



## USO DE LA ENERGÍA EN LA AGRICULTURA *USE OF THE ENERGY IN AGRICULTURE*

ORIGINAL ARTICLE

# Use of an artisan Solar Grain Dryer to dry soybeans and black beans grains

## *Uso de una secadora solar de granos artesanal para secar granos de soya y frijol negro*

M.Sc. Yanoy Morejón Mesa, Ing. Gemma Domínguez Calvo, Ing. Yoel Rodríguez Gago, Ing. Javier A. León Martínez  
Universidad Agraria de La Habana, Facultad de Ciencias Técnicas, San José de las Lajas, Mayabeque, Cuba.

**ABSTRACT.** The drying process in grains is a principal activity in postharvest operations; with the goal of economizing on energy sources and reducing pollution of the environment, it is possible to develop solar grain dryers. For that reason, the fabrication and testing of a solar grain dryer was done. The following show the main results for the grains of soybeans and black beans: the average moisture content before the drying of the soybeans was 15% and after the process it was 10, 24%. In the case of black beans the average moisture content before their drying was 16% and after the process it was 12,15%, being the moisture content reduction rate 1,58%/h and 0,54%/h for both grains soybeans and black beans respectively. Before drying, the mass of soybeans was 116 kg and after the drying process, it was 104 kg, therefore 12 kg of water were removed; in the case of black beans the initial mass was 150 kg and after, it was 142 kg, therefore 8 kg of water were removed; the fuel consumption was null as well the emission of gas. The structural shape of this prototype supports the loads, and the heat transference laws validate that the prototype have characteristics of drying machines. It was also determined the operation cost being of 2,71 peso/h.

**Keywords:** Solar Grain Dryer, moisture content, handmade solar dryers.

**RESUMEN.** El proceso de secado de granos es una actividad principal en las operaciones de poscosecha, con el objetivo de economizar en fuentes de energía y reducir la contaminación del medio ambiente es posible desarrollar secadoras solares de granos. Por esta razón se fabricó y evaluó un prototipo para el secado solar de granos. Los principales resultados obtenidos para granos de soya y frijol negro fueron los siguientes: el contenido medio de humedad antes del secado de la soya fue 15% y después del proceso fue 10,24%, en el caso del frijol negro el contenido medio de humedad antes del secado fue 16% y después fue 12,15%, siendo la tasa de reducción de humedad 1,58%/h y 0,54%/h para ambos granos respectivamente, antes del secado la masa de soya fue de 116 kg y después fue 104 kg, por lo tanto fueron separados 12 kg de agua; en el caso del frijol negro la masa inicial fue de 150 kg y después fue 142 kg, por lo tanto se separaron 8 kg de agua; el consumo de combustible fósil fue nulo, así como la emisión de gases productos de la combustión; este prototipo resiste las cargas a las que se somete y las leyes de transferencia de calor validan que el mismo cumple con las características que deben tener las máquinas secadoras, también se determinó el costo de explotación el cual fue de 2,71 peso/h.

**Palabras clave:** secador solar de granos, contenido de humedad, secadores solares artesanales.

## INTRODUCTION

Since ancient times the drying of medicinal plants, grains and meats have been a habitual practice of conservation to keep them during all the year. At present, the drying of the agricultural products offer a productive and commercial alternative to the national and international market. The actual tendency is the increasing of consumption rates of healthy and natural products, considering the quality standards established (Soliva, 2002).

Post-harvest systems are made of a series of processes that have an influence in the product qualities. The drying process have a great importance, because the moisture content is the

physical property most important to determine if the agricultural product can deteriorate and/or have microbiological and biochemical changes during the storage (Morejón, 2011a).

The drying process is carried out to inhibit the seeds germination and reduce the moisture content with the goal of preventing the mushroom from growing. Various authors define this process as: "Universal method to prepare the grains by the water removal until a level that gives the possibility of leverage with the environment air, so that it preserves their features, nutritious characteristics and seed viability (Morejón, 2011b).

