Heat pump drying of red grape

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Abstract. Heat pumps have been known to be energy efficient when used in conjunction with drying operations. The principal advantages of heat pump dryers (HPD) emerged from the ability of heat pumps to recover energy from the exhaust as well as their ability to control the drying gas temperature and humidity. The red grape grains were dried with and without treating by hot sodium-carbonate solution in 3% concentrations. That osmotic treatment is necessary, because the grape grains have waxy layer in the skin which makes difficulties in the dehydration. The drying time was eight hours, till equilibrium weight. The received product has very low humidity (about 70 % dry base), which is already good for storage and stable from the viewpoint of microbiology. To control the effect of treatment not treated samples were also dried for 10 hours (technological time). The received material had smaller dry content about 37 %. Dielectric parameters (between 20Hz and 1MHz) were investigated in every hour. The aim of the experiment series was to see, if the method is useful to follow the drying process.

Keywords:
impedance parameters,
non-linear regression,
drying trends,
correlation matrix,
gentle drying,

INTRODUCTION

In order to reduce the cost of water and energy the food industry takes steps to develop processes that use significantly less of these resources and generate less waste. (Lee and Okos, 2011). The application of heat pump technology allows the production of high quality products based on better heat and energy efficiency, without damage to the environment, reducing production cost and power consumption (Pereira and Vicente, 2010). With appropriate choice of temperature-time variation, it is possible to reduce the overall color change while maintaining high drying rates (Chua and others 2000a, b). The endpoint of the drying is the "equilibrium moisture content". It is the moisture content remaining in a dry material, when the drying rate drops to zero at specified conditions of the drying medium is called the equilibrium moisture content. It is in equilibrium with the vapor contained in the drying gas and its magnitude is a function of the structure and type of the subject food and of the prevailing drying conditions. The equilibrium moisture values predicted by the static and dynamic moisture sorption do not always agree over the whole range of relative humidity of the drying air. The drying of the fruits requires energy for removing of free water (evaporation or sublimation) and for removing of water associated with the food matrix.

Fruit pretreatments including chemical pretreatment, freezing, thawing and osmotic dehydration can influence the dehydration or drying rates as well as maintain an overall quality of the final product. Waxy layer in the skin makes it difficult to dry the product. Dehydration of small fruits; such as grapes, blueberries, cranberries, cherries and gooseberries, is restricted by the outer surface (cuticle) which plays a major role in the control of transpiration and in protecting the fruit against weather in clemencies or attacks from insects and parasites (Somogyi and Luh, 1986; Somogyi et al., 1996). According to Kostaropoulus and Saravacos (1995) and Grabowski and others (1994), the drying time of surface pretreated grapes (immersed in ethyl oleate, etc) was reduced by about half. Salunkhe and others (1991) had reported that alkaline dipping facilitates drying by forming fine cracks on the fruit surface that was determined by Ponting and McBean (1970) that, pretreating with ethyl esters of fatty acids would be the effective treatment for fruits with waxy surface layer. Venkatachalapathy (1997) used an alkaline solution of 2% ethyl oleate and 0.5% sodium hydroxide (NaOH) as a pretreatment for strawberries and blueberries. The above authors have also dried osmotically pretreated cranberries. The use of osmosis allows decreasing water activity in food. The permeability of plant tissue is low to sugars and high molecular weight compounds; hence the material is impregnated with the osmoactive substance in the surface layers only.

Dielectric spectroscopy in a wide range of frequencies has been used earlier by for monitoring the changing of the electric impedance of vegetables during drying (Zsivanovits, G. and E. Vozáry, 2011) and during long or short time controlled storage of apples and other fruits. The correlations between dielectric parameters and for example quality of melons were analyzed by Wen-chuan Guo and others (2010). They reported relationships between fruit ingredients and dielectric parameters in high frequency range (from 10 MHz to 1.8 GHz). However, the prediction of soluble solid content by the dielectric properties was not as high as expected. Measurement of dielectric properties of agricultural material is essential for understanding their electrical behavior (Nelson, 2008) level of mechanical damage (Al-Mahasneh and others, 2007) and also for the development of indirect nondestructive methods for determining their physical characteristics, including moisture content and bulk density. Venkatesh and others (2004) found that corn samples chopped to different degrees showed a difference in dielectric response at similar bulk densities and moisture contents which indicated that some of the response was due to the chopping or size reduction. The dielectric properties of a food depend upon its composition. It is beneficial to conduct dielectric properties measurements for each product that is to undergo a dielectric heating process. Dielectric properties have primary importance to evaluate the suitability and efficiency of heat pump heating of the osmotically pretreated products.

