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Drying of Yacon (*Smallanthus sonchifolius*) as a potential food product for international commercialization

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Abstract. This paper describes the drying process conditions with the objective to minimise the negative effect over the final quality of the dry Yacon (*Smallanthus sonchifolius*) for international commercialization. Yacon is a tuberous root that grows throughout the Andean mountains in different South American countries. During the last years the interest for this product has been increasing and researchers have collected information that indicates the great potential of yacon. The product cultivation has been promoted over the past few years, due to the health benefits found after consumption. This agricultural product contains FOS (Fructo Oligo Sacarides) of low molecular weight, which is used as alternative sweeteners and, due to the small amount of calories is also attractive and good for overweight and diabetic people. Due to the outstanding importance of its health properties, this studied was carried out to achieve the best parameters of the drying process. For this paper, an experiment was performed considering two factors of the drying process: thickness of the layer (2cm, 4cm and 6cm) and temperature (60ºC, 70ºC and 80ºC), with measurements of the physicochemical properties in fresh, before drying and after the drying process, with three replicates for each combination of levels.

1. Introduction

Yacon is a tuberous rhizome that growths in the Andean region spreading throughout the humid mountains of Peru, Colombia, Venezuela, Ecuador, Argentina and Bolivia [1]. It is a high-producing crop that yields an average of 30 tons per hectare and has a lifetime of 15-20 days in normal conditions. Yacon is most commonly consumed fresh, in juices, extracts or capsules, and in cooked dishes [2]. The yacon contains FOS (Fructo Oligo Sacarides) of low molecular weight, normally used as alternative sweeteners with small amounts of calories. It is attractive and is good for overweight and diabetic people since the human body cannot absorb the sugars it contains. The sugars are called inulin and oligofructose, and contribute to a healthy diet in line with the World Health Organization's recommendations regarding nutrition, physical activity and health [3].

Global circumstances and new directions in food consumption are seen as essential components in order to try to find opportunities of commercialization of fruits and vegetables in Latin American countries [4]. The demand of agricultural products by countries around the world has increased over the years and has shown great opportunities to agricultural products like yacon, which is part of all the potential products in developing countries such as Colombia [5]. A need for conservation of food in different countries has also open a new way of consumption and a demand for processed food [6]. The significant interest of people with purchasing power is focused on natural and processed superfoods, which can assure easy consumption for a healthy diet [7].

International markets register an increase on the demand of functional food, forcing countries around the world to increase and diversify the agricultural products [8]. The production and distribution of functional products is risky, expensive and sometimes difficult, due to the individual requirement of the global commerce [6]. A way to minimize the risk is by processing and extending the life time of the products by using different agro industrial transformation processes [9].

Drying is one of the oldest processes used in the conservation of foods with notable effects on the quality of the product [10]. Not all products have the same features in the drying process [11]. That is why it is so important both to carry out research to define the drying parameters of each product in order to minimize the negative effects on quality, and finding the drying conditions that guarantee a quality product competitive in the international market [12]. Others studies in the costumer perceptions have already gave this researchers a starting point in the objective of a product that have good acceptance in a global level of commercialization [13].

2. Methodology

2.1. Materials

Yacon roots (*Smallanthus sonchifolius*) were purchased in local markets in the city of Bucaramanga (Colombia), and were selected taking into account similarity in both color and firmness. The yacons were washed and peeled, and immediately rinsed with cold water to remove the remains.

After washing the yacon it was cut into slices of 2 mm, 4 mm and 6 mm, immersed immediately in a solution of citric acid at 1.25% for 2 minutes and then put over paper towels during one minute.

2.2. Experimental design.

To evaluate the effect on the quality characteristics of the factors, drying temperature (levels 60,70 and 80 °C and thickness (levels 2, 4 and 6 mm), a factorial design of 3^2 was constructed. The measurement of the effect of the 9 treatments was carried out with three replicates and, to homogenize the environmental factors on the drying process, the order of the resulting 27 replications was randomized (9x3). To guarantee the homogeneous samples of the product used in each replica, the initial characterization of the fresh product was measured and compared before statistical analysis of the treatments.

