SOLAR DRYING OF SWEETPOTATO STORAGE ROOTS

Handouts

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1. INTRODUCTION

The majority of foods can be consumed fresh. However, if we wish to continue consuming these products year-round with only few losses in their nutritive qualities, it is necessary to preserve them. This must be done so that microorganisms which could cause decay and/or chemical-enzymatic reactions are not given the opportunity to develop.

Together with the application of salt, sugar, and fermentation, drying or dehydration is one of the oldest and most traditional forms of food preservation. In almost every culture, drying processes have been developed to preserve agricultural products.

1.1 DEFINITION OF DRYING

The process of food drying is the deliberate extraction of a food water content.

The original water content of perishable agricultural products varies between 30% and 90% of their weight. By means of dehydration processes, the water content is reduced to between 8% and 16%.

1.2 BASIC CONCEPTS OF FOOD DEHYDRATION

Drying food is removing its water content to the point where microbial deterioration and enzymatic activity are reduced to a minimum. Drying differs from other water extraction processes which employ heat, primarily because no cooking or overheating are applied. Thus, it results in a final product which retains most of its nutritive qualities.

The moisture content of many natural food products varies from 70 to 90%. Those dehydrated products labelled "dried" should have, at the end of the process, a 10 to 20% water content, whereas those products in the intermediate range may reach 50%.

In addition to the final moisture content of a dried product, another essential parameter which must be taken into account is the measurement of the water activity (aw). The preferred values for this parameter vary from 0.7 to 0.6 or less, as within these parameters good preservation is obtained.

Besides permitting better preservation, the drying of food products products offers other advantages such as:

(a) Expending the processing of large quantities of the product, thus avoiding loss of produce in times of abundant harvest
(b) Permitting year-round consumption of the product
(c) Facilitating its storage and transport

(d) Providing greater nutritive value due to the fact that, as a great part of the water content is removed, the carbohydrates, pectin, proteins, oils, and mineral salts are concentrated in the tissues od dried food products.

(e) Creating new opportunities for the food producer and generating new sources of work and income

1.3 DRYING TYPES

Many different techniques exist to carry out the drying of food products, such as: traditional solar drying, technical solar drying, and drying sing industrial equipment. In each of these techniques energy is applied to the product to eliminate the water contained.

The principal types of drying known are:

- Traditional solar drying
- Conventional drying
- Technical solar drying

1.4 DRYING TYPES

The simplest method used at present is the exposition of the product directly to the rays of the sun. However, this method presents certain difficulties such as: there is too much dependence on climatic conditions (it is sometimes necessary to gather up the product in case of rain), there is a need for manual labour to move the product during the drying time, there is difficulty in maintaining hygienic conditions.

The traditional drying of food products is difficult to program and there are risks of losing the product due to rain, wind, and the action of insects and rodents.

1.5 CONVENTIONAL DRYING

In this method several types of ovens for drying are utilized, fed with different kinds of fuels like kerosene, electricity or gas. These conventional dryers are designed in order to operate with controlled air temperature and flow, permitting the determination of optimal temperatures and flow to obtain a faster drying.

1.6 TECHNICAL SOLAR DRYING (TSD)

TSD attempts to take better advantage of solar energy by improving traditional solar drying, using specific equipment to increase the air water-absorption potential and control the flow of air through the product. In addition, the product can be better protected from environmental contamination and better control of the drying process can be achieved.

2. TECHNICAL SOLAR DRYING

To overcome the problems of traditional solar drying, solar drying, solar dryers are used, which, in their simplest form, are a modification of traditional solar drying. These dryers are a type of greenhouse in which the product is placed on trays. The average temperature in the interior of the dryer can reach 45°C or higher, thus reducing the relative humidity and accelerating the drying time.

By eliminating a part of the water content, the development of microorganisms is blocked. The quantity of water which should be eliminated depends on the product itself.

It is known that the function of the solar dryer is to heat the air, using the energy of the sun and the greenhouse effect. The air is heated to a certain temperature and circulates through the agricultural products, causing their dehydration.

The temperature conditions are governed by the type of dryer, which together with the processing method, must be approportionate for the specific product. The temperature, wind velocity and duration of the process are conditions which also should be taken into account to ensure that the nutritive properties of the product are preserved as much as possible.

The solar dryers can be direct or indirect, with or without a forced air flow, depending on the product to be dried.

2.1 ADVANTAGES OF TSD

(a) Increasing the total value of agricultural products: TSD facilitates the elaboration of better quality dehydrated products and leads to obtaining better prices in the market.

(b) Improving hygienic conditions: With TSD it is possible to carry out production processes under very hygienic conditions, according to quality control norms, including those required for exportation.

(c) Saving of conventional fuels: TSD technology does not require any other energy source than solar radiation, the cost of which is, to all intents and purposes, free

(d) Improving storage conditions and reducing post-harvest loss: TSD allows for the preservation and storage of excess production, thus reducing losses and making commercialization possible in periods when higher prices can be achieved.

(e) Saving of time: The drying time with TSD is much less, compared with traditional drying; in addition, a smaller surface area is required.

2.2 LIMITATIONS OF TSD

TSD is not a general solution for all dehydrated processes, as certain limitations must be taken into account:

(a) Potential solar radiation. TSD only functions if there is sufficient sun. In zones with heavy rainfall and high humidity, solar drying is not feasible.

(b) Initial cost. Acquiring a technical solar dryer could represent an excessively high investment, especially for small agricultural producers.

