PERFORMANCE CONTROL FOR SAFE AND PRECISION SOLAR DRYING OF CURATIVE AND AROMATIC HERBS

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1. Introduction

At present, the goal of Mexican agriculture besides of achieving a sustainable development is giving more emphasis towards improving productivity and product quality, farming profitability, low impact on the environmental and marketing competitiveness. Accordingly, energy saving, high productivity and reducing losses is the goal of many industrial and agricultural processing businesses. Rural communities in dryland areas are engaged on gathering cultivated and wild herbs, brushes and plants needed for medicinal and aromatic purposes. In order to enroll rural communities on a sustainable development, profiting from value added products comes from learning the harmful effects any unacceptable activities have on the environment. However, in order to fully understand their challengers at rural level it is important to evaluate all involved aspects, such as; non-rational exploitation of natural resources, they lack of a visionless entrepreneurship, many farms are disappearing because cultivation and gathering vegetative materials is a low yield and unprofitable activity, there is a steadily increase of importing farm products, a market structure is nonexistent so there are deficiencies to supply the quantity of farm produce requested and of standard quality. These factors are an obstacle to achieve adequate competitive levels; therefore, profitability is reduced, so this sector is far away from capitalizing.

On the other hand, shortage of water for farming and rangeland is a factor that influences low yields from crops, grasses and vegetative cover of pastureland. This has a negative effect on the economic welfare for local communities. Therefore, an increase of plants productivity on all these areas depends on making an optimal use of water from all sources (deep water, lakes, surface streams and rainfall and fog harvesting), where conservation measures vary according to the value of crops.

Thus, in order to improve productivity it is convenient to seek new alternatives for increasing competitiveness and sustainability. Being one of Mexico's landmarks, cactus prickly pear (*Opuntia* spp) is referred as one of the most important resources from a socio-economic point of view, as families and communities benefit from it on a wide variety of ways. Cactus prickly pear is spread all over the arid and semiarid regions; it subsist in his harsh environment and grows steadily and produces rapidly dry mater content, consequently it is widely used as an appropriate natural barrier for soil conservation, it has an organic matter content less than 1.0%, it is used as fodder for livestock, its fruit are highly appreciated and their young pad are raw material for many recipes. In the medicine area, it is considered as a natural alternative to control diabetes and other diseases. Consequently, for this study cactus prickly pear was chosen as the representative model for medicinal and aromatic plants.

However, despite of these benefits to local communities, cactus prickly pear is underutilized because processing is at low technological level. A foreseen alternative for optimizing its utilization is through innovative low cost processing and for safe conservation during storage. Especially, when learning the safe practices to preserve those essential oils, sap and gum contained in the herbs. Hence, the objective of this wok is aimed on reliable dehydration of vegetative material by using a solar dryer designed and operated to sustain cactus valuable nutritive and medicinal potential.

2. Methods and materials

Importance of drying

Usually, herbs are harvested when physical shape and health are optimal, as similar physiological features secure a precise control for environment conditions inside facilities. Drying is one of the oldest conservation methods that man knows. Drying technology has a positive economic effect on crop production due to optimal use of organic matter. However, process control for drying with minimum losses requires expertise, mainly knowledge on the type of vegetative material and prevailing ambient conditions. Accordingly, it is important to learn how to use the engineering tools available, i.e. generate the drying graph for a particular herb and interpret the meaning of its three main sections. In addition, it is important to comprehend the organic matter and energy balances, economic assessments and how technology is integrated into the farm production scheme.

Thus, to achieve the best performance, it is essential to understand certain factors, such as; temperature, humidity, wind velocity, surface area for the product to be dried, texture and structure from that kind of mass, atmospheric pressure, partial vapor pressure, intensity of solar radiation, UV range, humidity transport and boundary crossing during the drying method and the time taken for the whole process.

The important factors that intervene on drying experiments are:

- Level of radiation that reaches the dryer,
- Temperature at room conditions, c) useful area for drying,
- Flow of air inside the dryer, and
- Relative humidity.

