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Solar Drying in Developing Countries: Possibilities and Pitfalls

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ABSTRACT

People in developing nations are often faced with insufficient food supplies. These shortages may be seasonal in nature, lasting from the end of one growing season until the beginning of the next harvest, or they may be longer due to successive poor growing seasons. Countries faced with food shortages are often forced to import food and must pay world market prices which they can ill-afford to do. Reliance on imported food drains the country of its financial resources, which if spent domestically would stimulate growth throughout the local economy. It is a basic fact that the sustainable development of any nation or society depends on a safe, nutritious, dependable, and affordable food supply. Without this, economic growth and its associated advantages can be seriously impeded. This paper examines, questions, and challenges the feasibility of using solar drying at the individual farm level for food preservation. Solar drying of tomatoes is used as an example. Factors blocking the widespread uptake of food processing technologies and envisioned short-comings of the adaptation of these technologies to local economies are also discussed.

INTRODUCTION

This paper examines a real-life situation involving chronic seasonal food shortages in a developing country, along with the impact on the country's overall development and growth.

This small developing nation lacks much of the infrastructure required to promote the standard of living of its citizens. There are few paved roads and in most parts of the country there is no electricity or other utilities necessary for the development of food processing facilities. What limited and localized electrical generating capacity the country does have is unreliable with regular 'brown-outs' (i.e., fluctuations in voltage) and frequent 'black-outs' (i.e., complete power interruptions). The country is mainly agrarian with family holdings of several hectares. One of the main crops grown in this country is field tomatoes which have two growing seasons per year. Fresh tomatoes, similar to Roma tomatoes (Figure 1), form a dietary staple item for most of the residents.

Figure 1: Roma Tomatoes as Used in Solar Drying Trials

During a typical harvest period, tomatoes are extremely plentiful within the country and local markets are overwhelmed with their abundance. As a result, tomato prices are depressed and farmers who rely on them as a source of income receive low returns for their efforts. In addition, the lack of paved roads increases the time that it takes to get the product to markets in populated centres and often results in produce being damaged during transportation. While unsold tomatoes in the markets spoil and must be discarded, some tomatoes may remain unharvested and left in the fields literally rotting on their vines due to unfavourable market conditions.

At the end of the growing season, supplies of tomatoes diminish rapidly. Within a few weeks there is a shortage of fresh local tomatoes, and throughout the period until the next harvest, tomatoes must be imported to meet the country's demands. To pay for these imports, funds must be transferred to off-shore suppliers thereby reducing the domestic financial resources of the country as it is forced to import tomatoes and other perishable crops.

While overcoming the reliance on food imports is recognized as a priority for the country's development, finding a solution to the problem may not be an easy task.

DEFINING THE PROBLEM

The problem itself is relatively easy to define: there are simply too many tomatoes ripening in a very short time period. In more developed countries these excess tomatoes would be processed into tomato sauce, tomato paste, or ketchup; or they might be processed and canned whole, sliced, or diced. However, canning requires abundant, reliable energy to supply heat for retorts and other thermal processing equipment. These energy supplies are often lacking in developing nations. Even in countries where there is electricity in the major centres, there may be no power grid to distribute it to outlying areas.

EXAMINING POTENTIAL SOLUTIONS

Drying of the tomatoes was considered to be one of the few processing options that could be utilized under the constraints imposed in this country. The use of conventional forced-air dryers or ovens was considered not to be feasible in many areas. Once again, this was due to the lack of energy to power fans and appropriate instrumentation, as well as fuel to provide heat to the dryers.

Since this country, like many of the nations facing these problems, is in a tropical or sub-tropical area, solar energy was viewed as an attractive alternative for drying food products. Numerous projects have been undertaken to investigate the potential for solar drying of crops such as tomatoes. Dried tomatoes could then be stored in a relatively shelf-stable form for use until the next harvest of fresh tomatoes. An international assistance project was focussed on assessing food preservation at the individual farm level to provide shelf-stable products between harvests [4, 5]. It was reasoned that transferring food preservation technology such as solar drying to farming families would provide them with the means to set aside a portion of their crop for personal use during the period between harvests; thereby reducing their reliance on imported fresh tomatoes.