In underdeveloped countries where the majority of the people depend on agriculture to live is difficult to acquire conventional systems to dry, because they are very expensive, for that reason it is important the use of machines of easy construction and lower operation cost, besides that gives the possibility to use renewable energy sources. About this kind of machines to dry grains Shove (1977), developed researches.

The world tendency is attempting to reduce the use of conventional energy sources because the effect of the exhaustion of natural energy resources (hydrocarbons), being necessary the use of renewable energy sources, like the biomass, eolics, solar, among others. In the specific case of the solar energy, it is very important the availability of solar radiation that can be used (Buelow, 1958; Buchinger, 2001). Because of, the geographic situation, the climatic conditions and the annual solar intensity radiation average, which makes Cuba a suitable place for the use of solar technology.

The drying traditional methods used at present by the Cuban small scale farmers are producing considerable losses before and after storage. Among the principal causes it is possible to mention the impossibility to achieve a moisture content suitable for the storage; as a result, they carry out the drying on the fields or over lower traffic streets, therefore the product is exposed to the insects, birds and several climatic changes, that have a direct influence in the losses and in the contamination of grains. For that reason, the main goal of this research is to evaluate the drying process of soybeans and black beans grains using an artisan Solar Grain Dryer.

## METHODS

### Methodology for the evaluation of the drying process

To remove water content from the grains it is important to have dry air circulating; this is possible by fan or extractor, for that reason it is important to know the air flow that circulates between the grains.

$$W_{air} = S \cdot A; m^3 / s \tag{1}$$

where:

S- Stands for wind speed, m/s; A- Cross sectional area of duct, m<sup>2</sup>.

It is very important to know that products with high moisture content will not be kept for long periods in storage. The moisture content is a feature of the quality of the product and can be expressed on either a wet or dry basis. Also, this parameter is possible to be determined by a moisture meter (Sato, 1994; Klaassen, 1983; Ohshita, 1995; ASAE, 1972).

$$Mm = \frac{Mi - Ma}{to}; \% / h \tag{2}$$

where:

W- Water content, kg; Wa- Weight after drying, kg.

The degree of grain moisture is measured every one hour to observe changes in moisture content. In general, it is called moisture reduction rate per hour.

$$Mm = \frac{Mi - Ma}{to}; \% / h \tag{3}$$

where:

Ma- Moisture content after drying, %; Mi- Initial moisture content, %; to- Operating hours, h.

The mass of grains after drying may be exactly measured because it is not difficult to take out all grains from a sheet punched metal; for this reason, it is possible to use a balance, if there is no balance it is possible to use the following expression:

$$Wa = \frac{Wb(100 - Mcb)}{(100 - Mca)}; kg \tag{4}$$

where:

Wa- weight after drying, kg; Wb- weight before drying, kg; Ma- Moisture Content after drying, %; Mi- Moisture Content before drying, %.

## Materials

- Moisture meter (SAMAP);
- Thermometers;
- Anemometer (PROVA, AVM-05);
- Lux-meter (Lux-meter 0500);
- Mechanical Balance (certificate by PEXAC);
- Recipients to take sample.

## Methodology for the economical evaluation of the process

To determine the operation cost of the prototype ( $C_{exp}$ ), it is necessary to determinate the fixed costs ( $C_f$ ) and the variable costs ( $C_v$ ), (Iglesias, 2002; Hunt, 1983; Ulloa, 1981; Aguilar. *et al.*, 1989; Muñante, 2002; Iglesias. *et al.*, 1999):

$$C_{exp} = \sum_{i=1}^n C_{fi} + \sum_{i=1}^n C_{vi}; \text{peso/h} \tag{5}$$

Fixed Cost ( $C_f$ ). Don't depend on the machinery use, but consider the depreciation cost ( $C_d$ ).