Moreover, it is also necessary to measure; 1) temperature variation both inside the drying chamber and from the material placed inside it, 2) absolute humidity in the drying chamber and 3) weight variation experimented by the material. Those data are used to determine evaporated water, which verify that a natural drying process is taking place, losses are low and that dryer design is technological convergent with available facilities, such as glasshouses, store buildings, micro-tunnels for intensive cropping, power generating installations, etc.

Through precise control drying, it is possible to enhance by 20-30% the quality and quantity of valuable ingredients inside plants. Storage of dried material is more economic and with fewer losses compared to other conservation methods. It has been realized that during outdoors drying some nutrients and valuable active elements are lost.

Nowadays, the technological process for solar drying has the following benefits:

- Fewer losses of nutritional value and preserving foliage’s quality,
- Yield per land cultivated is increased,
- Mechanization for harvesting can be implemented,
- Handling, transportation and distribution is improved and better sanitation is achieved,
- Milling is improved and mixing additional nutriments can be easily done,
- Smaller space for storage, and
- Solar drying maintains the colour of natural vegetative material.

Expenditures for producing a dry material are rapidly returned once the new product is evaluated on its medicinal or aromatic attributes in terms of quality and quantity produced, and label shows its real added value.

Development of the solar drier

In this study several types of medicinal and aromatic herbs were used. In this paper, however, cactus prickly pear was considered as the model to begin with, its special physiology drove the design parameters for the dryer. On manipulating the drying graph for cactus pear (Fig. 1), it is possible to determine the speed of drying and the quality for the final product by deriving the respective polynomial equation for its three main process stages. This graph makes a representation on how water interacts in a chemical, physic-chemistry and physic-mechanical way inside an object being dried.

It explains the effect used for the drying process and how it is technologically realised inside the dryer. Inside wet vegetative materials there is a combination of effects affecting water movement in the capillary, as long as there is a difference of vapour pressure, likely as during drying blood or milk, for instance.

Accordingly, a low atmospheric pressure can be used to speed up the drying process. However, it requires an expensive technical installation to use this effect more efficiently. In organic, homogeneous and capillary materials, a constant temperature and a difference of water content produce a flow of moisture from the wettest point to the driest. Due to the above relationship it is possible to define the coefficient of moisture conductivity k (Müller, 1978).

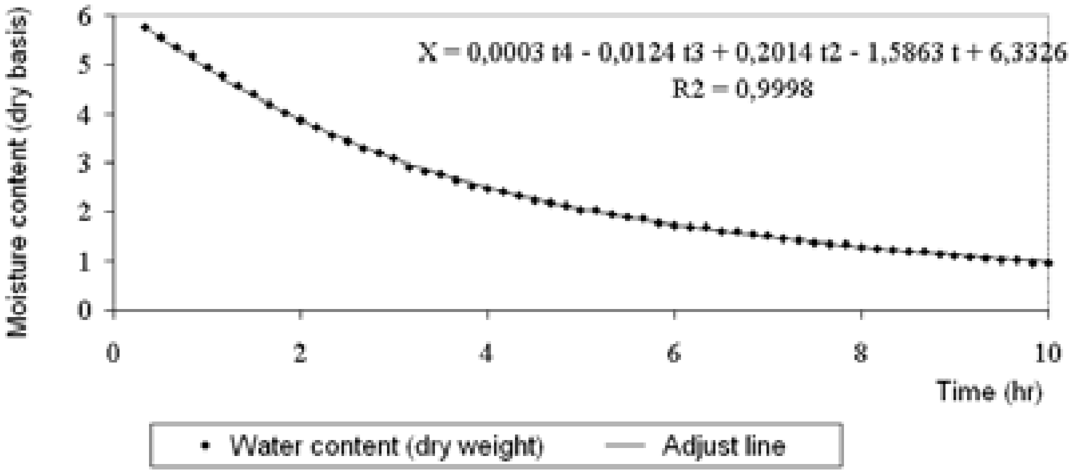

Fig. 1. Characteristic drying graph for cactus pear.

