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A continuous production roselle (*Hibiscus sabdariffa* L.) dryer using solar energy

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Abstract

There is now an urgent need to consume immediately products in short periods because they can quickly reach the decomposition. The use of solar energy in dehydrated agricultural products is an important element in our days, since through the appropriate use of technology high yields can be achieved in the postharvest products. With the designed and construction of solar dehydrator and using a system thermal control, it is possible to reduce the drying time of roselle (*Hibiscus sabdariffa* L.) 4 days for 5.098 h on average, with a standard deviation of 1.829. The experimental tests were run under a factorial design 3. The evaluation of the qualitative characteristics is performed by applying the methodology multi-criteria adjusts. This method of analysis compares the functionality of the dryer against other drying systems. The calculation tool is a powerful tool for food dryers that can simulate the drying system before building the prototype. The tool provides reliable results for good decision-making. With this, we obtain the equation that governs the process for drying time, it determines the capacity of the drying process, considering the response of variable final product moisture. The analysis reveals the behaviour of the roselle within the tolerance limits of the process; a lower humidity at 11.05% and the higher humidity in 14.64% are obtained to standard deviations. With the experimental run average value is obtained from the final product moisture to 12.84%. A continuous production roselle dryer using solar energy could improve the quality of production and integrate the use of zero energy design in the agricultural sector.

Key words: Drying technologies, energy consumption, dehydrated agricultural products, multi-criteria adjusts, embedded system, food dryers, conventional energy.

Introduction

Drying and dehydration of agro products is one of the most energy-intensive processes in the food industry and a promising method of reducing postharvest losses. The drying is a key industrial process that can save money by avoiding wastage of costlier energy. Improving energy efficiency by only 1% could result in 10% increase in profits; that accounts for about 10% of total energy consumption in industry [1]. Energy savings can be achieved through some approaches such as improved apparatus design, optimization and heat recovery [2]. The drying is described as the mitigation of the moisture of the material to be dried to the desired drying values within a particular period of time. However, food dehydration causes loss of volatile compounds and flavours, changes in colour and texture and decrease in nutritional values. The removal of water from the foods provides microbiological stability, reduces deteriorative chemical reactions and reduces transportation and storage costs. Drying of agro-products under direct sunlight is the traditional way of reservation of foods [3]. However, there are some things to watch for such as case hardening, scorching, souring, mold and insects. Therefore, the continuous dryer agro products using solar energy has the advantage of minimizing the negative effects of traditional drying in addition to being zero energy design (Fig. 1).

The problem of drying food in Mexico and in some developing countries is an important case in food preservation as a means to increase the benefits of agro-food production. There is now an urgent need to consume immediately products in short periods because they can quickly reach the decomposition. Additional growing and harvesting periods are in most cases temporary; thus, with the ability to take into the postharvest treatment, these products will achieve to benefit producers. Product drying is greatly stabilizing the efficiency of food preservation [4]. Generally, this technique is applied in tropical agricultural regions, considering that most rural towns do not have the technological knowledge on drying and the appropriate use of alternative energies, as in the case of using solar energy as an energy source capable of accelerating the process of dehydrated foodstuffs [5]. It is believed that the use of conventional energy in our environment is costly due to high fuel prices [6]. It is noteworthy that proper use of solar energy can give great benefit as adequate control of drying processes allows control over the essential characteristics of the products. However, progress in this area is still emerging, and most companies currently have these dryers that are handled through conventional energy, such as gas engine [7], thereby obtaining a basis for combustion and heating air drying [8].

Roselle (*Hibiscus sabdariffa* L.) is a tropical shrub found around the world [9, 10] with an approximate height of 2-2.5 m (Fig. 2). It is commercially harvested in several states in Mexico, most notably in Colima, Jalisco, Guerrero, Oaxaca and Veracruz [11]. As part of the plant's flower system, the calyx consists of the group of sepals which surround and protect the flower petals. This is what is

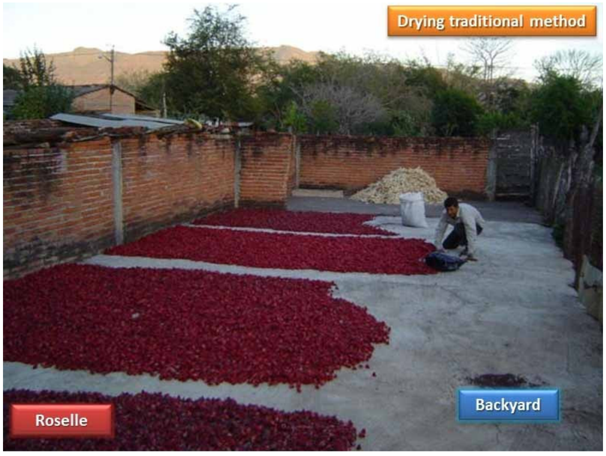

Figure 1. Drying traditional method of roselle for agricultural producers.

