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Review

Novel trends in numerical modelling of plant food tissues and their morphological changes during drying — A review

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ABSTRACT

Food engineers and researchers have been making numerous attempts to mathematically model and simulate the underlying mechanisms of plant food drying in order to optimise the process efficiency and product quality. Numerical modelling has been widely used for this purpose because it reduces time and improves resource efficiency compared to real world experimentation. Different grid based methods have been conventionally used for this purpose despite their significant limitations particularly when encountered with large deformations and multiphase phenomena. As an alternative, meshfree methods have been gaining popularity because of their unique abilities in handling such complicated physics. In this background, this application could be used to assess the capabilities of meshfree methods as it involves large deformations, extreme moisture content variations as well as multiphase phenomena. This article reviews the current developments of meshfree approaches which model and simulate plant cellular systems and their morphological changes during drying. It could be concluded that meshfree methods have unique advantages especially in terms of performance and versatility in this regard and there are potential future work in the areas of accommodating temperature variations, 3-D modelling and multiscale modelling.

Contents

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1. Introduction

Numerical modelling is an effective tool to investigate the fundamental mechanisms of plant cellular structures and their dynamics. It is applicable for a wide range of materials depending on the product or process requirements (Bruce, 2003; Heredia et al., 1995; Konstankiewicz and Zdunek, 2001; Rahman, 2008). It saves time, money and other resources spent on experimenting with real life plant samples and also provides detailed results leading to enhanced fundamental understanding on various phenomena associated. In this regard, cellular morphological behaviour during drying is one of the challenging application areas. Food drying is a popular technique for preservation of fruits and vegetables (Adiletta et al., 2016; Jangam, 2011; Sablani, 2006; Stefan et al., 2003). Therefore, fundamentally investigating the removal of water content and associated deformations in the cellular structure could aid on improving the process performance, dried food quality and their market value (Abbott, 1999). To engineer feasible food drying operations, it is imperative that these cellular structural deformations are optimally controlled (Luyten et al., 2004). In doing so, a deep understanding on cellular level deformations is necessary. And to study the cellular level deformations in fruits and vegetables (plant food), numerous modelling approaches are available. These approaches deal with different bulk level physical properties such as moisture content, drying temperature, porosity and internal sub cellular properties like cell size, turgor pressure and cellular level shape factors (Bolin and Huxsoll, 1987; Chaplain, 1993; Hettiaratchi and O'Callaghan, 1978; Lewicki and Drzewucka-Bujak, 1998).

Grid-based methods and meshfree approaches are the two main types of numerical modelling used to simulate plant food drying phenomena. The grid-based numerical methods have been successfully applied in solving problems in engineering and science for a long time (Anderson and Wendt, 1995; Chung, 2010; Gao and Pitt, 1991; Lardner and Pujara, 1980; Liu et al., 2010; Zhu and Melrose, 2003). However, they generally suffer from deficiencies in a number of aspects due to the inherent 'grid' nature (Loodts et al., 2006; Nilsson et al., 1958; Pathmanathan et al., 2009; Pitt, 1982; Smith et al., 1998; Wang et al., 2004; Wu and Pitts, 1999). There are disadvantages of their use in the areas of modelling free surfaces, deformable boundaries, moving interfaces, crack propagation and large deformations (Abera et al., 2013; Fleischer and Barr, 1994; Honda et al., 1984; Ishimoto and Morishita, 2014; Liu, 2010; Rudge and Haseloff, 2005). To overcome such deficiencies, grid-free (or meshfree) based numerical modelling methods have been recently researched with promising outcomes.

Table 1 presents a summary of numerical modelling techniques used to simulate plant food cellular structures and their drying phenomena along with information on their specific strengths and limitations. It should be noted here that this comparison is supposed to be understood in a relative manner rather than in an absolute meaning. One of the main intentions of this article is to inform the reader on the potentially best methods to develop a comprehensive model which can be used to analyse plant food tissues and their morphological changes under different circumstances (e.g. degree of moisture removal, turgor pressure loss, rate of drying etc.). At the same time, it is intended to provide a thorough comparison and a summary on the novel trends in numerical modelling of plant cells and tissues as well as on the related morphological changes during drying. A general guideline is then presented in Fig. 1, which can be used to select the most appropriate numerical modelling approach for a given application. For instance, if the scenario that has to be modelled consists of multiphase phenomena with large deformations, it is clear that a meshfree based method is more suited over a conventional grid-based method. For purely solid materials undergoing limited deformations, a grid-based approach like FEM/FDM may be used. It has to be emphasised here that this generic guideline has been brought up considering the capabilities of modelling techniques available in published literature to date and there can be exceptions being developed or already developed, but not published. In Fig. 2, the outcomes of recently developed techniques for numerically modelling plant tissues have been presented.

In meshfree based models, recent attention has been on modelling fruit-and-vegetable cellular structures especially through coupled SPH (Smoothed Particle Hydrodynamics) and DEM (Discrete Element Method) approaches. SPH and DEM models have produced much acceptable results by closely replicating the behaviour of true plant cellular structures. In the upcoming sections, such work will be critically reviewed. The fundamentals of the meshfree approaches will be discussed followed by their common applications in modelling plant cellular structures during drying. Also, aspects of numerical implementation and validation of these approaches will presented, followed by addressing their limitations and potential areas for future development.