$$\dot{m}_W = -Ak\rho_{tr} * \frac{du}{dl} \quad \text{(eq. 1)}$$

Where:

$\dot{m}_W$	flow of moisture (kg/h)
A	length of cross section of material (m)
k	sum of capacity for conduction of moisture (m^3/h)
ρ_{tr}	bulk density (dry) (kg/m^3)
du/dl	gradient of moisture in the direction of flow (kg/kgm)

Coefficient k is the characteristic for all the coefficients involved on transporting moisture. It is a function that depends directly from the spot where moisture is located (Werner, 1984):

$$k = k_W + D_k + D_k + D_D/R_D\, x\, d\, p_D/du \quad \text{(eq. 2)}$$

Where:

k_W conductivity of capillary transport of moisture (m^2/h)
D_k coefficient of vapour internal diffusion (evaporation and condensation) (m^2/h)
D_L coefficient of diffusion for the liquid (osmosis) (m^2/h)
D_D coefficient for the diffusion of gas-vapour (system vapour-air) (m^2/h)

In order to increase the surface area exposed to hot air, as well as to raise du/dl, it is important to finely cut the vegetative material. The efficiency of this will depend both on the amount of moisture flowing along the stream (kg/kgm) due to reduction of moisture in the air and for increasing the temperature in the drying chamber.

The drying process is defined as the transport of moisture by diffusion and convection from the surface of a solid or liquid material in a medium that allows the flow. In some cases, instead of using the difference among vapour density or the difference of vapour pressure, the difference of water content in the air between the surface x_O and the flow of air x_L is considered as the active force for transporting the material (Matthies and Meir, 2002). Hence:

$$\dot{m}_D = A * \sigma(x_o - x_L)$$

(eq. 3)

Where:

σ evaporation coefficient (kg/m^{2}h)

The evaporation coefficient σ and the transport coefficient for the material β have the following relationship (Kutzbach, 1989):

$$\sigma = \beta * \rho_L \frac{p - p_{Dm}}{p}$$

(eq. 4)

For small vapour pressures just air's partial density is important. It means that in a solar dryer, it is just possible to reduce the air density by increasing the temperature in the drying chamber, so to reduce the moisture in the air going inside the chamber. Because this effect is expensive technically, it is seldom used.

Coefficient β for transport of material is as important as coefficient for heat transfer α, both used in defining convection heat. Both methods for heat transport have many analogies, so it is possible to derivate some transport laws. Thus, it was important to use components with low heat conduction (i.e. wood) for constructing the dryer. This is necessary to avoid condensation on the elements used in the installation; also it will help to have an installation without leaks in order to avoid false flows and accumulation of solar heat due to the outside black paint.

In the drying technique, the transport of air is very important, as it has the following functions:

- Heat transportation, as a heat exchanger,
- Transportation of heat needed for moisture evaporation from inside to the surface of each body,
- Transportation of moisture leaving the material as vapour,
- Transportation of moisture,
- Surpass the resistance in the tubing for the flow of air and the flow resistance, and
- In pneumatic dryers able to transport both wet and dry material.

Therefore, air inside the drying facility should move the shortest possible distance, this will help to reduce the flow in the dryer, to be directed from bottom to the upper part (using the density fall) and a lower flow before the fan, with a chamber for drying of large diameter and without dragging dry material in the stream.

Nature of bulk material influences the amount of air pressure losses. Main factors are: size and shape of each piece of material, as well as the condition of the heap's surface and the amount of impurities, and also the air velocity as a function of pore space volume (Kutzbach, 1989). Therefore, the material to be dried has to be placed as a layer of constant depth with free pores distributed regularly on the entire tray.

Leaves from some plants have ≈ 10% of dry matter and ≈ 90% of water. Under those conditions, drying reduces much of material's volume. Water moves through the capillary. Soon after, the material structure gets stiffer, although its volume does not reduce at the same rate as the volume of water, creating more pore space. In the second section for drying, movement of water is realized by diffusion of vapour. In the last section, evaporation is characterized by material hygroscopic feature.

