could be due to their perishable nature, poor postharvest handling and lack of cheap and appropriate postharvest technology. Hence, much effort is needed in the area of generating efficient, low-cost, indigenous technology that minimizes postharvest loss of fruits. One of these methods is to produce local value-added products through the development of micro- and small-scale agro-industries. Solar drying of fruits is one of such agro-industries that can enhance the shelf life of fruits. Therefore, the main objective of this paper is to review the potentials and possible methods and procedures of solar drying of fruits in Ethiopia with major emphasis on methods of drying and types of solar dryers; nutritive value of dried fruits, influence of drying on quality and utilization methods of dried products; basic procedures for solar drying, and problems and opportunities in the country to begin fruit solar drying as a business. This review demonstrated that Ethiopia has favourable conditions such as increased fruit production, favourable weather for solar drying, cheap labour, strong market linkage, air transport and favourable policy. These conditions favour the establishment of solar drying as a business in the country. Therefore, Ethiopia has to use these windows of opportunities to reduce postharvest loss of fruits and achieve the multiple benefits that can be obtained from solar drying through introduction and adoption of fruit solar drying technologies from abroad and developing appropriate technologies within the country.

Key words: Ethiopia, fruits, solar dryers, solar drying.

INTRODUCTION

Fruits are vitally important food items at both producer and non-producer countries. They play vital roles in the diets of humans and are chief sources of essential dietary nutrients including vitamins, minerals and fiber (Sagar and Kumar, 2010). The area harvested and the total annual production of fruits in Ethiopia in the year 2000 were 7,800 ha and 115,000 Mega gram (Mg) whereas increased to 10,000 ha and 150,000 Mg, respectively in 2008 (FAO, 2010). Most of the fruits produced in Ethiopia are consumed locally.

Fresh fruits are regarded as highly perishable and bulky commodities as they contain more than 80% moisture (Atungulu et al., 2004; Orsat et al., 2006; Sagar and Kumar, 2010). Consequently, their transportation to distant places is costly and their condition on arrival in the importing country may be less than satisfactory (Burdon, 1997). The best way of maintaining the nutritional value of fruits is by keeping the products fresh. However, most of the storage methods require low temperatures, which are difficult to maintain throughout the chain mainly in the developing countries (Sagar and Kumar, 2010). At average storage temperatures fruits have an average shelf life of 7 to 36 days (Anonymous, 1991). The difficulties with short storage life of fruits are worsened by the poor transport and marketing system in developing countries like Ethiopia. Post-harvest losses of fruits can reach as high as 40 to 50% in the tropics and sub-tropics (Kadam and Salunkhe, 1995). These losses could be due to the perishable nature of the produce, poor postharvest handling and marketing conditions and lack of cheap and appropriate postharvest technology (Brett et al., 1996b; Sagar and Kumar, 2010).

In Ethiopia, even during years when food production is normal most people suffer from shortage of fruits in their diet. This is most acute in the long dry season whilst the inhabitants of the arid and semi-arid areas suffer from a permanent shortage throughout the year. During and after the rains more is often produced than can be used directly or marketed and this surplus is therefore wasted. Most fruits are marketed at nearly the same time of the year creating market glut. This surplus production could be preserved by solar drying for use until the next crop will be harvested. Furthermore, solar dried fruits could be transported cheaply for distribution to areas where there are permanent shortages of fruits (Jackson and Masry, 1977; Sagar and Kumar, 2010). Therefore, much effort is needed in the area of generating efficient, low-cost, indigenous technology that minimizes postharvest loss of fruits. One of these methods is to increase local value-added food products through the development of micro- and small-scale agro-industries. Solar drying of fruits is one of these technologies, which can enhance the shelf life of fruits. Besides, it improves nutritional standards in diets, minimize seasonal gluts, and reduce transportation cost. It also resolves the problems of high prices and shortages of fossil fuels by using alternative renewable energy sources (Janjai et al., 2009; Sagar and Kumar, 2010).

There are three broad categories of drying methods including sun drying, solar drying and mechanized drying. Sun drying and solar drying utilize sun's energy. Solar drying is more effective than sun drying, but has lower operating costs than mechanized drying. Solar drying of fruits is a cheap method of preservation because it uses the natural resource, sunlight. This method can be used on a commercial scale and at the micro- and small-scale level (Jackson and Masry, 1977). Solar dryers are specialized devices that control the drying process and protect produce from damage. Traditionally, fruits are dried in an open sun (Bala and Janjai, 2009). Compared with drying in the sun, solar dryers can generate higher air temperatures and lower relative humidity (Brett et al., 1996b). This results in shorter drying times and lower product moisture contents (Dadashzadeh, 2006), and reduced spoilage during the drying process and in subsequent storage. The higher temperatures attained in solar drying also act as a deterrent to insect and microbial infestation (Bala and Janjai, 2009). Protection of the drying fruit against rain, dust, insects, and other pests is also improved when drying in an enclosed structure compared to open sun drying. All of these factors contribute to improving quality and providing a more consistent product (Smitabhindu et al., 2008; Lotfalian et al., 2010).