Solar drying of tomatoes is not a novel idea [1, 2, 3, 7]. Indeed, it continues to be practised successfully on a commercial scale in several countries where conditions are suitable. However, the real issue in this example is the applicability of solar drying at the individual farm level. There are numerous drawbacks associated with solar drying that must be considered. In order to understand the situation, it is necessary to examine a combination of factors including: the drying properties and kinetics of the product; prevailing environmental conditions; finished product storage, usage, and attributes; and the potential for technology uptake by the target user group.

TOMATO DRYING

PROPERTIES AND KINETICS OF TOMATO DRYING

Understanding the process of how a particular material actually dries is a commonly over-looked aspect of food drying. Many processors feel that it is sufficient to expose the food product to as much heat as possible to remove the required amount of moisture in as little time as possible. Their failure to understand that the manner in which the water removal takes place can result in such negative impacts as:

- Nutritional degradation (e.g., vitamin loss)
- Flavor changes (e.g., burnt, toasted, or carmelized)
- Color changes (e.g., toasting or browning)
- Reduction of functionality (e.g., starch gelatinization during drying)
- Loss of structural integrity (e.g., stress-induced cracking)
- Case hardening (i.e., formation of an outer hard dry shell)

To avoid heat damage, temperatures below 60°C are quite appropriate for many food drying applications. Higher temperatures may be used during the initial drying stages for some foods, but this is entirely dependent on the food itself and must be thoroughly investigated before use. Solar drying avoids exposing the food material to excessively high temperatures, since temperatures above 60°C are not easily achieved in small-scale drying units.

Another requirement for drying is an adequate supply of air to remove moisture from the surface of the product being dried. In forced-air dryers, this is usually not a problem since the same hot air that is used to bring heat to the product and evaporate the moisture from its surface will carry that moisture out of the dryer. However, air movement is an issue in solar dryers. While heat can be trapped inside the drying chamber, the moisture content of the air near the surface of the material being dried can increase to levels nearing saturation. The high moisture content of this boundary layer air can reduce the rate at which moisture can be removed from the surface of the product. The overall high humidity of the air inside the solar dryer itself can also reduce the dryer's water removal capacity. By increasing the flow of air, the efficiency of a solar dryer can be enhanced. In cases where air flow through the solar dryer relies on natural convection, it is often difficult to address the lack of sufficient air flow. Some solar dryers utilize electric fans for increased air circulation, which is not feasible in areas lacking access to electricity.

Tomatoes are very high in moisture content. On a wet basis, Roma or plum tomatoes contain approximately 93% to 95% moisture. As a comparison, mangoes may contain 80% to 85% moisture, and apples typically contain 84% to 85% moisture. Looking at the actual moisture content of these three products on a dry basis, tomatoes may contain approximately 13 to 19 grams of water per gram of dry solids; mangoes may contain about 4 to 6 grams of water per gram of dry solids; and apples may contain about 5 to 6 grams of water per gram of dry solids. From these values, it is obvious that much more water must be removed from tomatoes to reach a 10% final moisture target (i.e., 0.11 g water/g dry solids) than for the other two examples cited. This high water content makes tomato drying especially challenging.

Figure 2 is a plot of the dry basis moisture content versus time for tomatoes dried in a laboratory-scale tray dryer under a variety of conditions. The three curves shown are for drying at 50°C with an air velocity of 0.1 m/s; 58°C with an air velocity of 0.1 m/s; and 50°C with a 0.5 m/s air velocity. In this work, an air velocity of approximately 0.1 m/s was considered to be representative of the low air flows found in solar dryers equipped only with small fans to enhance air circulation, while 50°C is a temperature easily achieved in most solar dryers in strong sunlight under clear skies. 58°C was used as an elevated temperature for comparative purposes, as was the air velocity of 0.5 m/s.

Figure 3 shows the moisture ratio versus time for each of the three drying conditions used in Figure 2. By dividing the dry basis moisture at any time 't' by the initial dry basis moisture, a dimensionless value can be obtained [9]. In this way, the drying of numerous samples with different initial moisture contents can be compared directly. Inherent in this approach is the assumption that the initial moisture differences are not substantial enough to affect the overall drying kinetics.