Fig. 2 shows the typical drying process with its three sections, pointed from its three discontinuity ends. By inspecting it from above to below shows that the first section corresponds to a reduction of material's volume due to reduction of its surface area. The effect is important for evaporation. The first discontinuity in the graph is outside the hygroscopic range. The coefficient of water capillary movement σ / η (σ surface tension and η viscosity of cactus pear juice as a function of temperature and concentration) determines the range.

In the second section, deep inside the material is too wet and the external surface shows larger pore space, thus, the transport of vapour is realized by diffusion, as showed in Fig. 3. Therefore, as pores are being filled with water, the drying velocity is close to the final value $u \geq 0$ (dashed line in Fig. 3).

In the third section of the graph, the above tendency is broken and the portion inside the material enters in a hygroscopic range. Depending on the water content in the air used in the drying process, the drying lines come to an end.

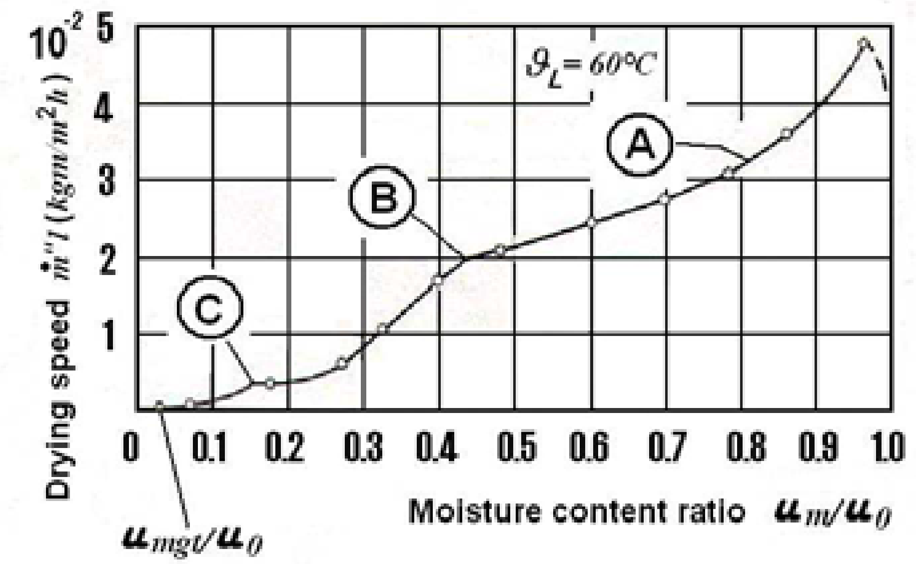

Fig. 2. Typical process for drying cactus pear's cladodes. A, B and C are points of discontinuity in the graph.