Solar drying of fruits is an activity that importantly provides employment for women; creates sustainable income-generating schemes; produce products to improve nutritional standards in diets; enhance foreign exchange earnings; improve shelf life of fruits; and produce value added food items (Brett et al., 1996d). Currently, fruits are dried world wide using various types of solar dryers (Brett et al., 1996). However, simple drying techniques are often the most appropriate for application in rural farming areas like Ethiopia that have limited technical, financial, and managerial resources (Brett et al., 1996b). In Ethiopia, though traditional drying is commonly used for other crops, little attempts have been made so far for drying of fruits. However, Ethiopia has favourable conditions for the solar drying of fruits including among others increased fruits production (FAO, 2010) and sufficient sunshine (NMA, 2010). In order to efficiently utilize these potential and minimize the postharvest losses of fruits and increase their availability though out the year while maintaining quality, Ethiopian small-scale farmers need low-cost, handy and efficient solar dryer. Though there are very many designs of solar dryers world-wide, experimental and technical evaluations carried out in Uganda have shown a Natural Resources Institute (NRI)-modified version of the local Kawanda cabinet dryer to be well suited for local conditions (Brett et al., 1996a). This dryer has been tested under Ethiopian condition and is suitable for solar drying of fruits.

Therefore, the main objective of this paper is to review the potentials and possible methods and procedures of solar drying of fruits in Ethiopia with major emphasis on methods of drying and types of solar dryers; nutritive value of dried fruits, influence of drying on quality and utilization methods of dried products; basic procedures for solar drying, and problems and opportunities in the country to begin fruit solar drying as a business. Finally, potential researchable areas will be indicated.

DRYING OF FRUITS

What is drying?

Drying is a process of removing moisture through simultaneous heat and mass transfer and is a classical method of food preservation that provides longer shelf life, reduced weight and volume (Yaldiz, 2004). There are three phases in the drying process (Geres, 1997). The first phase is short and it is the phase during which the drying velocity increases and corresponds to the rise in temperature of the product until it reaches equilibrium. This is the time when the product receives as much heat from the air used to vaporize water. The second phase is the constant drying velocity period. It corresponds to the evaporation of the free water on the surface of the product, which is permanently renewed by the moisture coming from inside of the product. The third phase is the slowing down phase and it corresponds to the evaporation of bond water. The technique of drying, mainly sun drying, is probably the oldest method of food preservation practiced by humankind (Bala and Janjai, 2009). It can either be used as an alternative to canning or freezing, or could complement these methods. Drying is removing a large portion of the water contained in a product in order to considerably reduce the reactions which lead to deterioration of the products (Doymaz, 2008). The removal of moisture arrests the growth and reproduction of microorganisms that would cause decay and minimizes many of the moisture-mediated deterioration reactions (Krokida and Marinos-Kouris, 2003; Araujo et al., 2004). Drying also slows down the action of enzymes that take part in many of the reactions, but does not inactivate them. It substantially reduces weight and volume and consequently minimizes packaging, storage and transportation costs, and enables product storability under ambient temperatures (Araujo et al., 2004; Sobukola et al., 2007). Fruit drying could play significant role in developing countries like Ethiopia to diversify the economy, reduce imports and meet export demands, stimulate fruit production, generate both rural and urban employment especially for women, reduce postharvest losses, improve farmer's nutrition, develop new value-added products and promote micro- and small-scale rural enterprise development (FAO, 1995; Hassanain, 2009).

METHODS OF DRYING

Fruits can be dried in a food dehydrator, in an oven, in the open air or in the sun, in the solar dryers by using the right combination of warm temperatures, low humidity and air current. Wide array of drying methods, each better suited for a particular situation are commercially used to remove moisture from fruits. The most applicable and widely used methods of drying include freeze, vacuum, osmotic, cabinet or tray, fluidized bed, spouted bed, ohmic, microwave and combination of those (George et al., 2004).

There are three basic types of drying process namely sun drying and solar drying; atmospheric drying including batch (kiln, tower and cabinet dryers) and continuous (tunnel, belt, belt-trough, fluidized bed, explosion puff, foam-mat, spray, drum and microwave); and sub-atmospheric dehydration (vacuum shelf/belt/drum and freeze dryers) (FAO, 1995). Hence, drying methods are broadly grouped into three categories. These include sun drying, solar drying and mechanized drying (ITDG, 2004). The first two rely on solar energy for drying whereas the last method utilizes either fuel or electricity. The choice of fuel mainly dependent on ones capacity to invest higher initial costs and continuous buying of fuel costs. Therefore, the choice of drying method depends on the type of the product, availability and cost of the dryer, energy source and consumption, cost of dehydration and the final quality of the dried product (Sagar and Kumar, 2010). Simple drying techniques are often the most appropriate for application in small-scale households in rural areas which are limited in their technical, financial and managerial resources (Brett et al., 1996c). Each of the aforementioned drying methods will thus be discussed hereunder.

Sun drying

Sun drying (open-air drying) is the most ancient method of drying foods and is still in use in many parts of the world (Sagar and Kumar, 2010). For thousands of years people have sun dried fruits to preserve for certain period of time as it is by far the cheapest source of heat (Salunkhe et al., 1991). Drying in the sun is cheaper as it has little or no equipment costs and the produce has to spread on suitable surface and allowed to dry in the sun (Mnkeni et al., 2004). The main problems for sun drying are dust, rain and cloudy weather (FAO, 1995; Salunkhe et al., 1991; Al-Juamily et al., 2007). It needs a continuous follow up throughout the drying period to protect domestic animals, and to remove the produce when the weather becomes too windy, dusty, or rainy. The dried product is often of poor quality as a result of dirt (Bala and Janjai, 2009) and unhygienic as a result of microorganisms and insects such as flies (Mnkeni et al., 2004). Furthermore, it requires about three times as much land compared to solar drying (ITDG, 2004).

