Mathematical modelling of convective drying of Galega kale

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Introduction

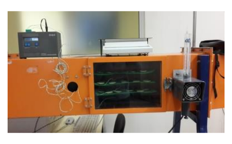
- Kale - *species Brassica oleracea*, Galega variety (Portuguese) has high contents of vitamins (A, B1, B2, C, D, E, K), mineral macronutrients (Ca, Mg, K, P), mineral micronutrients (Fe, Zn, Mn) and glutamine (anti-inflammatory properties).
- Used in Portuguese soup *caldo verde*, Spanish *caldo gallego* or Brazilian *couve mineira* and can be consumed as an ingredient of several soups and side dishes.
- Revived by consumers in USA as a 'super-food' (e.g. spicy chips).
- Modelling is crucial for designing drying equipment, predicting drying times and product loads.

Objectives

- To find adequate models that describe conveniently the drying process of Galega kale.
- To determine and model the sorption isotherm, in order to include the equilibrium water content in semi-empirical equations.
- To analyse the influence of air temperature and integrate this effect on drying rate, using a one-step methodology.

Materials & Methods

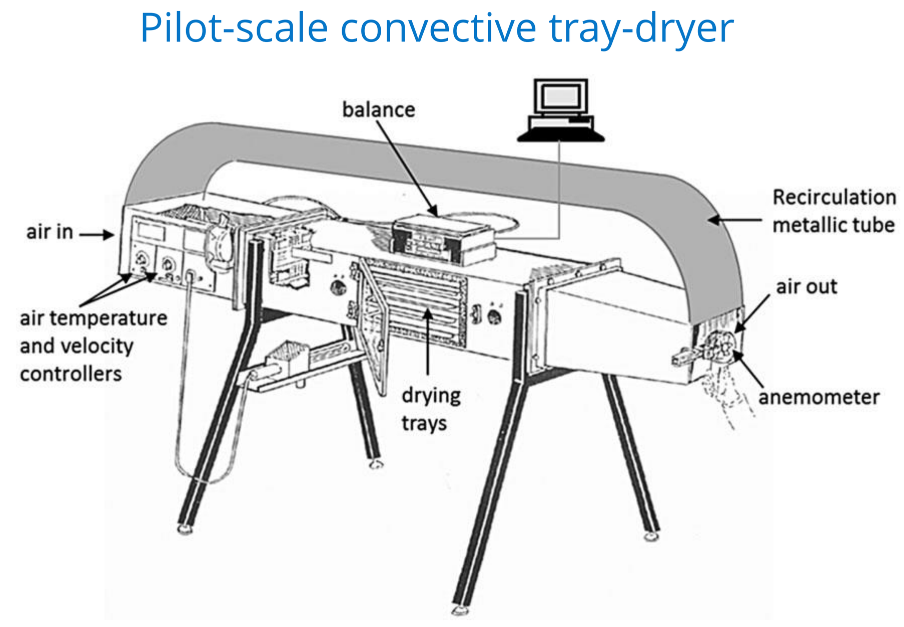
fresh Galega kale → Water Blanching 98±2ºC, 1min →



Tray-dryer →

dried Galega kale

Pilot-scale convective tray-dryer



Temperatures: 40, 55 and 70ºC
Air velocity: 1.20 ± 0.09 m s^{-1}

two replicates of each drying temperature

Thin-layer drying models tested

Newton or Exponential	$\frac{X-Xe}{Xo-Xe} = a\exp(-kt)$
Midilli-Kucuk	$\frac{X-Xe}{Xo-Xe} = a\exp(-kt^N) + bt$
Henderson & Pabis	$\frac{X-Xe}{Xo-Xe} = a\exp(-kt)$
Page	$\frac{X-Xe}{Xo-Xe} = a\exp(-kt^N)$
Two-term	$\frac{X-Xe}{Xo-Xe} = a\exp(-k_1t) + b\exp(-k_2t)$

X – water content
Xe – equilibrium water content
Xo – initial water content
a, b, k, N - model parameters

Desorption isotherm

hygroscopic method at 22ºC
AquaLab 3TE, Decagon Devices

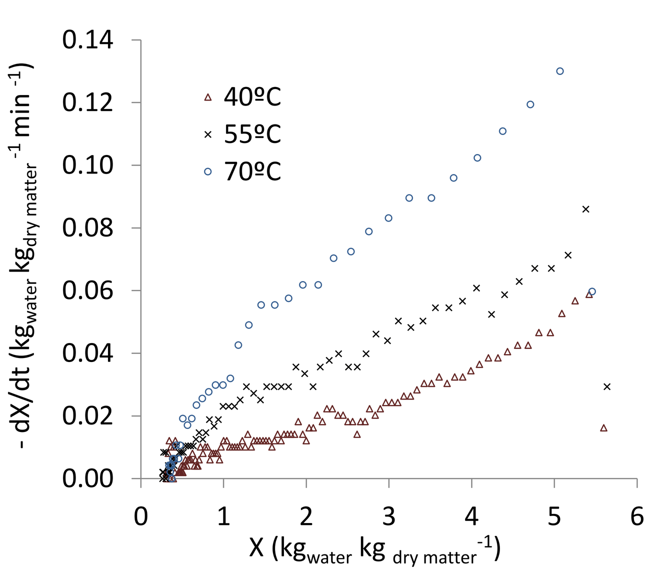
- Arrhenius equation

$$k = k_{ref}\exp\left[-\frac{E_a}{Rg}\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)\right]$$