Figure 2. Roselle (*Hibiscus sabdariffa* L.) harvested in Mexico.

usually harvested and processed, not the flower petals themselves (calyx which at times is simply referred to as roselle). The dark red calyx is used in the production of teas and juices and also in the treatment of various physical ailments, such as those related to the kidney or stomach [12]. Roselle is also believed to help lower harmful levels of cholesterol and fatty acids found within the blood, and thus is used in the prevention of cardiovascular-related diseases [13]. High levels of humidity make roselle calyx more susceptible to decomposition and high levels of dryness reduce colour and flavour [14]. Traditionally, roselle calyxes are spread over open-area floors and dried naturally by the incidence of solar radiation [15]. At sundown, the calyxes are gathered up and stored and the process is repeated the next day. This procedure takes an average of three to four days, depending on such conditions as ambient temperature and relative humidity. End-product quality is often adversely affected by open-air exposure to pollution and the like; lower quality output can in turn lead to lower economic profits for producers [16]. The drying process eliminates the water or humidity content of the calyxes, and yet maintains the nutritional properties specifically, the ascorbic acid content producers [17]. The dehydrated content of roselle specific to the region is fat 0.1 g/100 g, and carbohydrates 12.3 g/100 g, principally. In dehydrated foods, due to minimal water activity, microorganisms cannot proliferate and most of the chemical reactions which alter a plant's chemistry are stopped [18]. Thus, dehydration is a method used to preserve foods for long periods of time [19]. In this way, agricultural products such as roselle can be sold year-round, in and out of season [20].

This paper describes a continuous production of a drying system. It consists of a solar drier and a solar hotter system developed to obtain dried roselle calyx. In the present research, we developed an agricultural product drying works by heating the air by solar energy; this system would acquire significant advantages with respect to drying traditional system and some of these advantages are: low capital investment costs, reduced product contamination, fuel absolute independence, reliability dryness levels, improved product quality, and obtaining competitive advantages in marketing. For the design and characterization of the system, extensive literature review was carried out to summarize the most important one that corresponds to the theoretical framework of the research, the elements of the system, which corresponds to the proposal research, are showing the developed system and the components thereof. To validate the functionality of the system, the factorial experiment was run with four samples; in addition, a calculation tool design and simulation, which was obtained in optimal drying time, was also considered to evaluate the technique multi-criteria, and adjusted as a tool to evaluate the quality characteristics of roselle after drying and air drying against other systems. These results are shown in the results section of this research.

Materials and Methods

Theoretical considerations: For evaluation methods, generally used parameters are selected to evaluate solar dryers; these are mainly based on a review of test procedures and existing parameters for the design and operation of the proposed solar dryers. When performing a drying process in foodstuffs, the drying process simultaneously involves the study and understanding of, (a) heat transfer through the surface of the product being dried, combined with the heat transfer from the inner product and mass transfer inside the product and the surface (b) followed by a transport of moisture around the product. The parameters defined by the physical properties (size, density, texture and moisture content) and the coefficients of heat and mass transfer between air and product, are considered variables during the drying process. These variables are largely influenced by the external conditions of the product as the temperature, humidity and air flow during drying and causing changes in the chemical composition of the product. Each product tolerates a maximum temperature depending on the drying to which it belongs (vegetables, fruit and cereal grains) and in like manner to the moisture content and degree of ripeness [21].

There are many jobs related to the drying process of food. However, standardized tests and assessment procedures for design and construction of solar dryers are not fully available for designers. The design is influenced by solar dryers for construction materials, operating conditions, preferences and interpretation of quality by consumers [22].

In most of the dryers, the material is dried by contact with a mixture of air and water vapour. In this regard, an important variable in the drying of moisture in the air is in contact with moisture given solid. When a wet solid is contacted with an air stream with constant temperature and humidity H, using a large excess of air, so that the conditions remain unchanged, and the solid when exposed long enough to reach equilibrium reached the time that this has a defined moisture, determined value is referred to as equilibrium moisture content of the solid in the specified conditions of humidity and air temperature. Generally, the moisture content is expressed as dry basis kg of water per kg of solid without humidity. For some solids, the value of the equilibrium moisture content depends on the direction in which the equilibrium is reached when the material to be dried contains more moisture than its equilibrium value when in contact with the gas (air) humidity and temperature determined; the material will dry until its moisture balance, and if the material has less moisture than its equilibrium value, absorb water to reach equilibrium.