MATERIALS AND METHODS

Materials

The investigation was carried out with red grapes, bought from the market. The grains were separated from the clusters before the drying or the pre-treating for drying. Following pre- treatment methods were applied for grains, separated from the grape cluster:

a) Thermal untreated;

b) Thermal treated
(washing → dipping in hot 3% sodium carbonate solution for 30sec → straining off → triple immersion in hot and cold water → spray washing with cold water).

Methods

Drying was applied by highly energy-efficient and environmental protective heat pump drying (HPD). The applied drier was developed by FRDI – Plovdiv (Figure 1). The process was carried out at 45 ± 2°C and low relative humidity (average 10%) of the circulating air. The mass of grape grains was measured during drying at every half an hour.

Figure 1
HPD configuration

The drying was finished when the mass was not changed further. The received technical time for treated samples 8 hours, and for not treated samples 10 hours. The dry content was investigated by „Sartorius Moisture analyzer" at 70 °C for 3g samples with 3 repeats before, during (after 4 hours) and after the drying. The antioxidant activity (µmol/kg TE) was detected by UV/VIS spectrometer "Thermo „EVOLUTION 201" also before and after the drying. These experiments were done by the accredited laboratory of FRDI. (AOAC, 1990)

Dielectric parameters of grains (20 samples) were investigated in every hour. The impedance was measured by Quad Tech 1910 Inductance Analyzer in frequency range between 20 Hz – 1 MHz with stainless steel pin electrodes (gap 5 mm) (Figure 2). Similar method and calculations were used earlier for monitoring the changing of the impedance during drying by Zsivanovits, G. and E. Vozáry (2011).

GW INSTEK 8110G precision LCR meter

pin electrodes (gap 5 mm)

Figure 2
Instrument for investigation of dielectric impedance spectra with pin electrode

Dielectric impedance and phase angle (θ_m) were used for the calculations in that experimental series. To show the effect of treatment and follow the drying process, maximum and minimum points of the phase angle with frequency and impedance coordinates of these were used in function of the drying time (Figure 3). The experimental values (Z_m and θ_m) were averaged over measurements of twenty grains in every hour.