Solar drying

Recent efforts to improve sun drying have led to solar drying. Hence, solar drying is said to be an elaboration of sun drying and is an efficient system of utilizing solar energy (Zaman and Bala, 1989; Bala and Janjai, 2009). Similar to sun drying, solar drying also uses the sun as the source of energy. Hence, it refers to methods of using the sun's energy for drying, but excludes open air "sun drying" (Mnkeni et al., 2004). Solar drying is more effective than sun drying, but has lower operating costs than mechanized drying. Solar drying has the following advantages over the open sun drying. In the first place, the product is protected from rain, insects, animals and dust which may contain faecal materials that alter the quality of the dried product. Second, the faster rate of drying reduces the chance of mould growth. Finally, complete drying is possible due to higher drying temperatures and this may allow much longer shelf life (Bala and Janjai, 2009). This method is adaptable to Ethiopian condition since it is less costly as compared to mechanized drying and effective and hygienic as compared to sun drying. Thus, this paper focuses on the potentials of this method of drying fruits under Ethiopian condition.

Mechanized drying

In industrialized regions, open-air drying has now been largely replaced by mechanized drying, in which boilers are used to heat incoming air, and fans used to force it through at a high rate to hasten drying of the produce. Mechanized drying is faster than open-air and solar drying, uses much less land and usually gives a better quality product. Fuel heating usually allows better control of the drying-rate than solar heating; it also enables drying to be continuous (ITDG, 2004). However, the equipment is expensive and requires substantial quantities of fuel or electricity to operate. As a result, it would not be an option for smallholder farmers in Ethiopia.

NUTRITIVE VALUE OF DRIED FRUITS

Dried fruits and their products are chief sources of energy, minerals and vitamins (Sagar and Kumar, 2010). Recent advances in technology have opened a new era in developing various new fabricated products by utilizing dried fruits. They are used in the manufacturing of items like powdered drinks, extruded snacks, and compressed bars among others. These well-designed fabricated foods that have been rich with vitamins and proteins are going to provide the daily nutritional demands of consumers as dried fruits are at least equally, nutritious as other fruits processed through other methods (Salunkhe et al., 1991).

INFLUENCE OF DRYING ON QUALITY

The quality of the dries product can be affected by both the method of drying and the physicochemical changes that resulted in tissues during the course of drying (Krokida et al., 2001). Straightforwardly, the drying method affects dried product properties such as colour, texture, density, porosity and sorption characteristics (Yang and Atallah, 1985; Krokida et al., 1998; Al-Juamily et al., 2007). Fruits are thought to be safe to dry in the sun due to their high sugar and acid content. However, changes in taste are inevitable when drying which is brought about as a result of enzymatic browning and maillard type reactions (non-enzymatic browning). Other adverse effects of fruit drying include, physical changes including cell wall collapse and shrinkage that affect the texture (Tsami and Katsioti, 2000; Panyawong and Devahastin, 2007), deformations due to higher drying temperatures (Markowski et al., 2003), changes in organoleptic properties including colours resulting from browning reactions and pigment degradation (Maskan, 2001), a limited loss of aromatic compounds, and loss of vitamins mainly A and C (Rozis, 1997). Maskan (2000) reported that prolonged drying times (slow drying velocity) increase shrinkage and toughness, reduce the bulk density and rehydration capacity of the dried product and seriously damage the flavour, colour and nutrients.

UTILIZATION OF DRIED FRUITS

Dried fruits can be consumed directly or used as a raw material for secondary products (Kaleta and Gornicki, 2010). They can be eaten directly or reconstituted. The dried fruits are reconstituted by soaking with water until the desired volume is restored (Witrowa-Rajchert et al., 2009). Once reconstituted, dried fruits are regarded and consumed as fresh (Rozis, 1997). A large volume of dried fruits are marketed in the ground or paste form. Some of this product is formulated in to a “jam” type material and this can be used in remanufacture of institutional products. Dried fruits form important components of various prepared foods such integral breakfast foods and snack preparations to mention few (Velic et al., 2004; Vega-Galvez et al., 2008). Dried fruits are utilized mainly in bakery, cooked sauces, and for eating out of the hand (Salunkhe et al., 1991). They are unique, tasty, and nutritious and in places where fresh fruits are not readily available during certain parts of the year, dried fruits can be used as a substitute.

SOLAR DRYERS

Solar dryers are specialized devices that control the drying process and protect agricultural produce from damage by insects, dusts and rain (Al-Juamily et al., 2007). In comparison to drying product in the open air, solar dryers generate higher temperatures and lower relative humidity which results in shorter drying time, lower product moisture content and reduced spoilage (Rozis, 1997). Hence, solar dryers have the following advantages over the sun drying (Mnkeni et al., 2004; Al-Juamily et al., 2007). These include drying is faster and as a result less risk of spoilage; 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; and the quality of the product is better in terms of nutrients, hygiene and color.