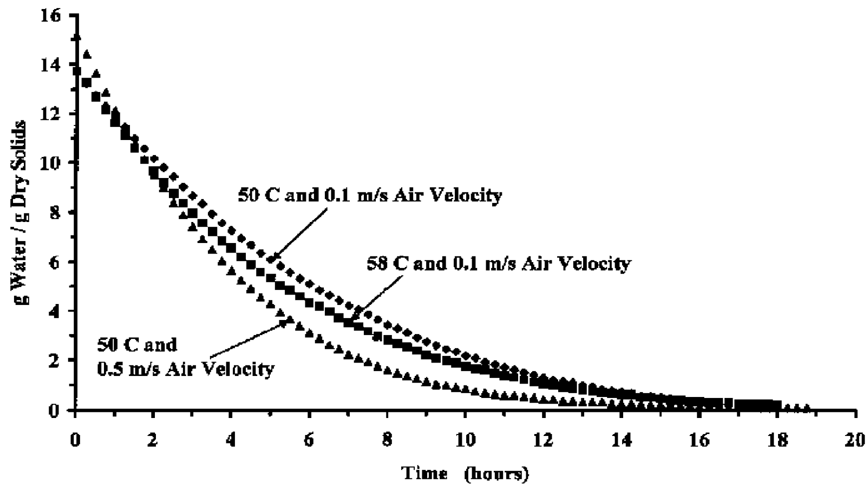

Figure 2: Dry Basis Moisture versus Drying Time for Roma Tomatoes in a Tray Dryer

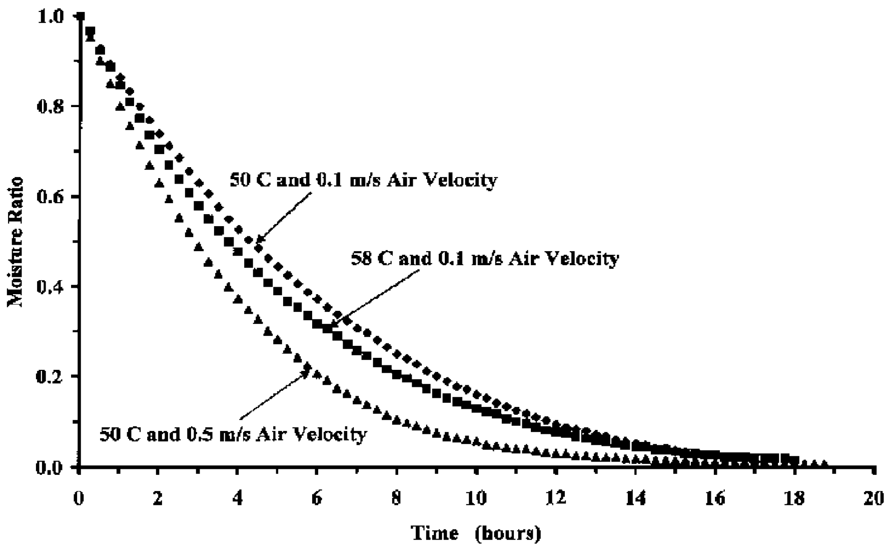

Figure 3: Moisture Ratio During Drying for Roma Tomatoes in a Tray Dryer

Table 1 shows the water removal rate in the constant rate drying period based on the linear portion of each of the three curves during the first 2.5 hours in Figure 2.

Table 1: Initial Water Removal Rates for Various Drying Conditions of Roma Tomatoes

Drying Conditions	**Water Removal Rate (during first 2.5 hours)**
0.1 m/s air velocity at 50°C	1.73 g water/g dry solids/hour
0.1 m/s air velocity at 58°C	2.01 g water/g dry solids/hour
0.5 m/s air velocity at 50°C	2.71 g water/g dry solids/hour

Figures 2 and 3, plus the information presented in Table 1, indicate that achieving a relatively high air velocity through a dryer may be more important for water removal than having a higher temperature inside the dryer. This is particularly relevant to solar drying where the natural convective airflow within a solar dryer is very slow, and may not be sufficient to disrupt the saturated boundary layer of air around the bed of wet product inside the dryer. Designers of some prototype solar dryers intended for use in developing countries have included large fans for improved air circulation. Such design features prevent the use of these dryers by those who do not have electricity available, for whatever reason.