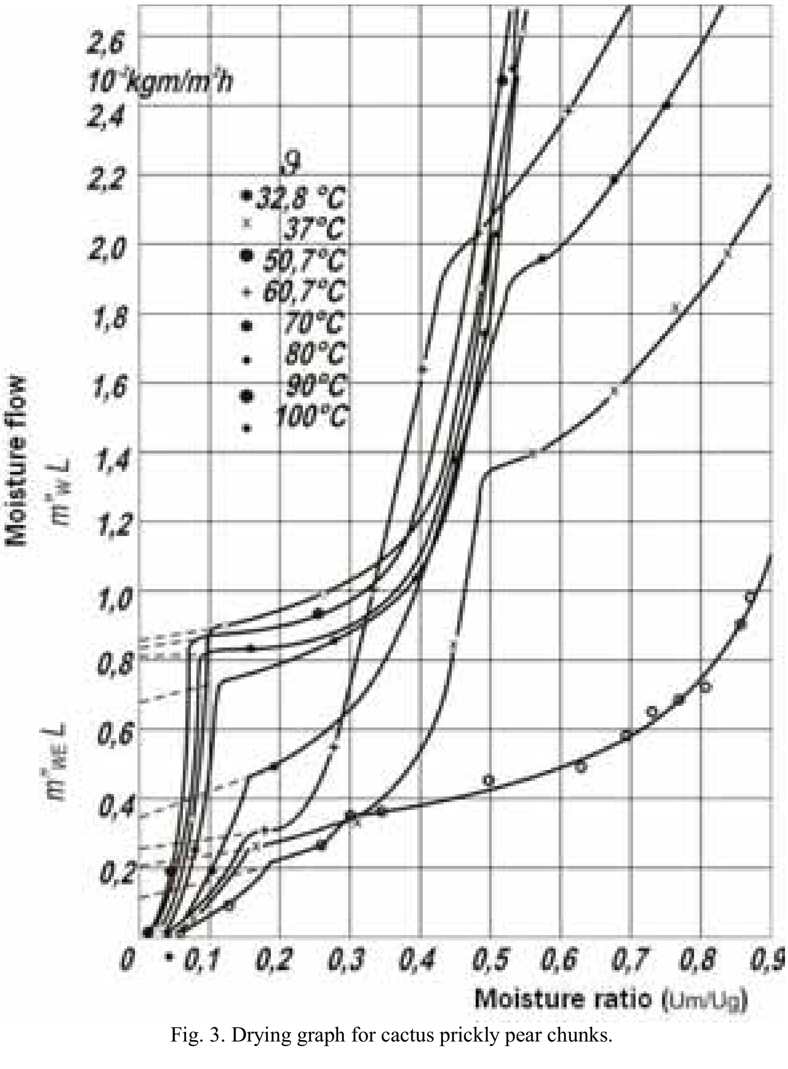

Fig. 3. Drying graph for cactus prickly pear chunks.

In the drying process, moisture in the skin is eliminated first, creating a boundary layer. This boundary line avoids that unnecessary moisture travels to the body's surface, in that way, the evaporation point moves inside the body. Resistance to water loss is increased and drying velocity reduces notably.

Effect of boundary layer for the drying process

The effect of boundary layer is important to define the level of technology to be used in the dryer, for example, the horizontal dryer constructed at our site was designed to be operated by carefully changing the parameters for the process, in order to obtain a better functioning from the dryer. Its efficiency depends on the material's characteristics exhibited in the three stages. From a technological point of view and for optimizing the process, trays can be changed twice from one specific location to the next, or three chambers inside the drier can be used with different timing for drying.

The technology for using the dryer can be described as follows:

- How small the material should be cut? and how it is cut?,
- Preparation of material; quantity and how? There is a natural resistance from the material to dehydration and drying is achieved by using environment conditions – air, temperature, etc. how to reduce the resistance to extract water from the plant?; chopping cactus pear's cladodes, improving the flow of air inside the layer of wet material, changing the material's structure using a mixture of highly chopped cladodes, very wet and creamy with a dry material like straw, hay, oat, maize, or forming layers with those materials; dry material at the bottom and wet material at the top, and finally place the wettest material on the tray closest to the entrance of air in the block,
- Use mechanical cleaning by means of brushing to select material dry enough from the trays. Thus, tray at the top will have the wettest material and those at the bottom the driest,
- Dried material can be stored or it can be milled to produce flour of green vegetative material, with the aim of improving its technological, nutritious and technical parameters,
- Tray are filled with suitable instruments in order to have an average depth layer of 20-30 mm (Fig. 4),
- Performance of the dryer is increased by guiding outside air through flap windows and by directing hotter air from the upper part to the entrance port in the dryer,
- Block have an orientation North-South, with an inclination of 23°, which depend on the site for the dryer to make an efficient use of solar radiation,
- Chopping of cactus pear is done just before placing it inside the dryer to avoid losses and diseases from bacteria, and
- On days, when air has a high relative humidity it is necessary to open the dryer for around 30 minutes to maintain a low temperature.

