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Adsorption measurements and modeling of thyme treated with gamma irradiation and thermal–biochemical treatment

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ABSTRACT

Thymus satureioides is one of the most produced and consumed aromatic herb in Morocco. Hence, it is crucial to control its moisture content during storage. The aim of this research work was to compare the effect of thyme preservation methods on adsorption at different temperatures (30, 40 and 50 °C) and relative humidity (5–90%). For that, saturated salt solutions method was used. The behavior of untreated, irradiated and treated thyme during storage was studied by the experimental determination of adsorption isotherm curves. Then, the experimental data of adsorption were investigated and described by four mathematical models. Adsorption capacity of thyme decreases with the temperature rise, at constant relative humidity. The empirical Peleg model was found to best represent the treated thyme. However, untreated and irradiated thyme were approached by the Enderby's model. Hence, treatments by thermal–biochemical process and irradiation had significant effects on adsorption, optimum water activity and physical properties of thyme.

1. Introduction

The medicinal and aromatic plants have an enormous value for both the pharmaceutical industry and the traditional medicine in Morocco. Several plants are specific to some countries, especially *Thymus satureioides* which is an endemic plant of Morocco. *T. satureioides* is characterized by its rich composition in *p*-cymene (27.59%) and thymol (14.09%) (Benkhnigue et al., 2014; El Ouali Lalami et al., 2013). Moreover, this plant is known by its anti-inflammation and anti-oxidation effect due to its chemical composition specially the borneol (Liu et al., 2011; Tahraoui et al., 2007). Making plants suitable for human consumption and commercialization, acquire high hygienic quality of the plant material. The use of industrial decontamination processes were tools promising solutions to prevent the growth of microorganisms and to facilitate storage and transportation (Jordan et al., 2010). Hence, enormous conservation processes have been developed for plant materials, for example, vapor treatments, ohmic heating, thermal shock (HTST: high temperature short time), controlled sudden decompression (DIC), pulsed light or microwave (Fine and Gervais, 2004; Soran et al., 2014). In general, plant conservation is based on two processes: drying and gamma irradiation. On the one hand, drying process provides valuable conservation. The industry used it in order to preserve and store the seasonal plants and make them available to consumers all year round (Bonazzi and Dumoulin, 2011; Fudholi et al., 2015). On the other hand, Gamma irradiation improves the hygienic quality of various herbal materials and reduces losses due to microbial contamination. Furthermore, gamma irradiation has several advantages in increasing yield, improving the content of polyphenol compound and the antioxidant activity (Banerjee et al., 2015; Machhour et al., 2011). The sorption isotherms are an excellent way to determine the distribution and intensity of the connections of water and its availability in functional biochemical and biological substances. They are also

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Nomenclature

A, *B*, *C* & *D*	Model coefficients
a_w	Water activity
$a_{w(op)}$	Water activity optimal
Cste	Constant
CEC	Cation exchange capacities
CTACl	Cetyltrimethylammonium chloride
d.b.	Dry weight basis
EMC = X_{eq}	Equilibrium moisture content (kg water/(kg d.b.))
GAB	Guggenheim, Anderson and De Boer model
LESPAM	Laboratory of Solar Energy and Medicinal Plants
M_d	Mass of dry matter (kg)
M_w	Mass of wet matter (kg)
MRE	Mean relative error (%)
N	Number of data points
Rh	Relative humidity (%) ($a_w \times 100$)
R	Universal gas constant (8.3145 J mol^{-1} K^{-1})
r	Correlation coefficient
SIP	Streaming induced potential
T	Temperature (°C)
$Xeq_{i,exp}$	*i*th experimental EMC (% d.b)
$Xeq_{i,pred}$	*i*th predicted EMC (% d.b)
θ	Absolute temperature (K)
Δh_d	Net isosteric heat of adsorption, kJ mol^{-1}
ΔH_d	Isosteric heat of adsorption, kJ mol^{-1}
ΔH_{vap}	Heat of vaporization of pure water at 35 °C (43.53 kJ mol^{-1})

necessary in drying products (Bahloul et al., 2009). The sorption isotherms determine the optimum water content and the water activity that must be achieved during drying to approach a stable steady state. Consequently, the process ensures better preservation for the product during storage (Belghit et al., 1999).