PREVAILING ENVIRONMENTAL CONDITIONS

A major problem associated with solar drying is the prevailing environmental conditions [4, 5, 6]. For efficient and effective solar drying, lengthy periods of uninterrupted sunlight are required. Cool, cloudy, and rainy conditions may persist at the later stages of the harvest season, making solar drying entirely inappropriate.

From Figure 2, it can be seen that an extensive drying period is needed to reduce the moisture of the tomatoes to approximately 10% (wet basis) or 0.11 grams of water per gram of dry solids on a dry basis.

Figure 4 shows a prototype solar dryer used in the studies presented here. It consists of a small metal-lined cabinet from which air is exhausted by two solar-powered fans. These are the two circular devices mounted on the front of the dryer near the top of the drying chamber in Figure 4. Air is thereby drawn into the bottom of the drying chamber through the black metal heat collector. The weight of the material being dried can be monitored by the balance on the top of the dryer from which a rack inside the dryer is suspended. The entire dryer is mounted on a rotating platform to follow the course of the sun throughout the drying period.

Figure 4: Prototype Solar Dryer Used in Drying Studies

Figure 5 shows partially dried tomato wedges (each one-eighth of a Roma tomato) on the rack inside the dryer. The temperature of the air contacting these tomato wedges can be measured by a sensor attached to the bottom of the drying rack.

Figure 5: Partially Dried Tomato Wedges Inside the Solar Dryer

Figure 6 shows an example of the dry basis moisture content versus time during two separate solar drying trials with Roma tomatoes.

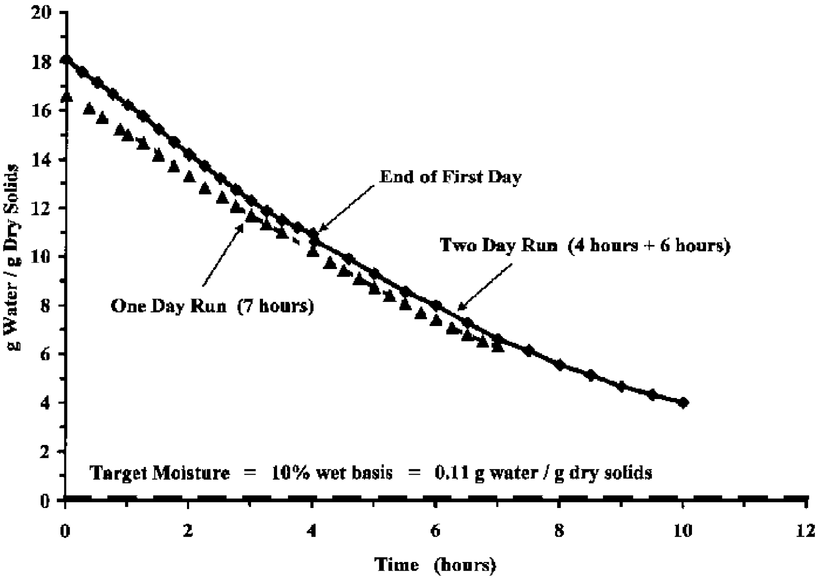

Figure 6: Dry Basis Moisture versus Time for Roma Tomatoes in Prototype Solar Dryer

The solid line in Figure 6 is for a two-day run using tomatoes with a relatively high initial moisture content (18.0 grams of water per gram of dry solids or 94.7% wet basis moisture). The temperature in the dryer was approximately 45°C and the air velocity was approximately 0.1 m/s. During the first three hours of drying, the water removal rate was 1.95 grams of water per gram of dry solids per hour. After four hours of drying, conditions became unfavourable and drying had to be halted for the day. The tomatoes were removed from the dryer and stored in a sealed glass jar under refrigerated conditions until the following day. Drying continued for an additional six hours before the test was terminated. After ten hours of drying the moisture content had fallen to 4 g water/g dry solids or 80% wet basis moisture. An additional 3.9 g water/g dry solids would still have to be removed to achieve the 10% wet basis target moisture shown by the dashed line near the bottom of Figure 6. When the tomatoes were re-introduced into the dryer on the second day, an interesting response was observed in the moisture removal rate. Due to moisture diffusing to the surface of the tomato wedges during overnight storage, there was more water available for removal from the surface of the tomatoes at the start of the second day than there had been at the end of the previous day. This created a short increase in the water removal rate before diffusion control of the drying process once again took over.