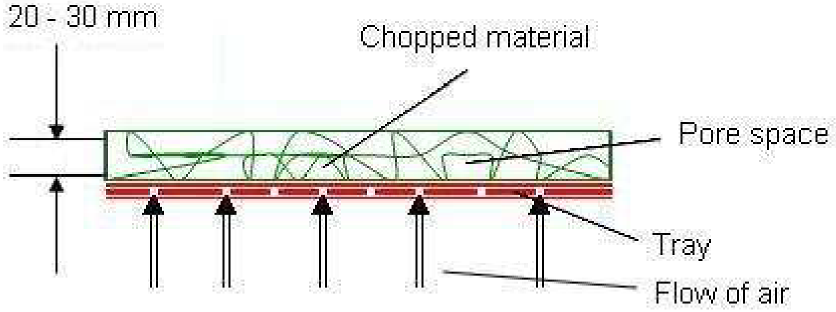

Fig. 4. Tray with chopped cactus prickly pear.

Selection of the dryer

The ability to obtain as much homogeneous distribution of air inside the dryer is the most important factor in selecting a dryer. The aim is to achieve as much contact as possible with the biological material inside the block. Generally, there are two methods: a) supplying pressurised air and b) extracting the air from the block.

In using the first technique, the entrance port to the dryer is simple; however, the distribution of air is not good enough due to the flow stream produced. While, in the second method, it is possible to achieve a homogeneous distribution of air, however, air stream can drag corrosive vapours from some vegetative material that can damage the fan. After some evaluation, a dryer using a system for supplying pressurised air was selected (Fig. 5). Drier is attached on one end to a 240 m^3 glasshouse which is used as a heating up air chamber as inside temperatures can reach up to 70°C. Drier effective drying area is 5.8 m^2 which can be split into equal size three sub-chambers, run by three separated fans; each one is connected to its own solar energy source, where air flow settings are adjusted to dry different plant materials. It was operated with 2 X 3 trays placed parallel for the vegetative material.