Our study lies in the contrast between the transfer of water in the Medicinal and Aromatic Plants (MAPs) "*T. satureioides*" and the thermodynamic properties in hygroscopic equilibrium. The objective of this study is the experimental determination and modelling of adsorption isotherms at different temperatures were carried out for untreated thyme, treated thyme by gamma irradiation (1 kGy) and thyme reserved by thermal–biochemical process using renewable energy. The temperatures of 30, 40 and 50 °C were chosen to typify tropical storage conditions. Using an experimental approach, the equilibrium curves are determined by the saturated salt solution method. The experimental adsorption curve was described by four different models to identify the most appropriate mathematical model for a better description of the product equilibrium state. Then, we investigate from the experimental data the isosteric heat and the optimal water activity for the storage of untreated and preserved thyme. The observed difference of water activity between various samples was explained by the measurement of the streaming induced potential (SIP) and the determination of the cation exchange capacities CEC.

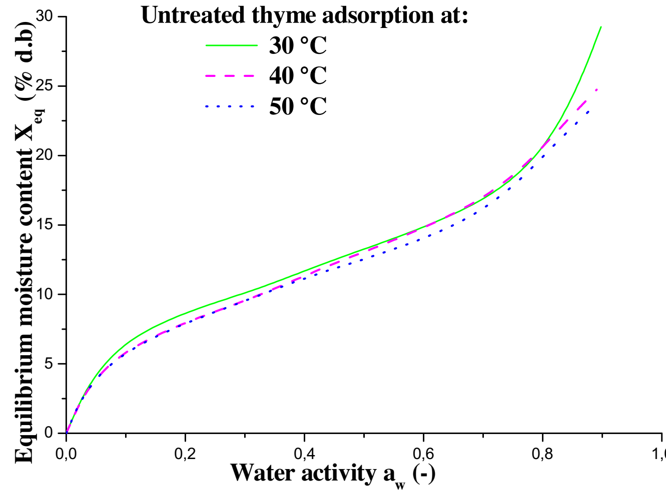

Fig. 2. Adsorption isotherms of untreated *Thymus satureioides* at 30, 40 and 50 °C.

2. Materials and method

2.1. Treatments & adsorption study

T. satureioides was collected at Marrakesh region. The plant was identified by the Regional Herbarium of the Faculty of Sciences Semlalia Marrakesh where a sample (MARK-8003) was filed.

The samples were treated by three preservation methods. The untreated thyme was dried at room temperature. The irradiated thyme was preserved by gamma irradiation at low dose 1 kGy (Machhour et al., 2011). The treated thyme was preserved by combined thermal–biochemical treatment which is based on the pulverization of citric acid followed by drying at 80 °C using a solar dryer with convective heat (Machhour et al., 2008).

The hygroscopic equilibrium is achieved by a static method (Lamharrar et al., 2014). The method is based on the use of saturated salt solutions to maintain a fixed relative humidity Rh. The mass transfers between the product and the ambient air are assured by natural diffusion of the water vapor. The experiment consists in putting the samples in glass jar contain different saturated standards salts so as to have a relative humidity which varies from 5% to 90% (Table 1) (Greenspan, 1977). A sample holder containing 0.3 g (±0.001) of aromatic plant is put on a tripod, which is placed in the glass jar (Fig. 1). The samples are weighed every two days in order to determine their equilibrium moisture content EMC (X_{eq}). As soon as the masses become stationary, the experiment is stopped and the samples are weighed and placed in a drying oven whose temperature is fixed at 105 °C for 24 h. Thus, the difference of mass before

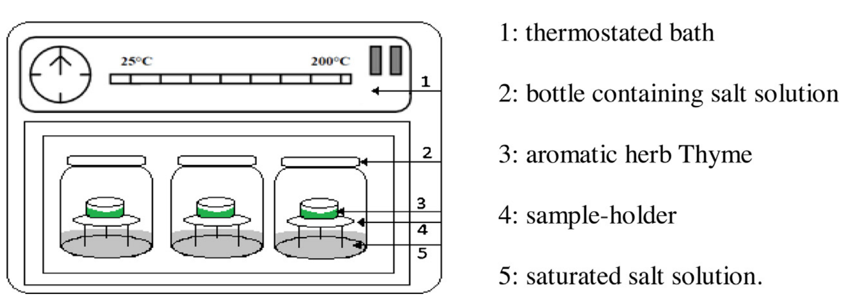

Fig. 1. Experimental apparatus for the sorption isotherms measurement.