Variable Cost ( $C_v$ ). Depend on the utilization level of the machinery and its use. They include: fuel cost ( $C_f$ ), lubricant cost ( $C_l$ ), maintenance cost ( $C_m$ ), reparation cost ( $C_r$ ) and salary cost ( $C_s$ ).

Specific cost ( $C_{esp}$ ). Are the cost in peso per every unit of work carried out, it is expressed in peso/t:

$$C_{esp} = \frac{C_{exp}}{W}; \text{peso/t} \tag{6}$$

## RESULTS AND DISCUSSION

### Results of the drying process evaluation

The evaluation of the prototype was carried out on April 3<sup>rd</sup> and 23<sup>rd</sup>, 2013, using grains of soybeans LIS1P10 and black

beans Secano 7 INCA respectively. This study was carried out in the Technical Sciences Faculty areas, Agraria University of Havana, Mayabeque, Cuba, having good climatic conditions for developing the drying process.

Before starting the drying process, it was determined the initial mass and the moisture content as shown in Table.1.

**TABLE 1. Initial values of mass and moisture content in grains**

Grains	Mass, kg	Moisture content, %
Soybeans	116	15
Black beans	150	16

Another variable checked during the evaluation of the prototype was the air speed, which goes from the dry chamber until the extractor crossing a punched metal of 1,71 m<sup>2</sup>, with 1 500 000 holes of 1,2 mm of diameter, obtaining an average speed of 4,67 m/s; and having a duct area of 0,3 m<sup>2</sup>, it was possible to determine the air flow with a value of 1,40 m<sup>3</sup>/s.

With the objective of evaluating the drying process, it was determined it's kinematic in the surface and bottom of the dry chamber, as it shows Figures 1 and 2.

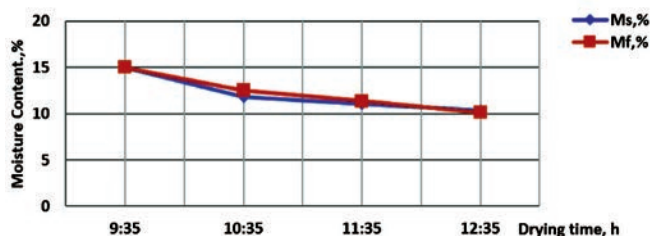


FIGURE 1. Kinematic of drying process of soybeans LISI P10.

In the Figure 1 is shown that the moisture content of soybeans was reduced of 15% until 10,24% in 3 h, without necessity of turning over the grains because the drying process was homogeneous.

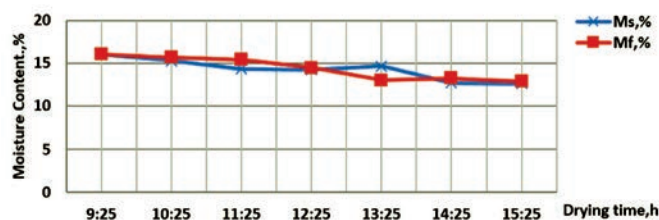


FIGURE 2. Kinematic of drying process to black beans Secano 7 INCA.

In the Figure 2 is shown that the moisture content of black beans was reduced 16% until 12,15% in a time period of 6 h; with the objective of getting a homogeneous drying the grain was turned over after 4 hours of operation (13:25 h).

Using the expression (3) it was determined the moisture reduction rate, having values of 1,58%/ h y 0,54%/ h, for soybeans and black beans grains respectively.

Another important result is the mass of grains obtained after the drying process, being of 104 kg and 142 kg for soybeans and black beans, removing 12 kg and 8 kg of water in both grains respectively.

To evaluate the performance of the prototype, it was con-

trolled its temperature in the drying chamber on the surface and the bottom, showing that in the surface was higher than the environment temperature but the bottom temperature was almost the same to the environment, is because the drying direction is oriented from the surface to bottom, demonstrating that the prototype gathers the requirements of drying machines, as shown in the Figures 3 and 4.

