Towards a better prediction of fruit dehydration: a multiscale hygro-mechanical model

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ABSTRACT

In line with the increasing demand for high quality dried fruits [1], several studies aim at improving fruit dehydration methods. Apart from experimental studies, numerical simulations have become essential in the optimisation of dehydration techniques. Convective dehydration is the most commonly method used in the fruit processing industry. From the physical point of view, this process poses several challenges. These involve an accurate understanding of the coupling of heat and mass transport within the fruit, of the exchange at the fruit-air interface, and also of the large deformation of the fruit tissue.

Continuum modelling is widely used to evaluate dehydration processes of several materials. Yet, the accuracy of such models depends strongly on the macroscopic material properties. For fruit, particular difficulties arise because the fruit cellular microstructure deforms significantly during dehydration. This large deformation affects the fruit macroscopic hygric and mechanical properties. Further these properties vary with respect to dehydration state or moisture content. How much and by which mechanisms the changes in fruit microstructure affect moisture permeability and thus drying kinetics is yet to be determined. Nevertheless, most studies do not take these effects into account.

The present study addresses the aforementioned knowledge gap using a multiscale approach, where the effective moisture permeability of the fruit is derived from microscale modelling of the cellular structure. Different dehydration states of the cellular structure at corresponding levels of water activity are modelled. The effective moisture permeability as a function of water activity and sorption isotherm are obtained, which enables upscaling towards a continuum model.

A coupled hygro-mechanical model at the continuum scale is developed to study the response of a piece of fruit to the variation of drying conditions (temperature, RH, air velocity). The model solves the heat and mass transfer within the fruit by assuming conductive heat transfer and diffusive moisture transfer. Evaporation occurs at the fruit-air interface and the air domain is explicitly solved by means of conjugate modelling. Large deformation is accounted for by considering the fruit as a hyperelastic material [2]. The coupling between moisture transport and deformation is performed one-way, as such that the moisture losses, thus the fruit volume changes, develop a strain field that is used to solve the momentum balance of the fruit solid matrix.

This study investigates the apple dehydration process, as dried apple is one of the most consumed dried fruits in some parts of the world, including the EU [3]. A fresh apple cell that has diameter of 200 μm is used in the microscale model. For the continuum model, a fresh apple tissue is set to have a dimension of 4 cm x 2 cm x 1 cm. Parametric analyses assess the dependency of three quality criteria for dried apple products, i.e. moisture content distribution, nutritional retention and final product size, on the drying conditions.

REFERENCES

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