E_a – activation energy
Rg – universal gas constant
ref – reference value

Results & Discussion

Characteristic drying curve



fresh Galega kale

convective dried

A constant-rate period was not detected and different falling-rate periods were observed

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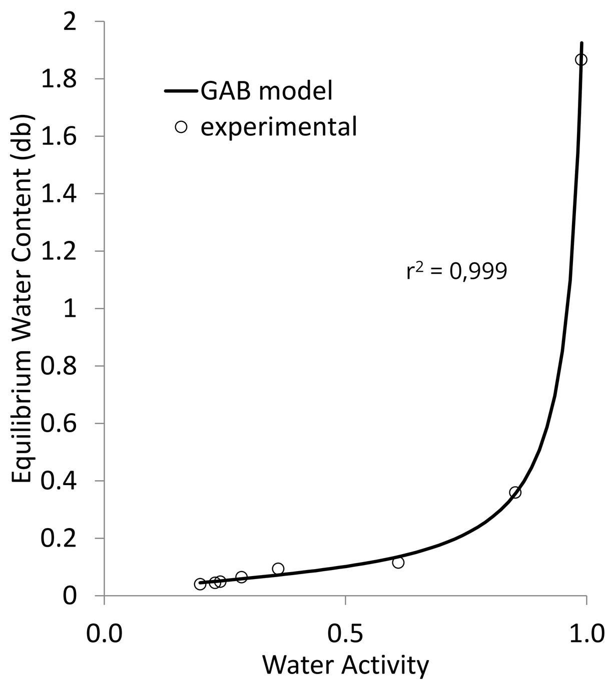
drying is mainly regulated by the diffusion of water through the kale

Water desorption isotherm (22ºC)



Guggenheim-Anderson-deBoer (GAB) model

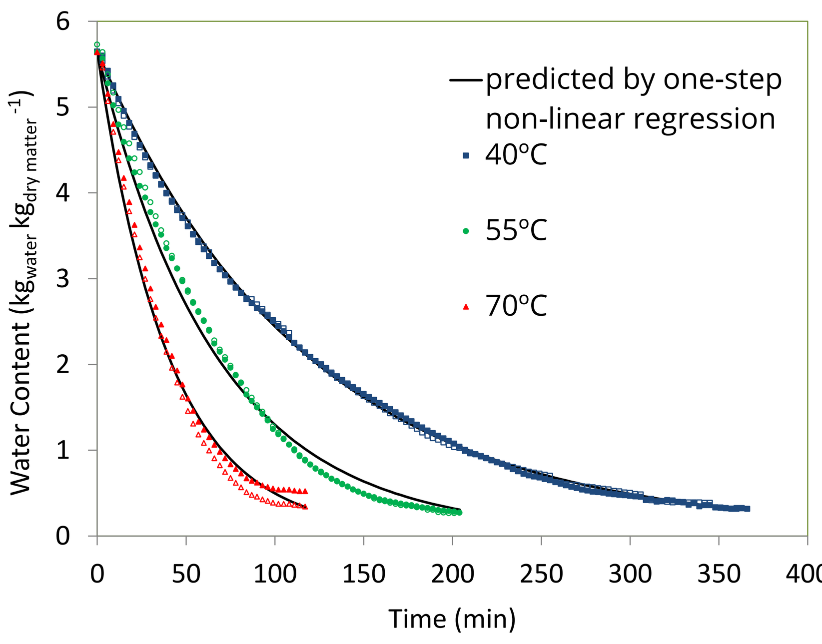
$$\frac{Xe}{Xm} = \frac{CKa_w}{(1-Ka_w)(1-Ka_w+CKa_w)}$$

Xm = 0.0609 kg_{water} $kg_{drymatter}^{-1}$
(monolayer water content)
C = 6.00
K = 0.979

One-step non-linear regression

Coupled Midilli-Kucuk and Arrhenius models

$$\frac{X-Xe}{Xo-Xe} = a\exp\left\{-k_{ref}\exp\left[-\frac{E_a}{Rg}\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)\right]t^N\right\} + bt$$



a = 0.990 ± 0.004
b = 4.491x10^{-5} ±1x10^{-5} min^{-1}
N = 1.10 ± 0.01
k_{ref} = 9.9 x10^{-3} ± 5x10^{-4} min^{-1}
E_a = 501 ± 5 J mol^{-1}

Conclusions

- The Midilli-Kucuk semi-empirical equation presented the best fit, evaluated by the best statistical indicators for the six experiments: higher values of R^2 and lower values of the standard deviation of the experimental error.
- The estimated drying rate values (**k**) and activation energy (**E_a**) were in the same range of the ones found in literature.
- The one-step methodology coupling the Midilli-Kucuk and Arrhenius equations, is an efficient tool to predict the engineering parameters necessary to model the drying process.

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