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RESEARCH ON CARROT DRYING BY MEANS OF SOLAR ENERGY

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Abstract: *This paper presents a possibility of carrot drying by using solar energy and a technical equipment that was personally designed and manufactured. The quality restrictions imposed to the dehydration process refers to maintaining the nutritional components appreciated by the content of vitamin C and keeping the color as close as possible with the color of fresh products. The methodology of research is complex and it takes into account the possibilities of the technical equipment that was used. It highlights the influence of slice size, the color of the surfaces that the products are put on, the inclination angle and the horizontal position of the stand, eventually forced ventilation etc. A few results and conclusions are presented.*

Key words: *carrots, dehydration, solar energy.*

1. Introduction

The carrot (*Daucus carota L.*) is a herbaceous plant, which performs its life cycle in two years. In the first year it forms a root system and a rosette of leaves, and in the second year it forms the floriferous stems [1], [3]. It is a less demanding plant in point of temperature, because it is specific for the temperate climate.

The minimum temperature for the seeds to germinate is 3...4 ^{0}C, and the optimum is 20...25 ^{0}C. The optimum temperature for the growth of comestible roots is 18...20 ^{0}C. The young plants hold on temperatures from -3^0 to -5 ^{0}C. The tuberous roots hold on temperatures until -2 ^{0}C. The carrot (Figure 1) requires a large amount of water, especially in the seeds' germination time and in the first weeks after the plant rises, when the roots and the foliar mass are formed.

The carrot requires plenty of light in all the growing phases.

Light insufficiency in the first growing phases leads to leaf elongation and weight loss in roots.

Fig. 1. *The carrot* [7]

The types of soil in which they grow well are the ones that have light or middle texture, loose, permeable, deep, the humus should be between 4...5%, with neutral pH (between the values: 6.5...7.5). The carrot reaction is good concerning the administration of chemical fertilizers, especially on light soils, but it can't stand natural fertilization in the crop year, that's why the natural

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fertilization is made 2…3 years before growing carrots.

Carrot varieties are grouped according to *earliness* or *length of vegetation* in: very early varieties (until 80 days), early (80…110 days), semi-early (110…130 days), semi-late (130…150 days) and late varieties (over 150 days).

The main carrot varieties are:

- *Nantes 2* is a semi-early carrot variety, with cylindrical roots, with a length of 16…18 cm;
- *Nantes 6 Fancy* is a semi-early carrot variety;
- *Flakker* is a late carrot variety;
- *Royal Chantenay 2* is a carrot variety with a good foliar mass;
- *Scarla* is a carrot variety with early growth, with cylindrical shape and high potential of production.

In Table 1 the medium nutritional values for 100 g of fresh product are presented.

Chemical composition of carrots Table 1

Substance	**Value**	**UM**
Water	89	[g]
Calories	40	[kcal]
Proteins	0.98	[g]
Carbohydrates	8.71	[g]
Lypids	0.24	[g]
Vitamin A	12	[mg]
Vitamin B1	0.039	[mg]
Vitamin B2	0.053	[mg]
Vitamin B6	0.09	[mg]
Vitamin C	7.1	[mg]
Vitamin PP	1.2	[mg]
Iron	0.66	[mg]
Calcium	33	[mg]
Magnesium	18	[mg]
Phosphorus	35	[mg]
Potassium	240	[mg]
Sodium	2.4	[mg]
Fibre	3	[g]

The **physical** properties that influence the drying process are represented by: *shape*, *size* (appreciated by mass of 25…200 g), *specific mass*, *volumetric mass* (500…650 kg/m^3), *specific heat* (0.93 kcal/kg^{0}K), *thermal conductivity* (*carrots* have poor thermal conductivity), *slicing system* (*halves, quarters and slices*) etc. [3].

The color, flavour and *taste* have a great importance in establishing the comercial value of carrots. Taste is determined by the content in sugar, organic acids, polyphenols etc. Flavour is the result of sensations produced on olfactory organs by some volatile substances that develop in different phases of the product's growth and maturation. At full maturity the flavours are variety specific [2].

2. Material and Methods

Drying is defined as the process based on natural heat transfer that assures the water evaporation from the product surface, which allows the moisture removal from the material presented as in nature or as paste, granules, and slices.

Two agents participate in the drying process: material to be dried, which receives a quantity of heat and determines that a part of the surface humidity be transformed in vapors; the air from nature, naturally heated by the sun, which becomes a gas thermal agent, with a double role: to bring the necessary heat from drying and to collect and remove the formed vapors from the system [6].

Sun drying is one of the oldest methods for vegetable and fruit conservation. In the past, fruits and vegetables were dried in the sun, in sunny and well ventilated places. The drying process in the sun could last for a few days, while the fruits and vegetables had to be protected by being covered with a rare canvas against insects and birds.

