Integrated heat and mass transfer model for solar drying simulation of grapes

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OBJECTIVES

1) to develop a computer program in order to simulate solar drying, which includes an integrated mass and heat transfer model.

2) to quickly assess kinetics and total drying time of field solar drying of grapes submitted to different pre-treatments.

INTRODUCTION

- The consistent increase of society demand for a sustainable development is reinforcing the use of solar drying, due to being a renewable energy technology.
- Raisins are easily produced with solar energy, and are an excellent source for providing vitamins, minerals (essentially iron) polyphenols, flavonoids, crude fibre and antioxidants in general. Besides their nutritive value, they also present functional properties, benefiting human health.
- In order to design drying equipment, it is essential to model the process. Mathematical modelling is also important to predict and simulate the drying behaviour. Drying is a complex phenomenon simultaneously involving mass and heat transfer.

MATERIALS & METHODS

- Red seedless grapes *Monukka* cultivar

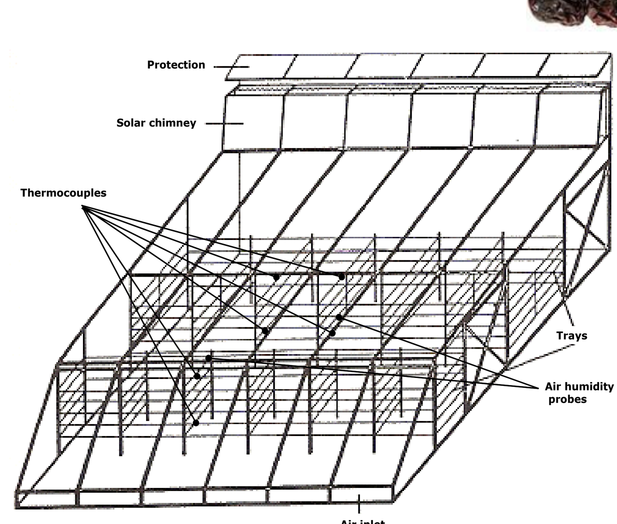

Fig. 1 *Solar dryer at Mirandela, Portugal.*

THEORETICAL CONSIDERATIONS

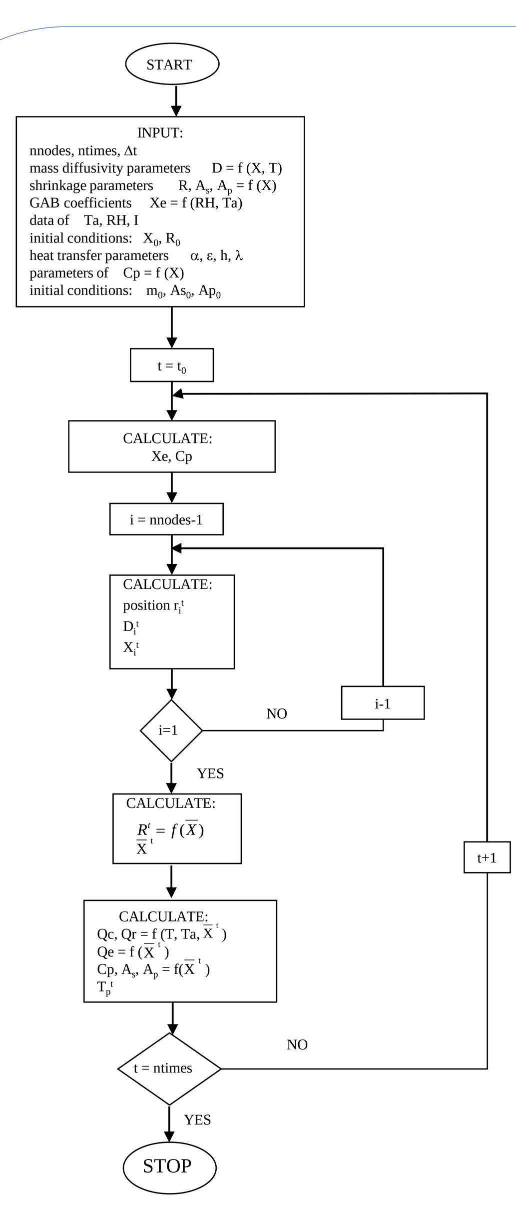

Fig. 2 *Schematic flowsheet of the computer program for prediction of grapes solar drying curves.*