2.3. Moisture content:

The moisture content was determined according to norm AOAC 2013, using the oven method, that is, to carry a sample of 100 grams of (*Smallanthus sonchifolius)* at 103 °C +- 2 to constant weight and then using equation $H = \frac{W_i - W_f}{W_i} * 100$ where W_i is the weight of the solid + water (total kg of water plus dry solid) before the drying process, W_f is the weight of the sample after the drying process. The moisture content was determined before the drying process in triplicate, and to ascertain moisture content at the end of the drying process estimations were carried by in triplicate and by combinations of the levels of the factors.

2.4. Color:

For color measurement, an expandable polystyrene (EPS) made chamber was used, with an opening in the upper part to guarantee that the light input and the distance to the sample were always the same. The measurements were made with a Colorimeter Model CR400, Konica Minolta through the CIELAB system. The measurements were taken at the same time of the day to reduce variability. The colorimeter was calibrated with a white pattern. The values of the coordinates were taken; L*(dark - light), a* (green - red) b * (blue - yellow) and was calculated ΔE, by means of the following equation:

$$\Delta E = \sqrt{(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2} \quad (1)$$

The system used to measure the color takes into account three parameters: Lightness (L*), saturation (C*) and tone (h*). Subsequently, the fresh samples were compared with the samples submitted to the different drying treatments [14].

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \quad (2)$$

$$h^* = tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (3)$$

2.5. Sugars content: sucrose, fructose, glucose and inverted sugar

10 milliliters of the juice of the pulp was extracted by compression of Xg of yacon pulp in a container. The types of sugars were measured by means of 4 refractometers: %Brix, %fructose, % glucose and % inverted sugar (Hann instruments 96801 / Hann instruments 96802 / Hann instruments 96803 / Hann instruments 96804 respectively). Tests percentages were done by triplicate.

2.6. Drying process

For the drying tests, a Binder FD 115 forced convection oven was used. For the drying loss curves, moisture loss control is carried out, weighing the samples throughout the entire process. The first hour the samples are weighed every 15 minutes, then every half hour for 2 hours and then every hour until constant weight is achieved.

During the process of drying, the color change and size of yacon slices and weight loss were recorded.

2.7. Volatile Organic Compounds (VOCs) from Yacon fresh and after a drying process Extraction by Headspace-Solid Phase Micro Extraction (HS-SPME).

The solids obtained from yacon slices fresh and after drying were homogenized and placed in a 10ml vial. The vial was sealed by an air-tight Teflon septum, an aluminum cap and incubated at 30ºC for 15 min in a water bath. A 1-cm SPME fiber (50/30um DVB/CAR/PDMS; Supelco, Bellefonte, PA, USA) was manually inserted into the headspace of the sample vial and exposed for 15 min. The volatile compounds were thermally desorbed in the GC injection port (splitless mode) for 5 min at 250ºC.

2.8. Gas Chromatography-Mass Spectrometry (GCMS) analysis

GCMS analyses of the SPME fiber were conducted using a Shimadzu GC5050 chromatograph coupled to mass spectrometer. After desorption of volatile compounds from SPME fiber, the analyses were separated made on a HP-5 column (30m x 0,25mm i.d., 0,25 um df) (Agilent Technologies, USA) and a DB-WAX column (30m x 0,25mm i.d., 0,32 um df) (J&W Sci) according with the following temperature program: started at 50ºC, then increased to 190ºC at a rate of 6ºC/min, and then to a 240ºC at a rate of 12ºC/min, with a final hold time of 2 min. Helium was used as a carrier gas at a flow rate of 1,5ml/min, injector and detector temperature, 250ºC. MS was operated in electronic impact (EI) mode 700eV, with mass range 40-350 atomic mass units, a source temperature 280ºC, and transfer line temperature 250ºC.

2.9. Volatile compound identification

Tentative identification was attempted by comparison of the retention index (RI) and mass spectra against NIST spectrum data base using NIST MS Search 2.0 (NIST, Gaitherburg, MD, USA). Retention indices (RI) were calculated using a homologous series of C6-C25 alkanes standard solution. Chemical authentic standards, when available, were analyzed under the same chromatographic conditions and their RI and mass spectra confirmed compounds identities.

2.10. Statistical analysis

The data collected on the different characteristics of interest were described by averages and medians (measures of central tendency), standard deviations (SD) and coefficients of variation (homogeneous measures CV% <10%) in the case of quantitative variables. To identify the shape of the distribution of the variables, asymmetry and kurtosis coefficients were used. Between treatments comparisons were made with the test of medians.

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3. Results

Rhizomes were purchased in the last six months of study in different local markets, searching products with similar characteristics. See Figure 1, below.