(c) For some products, the difference between the cost of production and that of sales is so small that the use of any type of improved drying technology is not feasible.

2.3 RELATIONSHIP BETWEEN THE DRYING PARAMETERS AND THE FOOD CHARACTERISTICS

The drying behavior of water-absorbing substances such as foods is complex and varies from one food to another. This behavior can be studied experimentally in various types of dryers, measuring the loss of weight of a solid product during a period of time, using different parameters (e.g speed, temperature and the humidity of the air in the dryer).

The “drying curves” are obtained by plotting the water content of the product and speed of drying related to time. The speed of drying can also be represented in relation to the water content of the product.

3. FACTORS GOVERNING THE DRYING PROCESS

During the drying of food products the following physico-chemical changes may occur: caramelization, decoloration, loss of texture and shape, loss of volatile substances and loss of nutritive qualities. The nature of these changes is affected by the transfer of heat and mass (the drying parameters) and by the physical-chemical characteristics of the product to be dried.

3.1 MOISTURE CONTENT

This is the percentage of the water mass divided by the total mass of the product. It is identified as M and a distinction is made between the initial moisture content at the beginning of the drying process (M_1) and the final moisture content of the preserved product (M_f). Both parameters depend on the internal structure of the material. The final moisture content (M_f) is not zero, but is the maximum value which permits preservation. Drying in excess of this value represents an economic loss.

Based on their initial humidity content, the products can be classified in four groups:

1. Very high: IM>80% e.g fruit, vegetables, etc
2. High: IM (60-80%) e.g. coffee, cassava, sweetpotato
3. Intermediate: IM (35-60%) e.g cocoa, peanuts, etc
4. Low: IM (15-35%) e.g cereals, oleaginous products, etc

3.2 MAXIMUM TEMPERATURE

By this we refer to the maximum temperature which a product can tolerate without suffering significant losses of its active elements or characteristics nutritional components.

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Each product will tolerate a maximum temperature dependent on its use, the type of product (fruits, cereal, vegetable, etc), its moisture and its degree of maturity. This value also depends on the length of time the product will be exposed to that temperature.

The following table lists the characteristics of diverse products.

3.3 UNIFORMITY OF SEGMENTS

The dried products destined for industrialization and prolonged storage need uniform distribution of moisture in order to facilitate the evaluation and control of their physical and chemical changes during processing and their subsequent storage.

The uniformity of size of the product segments to be dried influences the evenness of the water content.

For each product there are optimum shapes and sizes which need to be previously determined.

The following list shows the most important size parameters.

Characteristics of Diverse Products

Product	Initial moisture (% of total mass)	Moisture recommended for preservation	Maximum tolerable temperature °C
Grains			
Unshelled rice	22-24	11-14	50
Corn	35	14	60
Wheat	20	13	50
Vegetables			
Peas	80	5	60
Cauliflower	80	6	50
Carrots	70	5	60
Onions, Garlic	80	8-10	50
Potatoes	75	11	55
Sweetpotato	70	10	50
Leafy vegetables	80	10	50
Peppers	86	5	60
Fruit			
Apples	84	14	50
Grapes	80	15	55
Figs	76	16	55
Banana/Plantain	78	15	55

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The following list shows the most important parameters.

Parameter	Large segments	Small segments
Dryer load	+	-
Drying time	+	-
Loss in cutting/slicing	-	+
Cutting/slicing time	-	+
Segment uniformity	+	-
Fragility of dried product	-	+
Loss of manipulation of dried product	-	+

Source: Rebohle Thomas: Asesoria sobre la tecnologia de alimentos sometidos as secado solar. Lima, 1988:3

3.4 PRE-TREATMENTS OF THE PRODUCTS TO BE DEHYDRATED

A. Pretreatments

The pretreatments have a great influence on the quality of the final product on the organoleptic level, as well as in the resulting final composition of the product.

During the treatment processes, preservatives and additives are used to produce different effects, such as the acceleration of the drying process, bleaching, the reduction of microbial flora, and the slowing down of the browning effect.

The pretreatments most frequently employed due to their ease of application and effectiveness are: blanching, bleaching, peeling, scoring, salting and sugaring.

The applications of the pretreamtnets vary as to the time the product to be dehydrated must be immersed in the reactive solution, the concentration of the reactives, the temperature of the solution, etc, taking into account the different products and including factors such as the stage of maturity of the raw materials, its variety and size.

There are norms which should be observed when utilizing certain types of frequently employed reactives. For example, when using sulplur derivatives, the maximum permitted proportion are specified, as well as forms of usage and the foods in which their use is permissible. However, other types of substances exist, such as sugar and salt, in which there is practically no legal limit as to quantity, the only guideline being the need for taking into consideration the quantity present in the product, as it will influence the taste which is obtained.

B. Preservatives and Additives

A preservative is any substance which when added to a food, prevents or retards its spoilage. The additives contribute texture, taste, and colour to the product.

PRESERVATIVES

- **Sulplur dioxide:** is toxic to moulds, bacteria and in a lesser degree to yeasts. It blocks the enzymatic action, stopping the decoloration of the product while reducing the loss of some vitamins

- **Carbon dioxide**: has a preservative effect on certain microbia at higher than atmospheric concentrations

- **Benzoic acid**: is, together with salts, more effective against yeast and bacteria than against mould. It can be used in concentrations of up to 0.1%. This preservative is most used in cider, apple, juices and pickles

- **Ascorbic and citric acid:** are agents which affect tissue darkening in the fruit and vegetables which have been segmented by cutting, peeling or grinding

4. PRE-TREATMENTS USUALLY EMPLOYED IN SOLAR DRYING

4.1 Blanching

Consists of immersing the product in water at a temperature of 95°C. for a variable period of time. The temperature and the duration depends on the species, its state of maturity, and its size.