Mass and heat transfer approach

- Fick's second law and a heat balance equation - solved by explicit finite differences.
- Negligible resistance to external mass transfer and to internal heat transfer
- Integrated model considering:
1. changes in effective mass diffusivity and thermal properties with water content and temperature, along drying and within grapes (non-isotropic characteristics)
2. shrinkage of the product with subsequent changes on its surface and projected areas, and distance between nodes
3. changing boundary conditions (equilibrium changes with variable air conditions).

Developed equation to express mass diffusivity dependence on water content and temperature:

$$D_i = D_0 \exp\left[a\frac{X_i}{X_0} - b\left(\frac{X_i}{X_0}\right)^2 - c\left(\frac{1}{T} - \frac{1}{T_{av}}\right)\right]$$

Heat transfer model:

$$\frac{d(m\,Cp\,T)}{dt} = \alpha\, A_p I(t) - \bar{h}\, A_s (T - T_a) - \frac{d(\lambda\, m_w)}{dt} - A_s\, \varepsilon\, \sigma\, (T^4 - T_a^4)\, F$$

Meteorological model: To generate data of climatic diurnal variation in radiation, developed by Charles-Edwards and Acock (1977).

$$I(t_d) = \frac{J_N}{g_N}\left\{1 + \cos\left[(t_d - 0.5) \times \frac{2\pi}{g_N}\right]\right\}$$