Efficiency of dryers: The efficiency of the drying system is normally reported as efficiency of the dryer, heat collection efficiency, the collector efficiency, and is specified by the rate of change in the extraction of the specific humidity, measured for a solar dryer by the following relationship; where the efficiency of removing the product by means of air in the dryer is determined by efficiency equation [1]:

$$\eta_p = (h_o - h_i / H_{as} - h_i) = W / pVt(H_{as} - h_i) \qquad (1)$$

This expression shows that the efficiency (pick-up) generally decreases as the moisture of the product decreases. The efficiency of solar drying system is measured from the effectiveness of the energy input to the system and concerning the operation representation thermal efficiency including the manifold. In the drying chamber, when the drying is being evaluated by natural convection, the natural efficiency equation is used [23]:

$$\eta_s = WL / (IA - P_f) \qquad (2)$$

For hybrid dryers that use energy as second resource efficiency is measured by operation varieties equation [24]:

$$\eta_s = WL / (IA - P_f) + (mb{*}LCV) \qquad (3)$$

Some authors measure performance variations of dryers functioning as indices using the evaporation capacity; which is a measurement, which considers the effect of ambient air temperature and humidity in the solar dryer operation. Another index that is commonly used, SMER (Specific Moisture Extraction Rate), describes the effectiveness of the dryer and an inverse effect is specific energy consumption (SEC) and is expressed by the ratio of the moisture removed and the total energy that enters the system.

Kinetics in drying of solid products: Reducing the moisture content in products that are subjected to the drying operation is a process, which is generally considered as necessary dryer size, as well as the different conditions of humidity and temperature employed; furthermore, the time for achieving the level of drying is required. When it is desired to predict the equilibrium moisture content, it is difficult to determine with any mathematical model, so they must rely on experimental methods. To develop mathematical modeling, it is necessary to consider the variables of wind speed, humidity, temperature and direction of air drying. These variables are used to simulate the drying conditions of solid products. The data obtained from a batch drying process is usually expressed as the total weight (W) of the wet solid, which is equivalent to more moisture dry solid, and the solid is taken at different times of exposure in a period of time (t). The obtained values can be expressed in drying speed data by mathematical expressions described by drying equation [25]:

$$X_t = (W - W_s) / W_s = kg\ total\ water / kg\ dry\ solid \qquad (4)$$

The determination of the critical humidity is an important factor in the drying process since this is where the solid presents the change from the first to the second period of drying (a period of constant speed decreasing speed), and the critical moisture depends largely on the material type and relation of the first drying period. The shape of the curves in the second drying period varies depending on the characteristics of the material to be dried [23]. The equations for calculating this period is defined from the general equation of Fick's law for steady-state diffusion. For applying Fick's second law for steady state, Fick's equation is used:

$$\partial X / \partial t = DL\, \partial^2 X / \partial x^2 \qquad (5)$$

Such characteristic is usually broadcasted in the relatively slow drying of granular materials as well as in the later stages of drying of foods and other hydrophilic solids. The main difficulty in analysing data dissemination drying is that the initial distribution of moisture is not uniform throughout the solid at first, if the falling rate period is followed by a constant speed. During drying by diffusion resistance to mass transfer of water vapour from the surface is usually quite small and the diffusion in the solid controls the drying rate. Then, the free moisture content in the surface is in equilibrium at a value XE, which means that the free moisture content in the surface is essentially zero. Assuming that the initial moisture distribution is uniform at the time t = 0, the following expression of equation is obtained:

$$(X_t - X_E)/(X_{t1} - X_E) = X/X_1 = 8/\pi^2\,[e^{-DLt(\pi/2)*2} + 1/9e^{-9DLt(\pi/2)*2} + 1/25e^{-DLt(\pi/2)*2}] \qquad (6)$$

From this equation, it implies that DL is a constant, but in reality it is rarely constant and varying with the water content, the temperature and humidity in the case of long drying times, as is the case of foodstuffs. The only term in the equation of interest is the first expression and transformed equation defines the time of drying:

$$t = (4X_1^2 / \pi^2\,\mathrm{DL})\ \ln\,(8X_1 / \pi^2 X) \qquad (7)$$

From this equation, the mechanism starts broadcasting at $X = X_C$, differentiates with the speed and drying yields from this equation:

$$R = -L_s / A(dX/dt) = \pi^2 L_s DLX / 4X_1^2 A \qquad (8)$$

Therefore, when the internal diffusion effect is prolonged, the drying rate is directly proportional to the free moisture *X*, liquid diffusivity and inversely proportional to the square of thickness. With highly porous solids, where the pores are large, decreasing speed curve is usually straight and therefore the diffusion equations are not applicable. During the period of decreasing the solid speed, the drying process is no longer completely wet and in this case the drying rate decreases uniformly with time. In the process of decreasing rate drying, it is considered that the drying rate is a linear function with the free moisture content. This explains that when products lose moisture, there are two periods, the constant rate period and the falling rate period. This section describes the method for calculating the constant rate period. During this period of drying, the solid surface is very wet at first, and on it, there is a continuous water film that water is uncombined and it acts as if the sound was not present. In this case, the evaporation rate with the conditions set for the process is independent of the solid equals pure liquid surface. Also, if the product to be dried has undulations and indentations in the surface, they help to obtain a speed higher than it would be with a completely flat surface. When the solid is porous, most of the water evaporates during the constant speed period. This period continues while the water contained in the solid surface is maintained to the same reason; it is evaporating in the absence of heat transfer by radiation or conduction [23].