Solar dryers come in various forms and sophistication and so far, various types of solar dryers have been designed, developed and evaluated under different tropical and subtropical regions (Bala and Janjai, 2009). The choice of a dryer and drying method depends on the type of the product, availability and cost of the dryer, energy consumption, cost of dehydration and the final quality of the dried product (Sagar and Kumar, 2010). Hence, a dryer should be adapted to local climatic conditions, local materials, local competence in building the dryers, the products to be dried, the needs (quantity, taste, and aspect of the product), the end users demands, operating costs and overall financial feasibility, and flexibility to perform more than one function. Many designs of solar dryers have been evaluated and widely used world-wide (Brett et al., 1996b) (Table 1). However, assessments in Uganda have shown that the NRI–modified version of the local Kawanda solar cabinet dryer is well suited to local conditions (Brett et al., 1996b). The dryer consists of a main frame, with eight supporting legs, incorporating the drying chamber. The drying chamber measures 4.4 m long x 1.5 m deep x 0.8 m high overall and contains 12 trays to provide a total drying area of 10 m^2. Depending upon the type of produce to be dried and upon the loading density used, it can dry typically between 20 and 35 kg of freshly cut fruit over a period of two to four days. The dryer can be built using tools usually available to carpenters such as saws, chisels and screw drivers. Carpenters capable of building office and household furniture, such as tables and beds, should be able to construct the dryer with only limited guidance (Brett et al., 1996b) (Figure 1 and Table 1).

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 can not improve poor quality fresh fruit. High standards of cleanliness, quality control and care are needed at all stages from producer to consumer (Brett et al., 1996c). Factors to consider while processing and operating the 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 (Brett et al., 1996c) (Figure 2). Quality needs to be continually checked by the producer as buyers are always seeking good quality product. If fruit has been carefully selected and dried properly, then it should be possible to achieve a good quality product. In general terms, to be sold as “natural”, products must be pure and without added colouring agents, preservatives, sugar or other additives. If produce has been carefully selected and processed, then it dry, product should be checked for color, odour, flavour, size, defects, and contamination and compared with reference cards (Plate 1) (Brett et al., 1996c). The person responsible for packing the dried fruits needs to be clear about what is acceptable and what should be rejected and hence this person is responsible for the quality assurance of the business. Ideally, all products with the following features should be rejected: poor in colour - very light or dark; have an off-odour or smell; sour or do not taste naturally of the original fruit; improperly dried or over-dried; and moldy, have dirt, dust, insect, dead flies or that are contaminated (Brett et al., 1996c) (Figure 2).

PROBLEMS, OPPORTUNITIES AND PROSPECTS IN ETHIOPIA

Problems

1. Postharvest deterioration of fruits: Fruits are highly perishable food products (Atungulu et al., 2004; Orsat et al.; 2006; Sagar and Kumar, 2010). Harvested fruits are still living and continue to respire and loss water as if they were still attached to the parent plant. They therefore liable to detrimental changes after harvest (Burdon, 1997; Sagar and Kumar, 2010). Water loss and postharvest decay account for most losses estimated to be more than 40 to 50% in the tropics and subtropics (Kadam and Salunkhe, 1995). At optimum storage temperatures fruits have an average shelf life of 7 to 36 days (Anonymous, 1991) (Table 2).

Estimated crop losses in developing countries for more perishable food products including fruits are very high as compared to field crops (NAS, 1978). The average postharvest losses of field crops such as tef, sorghum, wheat and maize are 13, 15, 14 and 11%, respectively. On the other hand, the postharvest losses of perishable crops such as fruits are about 30% (Admasu, 2004). The postharvest losses of selected fruits in Horticultural State Farms in Ethiopia were recorded in the years 1985 to 1988 (Tadesse, 1991) (Table 3). From this one can appreciate how the condition is severe at farmer’s level where fruits are marketed without any consideration to postharvest management. In countries like Ethiopia where production is much lower than the national demand and supplemented with the above stated level of postharvest losses, much effort is needed in the area of generating technology that minimizes these losses. One way of the methods to overcome this problem is to increase local value-added food products through the development of rural agro-industries. Drying of fruits to a form which has a longer shelf life and adding value to the original fruit helps the farmer not only to overcome the spoilage and losses, but also fetches more money due to the newly added value and to achieve the multiple benefits of fruit drying.

2. Socio-economic problems: The short storage life of fruits is worsened by the marketing system. The marketing system in Ethiopia usually involves several retailers and buying and selling takes time and leads to increased fruit damage. Transport is often delayed, and can even fail altogether, because of poor conditions of vehicles and roads. The smallholder farmers have no storage facilities at their disposal and the products they

Table 1. Comparison of different types of solar dryers.