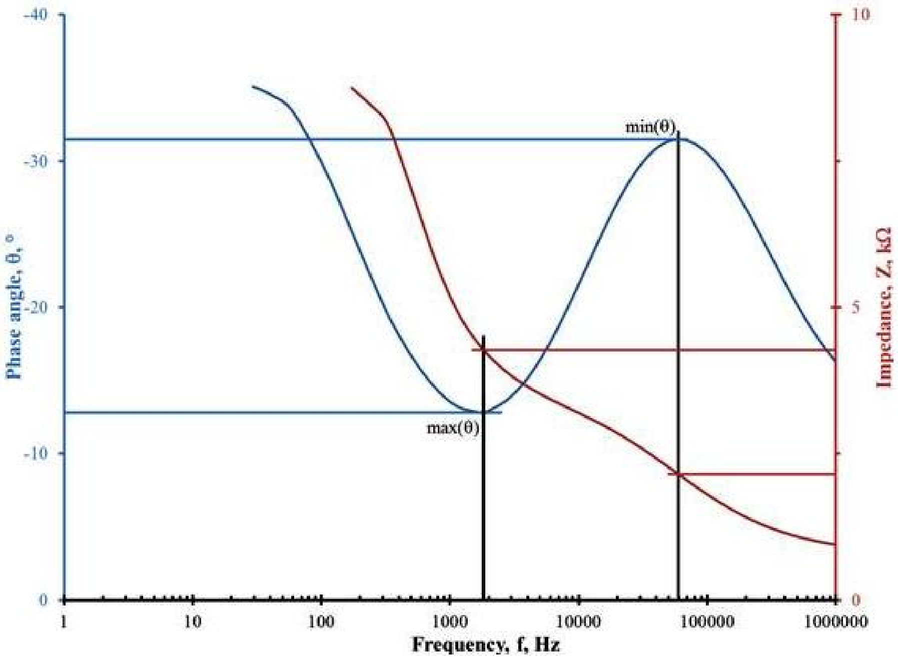

Figure 3
Phase angle in function of frequency of grape grain before drying and without treatment

The received data were processed statistically by non-linear (iteratively fitted sigmoid curve) regression in function of drying time. For the calculations Table Curve software was used. The used approximation formula was:

$$y=a+b/(1+\exp(-(x-c)/d)) \qquad (1)$$

The trend functions may useful to follow the drying process and to mark the endpoint (equilibrium water content) of it.

RESULTS AND DISCUSSION

The applied drying method with low temperature interval assures the preservation of the natural ingredients in the product. The ongoing drying is at closed cycle and the outside microbiological contamination is eliminated. The used treatment shorted the technological time for drying, and gave better (drier) product. The decreases of the AOA during the drying is very similar for the treated sample also, but the lower moisture content (about 30 %) give the stability of the product without other treatments for longer shelf-life time (Table1).

Table 1 Physico-chemical parameters of the raw-material and the dried products

Samples	Moisture content, row material, %	Moisture content, during the drying, % (4h)	Moisture content, end product, %	Technological time of the process, h	AOA*, µmol/g TE
Raw material	68.22	-	-	-	80.03
Not treated	68.22	66.46	63.02	10	33.93
Treated 3% $NaCO_3$	68.22	42.38	29.23	8	35.58

*Calculated for 100% dry material

Comparison of the samples before treatment

The examined two experimental series were done on different days, but on the same item. They had the same dry content and the dielectric properties of untreated samples before drying (control) were very similar on both days (Figure 4).

Results during the drying

Untreated samples

The phase angle curves of the untreated samples have one maximum (at lower frequency) and one minimum (at higher frequency) point in the examined diapason. During the drying these parameters were changed. The trends of the changes were followed by regression.

The calculated curves are shown on the figures (Figure 5-7) and their constants in table 2. Based on the results the drying was slowly, but it had more or less constant speed. The received product still had high humidity, and not suitable for longer shelf-life at cool and dry place.

Treated samples

The phase angle curves of the treated samples have just one maximum (at higher frequency) point in the examined diapason. The drier process was much faster, and the end product has low humidity and high stability. The received trends also show high correlations with the drying hours.