Figure 3 shows the constant speed period in which a product is subjected to the drying process according to the concepts here. Discharges drying or solid material is obtained by the mass transfer of water vapour saturated solid surface, though, for an air stream to the overall gas phase surrounding atmosphere. In this respect, the speed of movement of moisture within the solid is sufficient to maintain the saturated surface.

Experimental details and treatments: In this section, the design, analysis and proposal of solar drying system are presented. Four stages were defined in the design and analysis of the proposed solar drying system by designing a solar thermodynamic drying system based on the prototype analysis. There are a lot of applications, where energy needs to be released at high temperatures; this resource could not be achieved without the use of solar concentrators, since the use of flat plate collectors is limited by their characteristics. It is mainly because solar radiation has low energy intensity, accordingly for temperatures above 100°C, the intensity of solar energy will have to increase. Appearance can be achieved by decreasing the area, where heat losses occur, and interposing an optical device between the radiation source (sun) and the absorbing surface, which must be small compared with the optical device. In this way, the manifold can have energy densities ranging from 1.5 to several thousand times. The solar radiation reaching the optical system can also have temperatures of 100-500°C depending on the finish of the solar collectors. Although this type of solar collectors can achieve high temperatures, several technical problems arise from the engineering point of view compared with the flat solar collectors; generally, the energy concentrators must be directed continuously to the sun precisely, because this type of collector uses only solar energy. Moreover, the surface finish, which is the optical system, should not only be of good quality, but must keep their properties for long periods of time without being damaged by rain and the environment, where there are generally oxidizing and corrosive components. Another important consideration in this type of collectors is the materials used in the receiver (thermal insulation, the working fluid, absorbing and protective tubes for heat transfer), as it is the part of the collector, where the maximum temperature is obtained. There is a wide variety of hubs, but they can all be classified into two categories of approach and the fixed or semi-fixed. Approach concentrators consist of three main parts, which are: the hub or optical system, the receiver sun absorber and follower mechanism. The receiver is the part where solar energy is converted to heat. It can be designed in different ways depending on the needs and ease of converting the energy into heat, which is most commonly handled such as concave, convex, flat, hemispherical, cylindrical, elliptical depressions, where everyone can be linear or punctual [22].

According to El-Sebaii and Shalaby [26], a classical problem is the effect of axial driving on a laminar flow of a viscous fluid through several geometric sections. A simplified mathematical model for concentric tubes carrying fluids gives a significant contribution to analysis of multiphase problems with internal or external recirculation. The equations for the temperature distribution in two concentric tubes with recirculation (Fig. 4) is determined under the following conditions.

System instrumentation: Physical characteristics by drying are defined as type, size, shape, product density and load capacity of the tray area, number of trays, convenience of loading and unloading the dryer. Furthermore, the type of dryer is defined by the materials used for its construction, usually constructed with flat absorber plates, made of aluminum, galvanized steel, painted iron sheet of reflective materials, which are used when trying to reach temperatures above 40°C [27]. The dryer size is directly related to the drying capacity and is based on the amount of drying load or batch of fresh product, regarding the shape of the dryer. Drying food crop product is one of the oldest preservation methods known and practised; at present, the methods are used by agro-processors worldwide. The wide variety of natural drying methods exist for different agro-industrial products and marine products such as shrimp and fish, suggesting that there must be a better method for drying of roselle, without making it to lose its basic nutritional properties as ascorbic acid, colour and tastes. It should be considered that traditional drying of food depends largely on the climatic conditions, humidity levels, as well as air currents and heat. Therefore, for roselle, it is

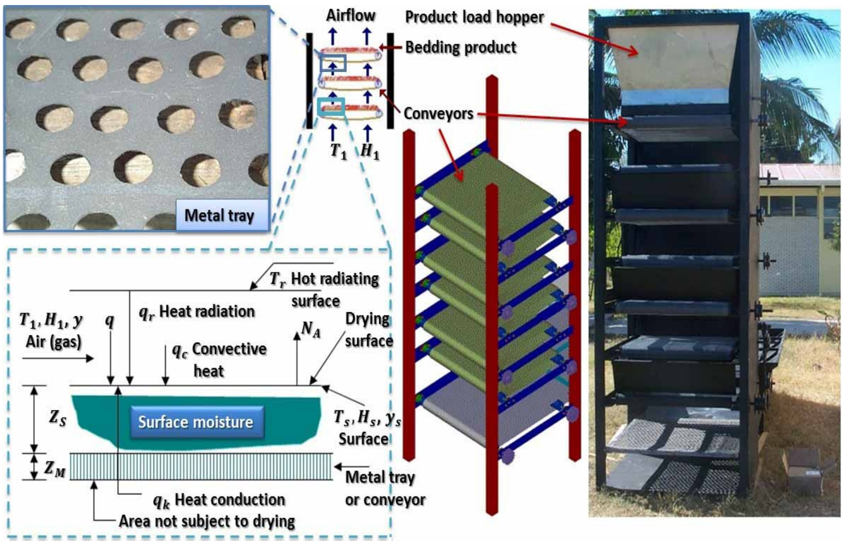

Figure 3. Schematic diagram showing the variables in the surface moisture.