The experimental research was done according to a methodology that consisted of two stages: preliminary actions and the actual experimental research which was carried out on the experimental stand which had been especially designed and manufactured.

2.1. The preliminary actions before experimental research

Preliminary activities before experimental research are presented in Figure 2.

Analyzing reference and related documents

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Choosing the objects used in the research

↓

Choosing appliances

↓

The research appliances in exploitation

↓

Preparing for experimental research

Fig. 2. *The working methodology regarding preliminary actions before experimental research*

For the experimental research the following documents were analyzed and observed: STAS 6952-83: *Fresh fruits and vegetables;* STAS 12920-90: *Vegetables. Nomenclature;* STAS 2445-83: *Dried vegetables and fruits.*

2.2. Experimental research objects

The experimental research objects are represented by carrots with 15 and 20 mm in diameter cut in quarters, 5 and 10 mm slices and also the stand that was designed and manufactured for this operation [4].

The experimental stand for drying carrots (Figure 3), which uses solar energy, consist of the dryer framework 1, drying surfaces 2, fans 3, photovoltaic panel 4, the adjuster of the inclination angle of drying surfaces 5.

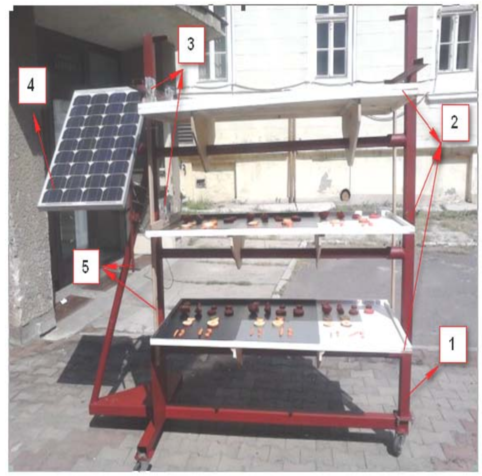

Fig. 3. *Stand for research of carrots drying with solar energy*

The framework is made from metallic profiles joined by welding or by screws and it is placed on three wheels which permit the stand movement in the optimum position for solar energy capture or to avoid bad weather. The three drying surfaces are wood decks divided into three equal parts, painted in black, grey or white. The wood decks are placed on three levels, and with an adjuster they can be inclined so they can value the solar energy as good as possible. On the framework, the photovoltaic panel device was also set up to assure the electrical energy needed for the fans to function, which are attached to every exposed surface of products to be dried. The stand can be used in the uncovered variant or with transparent foil covering. In both variants forced ventilation can also be obtained.

2.3. Conducting research

The experimental research on the stand took place in the yard of the N Building of the *Transilvania* University of Bra□ov from August to September 2012, abiding by the research methodology presented in Figure 4.

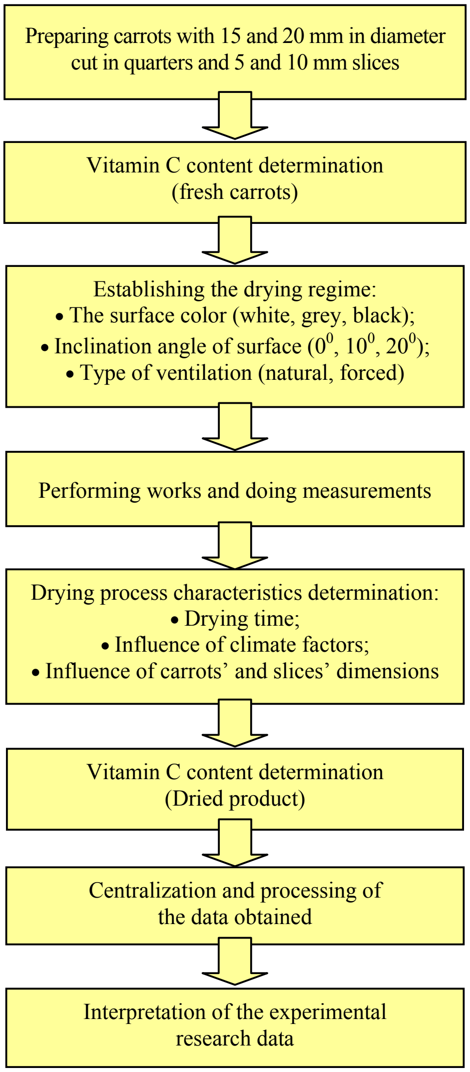

Fig. 4. *Experimental research methodic*

2.4. The devices used for experimental research

For the experimental research, many devices and instruments were used namely:

- thermo-hydro-anemometer KIMO type VT300;
- infrared thermometer Fluke 568;
- pyranometer SDL-1 Solar Data Logger;
- analytical balance Sartorius;
- Desiccator, tubes, chemical reagents etc.