Criterion for comparison	Dryer types			
	NRI-modified frame dryer	**GERES/GRET shell dryer**	**CEAS/ATESTA banco dryer**	**Hohenheim-type tunnel dryer**
Materials used	Hard and softwood, transparent polyethylene sheet, mosquito mesh, papyrus, nails.	Iron sheet, metal rods and angle iron, trays with fiber glass netting, thin galvanized iron wire mesh, black mat, antirust paint .	Banco, cement, galvanized iron, wooden trays, nylon rope, mosquito netting type nylon mesh.	Concrete, iron rods with Different shapes, Galvanized sheet metal, cork, wood, polyethylene sheet, and nylon mesh.
Energy	Natural convection direct solar dryer.	Natural convection indirect solar dryer.	Natural convection direct solar dryer.	Forced convection direct solar dryer.
Capacity	20-35 kg of fresh product per dryer.	2.1 to 10 kg of fresh product depending on the model 2.2.	120kg of fresh product per dryer.	600-800 kg.
Feeding system	Batch feeding	Discontinuous or semi continuous operation.	Discontinuous operation.	Discontinuous operation
Products dried	Bananas, pineapples, mangoes, tomatoes, mushrooms.	Mangos, okra, tomatoes, onions, meat, fish, local miller.	Mangoes	Apricots, raisins
Length of drying cycle (h)	36	Clear sky = 36 Cloudy = 60	36-60	Apricot = 48 Raisins = 150
Period of use	All year round (6-8 months a year).	Dry seasons	Dry seasons	Dry seasons
End users	Cooperatives, villages groups, families.	Families, cooperatives groups of women.	Cooperatives, groups of women, individuals.	Domestic
Out let	National market, export to Europe.	Home consumption, local Market.	Export to Europe, local market	Export to Europe
Life span (years)	5	10	Several	10
Significance	Easy to build, low construction and maintenance cost, easy to use, good protection against insects and dust, good quality of dried products which can be exported.	Can be built from locally available material, low construction and maintenance cost, well-accepted shape by women end-users, good hygiene and taste of the finished product.	Can be built with local material, limited maintenance cost, good dried product quality, high dried product output.	Can be built mostly with local material, limited construction and maintenance costs, good dried product quality, good energy efficiency, high product output, several models of dryer.

Source: Geres (1997).

harvest are usually exposed to the influence of weather until they reach the end users. The marketing system also does not provide any intermediate storage system for carrying over-supply to obtain better prices (Ferr, 1997).

Figure 1. NRI-modified Kawanda solar cabinet dryer (front view) constructed at JUCAVM, Ethiopia. The dryer consisted of a main frame with eight supporting legs, incorporating the drying chamber covered with transparent polyethylene sheet. The drying chamber was 4.4 m long x 1.5 m deep x 0.8 m high overall and contains 12 trays to provide a total drying area of 10 m^2.

Several transportation mechanisms are used to market fruits in Ethiopia. These include the human labour, donkeys, mules, and some public transport including different kinds of vehicles and trucks. Products are loaded on to the transport vehicles and lose their quality and weight. Limited availability of the means of transport at the farm level poses serious problems to the smallholder farmers. Packaging, which is important in the marketing of fruits, is undeveloped in Ethiopia. The type of containers used by the general trade includes baskets with no uniform size and jute sacks. The environment within the market is also not suited for long-term storage. The naturally highly perishable nature of the fruits combined with high ambient temperatures, and poor postharvest handling leads to losses in fruit quality, and ultimately to postharvest losses. To reduce these losses, great effort is needed to extend storage life. One way of extending storage life is by changing the fresh fruit into a dry product by solar drying (Ferris, 1997).

Nearly most of the Ethiopian people are under absolute poverty mainly due to lack of non-farm technological innovation and limited employment opportunities outside agriculture to mention few (Halluka, 2000). Even during years when food production is normal, most people suffer from shortage of fruits in their diet. This is most acute in the long dry season. However, the inhabitants of the arid and semi-arid areas in the country suffer from a permanent shortage of fruits and fruit products in their diet. However, during and after rains more is often produced than can be consumed or marketed and this market glut is wasted (Jackson and Masry, 1977). These authors also pointed out that the surplus production could be preserved by solar drying for use until the next crop can be harvested. Solar dried produce could also be transported cheaply for distribution to areas where there are permanent shortages of fruits. Solar drying of fruit can also provide employment for rural women; create sustainable income-generating schemes at low cost; produce products to improve nutritional standards in diets, and enhance foreign exchange earnings through export (Brett et al., 1996d).

Opportunities

1. Increased fruit production: Fruit production is relatively new to Ethiopian agricultural system. Thirty years ago, even in Addis Ababa, fruits were sold only at gates of hospitals as they were meant for sick people and children. As a result, their consumption was very low. In the last three decades, however, tremendous changes were observed in the production, marketing and consumption of fruits in the country (Gebremariam, 2003). Evidently, fruit production in the country showed an increasing trend (FAO, 2010) (Figure 3). Fruit prices in Ethiopia are usually low especially at pick production season. Average fruit prices of different fruits at retail level range from 0.2 to 3 USD/kg (Gebremariam, 2003).
2. Favourable weather conditions: Ethiopia is a country with great diversity of climate, diverse topography and 13 months of sunshine with relatively longer sunshine hours per day (CSA, 2002, 2003) (Table 4). Solar drying in Uganda using the modified Kawanda cabinet dryer typically requires an average daily temperature of 28°C or higher, with a relative humidity of approximately 35% or less, and an average daily sunshine of six hours or more. Furthermore, a reasonably regular weather patterns which allow the processor to plan production for two to three days in advance is required (Brett et al., 1996a). Ethiopia, therefore, has a similar and promising weather conditions for drying of fruits.
3. Labour availability: Ethiopia is a country with cheap