Blanching is undertaken to achieve the following objectives:

- Inactivation of the enzymes
- Softening of the product (which facilitates the packing process)
- Partial elimination of water content from tissues
- Fixing and heightening of the natural colour
- Bringing out the characteristic flavor and smell of the product
- Partial reduction of the microorganisms present.

The inactivation of the enzymes improves the quality of the product, reducing undesirable alterations in its colour, taste and smell. In addition, it aids the retention of certain vitamins, such vitamin C.

Blanching is an activation of the enzymatic systems and is applied frequently in order to inhibit darkening or enzymatic browning in the product. These reactions are very common in fruits and vegetables and have as their final product a dark pigment called melanin

4.2 USE OF SULPHITES

The addition of sulphites inhibits the browning process in the products to be dehydrated, since they act upon the products' sugars, minimizing the possibility of browning.

Sulphites and derivatives such as: sodium bisulphite ($NaHSO_3$), potassium bisulphite ($KHSO_3$), calcium bisulphite $Ca(HSO_3)_2$, sodium metabisulphite ($Na_2S_2)_5$), potassium metabisulphite ($K_2S_2O_5$), are applied. This process is carried out by immersing the products to be dehydrated in solutions of the additives with a concentration of between 0.5% and 1%, for a period of 5 to 10 minutes at room temperature.

To obtain the above concentrations, 5 grams of sulphite should be dissolved in each litre of water to obtain a concentration of 0.5%, and 10 grams for each litre to obtain a concentration of 1%.

4.3 THE USE OF SODIUM BICARBONATE (N_aHCO_3)

Sodium bicarbonate stabilizes the chlorophyll (the green pigment in plants) in the products ad makes them more resistant to the direct action of solar rays when the products are processed in the solar dryer; thus they retain more of their original green colour. The sodium bicarbonate also softens the exterior layers of the product, making it easier for the water to exude during drying and avoiding the formation of crusts.

For the dehydration of products which are green in colour, i.e vegetables and legumes such as lima/broad beans, peas, spinach, etc., blanching with a solution of 3-5% sodium bicarbonate and 0.3% salt is recommended. (Dissolve 30 grams of sodium bicarbonate and 3 grams of salt in each litre of potable water). The blanching process should be carried out from 3 to 5 minutes at boiling temperature.

The sodium bicarbonate content in the blanching water should reach a pH of nine. This can be controlled with pH indicator paper. (Place a small piece of the paper in the blanching water for a couple of seconds, then remove it and compare it with colour pattern for the indicator paper which was used).

4.4 CHEMICAL PEELING (IMMERSION IN SODIUM HYDROXIDE SOLUTION)

The peeling can be undertaken using either physical and/or chemical methods. Among the physical methods employed is either manual or machine peeling, and the chemical method most commonly employed is that of immersion in lye soda (sodium hydroxide solution).

The factors that contribute to the efficiency of the peeling, using the last method mentioned, are: the concentration of the soda, the temperature of the solution and the immersion time.

The product should be removed from the solution with almost all its skin still adhering to it, but the skin should be on the point of breaking free. If part of the product's pulp has been eliminated, the immersion time has been excessive. A too lengthy treatment leads to product loss and an unsatisfactory finish.

In small-scale productions, the elimination of the skin should be carried out manually. After the immersion in lye, the product is covered with cold water and the skin is eliminated manually. The product is then submerged for five minutes in a 1% citric acid solution (10 grams of citric acid for each liter of water), to neutralize the residual soda. Lemon juice can also be used for neutralizing, preparing it as follows: 250 milliliters of lemon juice to 750 milliliters of water (the pH should be 3). With either citric acid or lemon juice, the solution looses its strength after neutralizing a certain quality of the product. For this reason, the strength of the solution must be controlled regularly with pH indicator paper so that the pH value is kept constant at 3. If the pH goes up to 4, citric acid or lemon juice must be added to the solution in order to lower the value to 3.

In the peeling of peaches for example, the sodium hydroxide solution (NaOH) should have a 3% concentration, with a temperature of approximately 85^0C. and an immersion time of from 3 to 5 minutes. The solution is prepared by dissolving 30 grams of sodium hydroxide (NaOH) in each liter of cold water, taking care to use industrial gloves and protective glasses or goggles. Pyrex or plastic containers should be used as well, because the process is exothermic and the solution easily reacts with metal, producing oxidation. When heating the solution to 85^0C., stainless steel or enamel pans and containers in excellent condition should be employed. These pans are resistent to the attack of the hydroxide and the high temperatures. Aluminium vessels can't be used.

4.5 SCORING

This treatment is used principally with fruits such as plums, figs, and grapes, to obtain a scoring in the epidemic layer of its skin, thus easing the drying process.

The scoring consists of the immersion of the fruit in a hot (80°C) 1% solution of sodium hydroxide (use 10 grams of sodium hydroxide for each litre of cold water). The product should be immersed from 5 to 10 seconds, then washed with potable water and neutralized for ½ minute with citric acid at 0.2% (2 grams of citric acid in one litre of potable water) before being taken to the dryers.

