



Physicochemical properties and relaxation time in strength analysis of amorphous poly (vinyl-pyrrolidone) and maltodextrin: Effects of water, molecular weight, and lactose addition

Wenli Liu ^a, Yrjö H. Roos ^b, Fanghui Fan ^{a, *}

^a Department of Food Science and Engineering, College of Chemistry and Environmental Engineering, Shenzhen University, Guangdong, China

^b School of Food and Nutritional Sciences, University College Cork, Cork, Ireland

ARTICLE INFO

Article history:

Received 27 November 2017

Received in revised form

21 January 2018

Accepted 23 January 2018

Available online 3 February 2018

Keywords:

Poly (vinyl-pyrrolidone)

Maltodextrin

Strength

Water

Molecular weight

Lactose addition

ABSTRACT

Fundamental knowledge of physicochemical properties of polymeric food materials is of practical importance in food and pharmaceutical industry. Effects of water, molecular weight, and lactose addition on glass transition temperature (T_g), α -relaxations, and relaxation time (τ) of amorphous poly (vinyl pyrrolidone) (PVP) and maltodextrin (MD) were studied at various a_w and 25 °C. Water sorption behaviour of amorphous PVP and MD was M_{wavg} -dependent at $a_w \leq 0.44$, whereas the molecular size effects dominated the sorption process of MD at $a_w \geq 0.56$ and 25 °C. Fractional water sorption was confirmed in studied polymers/lactose mixtures at $a_w \leq 0.44$ in molecular scale, whilst collapsed structure of above mixtures were observed at $a_w \geq 0.44$ during storage up to 20 days at 25 °C. Despite of the calorimetric onset T_g of amorphous polymers/lactose mixtures showed a composition-independent at $a_w \leq 0.44$, T_g , α -relaxation, and τ of PVP and MD were disturbed by water, molecular weight and size, and adding lactose. Structural strength (S) of PVP was determined by its molecular weight at $a_w \leq 0.44$, whereas molecular size dominated the S of MD at $0.44 \leq a_w \leq 0.76$ due to water migration. The changes of a_w and lactose addition significantly disturbed the S of studied polymers. Moreover, a combined use of water sorption isotherm and the relationship of S and a_w gave a quantitative measurement of compositional effects and could be used to control the physicochemical properties of amorphous food polymers, such as collapse.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

Knowledge of physicochemical properties of food components, such as modulus and viscosity, volume and thermal expansion, mechanical and dielectric properties, is essential for understanding of the process and stability of food and pharmaceutical products. Physicochemical properties of food solids are proved highly dependent on their physical states, including crystalline and amorphous state, because of its importance for both quality and storage stability (Liu et al., 2006; Mullin, 2001; Yu, 2001; Slade et al., 1991). At temperatures close to or above glass transition temperature (T_g), the amorphous state of materials are change dramatically as a result of rapid molecular mobility and exhibit phase and state transitions, time-dependent soften, viscous flow,

and structural deteriorations (i.e., stickiness, agglomeration, and collapse), which can significantly affect the processability and storage stability of food and pharmaceutical products (Roos, 2010; Meste et al., 2002). Numerous publications have reported the T_g data for many food components, e.g., carbohydrates (Ruiz-Cabrera and Schmidt, 2015; Weng and Elliott, 2014; Descamps et al., 2013), lipids (Castellano et al., 2006; Nelson and Labuza, 1992), and proteins (George et al., 2014; Porter and Vollrath, 2012). Although the T_g is considered as a useful material descriptor can correlate with the structural and thermodynamic properties of amorphous food system in various processing and storage conditions, T_g of a material alone provides little information about describing the kinetic processes of molecular mobility associated structural transformations of amorphous food materials.

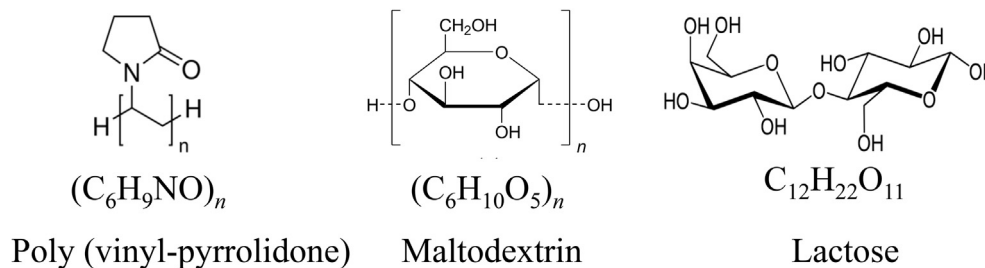
The molecular mobility within amorphous materials changes from local (vibration and reorientation) to translational above their T_g and such changes can result in the kinetics of various structural transformations related to glass transition in physical state of such

* Corresponding author.