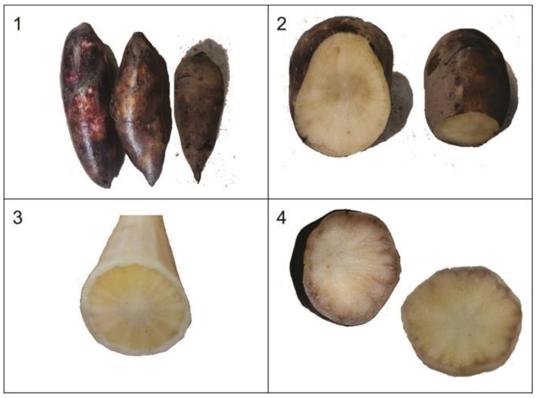

Figure 1. Presentation of the tuber Yacon. Notes: 1 tuber available in local markets. 2 Color and internal appearance of the Yacon. 3 Peeled Yacon ready for consumption or processing. 4 Yacon cuts for the drying process.

Lengths of Yacon varied between 6 and 31cm in the studied sample, with external shades of light brown, dark brown and purple. Internally the tubers presented diverse colors, as shown in figure 2.

Figure 2. Shades of Yacon in fresco.

Yacon showed very homogeneous initial moisture values, with an average moisture content, and a dispersion percentage of only 6.4% with respect to their mean. The minimum value of moisture found was 73.94% and the highest value was 93%. Table 1. presents the percentage average values of glucose, inverted sugar, fructose and Brix sugar, with coefficients of variation higher than 20%, indicating a high dispersion of these measurements among the different analyzed roots. Despite the dispersion of the sugar measurements, the behavior of the variables is normal, according to the Shapiro-Wilk test (See Table 1).

Table 1. Description of the initial characteristics of the fresh yacon

Measurements	Moisture content	Glucose	Inverted sugar	Fructose	Brix
Promedio	84,72%	11,81%	12,34%	12,76%	13,29%
(CV%)	(7,07%)	(27,8%)	(26,17%)	(25,93%)	(24,13%)

To establish the initial homogeneity of the product conditions, the initial moisture content between the different treatments was compared, using the non-parametric median comparison test (see table 2).

Table 2. Moisture content of Yacon under the assignment process

Teatments	*%Moisture content (initial)*	*%Moisture content (final)*
60°C 2mm	84,4	1,66
60°C 4mm	86,3	1,70
60°C 6mm	86,3	1,79
70°C 2mm	85,5	1,35
70°C 4mm	75,9	1,58
70°C 6mm	80,7	1,44
80°C 2mm	93,0	0,82
80°C 4mm	83,7	1,09
80°C 6mm	80,1	1,35
$X^2_{(8)}$ *(p<0,05)*	*4,33 (0,836)*	*12,667 (0,027)*

The initial moisture content did not show significant differences according to the test of the medians comparisons ($X^2_{(8)} = 4.33$, p = 0.836), while the medians of the moisture content in the dry Yacon offered significant differences($\chi^2_{(gl=8)} = 12{,}667;\ p = 0{,}027$). As observed in table 2 the moisture content of the dry Yacon at 60°C did not show differences between the diverse thicknesses compared ($\chi_{(gl=2)} = 0{,}9;\ p = 0{,}638$), likewise at 70°C; however, at 80°C the slices of 6mm presented higher moisture content than the slices of 2mm and 4mm ($\chi_{(gl=2)} = 6{,}3;\ p = 0{,}043$).

Table 3. Time of drying process under assignment conditions

Treatments	*Time (hours)*[a]
60°C 2mm	13,44
60°C 4mm	14,40
60°C 6mm	14,59
70°C 2mm	12,00
70°C 4mm	12,50
70°C 6mm	12,46
80°C 2mm	7,00
80°C 4mm	7,50
80°C 6mm	9,50
$X^2_{(8)}$ *(p<0,05)*	31,11 (<0,001)

Note. a= median of time.

Regarding drying time, significant differences were observed in the median time taken by the Yacon slices to find the equilibrium moisture, which is affirmed with a confidence level of 99% (see table 3). At 60°C half of the samples elapsed less than 14.4 hours while the other half had a longer drying time. In the case of the samples dried at 70°C, the drying time of 50% of the samples was less than 12.5 hours and, finally the samples dried at 80°C were 8 hour in the oven.