4.6 SALTING AND SUGARING

Salting refers to the addition of sodium chloride (common salt) which, depending on the product to be dehydrated, can accentuate the original flavor. Sugaring refers to the addition of sucrose (sugar). In these two processes there is no limit to the quantity of the additive except taste. It is only necessary to clearly specify the quantity that has been added.

The common action of both salting and sugaring is the reduction of the activity of water, which inhibits, or at least retards, microbial development. They are especially useful as a means of facilitating the first phase of the drying process. These pretreatments are also used for other products such as jellies, marmalades, pickled products, etc although dehydration is not employed in their processing.

5. HYGIENE

5.1 Water

Due to the multiple uses of water (washing, blanching, thermic treatment, and cleaning) in the process of food dehydration, a large quantity of that liquid is necessary. It can be classified as:

- Potable water
- Water for disinfecting

5.2 MAKING WATER POTABLE

Potable water is general-use water for processing the food and for cleaning the plant, the equipment, the utensils, etc. This water should be soft water that is free of soluble salts that can influence the texture of certain fruits an/or produce deposits on the equipment or glass containers. The water should be clean and stable sanitarily, i.e potable and clear with no colour, taster, toxic ions or pathogenic bacteria.

All products to be dehydrated should be washed in potable water to eliminate surface impurities and make the process more effective. The water is made potable using sodium hypochlorie, calcium hypochlorite or chlorine in adequate concentrations, followed by an evaluation of the final chlorine content using a chlorometer, which should indicate from 3 to 5 ppm of free chlorine. In order to produce this concentration dissolve from 3 to 5 miligrams of sodium hypochlorite in each litre of water. (For 1000 litres of water use 3 to 5 grams of sodium hypochlorite).

A food dehydration plant must always use potable water in all its installations, and the quality of the tap water in the plant should not be trusted. Before beginning the processes the content of active chlorine in the water should be controlled, the minimum acceptable concentration being 3ppm.

5.3 DISINFECTION OF THE PRODUCTS

The products are exposed to being infested by a wide variety of microorganisms which are carried by the wind, the rain, or the atmosphere and are then deposited on the products, which also run the risk of coming into contact with contaminated material such as animal manure or water used for irrigation.

In order to guarantee the microbial quality of the final product, the majority of the products, after being washed in potable water should be disinfected by immersion in chlorinated water (15-30 ppm of free chlorine) for 3 to 5 minutes before going on with the following processes.

The water used for disinfection requires the addition of sodium hypochlorite or chlorine to reach a final chlorine content (measured with a chlorometer) of from 15 to 30 ppm (30 to 60 miligrams of sodium hypochlorite for each litre of water, or from 30-60 grams for 1000 litres of water).

Disinfection with chlorinated water is effective in food products such as fruit, legumes and vegetables.

The chlorine in the water is consumed as the disinfection of the products is being carried out. For this reason, the person in charge should control the concentration of the chlorine after every 1000 units or failing that, every half hour.

The chlorine concentration should be controlled by using the kit designed for this purpose according to the instructions included with the equipment.

5.4 THE USE OF JIK FOR MAKING WATER POTABLE AND FOR DISINFECTION

We can also use jik or any other product which contains a sodium hypochlorite solution with an active chlorine concentration of 80 grams per litre, and which can normally be found in all markets and supermarkets.

In order to make 100 litres of water potable, add 3.75 millilitres of Jik (3-5 ppm of free chlorine). The quantity of jik should be reduced for smaller quantities of water, e.g for two litres adding 3 normal drops is sufficient.

For disinfection add 37.5 millilitres of jik (15-30 ppm of free chlorine) to 100 litres of water. For two litres add 14 normal drops. The Jik should be handled with gloves and once open should be stored in a well-covered plastic or glass container. It should be kept in a cool, dark place to avoid loss of strength.

5.5 SANITARY CONTROL OF THE PERSONNEL AND INSTALLATIONS IN A FOOD DEHYDRATION PLANT

The quality of the dehydrated products depends on the health and hygiene of the personnel as well as on cleaning and disinfecting the installations in the plant. If these two aspects of sanitary control are not taken into account, the quality of the product will diminish.

A. Personnel Health and Hygiene

The personnel in charge of dehydrating the products should be examined periodically in order to determine their state of health. These examinations should include a blood test, urine analysis and stool analysis, to check for parasites and other illnesses in the workers organisms.

The personnel should also comply with sanitary norms, as any negligence could endanger the health of the consumer. It has been proved by experience that contamination originates with dirty or ill people.

All the personnel, including the administrators, should wear some kind of head covering and should wash their hands before entering the processing area.

Workers suffering from diarrhoea or stomach aches, or showing signs of skin infections or burns should be sent home for immediate treatment.

B. Cleaning and Disinfection of the Installations

Cleaning the installations consists of eliminating residue and other impurities. Disinfection consists of destroying pathogenic germs and other microorganisms that could deteriorate the quality of the product. Cleaning and disinfection are two consecutive operations. The disinfection should be carried out moments before using the equipment.

Loose impurities and adherences of hard material can both be present. As dirt adheres to irregular surfaces more firmly than to smooth ones, the equipment should be mad eof smooth material and its make-up should facilitate cleaning it.