RESULTS & DISCUSSION

Mass and Heat transfer approach

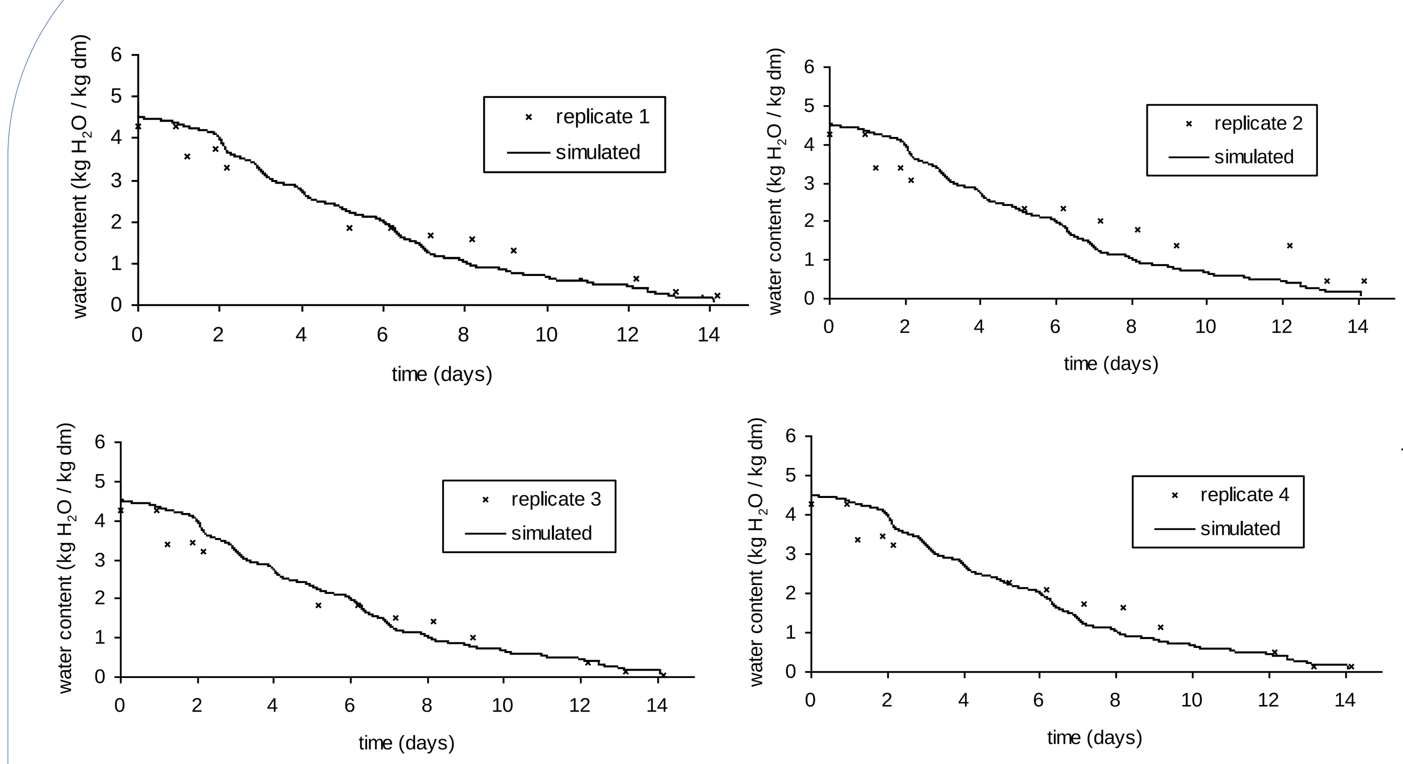

Fig. 3 *Simulation of solar drying curves (4 experimental replicates) for grapes blanched in water during 15 s.*

Kinetic approach:

Normalised Newton model

$$\frac{X}{X_0} = \frac{Xe}{X_0} + \left(1 - \frac{Xe}{X_0}\right)\exp(-k\,t)$$

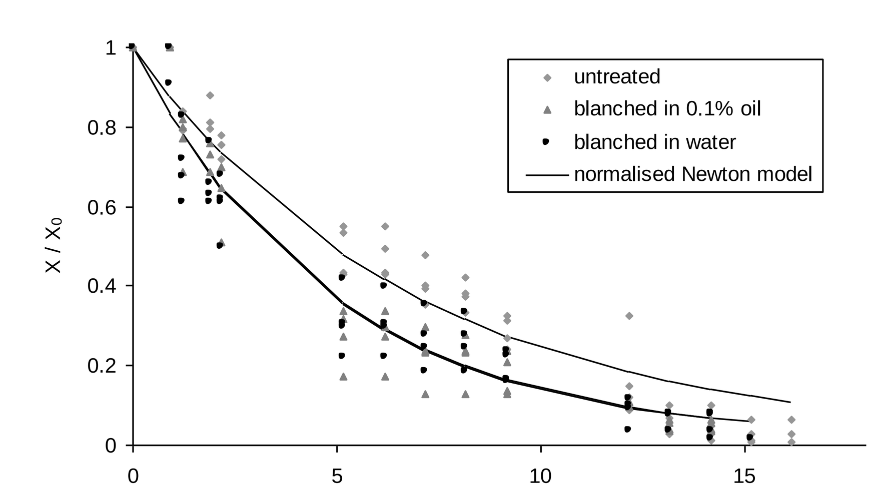

Fig. 4 *Comparison between different pre-treatments on grape drying kinetics.*

- It was observed that pre-treated samples (blanched in hot water or in a 0.1% emulsion of sunflower edible oil at 99ºC, for approximately 15 seconds) had faster drying rates (Newton model) than untreated grapes, not implying a noteworthy difference in total drying time. However, pre-treatments had an important role accelerating initial drying rates, thus preventing moulds and bacterial grow and consequently increasing farmers' income.

CONCLUSIONS

- The modelling and simulation of dynamic experimental drying with cyclic air conditions, using water content gradients and shrinkage simultaneously, were innovative and represent a contribution in Food Engineering.
- A good representation of experimental solar drying curves was attained by simulation. The computer program may be easily applied for simulating solar drying of different foods, once known the specific characteristics of the product.

REFERENCES:
Charles-Edwards, D.A.; Acock, B. 1977. Growth response of a chrysanthemum crop to the environment. II a mathematical analysis relating photosynthesis and growth. Annals of Botany 1977, 41, 49-58. Quoted in France, J.; Thornley, J.H.M.; Weather. In Mathematical models in agriculture - a quantitative approach to problems in agriculture and related sciences; Butterworth: Kent, 1984; 95-113.

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