E-mail address: fanghui.fan@szu.edu.cn (F. Fan).

substances (Champion et al., 2000; Slade et al., 1991). Above time-dependent structural changes often appear as several relaxation processes, such as β -/ γ -relaxations, enthalpy relaxation, and α -relaxation (Liu et al., 2006; Roudaut et al., 2004). The α -relaxation reflects the tendency of the material from rigid glass towards to nonequilibrium liquid states around glass transition and can be characterised by its corresponding relaxation time, τ (Champion et al., 2000; Johari and Goldstein, 1970). The τ refers to the time factor corresponding to material response to a change in internal

functional properties in the finished products, such as stability against oxidation (Karaca et al., 2015), improved solubility (Spigno et al., 2013), controlled release (Kittisuban et al., 2014), and extend shelf-life (Lavelli et al., 2016). Although the importance of glass transition to amorphous PVP and MD have been well established, little information has given and contributed to the understanding of the molecular mobility associated relaxation processes and compositional effects on time-dependent physicochemical changes during processing and storage.



and external thermodynamic conditions, such as temperature, pressure, and relative humidity (Angell, 2002; Slade et al., 1991). It should be noted that τ is often related to viscosity and can imply to deformations resulting from variation in molecular motions and describe a viscous flow of amorphous material (Fan and Roos, 2017). Therefore, modeling of α -relaxation and its corresponding τ of food materials is practically important as small rheological variations in solids may result in dramatic changes of material performance in processing, storage stability, and sensory properties of foods. Recently, Roos and co-workers (Roos et al., 2016; Fan and Roos, 2016; Maidannyk et al., 2017) proposed a structural strength (S) concept based on William-Landel-Ferry (WLF) relationship, which combines temperature changes ($T-T_g$) and practically important time factors, at which τ decreases to a critical level. Such critical level, i.e., 10^{-2} s, often results the structural deteriorations, such as stickiness and caking, of food solids, such as lactose and milk powder (Roos, 2013; Maidannyk et al., 2017). As a new food property, therefore, the RFM S parameter can be used to describe time-dependent changes of noncrystalline food solid systems and formulate materials in order to improve material performance in typical processing and storage conditions, e.g., food drying and powder handling, where a component or miscible components within food structure may undergo phase and state transition.

Polymeric food components, e.g., polysaccharides, proteins, and some bio- or synthetic compounds, are available over a wide range of molecular weight and may undergo a change in state from a very viscous glass to a rubber over a specific temperature range referred to T_g (Rayner et al., 2016; Jones et al., 1991). Poly (vinyl-pyrrolidone) $[(C_6H_9NO)_n]$, PVP, as a synthetic polymer, often used as a model compound to model process performance of foods in industry, such as an excipient (Foltmann and Quadir, 2008; Oksanen and Zografis, 1990), a thickening agent (Franceschinis et al., 2014), a protective film (Malhotra et al., 2015), a clarifying agent in wine clarification processing (Mierczynska-Vasilev and Smith, 2015), and entrap/retain volatiles (Saha et al., 2015). Maltodextrin $[(C_6H_{10}O_5)_n]$, MD, as starch derivatives, can be described as a food polymer in which their thermal and time-dependent properties have similarities to those of polymers (Roos and Karel, 1991). MD is widely added during production of food powders in order to act as encapsulating or wall materials (Li et al., 2017; Rajabi et al., 2015), increasing viscosity (Castro et al., 2016), delaying crystallization behaviour (Potes et al., 2012), decreasing stickiness and hygroscopicity (Mitchell et al., 2017), and also contributed to keep the desired

Understanding physicochemical properties and glass transition-related relaxations of food polymers and their coupling with other components and molecular weight is essential for modeling the physical state and the design of complex food systems at various conditions. Water is of key importance to food systems. Unlike chemically bound water, the “free” or “active” water in samples (measured by water activity, a_w) could change “free volume” and affect the physicochemical stability of amorphous foods during processing and storage (Fan et al., 2017; Al-Muhtaseb et al., 2002; Slade et al., 1991). Besides, numerous studies have connected the physicochemical properties of amorphous polymers and polymer mixtures to molecular weight as the distribution of molecular weight can be related to free volumes (Lodi and Vodovotz, 2008; Slade et al., 1991; Fox and Flory, 1950). The importance of glass transition to amorphous polymers characteristics has been well recognized but few studies have contributed to understanding effects of water, molecular weight, and sugar addition on the physicochemical characteristics and relaxations processes in food polymers. Lactose [β -D-galactopyranosyl (1–4)-D-glucopyranose, $C_{12}H_{22}O_{11}$] is one of the most common and important ingredients in many formulated foods and pharmaceutical materials (Gänzle et al., 2008). In the present study, therefore, the freeze-dried MD and PVP with various average molecular weight (M_{wavg}) and mixes of MD10/lactose and PVP10/lactose were used as studied amorphous food polymers and miscible polymers/sugar models. The objectives of this study were to investigate the effects of water, M_{wavg} , and lactose addition on the physicochemical properties of amorphous MD and PVP, such as water sorption, glass transition, collapse, α -relaxation and corresponding τ . Moreover, the strength analysis was carried out to determine the S value for amorphous polymers and mixtures in order to show the applicability of S concept in characterizing structure changes. These set of data are useful for the understanding of compositional effects on fundamental physical properties and collective relaxation processes when presenting above food polymers in food and pharmaceutical products experiencing glass transition in processing and storage.

2. Materials and methods

2.1. Sample preparation

PVP (Sigma-Aldrich, St. Louis, U.S.A) of three M_{wavg} of 10000 (PVP10), 40000 (PVP40), and 360000 (PVP360), MD (Grain Processing

Download English Version:

<https://daneshyari.com/en/article/6664643>

Download Persian Version:

<https://daneshyari.com/article/6664643>

[Daneshyari.com](https://daneshyari.com)