C Detergents and Disinfectants

The detergents should meet the following requirements:

- Soften the water and prevent the sedimentation of non-soluble salts in the equipment
- Improve the moisturizing capacity of the water, in order to facilitate cleaning
- Emulsify the grease into small globules, so that it wont adhere to the surface
- Disperse the solid impurities so they can be eliminated easily
- Not be toxic or irritate the skin

There are two types of detergents: alkaline and acid. The alkaline detergents are principally made up of caustic soda, sodium carbonate, etc. The acid detergents contain nitric acid, phosphoric acid, citric acid and tartaric acid. These detergents eliminate the deposited mineral salts. They have the disadvantage of being very corrosive on metals, so substances should be added to inhibit the corrosive effect.

The disinfection can be carried out using:

(a) Physical means, such as:

- Applying steam with a sterilizing agent and heat, in a sterilizer
- Immersion in boiling water for 10 minutes
- Use of a direct flame on the surfaces to disinfect them.

(b) Chemical means are often used, due to the ease of their application. Chlorine is the most frequently used chemical disinfectant, keeping in mind that in high concentrations it produces corrosion, especially in aluminium and copper

Solutions of caustic soda can also be used as a disinfectant, as is shown in the following table:

Concentration	Temperature	Contact Time
3.7 a 5.0%	50°C	5 min
2.7 a 3.7%	50°C	10 min
2.7 a 3.7%	60°C	5 min.
1.4 a 2.0%	60°C	10 min.
1.2 a 1.4%	70°C	5 min.
1.0a 1.2%	70°C	10 min.

C. Cleaning and Disinfection Operation

The operation of cleaning the equipment and the production room is carried out immediately before they are used.

- Steps to be followed in cleaning and disinfecting:
  - Soaking: To eliminate thick impurities and to soften stuck-on dirt (potable water at 20-40°C
  - Cleaning: The scraping and elimination of dirt
  - Disinfection: The equipment is placed n a disinfectant to destroy microbes
  - Draining and drying: This is done when the equipment is not in use

The chemical concentrates are extremely caustic so gloves, an apron, rubber boots and protective glasses or goggles should be worn. For quick treatment of any possible burns, two neutralizing solutions should be kept prepared: a 2% solution of diluted acetic acid (2 millilitres of concentrated acetic acid diluted in one litre of potable water) and a 1% to 2% solution of monoacidic carbonate.

The efficiency of the cleaning and disinfection is evaluated to microbiological norms. The best-known norm is based on controlling the total number of germs per surface unit of the equipment that is in contact with the product being elaborated.

To reduce the risk of contamination hot water, soap and disinfection should be not just available, but easily accessible.

5.6 CLEANING AND DISINFECTION OF THE EQUIPMENT AND PROCESSING ROOM

The processing room in a food drying plant should have floors and walls that are easy to clean. These should be of smooth material impermeable to water and grease.

In general, cement is used for the floor and glazed tiles for the walls.

The equipment that comes into contact with the product (knives, plans, slicers, etc) should be made of stainless steel and easy to clean.

The floors, walls, processing tables, tubs and other surfaces should be cleaned by:
First, washing and scrubbing them with sponges and brushes with nylon bristles (to remove the hard dirt), detergent and potable water. Afterwards they should be rinsed with hoses to eliminate all the impurities present.

Second, distribution is carried out with a 0.4% solution of sodium hypochlorite (4 grams of sodium hypochlorite dissolved in each litre of potable water). This is effective for disinfecting the equipment, floor and walls, and should be applied with sponges. Care must be taken to thoroughly remove all this solution from the equipment and tools, with fresh, clean, potable water ten minutes after its application, in order to avoid corrosion of the equipment.

5.7 CLEANING AND DISINFECTION OF THE SOLAR DRYERS

The dryers should be washed routinely after each processing and they should be disinfected with chlorinated water before the products to be dehydrated are placed in them. The entire process should be carried out wearing gloves and aprons.

Washing

If the dryer trays are removable, they should be washed outside the dryer.

The trays should be washed using brushes with nylon bristles together with soap and potable water. Care should be taken to scrub all the tray area, tops as well as bottoms, with the brush. Afterwards the trays should be rinsed thoroughly with abundant potable water, so that no traces of soap or detergent remains.

The internal and external roof and walls of the dryer should be washed with only a hose, sponge and potable water taking care not to damage the stabilized plastic. The formation of a dust layer on the plastic should always be avoided, as this impedes the passage of the solar rays into the interior of the dryer.

All thick particles and deposited dust should be removed from the floor using a broom, hose, detergent and potable water.

Disinfection

The dryer trays should be disinfected with chlorinated water (see 5.6) before the products to be dried are placed on them. This is done to eliminate any undesirable microorganisms and thus guarantee the final microbiological quality of the dried product.

Put the chlorinated water in a plastic container and use a sponge to rinse the entire surface of the trays with it.

5.8 FUMIGATION OF THE PLANT

Carrying out a rigorous treatment to prevent attacks by insects and rodents is very important. The worst danger is from infestation by moths, which cause the most problems and are the most difficult to combat.

There are various methods for preventing moth infestation based on the use of synthetic or natural insecticides.

The use of synthetic insecticides or repellents is not advisable because they leave toxic residue on the product.

There are natural repellents which, when applied in the dryer and/or in the storage room, drive off the moths with no harmful effect on human health. Some of these are the chrysanthemum flower, "muna", certain types of "barbasco", smoke from eucalyptus leaves, etc. the degree of concentration of the natural repellent must be strictly controlled in order to achieve maximum efficiency without producing non-typical odours in the products.

So far, a good result has been achieved from periodic fumigation (every 15 days) of the entire plant with "Piretrina", a natural insecticide obtained from chrysanthemum flowers.