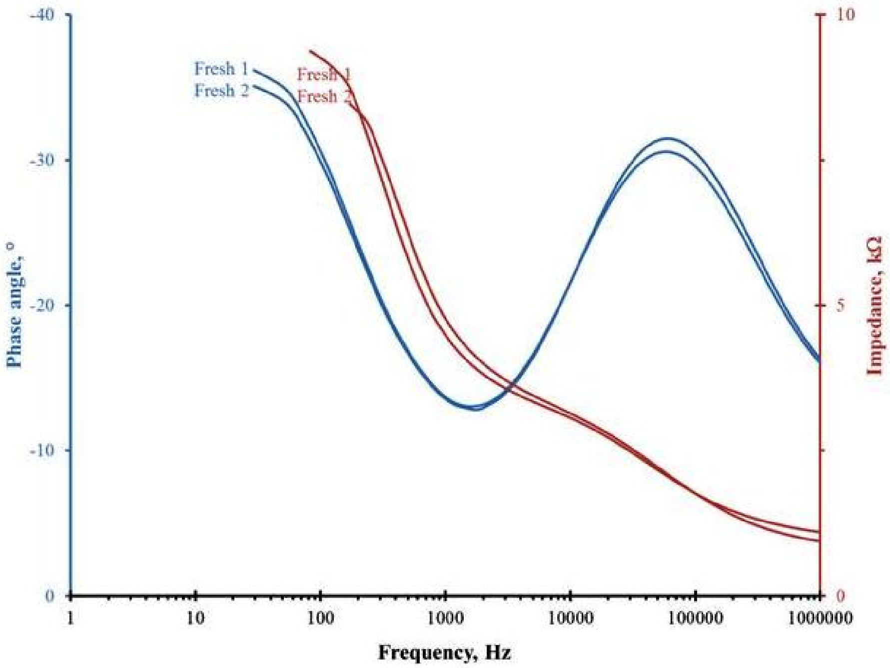

Figure 4

Dielectric average curves of the fresh grapes at both days before treatment or drying

The changes of the maximum phase angle (Figure 5) were very slowly in both untreated and treated case. The speed of treated changes seems to be more constant like for the untreated samples. For not treated samples the trend has an almost horizontal interval at the end of the drying, but with the shown very high moisture content the end product has not enough stability for storage in cool and dry place. It seems to be the technical endpoint of that drying, which means, the dry content cannot be higher without increases the temperature. The treated product has already enough high dry content for that stability.

Table 2 Constants of the trends and correlations between drying time and dielectric parameters

Parameters	Max (phase angle, °)		Frequency, kHz	
	not treated	treated	not treated	treated
A	-7.30	-14.57	-37.784	1.049
B	5.39	5.66	534.705	12.403
C	5.31	1.02	-0.023	0.006
D	3.40	3.28	-0.013	-0.002
r^2	0.9791	0.9883	0.9681	0.9896

Parameters	Impedance, k	
	not treated	treated
A	0.941	1.007
B	4.240	21.727
C	0.006	0.020
D	0.001	0.005
r^2	0.9957	0.9917