The second curve in Figure 6 (the broken line and triangular data points) shows the results of a single seven-hour run using tomatoes with a somewhat lower moisture content than in the two-day run. These tomatoes contained 16.6 g water/g dry solids (or 94.3% wet basis moisture) and were dried at 45°C with an air velocity of 0.1 m/s. The water removal rate during most of this test run was 1.60 g water/g dry solids/hour. After seven hours, the moisture content of the tomatoes had reached 6.3 g water/g dry solids (or 86.3% wet basis moisture).

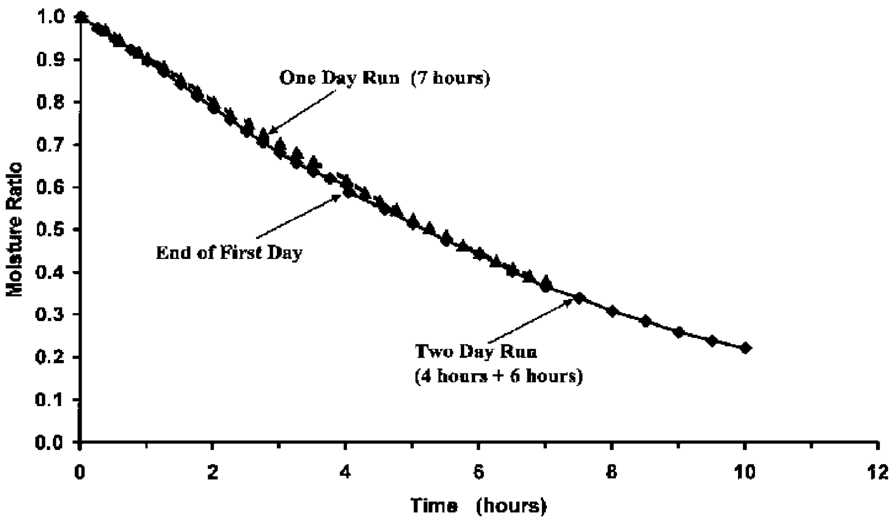

Figure 7: Moisture Ratio During Drying for Roma Tomatoes in Prototype Solar Dryer

Figure 7 is a plot of the moisture ratio versus time for the two solar drying runs from Figure 6. Once again, this allows comparison of the drying on a normalized basis accounting for the differences in the initial moistures of the two runs. Even though these two tests were conducted under similar drying conditions, the initial rates of water removal were slightly different. This could be attributed to the initial moisture contents of the tomatoes. Tomatoes with a higher initial moisture content may lose their moisture more readily at the start of the drying process, before diffusion of moisture becomes the rate-controlling step. Variations such as this complicate the drying process for those unfamiliar with drying kinetics and make it difficult to provide clear, unambiguous instructions to those using a solar drying unit at the farm level.

In all cases, solar drying of Roma tomatoes required more than one day of drying. Tests using a laboratory-scale tray dryer under conditions similar to those found in typical solar drying (see Figure 2: 50°C and 0.1 m/s air velocity) have indicated that 18 hours or more of consistently uniform conditions are required for adequate drying of the tomatoes before they reach a moisture level of 0.11 g water/g dry solids (i.e., 10% wet basis moisture). Typically, areas in the tropics and sub-tropics do not receive adequate sunlight intensities for more than six to eight hours per day. This necessitates holding the partially dried products overnight in the moist confined space inside the dryer. With overnight temperatures of 15°C or higher, there is little or no safeguard against the growth of contaminating microorganisms.