It is a biodegradable product, which leaves no residue and is non-toxic; therefore, it is not harmful to health.

The fumigation should be carried out in the room where the products are received, the processing room and the storage room.

The concentration of “piretrina” which is effective against infestation by moths, flies and mosquitoes is from 0.1-0.2%.

The use of mosquito netting before, during and after the drying keeps insects off the product.

The doors and windows on the plant installations should have screens to prevent the entrance of insects, rodents, etc.

Improving the quality of the process as well as achieving optimum results are goals to be achieved progressively, with continuing care and constant improvement in carrying out daily tasks, along with conscientious cooperation on the part of the workers.

6. SAFETY FOR PLANT PERSONNEL

It is very important that all plant personnel be aware of the importance of using the complete working uniform, which must be in a hygienic condition appropriate for the type of work to be done. For the plant personnel who will be in contact with the food this means: aprons, gloves, caps, surgical masks, protective glasses or goggles, and boots. These measures are taken, not only to guarantee the final quality of the product, but also to protect the workers from physical injury, as they are always at high risk from cuts, burns, poisoning, etc. above all when they are working with special equipment such as knives, machines, cookers at high temperatures, exothermic reagents, etc.

Appropriate warning signs should be posted in all the rooms where processes are carried out and they should be enforced, in order to avoid accidents. Some necessary warnings are: “High Voltage”, No Eating or Drinking”, “No Jewellery or Other Personnel Adornment Should Be Worn”.

7. ANALYSIS OF FINISHED PRODUCT

7.1 Water activity

There are various ways to define water activity, and some of them are listed here:

- “Moisture available for permitting chemical and microbiological reactions to take place”
- “Point of equilibrium between the relative humidity of the product and of the air”

The multiple functions which water fills in the development of microorganisms can be summarized in three areas:

- As a vehicle for nutritive substances
- As a solvent for salts, and
- As a catalyst for different chemical reactions

If the availability of water is diminished, it will affect microbial growth, which can be understood as incapacity for reproduction.

Resistance to lack of "available" water is not identical for all microorganisms. For example, it is greater in funguses (moulds and yeasts) than in bacterial.

The minimum water activities for the growth of microorganisms in food are the following:

Microorganisms	a_w
Normal bacteria	0,91
Normal yeasts	0,88
Normal molds	0,80
Halophylic bacteria	0,75
Zerophilic moulds	0,62
Osmophilic yeasts	0,62

It is relatively easy, when drying food with conventional energy, to reach a final moisture content of from 2-3%. When drying foods with solar energy, however, moisture contents lower than 8% are rarely achieved. Because of this difference, more care must be taken with the quality of the final product and especially with its water activity.

Water activity is a parameter which must be monitored, on one hand as an inhibitor of the proliferation or growth or microorganisms in a range of less than 0.70, and on the other hand, for its relation to the internal chemical reactions peculiar to the specific food. In respect to this last aspect, the possibility of an increase in non-enzymatic browning between 0.60 and 0.70 must be taken into account.

Much of the chemical, and especially the microbiological, deterioration can be avoided with adequate solar dehydration and strict control of the water activity in the finished products. This products microbiological stability and lessened chemical activity, resulting in increased shelf-life of the dried product.

In order to guarantee the stability of dried products, water activity between 0.55 and 0.65 is necessary.

I solar drying, one way to avoid bacteriological deterioration of the food is to begin the drying in the morning so that the range of water activity (0.8-1.0), which is optimal for bacteria, is rapidly lowered.

Measurement of water activity can be carried out with special apparatus and electronic instruments designed to determine water activity. These have reasonable capacity, speed and precision.

7.2 ORGANOLEPTIC EVALUATION

Organoleptic evaluation consists of the evaluation of characteristics such as colour, consistency, texture, taste and odour. This evaluation is what determines the acceptance or rejection of the product, as these characteristics influence the consumer even more than compliance with sanitary regulations. Organoleptic evaluation is carried out in order to stop, change or correct the elaboration process when the product does not reach the desired degree of quality, even if it meets sanitary regulations.

7.3 GENERAL PHYSICAL ANALYSIS

The weight, determination of percentage of dry material, ashes and moisture are analyses which are necessary for the evaluation of the dried product.

A. Weight Loss

The weight loss in a dried product is equal to the difference between the initial weight of the fresh product (before entering the dryer) and the final weight of the dried product: Wi-Wf. If the final weight of the dried product is known, we can determine the reduction index of the product, i.e the relation of the weight of the fresh product to the weight of the dried product (Ir = Wi/Wf), as well as the final moisture content of the dried product, percentage of wastage, loss, etc.

There are many kinds of balances, which can be used to determine weights. These vary according to the function, construction, capacity, and precision which is required.

The scales should be checked periodically in order to avoid any mulfunction.

B. Moisture

The percentage of dry material and moisture in a product can be determined based on the evaporation of the water contained in it. The evaporation can be carried out in a heater in which the temperature is constant, keeping a record and using a precision scale. The procedure is as follows: A sample of the fresh product is taken, weighed and then put into a heater which is at a constant temperature (50-70%°C). After 30 minutes, the sample should be withdrawn from the heater, note taken of its new weight, and it should be returned to the heater. This procedure is repeated until the sample reaches a constant weight, which will be final weight of the dry sample.

For better control, the analysis should be done twice, and there should be little difference between the results. If the results should differ considerably, this indicates either that the sampling was faulty, or that the handling of the samples was deficient.