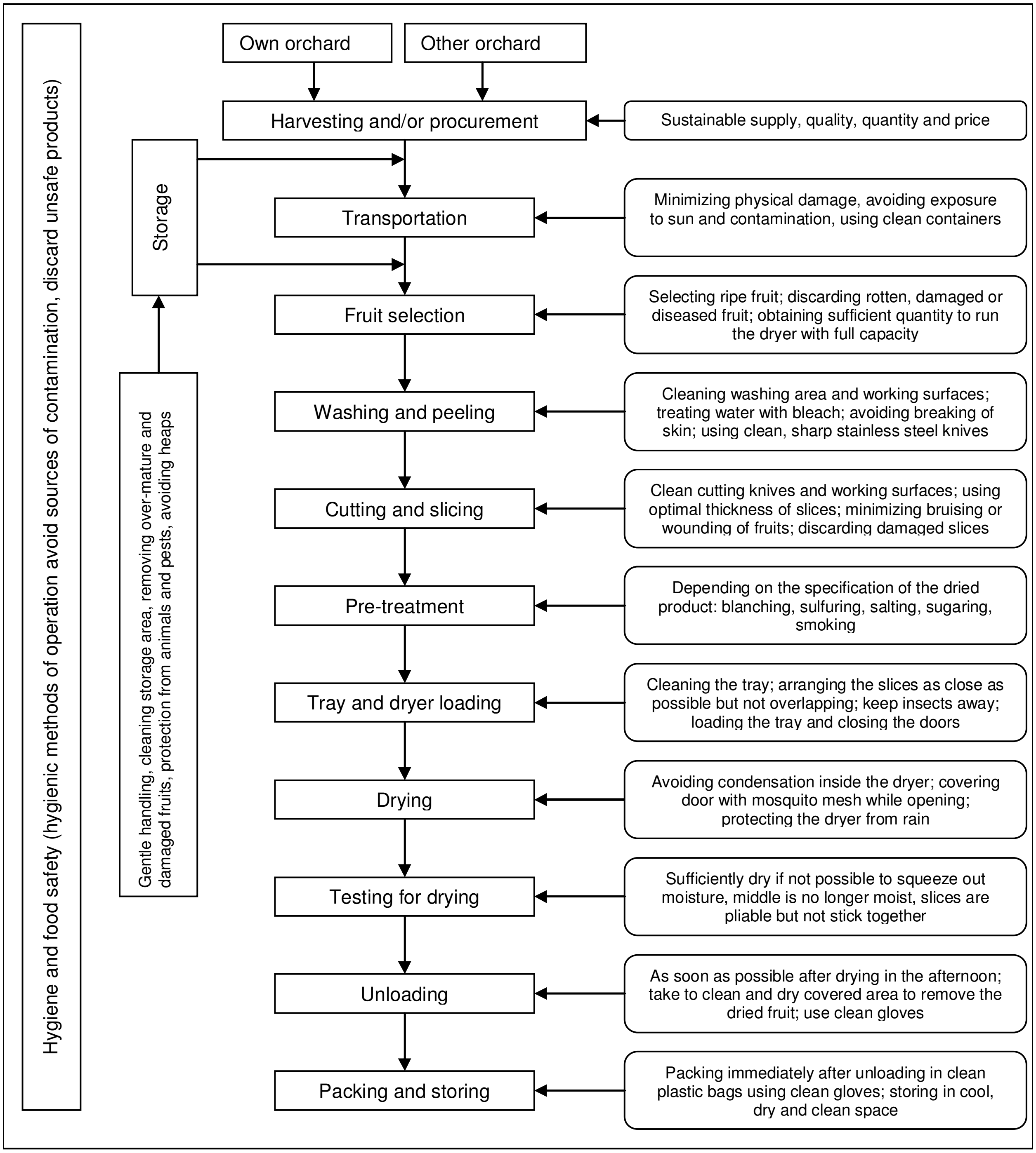

Figure 2. Basic procedures of and cares during solar drying of fruits.

human labour. Most of the Ethiopian people are under absolute poverty, failing to satisfy their basic needs of day-to-day. One of the causes is limited employment opportunity outside agriculture. Unemployment is more severe in the urban than rural areas. In urban areas, unemployment was 17.5 and 33.20% in males and females, respectively whereas 2.39 and 8.56% in males and females, respectively in rural areas. Though the available information indicates low unemployment rate in rural areas, there is high rate of underemployment where members of the family are used as family labor without payment (CSA, 1999). The Figure 3 indicates that unemployment rate was higher in women in both urban and rural areas. Solar drying of fruits require labor for

Plate 1. Reference cards for checking dried fruit product quality (Brett et al., 1996c): unacceptable banana (too light; fruit under-ripe and starchy; cardboard-like texture) (a); acceptable banana (good quality; no dusty appearance; pliable; chewy; natural sweet aroma) (b); unacceptable banana (too dark and with blackening; fruit over-ripe and/or too long in the dryer) (c); unacceptable mango (too light; under-ripe pieces showing white starchy colour) (d); acceptable mango (good quality product with a range of rich orange colours) (e); unacceptable mango (too dark and shriveled; fruit may have been over-ripe or dried slowly) (f); unacceptable pineapple (compacted; packed and stored in large piles; product at the bottom becomes hard and brittle) (g); acceptable pineapple (good quality product with a strong yellow colour; "leaf-like" appearance of pineapple; sweet aroma) (h) ; unacceptable pineapple (brown colour with sour odour; soft and wet feel) (i).

Table 2. Storage potential, indicated as postharvest life of some tropical fruits and the optimum recommended storage temperature.

Fruit	Post harvest life (days)	Optimum storage temperature (°C)
Avocado	14-28	5
Banana	7-28	10
Guava	14-21	14
Mango	14-25	10-12
Papaya	7-21	8-12
Pineapple	14-36	10-

Source: Anonymous (1991).