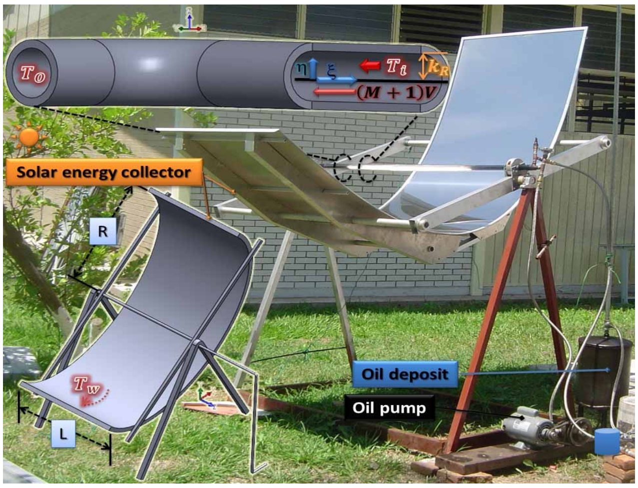

Figure 4. Solar concentrations for hot oil of the interchange.

important to look as life-sustaining food and reduce waste by not having a proper processing. The main problems of traditional process, in the benefit of roselle today, are related to harvesting and dewatering of the flower (chalice) and have not been able to design a computer that can wield the rod of Jamaica with a yield greater than 90%, which is low cost and easy to use. Another problem, which increases the cost of the consumer product, is drying. Today's roselle drawn once extends into eras or patios, to have a natural drying by sunlight, collected when the sun is in the twilight, repeating again operation the next day, and the drying process of roselle is carried out in an average of 3-4 days. It depends on the degree of insolation that exists at the time and place where the drying of roselle is done. Furthermore, by being exposed to the environment and lying on the roofs of houses or producers, roselle is susceptible to acquire pollutants that cause lower quality of the product, making it difficult to market and providing low economic returns to producers. Moreover, it is very common to use butane gas, which has the disadvantage of being brief, explosive and poison without notice, in addition to significantly increase the price of the final product. In low altitude zones for Mexico, the average relative humidity is about 80%, and the amount of water that can be absorbed by the surrounding air is small and the traditional dehydration process of roselle can be rather slow. Such high levels of relative humidity can be artificially lowered by warming the surrounding air. In this case, the proposed system utilizes controlled drying conditions under atmospheric pressure to achieve product dehydration. The proposed solar drying system uses continuous process drying, which offers certain advantages over batch process drying. One of these advantages is that continuous process drying is not constrained to individual process that runs potentially; all but one process cycle is needed to process any desired level of product. Another advantage to consider is that the method of heat transference used by continuous process drying offers better product dehydration results and end-product quality. With continuous process drying, the nature of the product and how efficiently surrounding air is mixed with this product influences the level of drying. With respect to a product's nature, low to moderate temperatures used during the continuous drying process could favour the proliferation of fungi and bacteria because of the presence of product humidity. The presence of microbial activity can quickly lead to product decomposition. Thus, a level of drying, which is not too low, must be determined that avoids product decomposition [28]. On the other hand, utilizing temperatures that are too high may destroy a product's nutritional content (i.e. certain vitamins that are important to colour and flavour may be lost). Therefore, an adequate level of drying, which is not too high, must be determined that prevents nutritional depletion. Four stages were defined in the design and analysis of the proposed solar drying system:

(1) Determine the basic properties of roselle in order to establish various control variables.
(2) Design and construct a solar dryer prototype based on the established control variables.
(3) Analyse the test results obtained using the first prototype.
(4) Design and propose a solar thermodynamic drying system based on the prototype analysis.

The first stage included determining several control variables based on the basic properties of roselle. These control variables were categorized as either qualitative or quantitative:

(1) Qualitative variables: colour, flavour, texture, purity, homogeneity and aroma.
(2) Quantitative variables: product weight, product humidity, product drying temperature and ascorbic acid content.

Initially, the variables for roselle were defined before any testing began. Next, 10 g of calyx was processed over 30 test runs in a thermo balance machine to simulate the traditional drying process. Finally, the product variables were measured after testing, the initial and final results as shown in Table 1.

After establishing weight, humidity and drying temperature variables of roselle, the second stage was designing and constructing a solar dryer prototype. Since drying temperature and air humidity are important to the drying process, the prototype was designed to incorporate tight control over these factors. Maintaining drying temperature affords better control in the preservation of roselle's basic properties during the dehydration process; managing air humidity enables better control over the speed of drying.

Plant harvesting: The proposed solar dryer consists of 17 elements as seen in Fig. 5. Surrounding air is introduced to a drying pre-chamber via a ventilator. After being heated, the air rises cross-currently in the drying chamber and dehydrates the product as it moves along on transporting bands. The band speed is controlled by a VFD, which controls the speed of the engine motor. The motor is connected to the transmission by a speed reducer, which decreases the speed by a 30:1 relationship. The system has a cylindrical parabolic solar energy collector, which

Table 1. Qualitative and quantitative variables of solar dehydrator products.