There are companies such as SARTORIUS that manufacture infrared moisture-measuring instruments. These instruments, consisting of a balance with infrared heating incorporated, have good accuracy and function quite rapidly. Direct results can be obtained for weight, moisture (on a wet base on a dry base), as well as determination of the drying curve.

The percentage of water in a product can also be measured two ways:

$$\text{Relative humidity HR} = \frac{\text{Quantity of water (kg)}}{\text{Total weight (kg)}} \times 100 \text{ (wet base)}$$

$$\text{Absolute humidity X} = \frac{\text{Quantity of water (kg of water)}}{\text{Dry mass (kg of dry mass)}} \text{ (dry base)}$$

Knowing the HR, X can be determined and vice versa, using the following relationships:

$$HR = \frac{X}{100-HR} \qquad X = \frac{HR}{1 + X}$$

The total weight of a product is defined as its total water content plus its dry mass:

$$M = Ma + Ms$$

7.4 CHEMICAL ANALYSIS

Chemical analysis are necessary to determine the colour and flavour content of the product as, well as its protein, vitamin, and chemical residue content, principally.

These analyses require specific techniques, instruments and reagents, i.e a very well-equiped laboratory and qualified personnel.

7.5 MICROBIOLOGICAL ANALYSES

The industrial production of dried foods demands measures for microbiological quality control. The results of the microbiological analysis of dried foods of vegetable origin should not surpass the figures on the following table:

Microorganisms	Col/Gram
Total germs	100,000
Coliforms	100
E. coli	10
Bacillus cereus	1,000
Staphylococcus	100
Fungi	300
Salmonella	0 in 50 grams

Source: Alimentos Sometidos al Secado Solar, Lima, 1988.

Microbiological analyses are important in quality control to detect microoganisms that may, or may not, be pathogenic. The microbiological analyses include the following:

- Routine analyses to control the production process
- Analyses to determine the degree of freshness of the raw material
- Analyses to investigate reasons for product spoilage
- Analyses of products suspected of causing poisoning.

The microbiological analyses mainly include the total microorganism count, the total count of molds and yeasts, the detection of colibacteria, the detection of streptococcus, and the detection of salmonella and Shigella.

7.6 SAMPLES

In order to carry out the physical, chemical and microbiological analyses of the dried products, samples representative of the production should be taken. If the production line is continuous, a sample is taken at random, at fixed intervals.

In discontinuous production, samples are taken of each lot. With small lots, 3% is taken as a sample. With large lots and continuous production, 0.5% is taken.

The sample taken should be numbered and organized into tables with the following data:

- Production lot
- Date
- Time sample was taken
- Sample's external appearance at time it was taken
- Person in charge
- Initial weight
- Internal temperature
- External temperature
- Air flow
- Relative humidity
- Observation of the weather (cloudy, sunny, rainy, etc)

The treatment received by the product should also be mentioned.

The samples taken in a pouch and should be analyzed as quickly as possible in order to avoid alterations.

8. PACKING AND STORAGE

This is undertaken with the aim of protecting the dehydrated product from rehydration problems, and/or risks of infestation by insects or other pests. Materials with little permeability to water vapour, such as cellophane, polyethylene or polypropylene should be used, and/or lined carbboard or wooden boxes, and/or cans. The decision is based on transportation requirements and storage time.

As soon as the product is placed in its package it should be sealed immediately, removing as much air as possible from inside the package. This is to avoid direct exposition of the product to the surrounding air and to avoid any insect attack.

The packaging to be used should not be opened without the hands protected by gloves. If plastic bags are used, they should not be opened by blowing. All the process should be carried out while wearing appropriate clothing (boots, surgical masks, gloves, caps).

For packaging the product should be cool, i.e at room temperature; if not, condensation and rehydration of the dry product within its closed or sealed package will take place.

The packed product should be stored in a fresh, dry, and preferably dark place until it is shipped to the consumer.

9. DEHYDRATION OF FRUITS AND VEGETABLES

Fruits are living species which continue breathing after being harvested, that is to day, absorbing oxygen and releasing carbondioxide. The breathing is accompanied by the expelling of the water contained in the cells. It is by this "sweating" process that the fruit shrivels.

The degree of maturity of the fruit is important in obtaining a product with the desired characteristics. The maturing of the fruit, either on the plant or after harvesting, is essential to an optimum balance of its organoleptic properties. The harvesting should take place at the most appropriate time. Collecting the fruit at an inappropriate stage can lead to the development of anomalies that can adversely affect the processing and preservation of the final product.

Too early harvesting impedes the ripening of the product during storage. Furthermore, too immature fruit is liable to physiological changes and a high degree of "sweating". Fruit harvested too late has a shorter preservation span. Futhermore, it is more liable to spoilage and the adverse effects of handling.

It is difficult to generalize when referring to the degree of ripeness of the products. For this reason it is advisable to carry out tests on each type of product under the prevailing climatic conditions.

In general, fruits have as their common characteristics a fibrous consistency, are rich in sugars, have relatively high acidity and pronounced aroma. They are usually eaten raw.

The majority of fruits contain an average of 85% water, 3% glucose, fructose, and sucrose, and 2% protein. The rest of their solid content consists of cellulose fibre, pectin compounds (which contribute by giving consistency to those fruits containing pectin), salts and vitamins. In general, fruits contain a greater proportion of sugar and organic acids, having less starch, protein and salts than vegetables. The proportion of the diverse chemical constituent parts varies considerably during growth, maturing, storage, etc.