Food safety is a major concern. There is great cause for concern when one considers that these tomatoes could be exposed to warm humid conditions for up to three days before being dry enough to place in storage for future use. In one solar drying run conducted by the author in a tropical country, unsatisfactory weather conditions forced experimentation to be stopped in the early afternoon. The tomatoes plus other fruits and vegetables being dried were left in the drying cabinet overnight in anticipation of better weather on the following day. Covers were placed over the air inlets and outlets on the dryer to prevent insects and rodents from entering the dryer. When drying was started on the second day, mold growth was noticed on some of the food surfaces and became more apparent after several hours in the sun. The entire batch of material had to be discarded and the interior of the dryer then had to be sanitized before processing the next batch of produce. Such risks would seem to be excessive, especially in light of the level of education and training that potential users of solar drying might have.

Long drying times can create additional problems for those interested in solar drying of tomatoes. There is a limit to how much material can be placed in a solar dryer. It has been suggested that dryer loadings should be limited to 6 kg of wet material per square metre of dryer bed surface [2]. On this basis, it would require rather large dryers to make solar drying a viable option for those with several hundred kilograms of tomatoes to dry.

Insects, rodents, and airborne contaminants such as dust can create unwelcomed challenges for solar drying if the dryers are relatively open to promote the intake of fresh air and exhausting of humid air.

FINISHED PRODUCT STORAGE, USAGE AND ATTRIBUTES

In addition to the problems with the actual drying, there are other complicating factors associated with solar drying of products such as tomatoes. Once its moisture has been reduced to the desired final level, the dried product must then be stored under appropriate conditions until it is used. While sealing the product in clean airtight jars or heat-sealed 'plastic' bags may be suitable for a variety of products, it can be difficult for those in developing countries to obtain suitable packaging and ensure that sanitary packaging conditions are met. Any moisture present in the sealed container that condenses in localized areas can promote the growth of molds or potentially pathogenic microorganisms. This is especially true in the case of low acid products such as tomatoes. Insects may also proliferate inside the sealed containers if the product has become infested during drying.

Unless the raw materials were properly blanched or otherwise treated prior to drying, there is also the potential problem of enzymatic degradation. While temperatures above 80°C are sufficient to reduce enzyme activity, these temperatures are generally not achieved in solar dryers; and even if they were, such high temperatures could have a negative impact on quality if the dried product was exposed to them for excessive lengths of time.

In areas where residents are accustomed to using fresh fruits and vegetables in meal preparations, there can be a need for consumer education in regard to how to use the dried materials. Something as simple as substituting dried tomatoes for fresh tomatoes when making stews and sauces can create problems. One question that arose in a demonstration of sun-dried tomatoes in a developing country was how to use them in salads and still get the appearance and flavour of fresh tomatoes. It had to be explained that there are cases in which dried fruits and vegetables cannot be substituted for their fresh counterparts due to their different product attributes.

POTENTIAL FOR TECHNOLOGY UPTAKE

The ability of the potential user to embrace a particular technology and manage it effectively must always be kept in mind. While solar drying could be the answer to food preservation needs, without proper regard for food safety, it could also be the source of additional serious problems.

The educational level of potential users in developing countries is generally quite low. Understanding of the risks associated with unsafe food handling and processing practices is correspondingly low as well. On top of this is the need for maintaining sanitary conditions and keeping the equipment in good repair. Due to a lack of electricity or affordable electricity, it may not be possible to include circulating fans in solar drying units. Even if the dryers are economical to build, the actual number of dryers required to have one dryer per household in a specific area, may make them prohibitive. There is also the problem of dryers falling into disuse and being cannibalized for parts to meet other more pressing needs such as the use of the glass or plexiglass panels on the dryers being used to replace broken windows in houses, and such.

Overall, experience has shown that the uptake of knowledge to conduct solar drying and maintain the equipment is lacking in many areas.

ASSESSING THE APPLICABILITY OF SOLAR DRYING

Solar drying has been shown to be an effective method of drying food materials under suitable climate conditions with properly trained personnel monitoring the operation [2]. Small-scale dryers on individual land holdings may seem to address the issue of providing families with the ability to preserve a portion of their crops for use after harvesting. However, there are fundamental shortcomings which must be taken into consideration before large-scale commitments are made to provide solar drying units to every family. Untrained persons attempting to apply drying technology to low acid foods, such as some varieties of tomatoes, under changing environmental conditions, with insufficient sanitation, is an accident waiting to happen. While certain individuals may be able to embrace this technology, the vast majority of the population may not. As an example, in many marketplaces in developing countries, merchants simply spread their products on the bare ground to dry in front of their stalls without apparent regard for the consequences. It has only been in recent years that they have begun to place plastic sheeting under the material they are drying. During the drying process, insects are ever-present and dust is blown onto the products whenever the wind blows.