Table 3. Four years summary (1985-1988) of fruits supplied to the local market, sold as first grade and quantity rejected.

Fruit	Quantity supplied	Quantity sold at 1st grade	Quantity rejected	Reject (%)
Banana	17673	16241	1432	8.10
Grape	1063	1017	46	4.33
Grape fruit	1303	1278	25	1.92
Guava	315	160	155	49.21
Lemon	703	694	9	1.28
Mandarin	3162	2612	550	17.39
Mango	634	467	167	26.34
Orange	28277	25686	2541	8.98
Papaya	653	578	75	11.48
Pineapple	1112	798	134	28.24

Source: Fekadu Tadesse (1991).

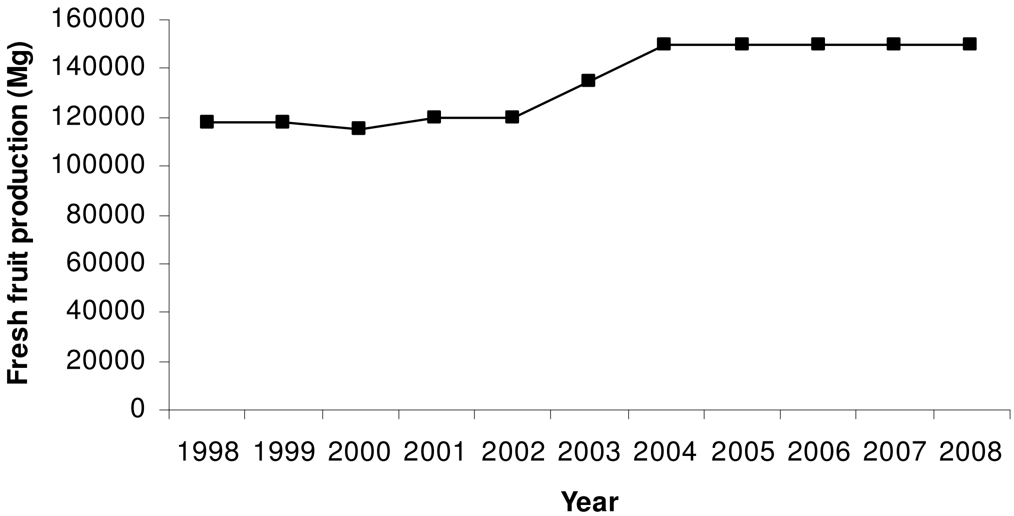

Figure 3. Fruit production in Ethiopia 1998-2008 (FAO, 2010).

Table 4. Altitude and daily average minimum and maximum temperatures (°C) of major weather stations (2001-2003) in Ethiopia.

Weather station	Altitude (meters above sea level)	Average minimum temperature (°C)			Average maximum temperature (°C)		
		2001	2002	2003	2001	2002	2003
Addis Ababa	2408	10.40	12.00	11.60	23.70	26.70	24.10
Bahir Dar	1802	12.20	13.70	14.00	27.00	27.30	29.30
Kombolcha	1903	11.90	13.70	13.20	26.50	28.10	27.70
Debre Markos	2509	10.30	11.20	11.60	22.50	24.70	23.60
Debre Zeit	1850	12.50	13.40	13.70	27.10	29.10	27.50
Dire Dawa	1160	19.10	20.10	19.40	32.40	33.40	32.90
Gore	2002	14.00	14.70	15.00	24.10	24.70	26.00
Jimma	1740	11.80	12.00	11.60	27.90	28.88	29.20

Source: CSA (2002, 2003).

purchasing fruits, preparation, operating the dryer, packing, loading, unloading and selling the dried fruit.

Strong market out-let: Ethiopia has locational advantage to export agricultural products to different countries. Market chain was already established with different countries and export commodities are now days increasing in amount and diversified in type. Out of the exports of all agricultural commodities the contribution of fruits and vegetables from Ethiopia accounted for 11% in value in 1987 (Wolde, 1989). Though there was fluctuation in volume, export of horticultural crops increases from 60,963, 127 kg in 1997 to 131, 971, 761 kg in 2002 (CSA, 2003). The major markets of the horticultural crops exports of the country have been the republic of Djibouti, the Middle East (Saudi Arabia, Israel, Yemen, etc) and the European countries (UK, Italy, The Netherlands, France, Germany, Denmark, etc) (Abera, 2000). However, the main export markets for Ethiopian fresh fruits are Djibouti, Saudi Arabia, Yemen and Sudan. The volume and value of export of fresh fruits in 2005 were 7631 Mg and 1959 million USD whereas 5151 Mg and 1236 million USD, respectively (FAO, 2010).

Though Ethiopia has never been involved in the export of dried fruits, the major importer countries of dried fruits include Belgium, France, Germany, Netherlands, UK, and USA (Table 5). Import statistics are lacking for dried tropical fruit in the US and Europe. The market has been estimated to be about US $60 million per year. In the major markets in the US and Europe, the market has been expanding and is expected to show continued expansion (ADC, 2001). Ethiopia has strong trade link with most of the importing countries. Besides, the country is located relatively nearest to the importing countries and has direct air transport with most of the countries.

4. Financial sources: Often the first question asked by a potential producer is how much does a dryer cost? Most of the costs are cost of the dryer made locally from the wood and labour costs in building it. These costs are

Table 5. Estimated annual import market size of dried/dehydrated tropical fruits in Europe and the US.