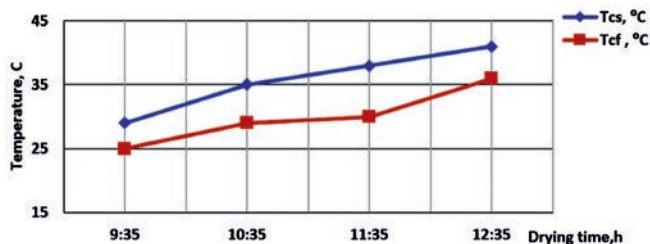


FIGURE 3. Temperature at the surface and bottom during the drying process using soybean grains (LISI P10).

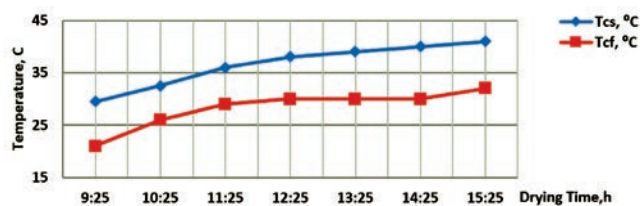


FIGURE 4. Temperature at the surface and bottom during the drying process using black beans (Secano 7 INCA).

## Results of the economical evaluation

Operation cost was determined with the expression (5) and its values, as shown in the Table 2.

**TABLE 2. Economical costs per prototype operation hour**

Costs	value
Salary Cost (Cs), peso/h	1,43
Fuel Cost (Cc), peso/h	0
Depreciation Cost (Cd), peso/h	0,039
Maintenance Cost (Cm), peso/h	1,24
Lubricants Cost (Cl), peso/h	0
Operation Costs ( Cexp), peso/h	2,71
Specific Cost (Cesp), peso/t:	
Soybeans	70,20
Black beans	108,4

Salary cost, has a basis the current minimum salary in the country which is 275 peso, as well as the work carried out per hour. The cost in fuel and lubricants are null because the prototype doesn't need any for functioning. Depreciation cost has a value of 0,039 peso/h, being the prototype initial price of 379 peso, and considering a annual percent of 15% of depreciation and a annual use of 180 days working 8 hours a day.

The battery is the only part in the prototype that requires maintenance, and considering the annual demand and the charge duration in this device that was 13 hours working continually with a maximum demand of the velocity regulator devices of 4 A of electrical current intensity, was obtained that the quantity

of maintenance required was 111, and knowing the electricity price for the maintenance is 0.09 peso (0-100 kWh) during 8 hours of maintenance, it is obtained a cost of 1,24 peso/h. The reparation cost is not considered because the devices that have the prototype are not repairable; therefore they must be replaced when they break down.

The specific cost to dry a ton of soybeans is 70, 20 peso/t and 108,4 peso/t for black beans, to obtain these results it was determined the prototype productivity for both grains, being of 38,6 kg/h and 25 kg/h for soybeans and black beans respectively.

## CONCLUSIONS

- The prototype fabricate have a weight of 115 kg, its geometrical dimensions are 1 900 x 900x 870 mm, it doesn't need conventional fuels to work, it doesn't emit products from combustion, resist structurally the load.

- The average speed of extracted humid air was 4,67 m/s, and as the duct area is 0,3 m<sup>2</sup>, the average air flow was 1,40 m<sup>3</sup>/s.
- The moisture content of soybeans was reduced from 15% to 10, 24% in 3 hours, being the reduction moisture rate of 1,58%/h.
- The moisture content of black beans was reduced from 16% to 12, 15% in 3 hours, being the reduction moisture rate of 0,54%/h.
- The initial mass of soybeans and black beans was 116 kg and 150 kg respectively and the obtained after the drying process was of 104 kg and 142 kg, removing 12 kg and 8 kg of water for both grains.
- The temperatures obtained on the surface were higher than the environmental temperatures, and at the bottom they were almost the same as the environment temperature, because the drying orientation occurs from surface to bottom.