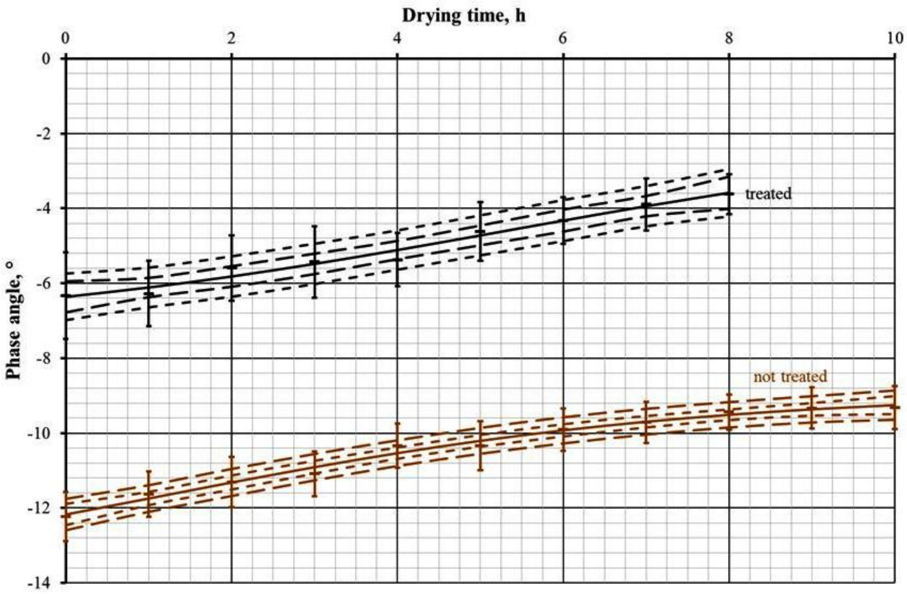

Figure 5
Changes of the maximum phase angle during the drying

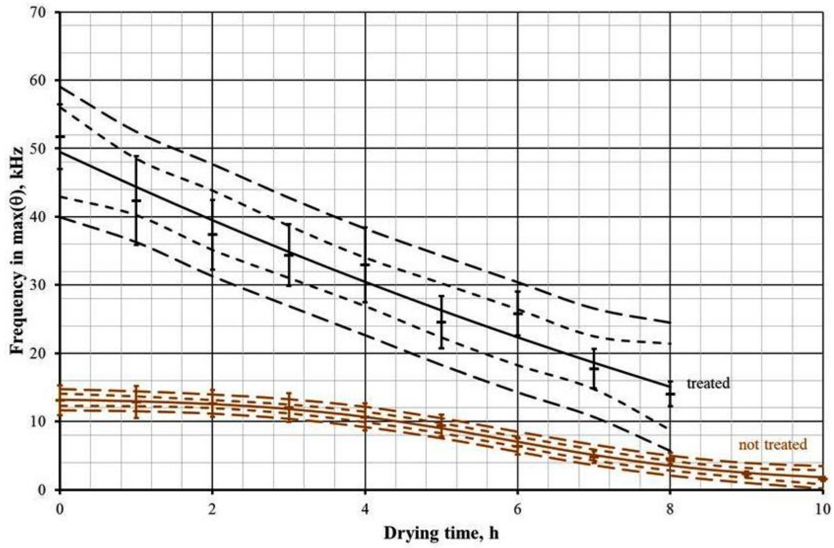

Figure 6
Changes of the frequency coordinate of the phase angle maximum during the drying

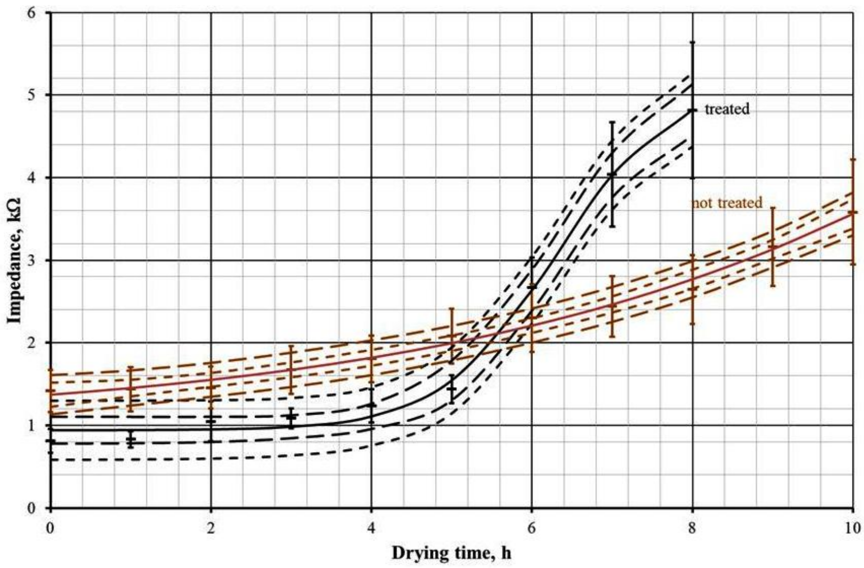

Figure 7
Changes of the impedance coordinate of the phase angle maximum during the drying

The frequency coordinate of the maximum phase angle was changed in bigger interval for the treated samples than for the untreated. The changes were almost linear (Figure 6).
The changes of the impedance coordinate were very slowly at the beginning of the drying of treated samples. The curve shows maybe that drying has 2 different phases in the change of impedance. To explain that in details, we should have measure the dry content more times, or other parameters as well (Figure 7).

CONCLUSIONS

The used drying method is useful and gentle enough for drying fruits till a stable product. The drying of berries with strong moisture barrier layer is very difficult and not enough effective without chemical treatments.

As it is shown in the table and on the figures the dielectric parameters are useful for following the drying process. The high correlations between the drying time and dielectrical parameters show the impedance parameters give information about the progress of drying.

FUTURE WORK

Next time we should repeat the work on more different treatments and with the examination of physico-chemical parameters during the drying process. The target of new experiments should be to look for connections between the quality parameters of dried products and the impedance parameters.

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