When comparing the observed drying time as a function of the temperature factor, it was found that the median drying time at 80°C is significantly lesser than the time needed to dry the product at 60°C 70°C ($\chi^2_{(gl=2)} = 11{,}22; p = 0{,}003$). No significant differences were observed between the required drying time at 60°C and 70°C.

The loss of moisture content of the Yacon presented greater dispersion in the slices dried at 60°C and the most representative variations were observed up to five hours after entering lthe convection oven; for drying at 70°C, the time in which Yacon shows the greatest moisture loss is four hours. Yacon slices dried at 80°C drop moisture with a higher proportion until three hours. Under the different drying temperatures used, the thickness of 2mm was always the one registering the highest moisture loss in the shortest time; the thicknesses of 4mm and 6mm under the temperature of 70°C showed well differentiated moisture loss, while the thicknesses of 4mm and 6mm at 80°C showed a very similar index of moisture loss (See figure 3).

The color of Yacon was recorded at the beginning and at the end, using coordinates L* a* b*. It was observed that the coordinates a* and b* showed greater variability (CV%) at the beginning. The lightness (L*) is presented as the most homogeneous characteristic recorded. The coordinates showed a symmetrical behavior with respect to the average (asymmetry less than 1 in absolute value) and a form of meso-acoustic Gaussian bell (kurtosis less than one in absolute value) as observed in table 4.

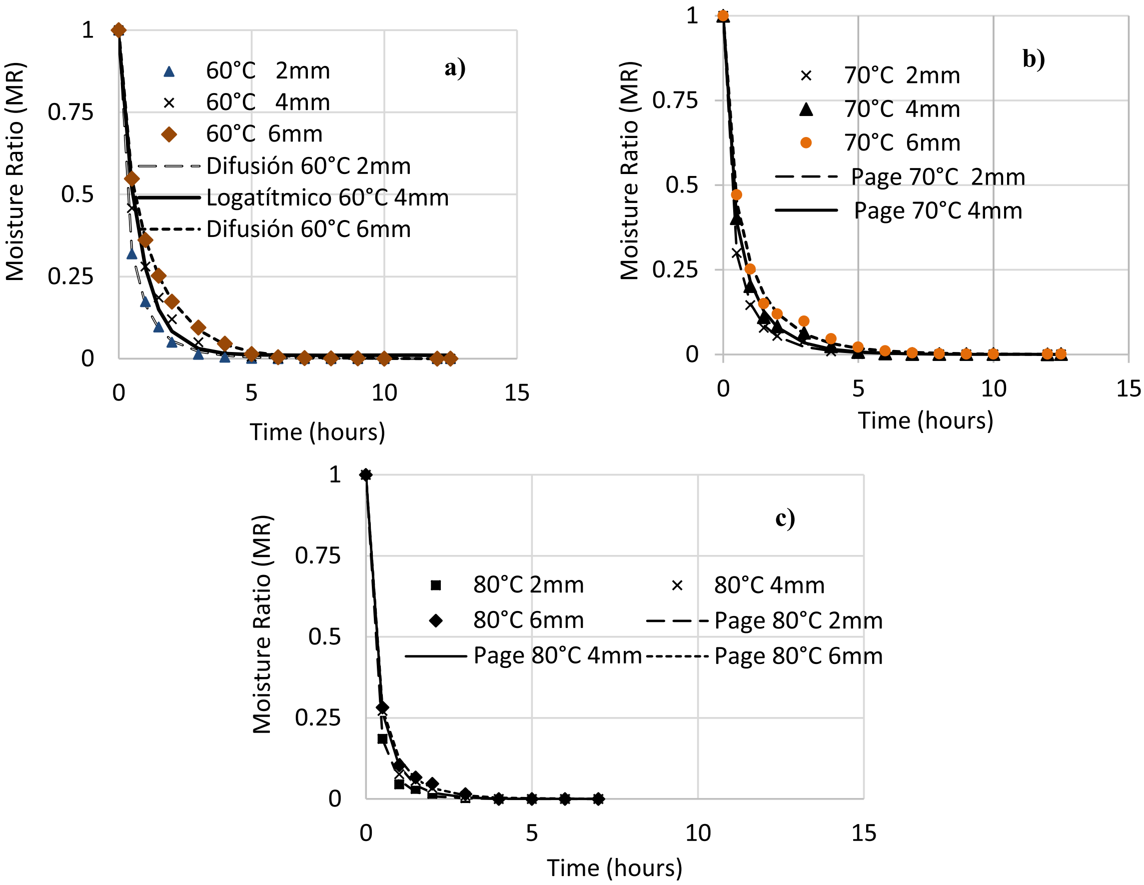

Figura.3. a. Curves of the drying process at 60°C. **b** Curves of the drying process at 70°C. **c** Curves of the drying process at 80°C