The scale on which solar drying can be pursued and the time required for drying are two other important considerations. Farmers may need to dry hundreds of kilograms of tomatoes and similar products. It will take approximately 12.8 kg of tomatoes at 93% wet basis moisture to give 1 kg of dried tomatoes with 10% wet basis moisture content. If dryer loadings should not exceed 6 kg of wet material per square metre of dryer area [2], obtaining 1 kg of dried tomatoes will require a solar dryer with over two square metres of drying area. In addition, based on the moisture content of the tomatoes and the associated kinetics of tomato drying, it could take up to three days of good drying conditions to achieve the desired final 10% wet basis moisture.

Coupling solar drying with hot air drying does not completely alleviate these problems; in addition it adds to the complexity of the overall process by creating an additional processing step that now requires external fuel.

Solar drying is viewed as a solution to the food preservation problem in tropical and sub-tropical areas. While these areas receive abundant sunshine, they may also experience daily rainstorms that block the sun for several hours and increase the overall humidity of the ambient air that is ultimately used in the solar drying process. In turn, this reduces the water removal capacity of the air and lowers the solar dryer's efficiency.

Great care should be taken before recommending solar drying of fruits and vegetables in developing countries. While it appears to be a solution to many problems, there are serious shortcomings that must be considered and potentially hazardous consequences if the drying is not conducted properly.

Based on the information presented here and personal observations by the author, solar drying at the individual farm level does not appear to be an acceptable solution to food preservation issues in developing countries.

CONCLUDING REMARKS

There are several issues that must be addressed in assisting economic growth in developing countries. Technology transfer is of major importance in this regard.

In attempting to solve food processing-related problems, every effort must be made to understand the situation into which the technology is to be transferred. This includes the lifestyles of the people and their ability for technology uptake. Showing a person that food can be dried in a cabinet using the heat of the sun is much different than teaching them how to do it, and having them do it on their own. Avoiding potentially harmful results caused by a lack of awareness of food safety issues is something that can easily be overlooked. It is not until scientists from more developed countries work under conditions found in the area to which the technology is to be transferred that they can realize the challenges being faced every day by the people living there. While solar drying may appear to be an appropriate solution to preserving various crops, it is not until attempts are made to actually dry these crops during the harvest season that the true magnitude of the problem can be understood and appreciated. Rather than trying to put a solar dryer in the hands of every farming family and expecting them to use the dryer to preserve their crops, it may be more advisable to address infrastructure concerns in the area (e.g., sanitation, safe drinking water, and passable roads to get crops to market). Expecting farming families to embrace technologies which they do not understand is not a realistic approach to solving the problem of food preservation. It would be more advisable to create centralized drying facilities run by trained individuals on a larger scale for these purposes.

Technology transfer is a process with three basic components. First, a source of the technology is required. In most cases, sources of technology already exist in the universities and businesses of developed nations. Second, a suitable medium for the transfer of information must be found. This could be through formal instruction, printed materials, local extension services, or a host of other methods. Unfortunately, there are many deficiencies in the pathway for technology transfer from developed to developing nations. This is further complicated by the sheer numbers of people involved. The final component for technology transfer is an appropriate recipient or receiver of the technology. Here is where one of the greatest challenges lies. Most technologies require a certain level of training or education for them to be successfully implemented. Trying to transfer technology to everyone is virtually impossible. Therefore, appropriate recipients must be identified before any technology transfer can take place.

For the reasons outlined above, the International Union of Food Science and Technology (IUFoST) has identified food industry workers as potential recipients for training in various food science-related subject modules. By training a group of selected individuals, in-roads can be made into creating a base for future technology transfer and uptake.

ACKNOWLEDGEMENT

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