Qualitative variables	Initial	Final	Quantitative variables	Initial	Final
Colour	Dark red	Deeper, darker red	Weight	1.0 kg of fresh product	0.152 kg of dry solid
Flavour	Acidic	Unchanged	Humidity	0.848 kg of water per 1.0 kg of fresh product	0.143 kg of water per 0.152 kg of dry solid
Texture	Moist & resilient	Less moist & fragile			
Purity	Some surface dust	Some impurities from drying process	Drying temperature	48ºC	68ºC

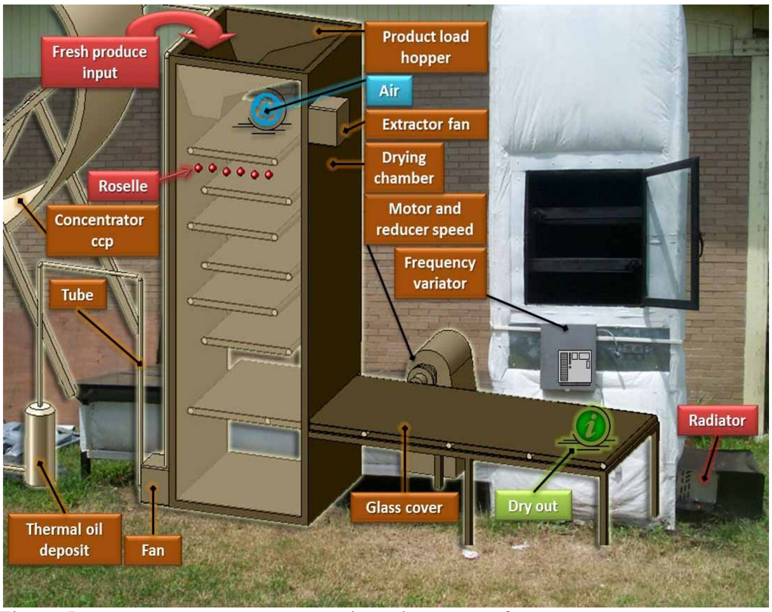

Figure 5. Proposed solar thermodynamic drying system for Roselle and other products.

warms fluid (i.e. water or thermal oil) fed to it by a pump from a thermally isolated container. The heated fluid then passes through a tube to a radiator, where the heat is transferred via forced convection to surrounding air introduced by a ventilator.

The heated air, along with product humidity, is expelled from the drying chamber to the environment by another ventilator. The product is fed to the drying system via a stainless steel hopper or funnel located at the top of the mechanism. After passing through the drying system and along the final band, the product is then collected in a glass-protected chamber, where its final humidity is measured for quality assurance purposes by a humidity sensor. The product is then ready for packaging and shipment.

Results and Discussion

Prototype testing, solar dryer: The results are shown in the form of digital data and downloadable files so that users can easily read the various qualitative and quantitative variables of the agricultural product. The prototype was constructed with a solar concentration to obtain roselle's temperature and drying time profiles, and a pyramid-shaped glass cover was used to improve the temperature performance of the prototype. The temperature profiles for the modified version were obtained in the same way as the flat glass model. This included analysing test results that were obtained using the original prototype. The environmental conditions are related to humidity (*H*) and dry bulb temperature (T_{db}). As the dry bulb temperature (or ambient air temperature) increases during the course of the day, air humidity diminishes and solar drying conditions are at their most favourable. This is to say, as air humidity decreases, there is less outside humidity available for product absorption and product humidification does not increase. On the contrary, the surrounding, unsaturated air actually absorbs the product humidity, furthering the dehydration of roselle. Fig. 6a-c demonstrate the drying kinetic process characteristics of roselle using 10 g of calyx over 4 sample runs.

Two different tests were conducted utilizing the original prototype: the first was under a vacuum pressure of 60 mm Hg (Fig. 6a) and the second was under atmospheric pressure using an air ventilator as an extractor (Fig. 6b). Finally, the comparison between the solar dryer against other commercial dryers different regions (Fig. 6c) was done. The temperature of each test sample against the exposure time period exhibited constant rate drying kinetics followed by a period of deceleration. The atmospheric