Market	Total imports (Metric tons)	Comments
Belgium	300	Principal items are banana chips, pineapples, and papayas
France	1800-2800	Banana chips (600-800), papayas (500-800), pineapple (500-800), others (200-400)
Germany	3500	Banana chips (1500), others (2000)
Netherlands	1600-1800	Banana chips (600-800), others (1000)
UK	3500	Banana chips (1500), others (2000)
USA	4500-6000	Banana chips (3000-4000), others (1500-2000)

Source: ADC (2001).

highly variable from location to location. Imported materials for a dryer, the solar plastic and nylon mesh, cost about US $ 50. In Uganda, the cost of building, labor and timber, is around US $ 300, but this figure will be different in countries where timber and human labor are relatively cheap. Finance is also specifically required to cover capital costs, working capital and reserve funds (Brett et al., 1996a). Funds can be raised in Ethiopia in a number of ways: from savings of individuals, loans from family members (informal loans), and loans from NGOs or other organizations (formal loans). Cooperatives established their own banks, so that they can give credit. Saving and credit banks are also available in Ethiopia and can support micro- and small-scale rural enterprise development among which fruit solar drying is one. Commercial Bank of Ethiopia is also the source of credit (Hulluka, 2000).

5. Organized cooperatives: There are several ways through which the drying business can be established. Brett et al. (1996d) pointed out that the dryer operation might be established and owned by individuals, by joint partnerships or by groups and cooperatives. In Ethiopia, the government introduced cooperative's proclamation No. 147/1998 since it came in to power in 1991. This favours the cooperatives to organize themselves into a higher-level business organization or unions by pooling their resources together. As a result, there are enormous producers and fruit marketing cooperative societies in the country. There is also strong national association called Ethiopian horticulture producers and exporters association.

6. Favorable policy: Production and processing of horticultural crops, vegetables and fruits have been placed by the Government in the list of high priority areas and various incentives have been provided for investors investing in this sub-sector (EIA, 2006). Government introduced a federal governance system, market oriented economic policy, Agricultural Development-Led Industrialization (ADLI) strategy and other reform systems. These favour free market economy and development of agro-processing units which utilize the cheap human labour in the country (Halluka, 2000). Furthermore, the current five year growth and transformation plan of the Ethiopian government highly favours industrialization. This creates favourable condition for the establishment of fruit solar drying as a business and/or sustainable income-generating strategy and impacting on the improvement of food supplies and foreign exchange earnings and improved livelihood of the people.

6. Previous experience: Sun drying is the oldest method of drying crops in Ethiopia. Attempts have been made in Ethiopia by food processing section at Melkassa before 1997 on sun drying of fruits and vegetables. That work has determined methods used, sanitation and hygiene, treatments, type of cut, average sun drying days, approximate shrinkage ratio, optimum moisture content after drying and cutters used for fruits and vegetables (Jackson and Masry, 1977).

Prospects

In a country like Ethiopia were production is much lower than demand and supplemented with high level of postharvest losses, much effort is needed in the area of generating technology that minimizes these losses. This can be achieved by increasing local value-added food products through the development of rural agro-industries. Thus, solar drying of fruits helps the farmer not only to overcome postharvest spoilage and losses, but also fetches more money due to the newly added technology and can achieve the multiple advantages of solar drying. For successful accomplishment of fruit solar drying, future line of work should focus on the following aspects. Organizing cooperatives in fruit production and solar drying areas and evaluating and selecting suitable types and sizes of solar dryers that are adaptable to the capacity of the farmers and local conditions need due consideration. It is also important to identify the potential and favourable months for drying in the year and determine amount of fruit required per dryer to run at full capacity. Appropriate thicknesses of slices for different fruits and standard quality parameters for dried fruits need to be determined. In addition, it is important to evaluate and select quality packaging materials for packing the dried fruits. Finally, awareness creation about the available dryers, the techniques of drying and utilization of dried fruits through establishment of training centres needs due attention and due consideration to women, who are the role players and the users, in all activities.

Conclusion

Ethiopia is a country with great variety of climate and soil types that can enable to grow diversity of horticultural crops including fruits. Despite these favourable resource endowments, agricultural production including fruit production has remained mostly close to subsistence level. Though there is an increasing trend, the country's fruit production is much lower than the national demand. However, attempts have been made to increase production and productivity of fruits. Despite these attempts, postharvest loss of fruits in Ethiopia is very high.

This could be due to their perishable nature, poor postharvest handling and lack of cheap and appropriate postharvest technology. Hence, much effort is needed in the area of generating technology that minimizes postharvest losses of fruits. One of these methods is to increase local value-added food products through the development of micro- and small-scale agro-industries like solar drying of fruits which is one of such agro-industries, which can enhance the shelf life of fruits. Besides, it enables to fetch more money, provide employment opportunity, create sustainable income-generating scheme, improve nutritional standards in diets, enhance foreign exchange earnings, minimize seasonal gluts, and reduce transportation cost.

On the other hand, Ethiopia has favourable conditions such as increased fruit production, favourable weather for solar drying, cheap labour, strong market linkage, air transport and favourable policy. These conditions favour the establishment of solar drying as a business in the country. Therefore, Ethiopia has to use these windows of opportunities to reduce postharvest loss of fruits and achieve the multiple benefits that can be obtained from solar drying through introduction and adoption of fruit drying technologies from abroad and developing appropriate technologies in the country.

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