Fruits contain the following organic acids:

- Citric acid, found in oranges, lemons, grapefruit, and strawberries
- Maleic acid, found in apples and bananas
- Tartric acid, found in grapes.

Fruits represent an important source vitamins, the most important being Vitamins A and C. The fruits rich in Vitamin C are the citrics, red currants and strawberries, while those rich in Vitamin A are the yellow fruits, such as apricots and mangoes.

Fruit is also a source of minerals: potassium, phosphorus iron, sulphur, and magnesium.

When undergoing technical solar drying, fruits lose approximately 60% or more of their vitamins A and C. This loss is much greater when the drying is carried out in direct sunlight. The use of sulphites helps to preserve the Vitamin C, but is has a destructive effect on thiamine.

Vegetables belong to a food group important source of vitamins in the human diet.

Vegetables subjected to dehydration can be kept available throughout the year, even in non vegetable-producing areas. In this way the human diet is improved, since vegetables are necessary from the first months of life, when they are included in the infant's diet in the form of carrot, potato, and pumpkin purees.

These are important during the post-lactation period when the infant is being introduced to new foods, thus receiving stimulation which widens his/her sensual reception as related to sight, smell, and taste. In addition, vegetables fill nutritional needs not covered by maternal milk alone, after the infant reaches six to eight months of age.

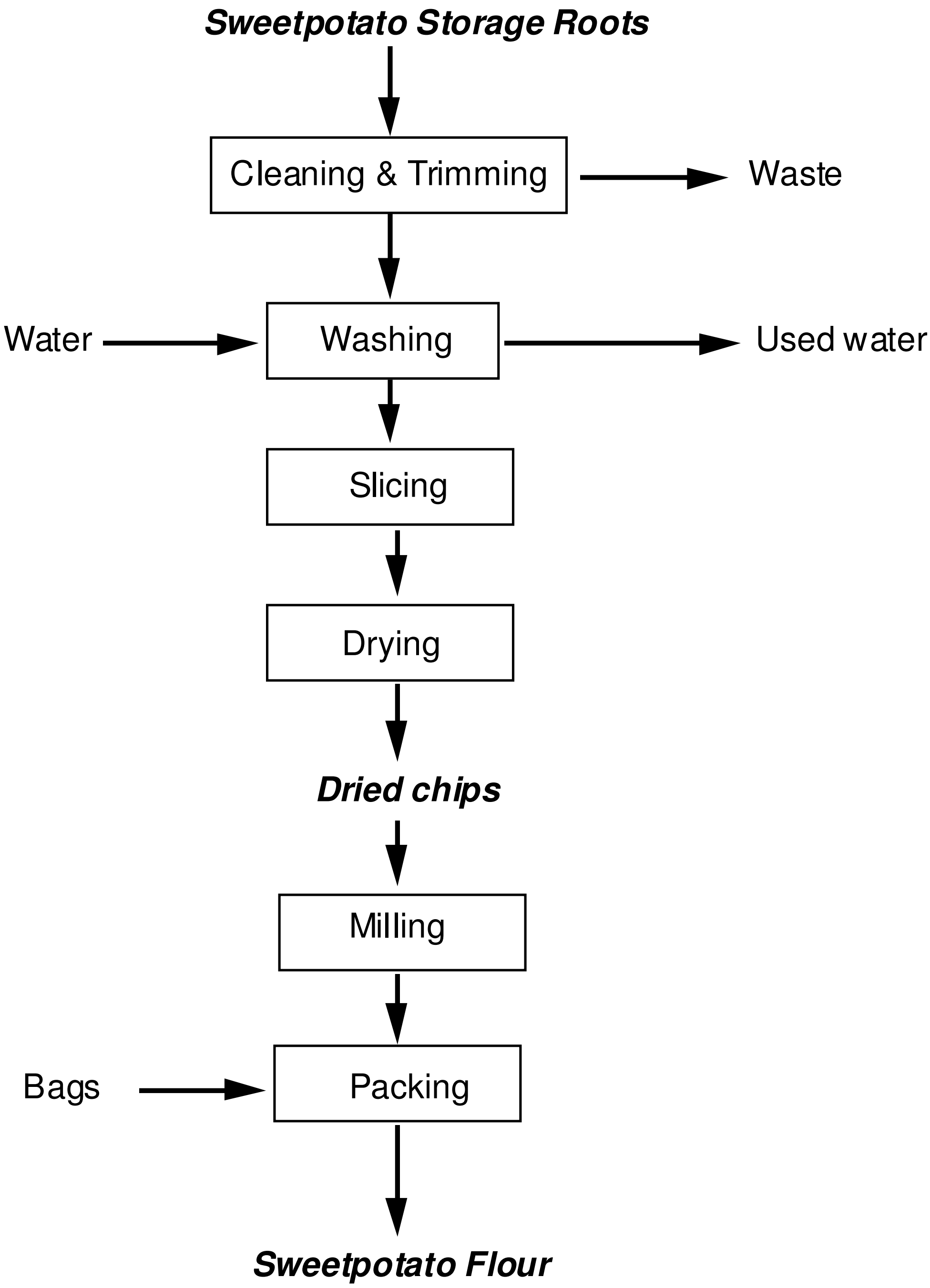

Figure 1. Process flow diagram for producing dried sweetpotato chips and flour

The steps to be followed to obtain dehydrated sweetpotato, are as follows:

- Selection of the raw material
- Cleaning and trimming
- Washing
- Pre-drying
- Slicing
- Drying
- Grinding
- Packing and Storage