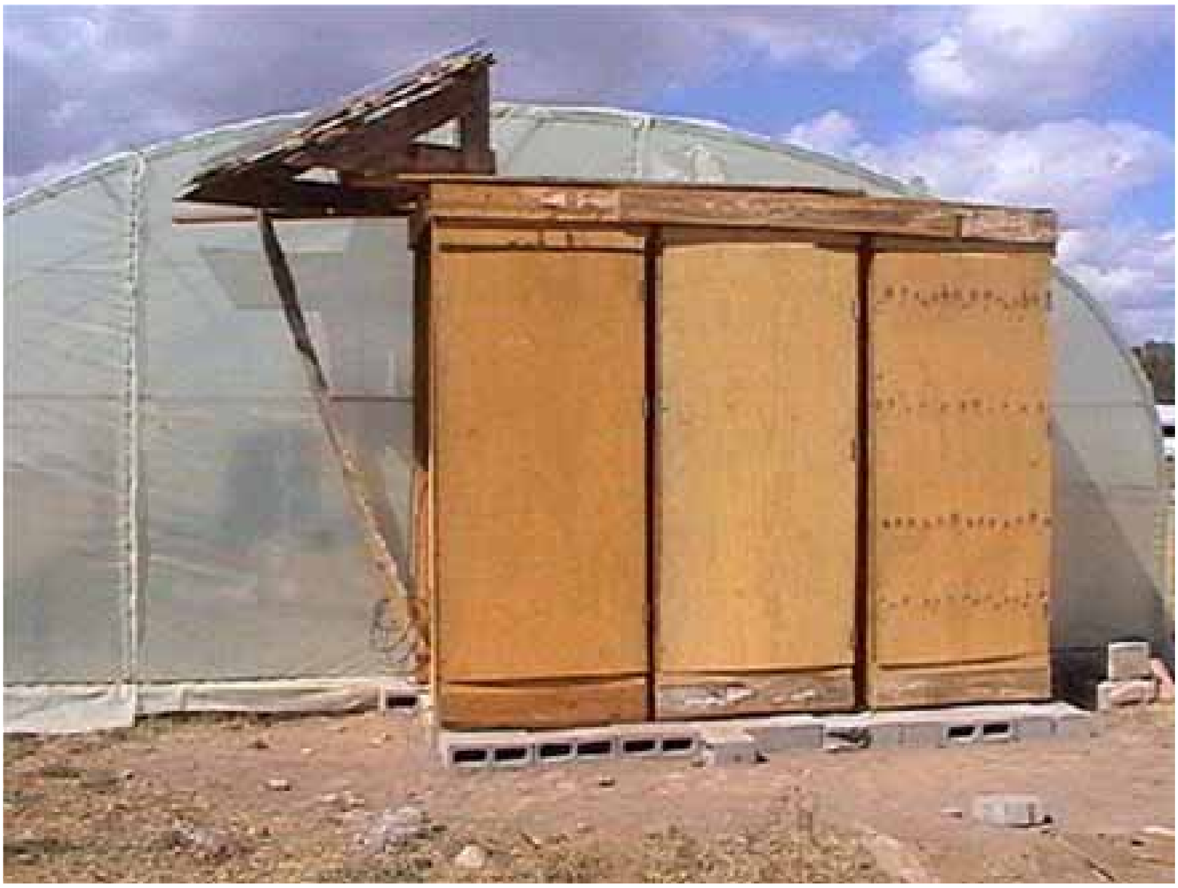

Fig. 5. Solar drier attached to the close end of a greenhouse. It shows the three drying chambers and photovoltaic cells.

Drying medicinal and aromatic herbs

There is a group of special herbs and it includes medicinal, aromatic and industrial plants. Very often it is necessary to enhance the ingredients from those parts of the plant that are used as reactive (raw material) for the pharmaceutical, aromatising and drug industry, where under adequate conditions provide conservation opportunities such as drying.

Conservation methods, such as refrigeration or preservation on salt or sugar facilitate the drying process. When drying medicinal or aromatic herbs, special care should be taken, because those plants have parts; flowers, leaves, roots, tubers, etc., that should be treated at different drying conditions.

Relationship of agricultural production to drying

The main problem is the large variety of plants, including also variability of those useful parts that gives a great difference on yield per year (Tab. 1). From all parts of those herbs; leaves, flowers, seeds and fruits a large variety of drugs can be obtained.

It was measured that for a full load of a single vegetative material with moisture content of 25% took about 8 hours to dehydrate this material to 12% moisture content. At the end, amount of losses for varying temperature from 40 up to 70°C were assessed.

3. Results and discussion

This drier facility attached to the glasshouse performed effectively. This feature facilitated its technological integration to the small farmer's productive process, and encouraged a yield increase of active ingredients from 20 to 30% compared to outdoors air drying, as well as to the improve the quality and purity of these components. Extracting drugs from tubers is equivalent as using the technique for harvesting potatoes. Drugs coming from leaves are the most important group for the drying process. Harvesting is likely the same as for green forage. Drugs from flowers have more problems for proper harvesting; mechanization is complicated and could be expensive to implement. For collecting drugs from seeds, the technique available for harvesting cereals is used. Driers and attached facilities have special shelves to place drugs.

Tab. 1: Attributes and drying requirements of some aromatic and medicinal herbs.

Type of herb	Harvest	Yield (dt/ha)	Drying ratio	Raw material preparation
Drugs from tubers				
Valerian (*Valeriana officinalis L.*)	Sep/Oct	80 up to 100	4 up to 5	Wash and slicing
Drugs from leaves				
Foxglove (*Digitalis purpurea L.*)	Sep/Oct	80 up to 150	5 up to 6	Chopping
Sweet majoram (*Origanum majorana*)	Aug/Sep	80 up to 150	3.5 up to 4.5	-
Mint (*Mentha piperita L.*)	Jun - Sep	200 up to 250	5 up to 6	-
Parsley (*Petroselinum crispum)*	Jul - Oct	120 up to 150	3 up to 7	Chopping
Kitchen sage (*Salvia officinalis L.*)	Aug/Sep	80 up to 100	4 up to 5	-
Thyme (*Thymus vulgaris* L.)	Aug/Sep	80 up to 100	3 up to 4	-
Drugs from flowers				
Chamomile (*Matricaria Chamomilla L.*)	May - Sep	30 up to 60	5 up to 7	Sieving
Drugs from leaves and fruits				
Cumin (*Cominum cyminum*)	Jun/Jul	8 up to 15	1 up to 1.3	Cleaning
Sweet fennel (*Foeniculum vulgare Miller*)	Sep	8 up to 20	1 up to 1.3	Cleaning
Dog rose (*Rosa canina*)	Sep/Oct	20 up to 40	2 up to 3	Extraction