3. Results and Discussions

3.1. Vitamin C content determination

The vitamin C content was determined by means of the *Iodometric method*, both for fresh and dried products. The method is based on the oxidation of ascorbic acid with excess iodine. The iodine obtained *in situ* in the reaction between iodated and potassium iodide can be used as oxidant. Chemically, vitamin C is γ lactone of a hexon acid. It is also named ascorbic acid [5].

Vitamin C content (mg/100 g product) can be calculated with the formula:

$$0.352(V_p \cdot V_m)\cdot 100\cdot\frac{d}{m}, \qquad (1)$$

where: V_p is the volume of KIO_3 solution used in the sample titration, in mL; V_m - blank volume = 0.3 mL; d - dilution volume = 25 mL; m - sample mass = 0.5 g.

In the case of ***fresh carrots***, V_p = 1.3 mL, and the vitamin C content is:

$$0.352\cdot(1.3\cdot 0.3)\cdot 100\cdot\frac{25}{0.5}= \\ =686.4\ [\text{mg/100 g product}]. \qquad (2)$$

In case of ***dried carrot***, V_p = 2.1 mL, and the vitamin C content is:

$$0.352\cdot(2.1\cdot 0.3)\cdot 100\cdot\frac{25}{0.5}= \\ =1108.8\ [\text{mg/100 g product}]. \qquad (3)$$

The equipment was used in many different variants depending on the usage of forced ventilation, the value of the inclination angle and the usage of the covering foil, as presented in Table 2. Also, the three positions of the drying surfaces were taken into account (S - superior, M - middle, I - inferior), and the fact that on every surface there were three zones painted in different colors (B - black, G - grey, W - white).

Variants of using the stand in the experimental research Table 2

Variant of equipment	**Forced ventilation**		**Inclination angle**			**Covered**	
	Yes	**No**	**0^0**	**10^0**	**20^0**	**Yes**	**No**
I		**x**	**x**				**x**
II	**x**		**x**				**x**
III		**x**	**x**			**x**	
IV	**x**		**x**			**x**	
V		x		x			x
VI	x			x			x
VII		**x**		**x**		**x**	
VIII	x			x		x	
IX		x			x		x
X	x				x		x
XI		**x**			**x**	**x**	
XII	x				x	x	

3.2. Drying time optimization

In this case the carrots' drying optimization consists in maximum capitalization on solar energy specific for the considered zone, in a given calendar period, by:

- *choosing the minimum dimensions of the products to be dried according to the qualitative indices imposed to the final products;*
- *slicing at minimum dimensions accepted by the quality imposed to the final product;*
- *establishing the color of the surface of carrots, according to the drying time necessary to obtain the imposed quality of dried products;*
- *adjusting the inclination angle of drying surfaces for the best capture of solar energy;*
- *rational usage of the overlapped drying surfaces without affecting the final products' quality;*
- *making a drying enclosure by using a transparent foil;*
- *assuring a controlled speed of the air in the area of the drying surfaces, both the covered and uncovered dryer, in order to avoid the overheating and degradation of dried products.*

Because the best results were obtained for the products cut into 5 mm slices, the results' interpretation will be done for these samples, which are considered the most efficient from the point of view of moisture content evolution in 24 hours. Also, the optimum variants of the equipment were the 3rd, the 7th and the 11th variant, where the equipment was covered, forced ventilation wasn't used, but the inclination angle of the drying surfaces was different (0^0, 10^0 and 20^0).

It has to be mentioned that during the experimental research the outside temperature by day was between 15^0...30 ^{0}C, and by night it was between 10^0...15 ^{0}C.

3.2.1. Optimization of drying process by choosing the color, the inclination angle and the position of the drying surface

For the carrot slices dried on equipment pertaining to the 9th variant, the influence of the color and the angle inclination of drying surface, and the regression equations of sample masses are presented in Figure 5.

The data presented in Figure 5 shows the fact that the best decrease of moisture content for the 5 mm carrot slices was registered in the case of drying on the 11th variant of the equipment, respectively covered, without forced ventilation and with a 20^0 inclination angle. So, after 24 hours, product humidity reached values of 4.4% on black surface, 6.6% on grey surface and of 7% on white surface.