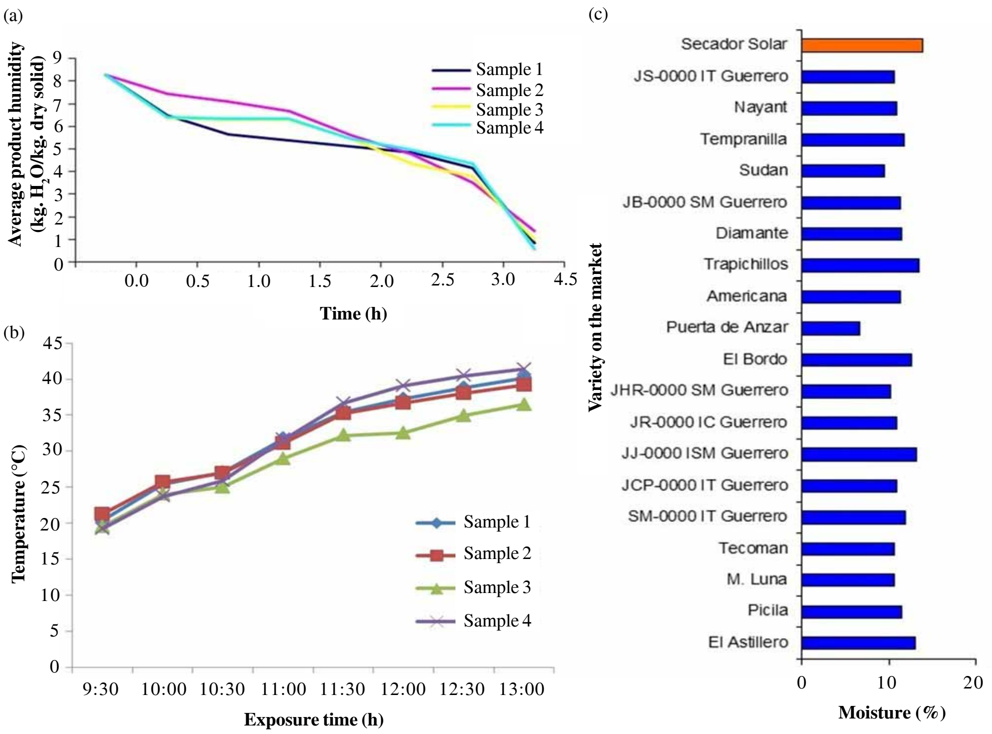

Figure 6. Original data versus results of the (a) drying kinetic process of roselle using prototype under 60 mm hg of vacuum pressure, (b) profile of temperature on exposure time and (c) varieties regions with respect to moisture.

pressure test only displayed a drying period at decreasing speed. The kinetic drying speed of roselle was calculated using the following kinetic drying equation [29]:

$$W = S/A\ (-dx/dt) \quad (9)$$

The prototype is proposing the design of an autonomous, low-cost and robust solar thermodynamic drying system for the dehydration of roselle and other agro-industrial products. This system was used to investigate the dehydration processes of roselle and other products. The roselle at different levels of the dryer is shown in Fig. 7 and the relationship between weight losses and pack relative humidity and temperature is shown in Fig. 8. It is observed that moisture weight and temperature decrease before sun exposure increases and, therefore, the optimal drying temperature is defined.

Figure 7. Roselle at different levels of the dryer.

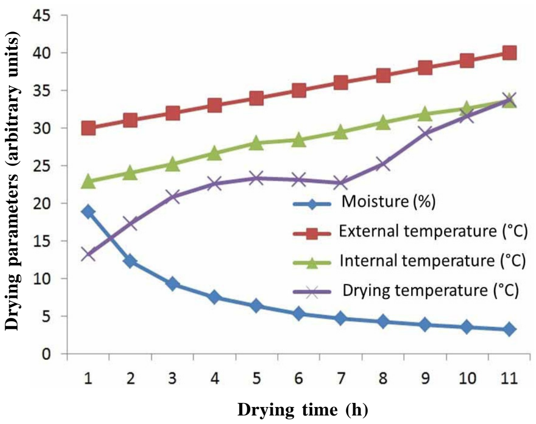

Figure 8. Graph of moisture loss pack versus internal, external and drying temperature over time.

For product marketing, the optimum final product moisture is 12.892%, which is achieved in a time of 1.5 h at the temperature of 30°C. The prototype to determine the maximum temperature was oriented at 19°N latitude. The proposed design works under the subsequent requirements:

(1) The mechanism needs solar energy to function.
(2) Solar energy through forced convection warms the air used in the drying process.
(3) The mechanism has to be intelligent enough to respond to the temperature and band-speed requirements during the drying process.
(4) The drying system will serve as the basis for the creation of other viable systems working with solar energy.
(5) The mechanism must keep the product free of contaminants, unlike traditional drying methods.
(6) The dehydration system must be economically feasible, allowing for the fast recovery of a purchaser's investment in the acquisition of the system.

The cost-benefit of the project refers to the ratio between the benefits to the producer and the cost of investment.

The project's economic calculation is based on the economic loss for producers to stop using the system proposed in this research. The economic loss has a family of roselle producers with a production capacity of roselle 400 kg of dry for a period of 7 working days, shown in Table 2. The results of economic production between traditional and solar method is shown in Fig. 9.

Table 2. Production costs.