Preserving ingredient's quality during drying process

The most important issue during drying process is to protect all valuable plant's contents. For curative and aromatic herbs it is very important to keep drying within safe temperatures limits. Medicinal and aromatic content should be divided into two groups as evaporation in concerned; the first one, regarding etherize oils which are very sensitive to extreme temperature levels and the second one, for those ingredients insensitive with different reaction respect to temperature. Another characteristic is sensibility to ultraviolet light.

Etherize oils are contained for most parts of medicinal and aromatic herbs. Etherize oils inside plants such as sweet majoram and chamomile require a maximum temperature level not higher than 45°C. In the case of drugs obtained from leaves and flowers, those oils are found in the young leaves and in the tiny hairs located above and under the leaves or in some parts of the flowers. In the case of drugs from tubers and seeds these oils are found in the skin

Plants with special thick and sticky juice ingredients such as cactus prickly pear and other having certain types of alkaloids, they withstand a maximum temperature up to 65°C without degradation. And finally, in the case of drugs with glucose the upper limit temperature is 50°C and for vitamins of 60°C.

Experimented recorded losses of vital ingredients were due to several factors: a) uncontrolled temperature levels were allowed; b) the plant material had insufficient surface area exposed to the incoming drying air; c) there was a direct exposition to ultraviolet radiation; d) a deficient air velocity control and e) inadequate procedure for drying this type of material where oils, gummies and juices are ignored.

Dying through cold air ventilation

Drying at ambient room conditions can be done but with many losses because of unforeseen and variable climate, contamination can occur also. This is the reason why plants used to obtain drugs are placed in technical installations provided with plenty ventilation to be active within a pressure difference in the range from 32 up to 19 mm of water column.

4. Conclusions

Generally, through knowledge and skills it is possible to increase precision and effectiveness of technology application. Sustainability, marketing and economic returns are valuable issues that rural communities should carefully engage when processing and adding value to herbs, plants and bushes through solar drying in order to obtain key components used in the medical and aromatic industries. The glasshouse 240 m^3 capacity provided sufficient hot air up to 70°C to the drier. Drier performed effectively when its 5.8 m^2 drying area is being safely controlled either entirely or by any of its individual sections. A full batch of same type herb material was loaded in the drier and it took 8 hours to reduce moisture content from 25% to 12%. It was recorded that yield of active ingredients was increased 30%, enhancing its quality and purity and losses were measured for undesirable varying temperatures, as well as influenced and technical factors that require improvement.

5. References

Kutzbach, Heinz- Dietr. 1989. Allegmeine grundlagen ackerschlepper fördertechnik (Specifications for tractors – transport technic). Paul Parey printing. Hamburg and Berlin.

Lahasni, S., Kouhila, M and Mahrouz, M. 2004. Adsorption-desorption isotherms and heat of sorption of prickly pear frut (*Opuntia ficus indica*). Energy Conversion and Management 45: 249-261.

Lahasni, S., Kouhila, M, Mahrouz, M., Idimam, A. and Jamali, A. 2004. Thin layer convective solar drying and mathematical modeling of prickly pear peel (*Opuntia ficus indica*). science@direct, Energy 29: 211-224.

Matthies, H.J. and Meir, F. 2002. Agricultural Engineering Yearbook, Landwirtschaftsverlag Münster.

Müller, M. 1976. Landwirtschaftliche technologie (Agricultural technology). Verlag Technik. Berlin.

Werner, M. 1984. Landwirtschaftliche trocknungs – technik (Drying technic in agriculture). Verlag Technik. Berlin.