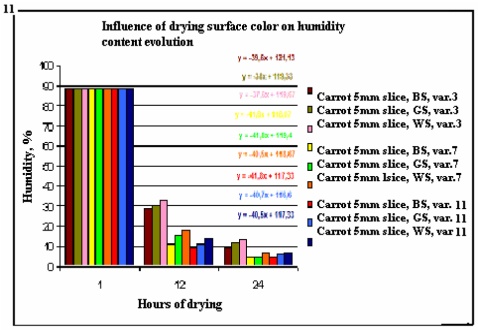

Fig. 5. *Influence of color and inclination angle of drying surface on humidity content evolution*

In Figure 6 we present the influence of color and position of the drying surface on the humidity content evolution for the carrot slices in the 11th variant of equipment and also the regression equations of the sample masses.

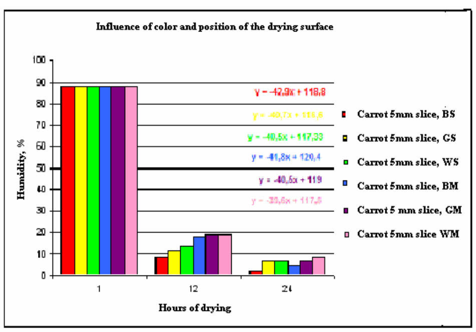

Fig. 6. *Influence of color and position of the drying surface on humidity content evolution*

From the chart presented in Figure 6 it result that the lowest moisture content (2.2%), after 24 hours of drying, was obtained on the black surface placed in the superior part of the dryer. Because the final humidity has to be smaller than 18…20%, the other results presented in the chart are valid, because the registered values are under the conservation limit: 6.6% - Grey surface, superior part; 7% - white surface, superior part; 4.4% - black surface, middle zone; 7% - grey surface, middle zone; 8% - white surface, middle zone.

3.2.2. Optimization of drying time by choosing dimension of slices

To highlight the optimum shape for slicing carrots in order to optimize the drying process by using solar energy, in Figure 7, the influence of the slicing system on humidity evolution and the regression equations of sample mass are presented. The sample dried on the black surface placed in the superior area of the equipment in the 11th variant of drying was taken into account.

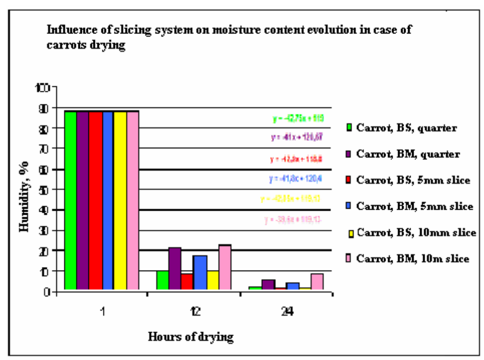

Fig. 7. *Influence of the slicing system on moisture content evolution*

From the chart presented in Figure 7 it can be observed that the most appropriate shape for slicing is the slice with a 5 mm thickness. So, the samples cut accordingly have passed the conservation limit in 24 hours with the following recorded values: **2.2%** - *slice of carrot* dried on the *black surface* from the *superior area* and **4.4%** - *slice of carrot* dried on the *black surface* from the *middle zone*.

4. Conclusions

1. The research objects of the drying process by using solar energy were carrots with 15 and 20 mm in diameter, cut in quarters and in 5 and 10 mm slices, and also the stand that was designed and manufactured for this operation.
2. As parameters of the drying process: the drying time, the vitamin C content of fresh and dried carrots and the color of the finished products were considered.
3. The carrots to be dried were prepared by successive sectioning in quarters and slices with a 5 and 10 mm thickness.
4. As a chemical component representative for fresh and dried products was the vitamin C content, and as a physical aspect - the way that the color of finished products was maintained.
5. Referring to the vitamin C content, this was 0.6864 g/100 g at fresh carrots, and 0.9504 g/100 g finished product at dried carrots. A vitamin C concentration 2.2…2.4 times higher than in similar masses of fresh and dried products is obtained, even if, by drying, there is a global loss of vitamin C.
6. The correct choice of drying surface color represents an optimization factor of time for this process. Even if the drying time was longer for the products exposed on the middle and inferior decks, they were dehydrated enough to consider the construction of the equipment with many drying levels.
7. In the case of the ventilation of uncovered drying surfaces, a growth of the drying time is noted, as a result of product temperature reduction. Ventilation is justified only when temperature exceeds 50 ^{0}C and has the tendency to degrade the vitamins from the products or their color.
8. If the drying surfaces were covered with transparent foil, the drying time was smaller than the drying with uncovered surfaces; an explanation is the removal of the air's natural movement and growth of product temperature. The result of forced ventilation was, in this case too, a longer drying time.
9. By the inclination of surfaces for the products' exposure, drying time reductions by 10…15% as compared to the horizontal position of the surfaces were obtained.
10. The color of finished products was good for the small dimension products exposed on black or grey surfaces. With big size products exposed on white surfaces, mold trends appeared.

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