As seen in table 4, the values of the color coordinates L*, a*, b* of the fresh yacon and, after the drying process, it can be affirmed that there was a color change due to the drying process. Initially the fresh yacon is more luminous and greenish than the dry yacon.

Table 4. Yacon initial color representation using coordinates L* a* b*

	Coordinates	Median	±DS	CV%	Asymmetry	Kurtosis
Initial	L*	61,52	4,488	7,29%	-0,115	-0,724
	a*	2,277	1,852	81,3%	-0,769	-0,301
	b*	20,083	6,015	29,9%	0,348	1,278
Final	L*	45,898	6,704	14,6%	-0,148	-0,072
	a*	55,134	8,245	15,0%	-0,061	-0,888
	b*	0,561	0,155	27,6%	-0,167	-0,44

Notes. L* ligthness. a* coordinates red/green (+a indicates red, -a indicates green). b* coordinates yellow/blue (+b indicates yellow, -b indicates blue). sd; standard dev. CV%; percent coefficient variation.

The temperature of the drying air has a significant effect on the color characteristic of the Yacon. The parameter that had the highest sensitivity was L* (lightness). The value varies on average between 61 for fresh and 46.5 for dry, having a decrease of 25% represented in a darkening, as can be seen in Figure 4. With respect to the parameters a* and b* it is observed that the green color was accentuated, the values varied from 3 to 8. For the parameter b, the values varied from 21 and 28, accentuating the yellow color.

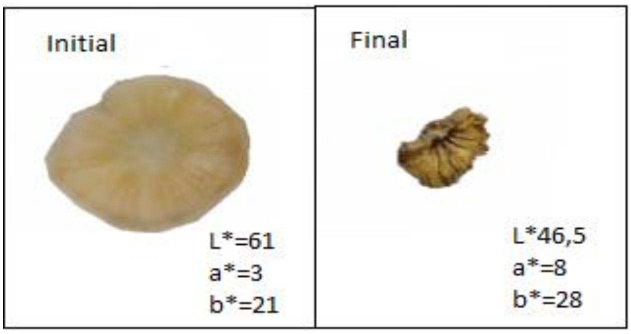

Figure 4. Color change in the yacon wheels of 6mm, in the process of drying the yacon at 80 ° C

To establish the change in the coloration of the product with the drying process, the median comparison test was used, finding no significant differences in the color change in the L* and b* axes (see table 5). In the coordinate a*, the color presented variations marginally significant, which implies that the magnitudes of the variations are slightly different between the treatments used ($p \approx 0.05$).

When analyzing the color changes that occurred due to the drying process, it was observed that the greatest color change was presented for the combination of 60°C and 4mm with a value $\Delta E = 39$ followed by the combination 60°C and 6mm with a value of $\Delta E = 34$, the lower temperature and greater thickness of the yacon slice, which leads to a longer drying time favoring browning; this is comparable with that reported by Cuervo-Andrade [14]. The smallest color change was presented for the combination of temperature parameters of 70° C and 2mm thickness.

The negative values of ΔH^* for all combinations of parameters indicate that the drying process increased the yellow color in the samples analyzed, the values between -1.26 and -1.45. In the case of saturation, it is observed that for all combinations of parameters the effect of the drying process was a decrease in saturation, which is reflected in the opaque color of the yacon slices as can be seen in Figure 4.