Labour wages	Cumulative production cost	
	Solar drying system	Traditional system
1	\$69	\$120
2	\$138	\$240
3	\$207	\$360
4	\$276	\$480
5	\$345	\$600
6	\$414	\$720
7	\$483	\$840

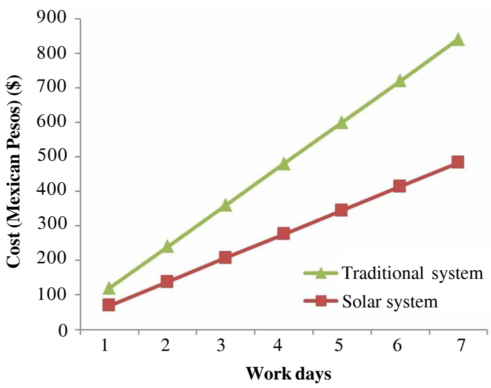

Figure 9. Production costs in the two drying processes.

Statistical analysis: These results are applicable to an analysis of the ability of the process, which is shown in the graphs of the figure obtained from an analysis consisted of process capability and corresponding normal tests. The analysis of drying process in the presence of environmental conditions of different locations or regions is defined by statistical process (Fig. 10).

As can be seen, the data were analysed in 22 subgroups, which perform the control chart. The graph in the middle shows that the averages of the subsets of data is in normal running around half general process having a moisture value of 12.84% with the corresponding natural process limits as 11.05% and 14.64%. According to the limits of 12 to 15% moisture as a requirement of the process, the process more adheres to the lower control limit. The standard deviation of 0.9187 and the process capability of 0.47 assure the good performance of equipment in the drying process of roselle, indicating that the product is less susceptible to microbiological attack caused by high moisture content and also acquires greater shelf life. The result was obtained by comparing moisture available to roselle market in different regions (Fig. 6c).

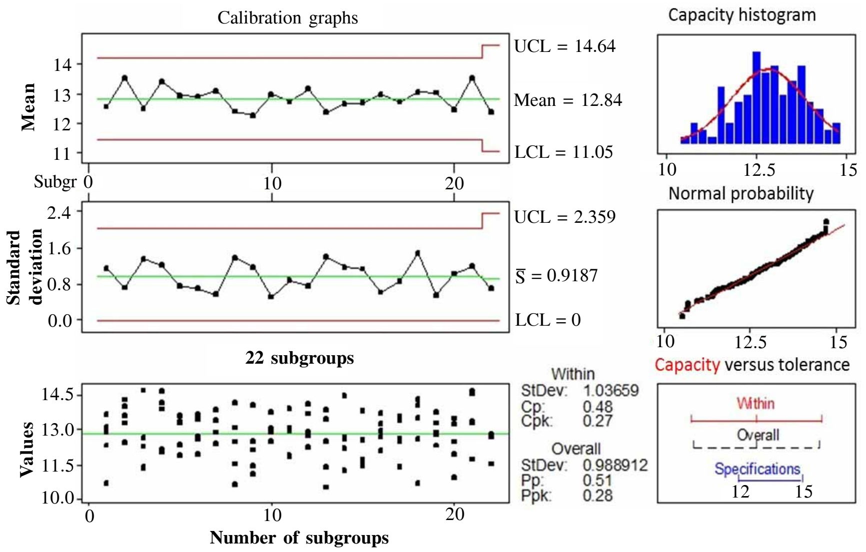

Figure 10. Statistical analysis in 22 subgroups for calculation values in drying process.

Conclusions

The proposed solar drying system for roselle was designed to decrease product dehydration time substantially and diminish pollutants acquired during the traditional drying process. System versatility allows for the adjustment of various process factors such as temperature and humidity. The product control variables were quantified and defined as: initial weight (1.0 kg of fresh product), final weight (0.152 kg of dry solid), initial humidity (84.8%), final humidity (14.3%) and dry temperature (48-68°C). Based on these control variables, the proposed system operates a continuously moving band at a constant speed. This process flexibility makes it possible for the system to be used with other agro-industrial products and affords better control over end-product quality by maintaining material content. Since the system uses solar energy (designed for this system), it does not depend on electricity or other costly forms of energy, providing further adaptability in the workplace. The manufacturing cost of the proposed system would be lower compared to most non-solar dehydration systems found on the market. The solar thermo-dynamic system provides several benefits over traditional and alternative drying methods. This system provides environmentally advantages to agro-producers from low altitude zones of Mexico and around the world. Thermodynamic prototype was designed for drying roselle for drying capacity of 54 kg/day, based on product characteristics and mode of operation of equipment. It reduced the drying time of the roselle from 48 h to 5 h on average achieved 89%, which is 27% above plan. With the development of the prototype, it was possible for the generation of technology for rural producers, impacting its economy as each producer may have an economic blow to your needs, and ensuring dryness levels and protection against microbiological attack counted by the formation of mold and bacteria that will deliver the product to the markets for sale. With the test, mechanism could be performed with other products. It did not dehydrate but obtained characterizations, since it is found that for products like banana, mango and carambolo, the drying time is very long. The current prototype can achieve improved energy efficiency by 1%, which could only result in a 10% increase in earnings, which represents about 10% of total energy consumption in the industry.

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