## REFERENCES

- AGUILAR, V. A.: *Administración agropecuaria*, Editorial Limusa, México, 1989.
- AMERICAN SOCIETY OF AGRICULTURAL ENGINEERING (ASAE): *Yearbook*, St. Joseph. Mich. USA, 1972.
- BUCHINGER, J.; W. WEISS: *Solar Drying* Ed. *Institute for Sustainable Technologies*, E-mail: [office@aee.at](mailto:office@aee.at). Austria, 2001.
- BUELOW, F.H.: *Drying grain with solar energy*, Mich. State Univ., *Agric. Exp. Stn Q. Bull* 41(2): 421-429, 1958.
- HUNT, D.: *Maquinaria agrícola, rendimiento económico, costos, operaciones, potencia y selección de equipo*, Manual de laboratorio y cuaderno de trabajo, Editorial Limusa, México, 1983.
- IGLESIAS, C.E.: *Administración de la maquinaria agrícola (apuntes para un libro de texto)*, 500pp., Universidad Autónoma Chapingo (UACH), México, 2002.
- IGLESIAS, C.E., P. PANEQUE, L. SHKILIOVA: *Evaluación y prueba de tractores y máquinas agrícolas*, 485pp., Universidad Autónoma Chapingo (UACH), México, 1999.
- KLAASSEN, G.: *Seed drying. International course on seed technology for vegetable crops*. University of the Philippines at los Baños the Philippines, 1983.
- MOREJÓN, Y.: "Fabrication and evaluation of a Solar Grain Dryer", *Revista Ciencias Técnicas Agropecuarias*, 20(3): 68-72, 2011.
- MOREJÓN, Y.: *Tecnologías de secado de granos*, (Notas de conferencia especializada sobre poscosecha). Ed. Universidad Agraria de La Habana (UNAH), Mayabeque, Cuba, 2011.
- MUÑANTE, P. D.: *Formulación y evaluación de proyectos*, (Apuntes para el curso), Ed. Centro de Educación Continua y Servicios Universitarios, Universidad autónoma Chapingo, México, (impreso), 2002.
- OHSHITA, S.: *Solar grain drying*, Group training course in post-harvest rice processing, Ed. Department of Agricultural Engineering, Faculty of Agriculture, University of Tokyo, Japan, 1995.
- SATO, J.: *Solar grain dryer*, Lecture Textbooks fourth edition, Farm Mechanization Course, Farm Machinery Design Course, Tsukuba, International Agricultural Training Centre, Japan International Cooperation Agency, Japan, 1994.
- SHOVE, G. C.: *Solar Grain Drying*, *Conf. Proc.*, Jan. University of Illinois, Urbana-Champaign, USA, 1977.
- SOLIVA-FORTUNY: "Effect of minimum processing on the texture properties of fresh-cut pears", *SCI Food Agric*. 82: 1688-1862, 2002.
- ULLOA, T. O.: *Maquinaria agrícola II* (apuntes de clases), Ed. Dpto. de Fitotecnia, Universidad autónoma Chapingo, Chapingo, Texcoco, México, 1981.

**Recibido:** 15 de diciembre de 2013.

**Aprobado:** 22 de julio de 2014.

Yanoy Morejón Mesa, Profesor, Universidad Agraria de La Habana, Facultad de Ciencias Técnicas, San José de las Lajas, Mayabeque, Cuba, CP: 32700, Correo electrónico: [yymm@unah.edu.cu](mailto:yymm@unah.edu.cu)

Nota: La mención de marcas comerciales de equipos, instrumentos o materiales específicos obedece a propósitos de identificación, no existiendo ningún compromiso promocional con relación a los mismos, ni por los autores ni por el editor.