Table 5. Differences of medians in the initial and final color, coordinates L* a* b*

Treatments	ΔL^*	Δa*	Δb*	ΔE*	ΔC*	ΔH*
60°C 2mm	2,00	-4,33	-8,33	24,68	-42,55	-1,26
60°C 4mm	37,33	-9,00	0,33	39,05	-40,13	-1,26
60°C 6mm	30,07	-11,00	-9,33	34,11	-37,36	-1,38
70°C 2mm	8,67	-1,67	5,33	19,05	-40,00	-1,43
70°C 4mm	10,67	-7,00	-11,33	22,06	-29,40	-1,43
70°C 6mm	21,33	-10,33	-7,17	25,74	-31,93	0,06
80°C 2mm	15,67	-4,17	-13,33	23,96	-29,82	-1,45
80°C 4mm	16,67	-7,33	-7,67	19,12	-28,12	-1,41
80°C 6mm	8,67	-2,67	-9,67	25,11	-24,61	-1,45
$\chi^2_{(df=8)}(p)$	10,86 (0,210)	15,1 (0,058)	8,33 (0,400)	8,267 (0,408)	12,13 (0,105)	13,3 (0,083)

Nota. Δ = difference. χ^2= statistic Ji-square. df=degrees of freedom. p=p-hypothesis value. L*=ligthness. a*= coordinates red/green (+a indicates red, -a indicates green). b*= coordinates yellow/blue (+b indicates yellow, -b indicates blue).

When comparing the median value of ΔE* between the different treatments, it was observed that there is no significant difference in color variation, since within each treatment the median is similar to the overall median of the set of measurements, regardless of the treatments employed, affirmed with a confidence of 95%. A similar behavior was observed in ΔC* and ΔH*, color parameters that did not show important variations between the drying treatments used.

Table 6. Comparison of VOCs from Yacon fresh and after drying process at 60ºC at different thickness

No.	Compound	RI (HP-5)	RI (DB-wax)	%Area Fresh	4mm	6mm
1	acetic acid	600	1450	11,0	ND	ND
2	2,2,dimethyl-1-propanol	640	<1000	0,2	2,5	1,7
3	1-butanol	675	1145	13,1	3,2	1,9
4	2-methyl-1-butanol	720	1210	ND	0,3	1,7
5	4-hidroxy-4-methyl-2-pentanone	820	1352	0,1	15,2	17,9
6	heptanal	903	1174	ND	0,2	0,6
7	α-pinene	939	1032	0,5	ND	ND
8	camphene	953	1075	0,5	0,6	0,7
9	benzaldehyde	960	1495	1,2	11,6	17,3
10	β-pinene	981	1116	ND	4,3	3,9
11	butyl butanoate	985	1223	0,3	18,5	19,7
12	β-myrcene	992	1145	2,4	ND	ND
13	1-octanal	1006	1282	2,2	27,6	31,5
14	E-β-ocimene	1030	1230	49,7	ND	ND
15	dibutyl carbonate	1113	<1000	ND	33,3	28,5
16	2-metoxy-2-methylpropane	1130	<1000	ND	0.6	0,9
17	decanal	1208	1484	0,2	ND	ND
18	isoamyl decanoate	1615	1863	0,3	ND	ND

Note. ND Not detected

Volatile compounds of yacon pulp fresh and after hot air drying with three different sample masses and two different temperatures were extracted by Headspace-Solid Phase Micro Extraction (HS-SPME). Table 1 show the volatile compounds, retention indices on two orthogonal columns (HP-5 and DB-WAX) and concentration (Area % normalized). A total of 18 volatile compounds from yacon pulp fresh and dried powders were identified.

The major volatile compounds in fresh yacon were acetic acid, 1-butanol and E-β-ocimene. When the drying temperature increases, the amount of this major compounds decreases; and the minors almost disappear. After the drying process at 80ºC was not possible to find VOCs. So we compare only the influence of the thickness when the material is dried at 60ºC. In this way, a major thickness is better to avoid the loss of VOCs. In materials with 2mm was not possible to find VOCs.

4. Conclusions

The initialmoisture content of the Yacon did not present a significant difference which guarantees the use of homogeneous samples. As for the final moisture content, it can be said that increasing the temperature decreases the final moisture content of the product and, on the other hand, if the thickness increases, the moisture content of the product also rises.

Drying treatments do not significantly affect the final Yacon moisture index, and the color finally obtained for each of the treatments did not present significant differences due to the control of previous enzymatic browning and also because a loss of the volatile compounds was observed by drying effects. As for the conservation of the volatile compounds the Yacon dried at 60°C and 6mm slices was the best treatment.

The parameter that obtained the highest sensitivity due to the effect of the drying process was ligthness, with a variation of 25% with respect to the color of fresh yacon.

The combination of parameters with the less changes on the color was obtained for temperatures of 70°C and thickness of 2mm; but with these same parameters all the volatile compounds were lost.

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