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Morphologies, volume fraction and viscosity of cell wall particle dispersions particle related to sensory perception

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ABSTRACT

Understanding the effect of cell wall particle structure on sensory perception could provide new strategies for the use of plant material based ingredients in the production of healthier food with desired sensory properties. The objective of this study was to establish relationships between physical characteristics of cell wall particles and their texture/mouthfeel sensory properties. Three carrot cell wall particle dispersions with distinct particle morphologies were produced using a combination of temperature, heating time and mechanical shear forces. These were: 1) cell wall clusters with an average particle size ($d_{0.5}$ of 225 μm), 2) single cells ($d_{0.5}$ = 92 μm) and 3) cell fragments ($d_{0.5}$ = 56 μm). A final set of ten particle dispersions (including a range of iso-viscous samples) were studied by sensory descriptive analysis using a trained sensory panel. Significant sensory differences were found between the carrot cellular systems which had different particle shape, size distributions and rheology. The dispersions containing cell wall clusters were perceived as the *grainiest*, most *crunchy* and *throatcatching*. The dispersions containing single cells or cell fragments were perceived as *creamy*, *cohesive* and *mouthcoating* with no *grainy* mouthfeel. The presence of biopolymers (xanthan or pectin) in the continuous phase decreased the textural perception of the particles, reducing *grainy* mouthfeel and increasing the perception of *creaminess*. The sensory data also indicated that carrot particles in the size range (30 −400 μm) were not perceived as *grainy*, demonstrating that these carrot structures are soft enough not to be mechanically detected as individual particles during eating.

1. Introduction

Important sources of dietary fibre in the human diet are hydrocolloids, bioactive oligosaccharides and plant cell materials (Redgwell & Fischer, 2005). Hydrocolloids such as starch and polysaccharide gums have swelling properties that have been extensively investigated resulting in their many applications in manufactured food as thickening, gelling and emulsifying agents (Elleuch et al., 2011). Recently, the technological functional properties of plant cell wall materials have gained interest as they can be a potential solution to the wastage of by-products from fruit and vegetable growers and the processing of plant materials. Plant cell wall materials can be designed to have functional textural properties and be used as ingredients in food formulations and contribute to an increase in the amount of fruits and/or vegetables and also dietary fibre in consumer's diets. This may help consumers meet the healthy eating guidelines (NHMRC, 2013) and would also be important for consumers that prefer more natural, clean label food products (Elleuch et al., 2011). Cellular structures from fruit and vegetables, as well as cellulose, hemicellulose and pectin have the ability to bind water and mimic the functionalities of many gums and stabilisers that are currently added to modify food texture (Kunzek, Müller, Vetter, & Godeck, 2002). This suggests that plant cell wall materials have both rheological and physicochemical characteristics essential for use as a texturing agent.

Controlling the rheological properties of cell wall particle dispersions or concentrates is important for their processability (mixing efficiency, pumping, filling, etc.) and for their functional behaviour and sensory properties (pouring or mouthfeel) (Appelqvist, Day, & Lundin, 2010; Espinosa-Munoz, Symoneaux, Renard, Biau, & Cuvelier, 2012; Harris & Smith, 2006). The most significant factors which influence the rheological behaviour of cell wall particle dispersions are the continuous phase viscosity, the visco-elastic nature of the particles, their concentration, size

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distribution and shape and the particle–particle interactions (Day, Xu, Oiseth, Lundin, & Hemar, 2010; Espinosa-Munoz, Renard, Symoneaux, Biau, & Cuvelier, 2013; Hemar, Lebreton, Xu, & Day, 2011; Lopez-Sanchez, Chapara, Schumm, & Farr, 2012; Moelants, Cardinaels, et al., 2013).

During oral processing of semi-liquid and semi-solid foods containing particles, chewing is not required to fracture the food material but instead a force is required (yield stress) to initiate flow. This is generated by the contact of the food between the tongue and the palate which squeezes and shears the food in preparation for swallowing (van Aken, 2010; Kokini, 1987; Shama & Sherman, 1973; van Vliet, 2002). Sensory perception of food systems containing particles is also affected by the rheological behaviour and size of the particles, their colloidal behaviour during hydration and dilution with saliva and their interaction with the buccal surfaces during the eating process (van der Bilt, 2009; Jackman & Stanley, 1995).

Sensory attributes that relate to texture such as hardness, thickness, stickiness, smoothness, graininess, creaminess and mouthcoating, are dependent on the behaviour of the food material and colloidal aspects of particles in the mouth (van Aken, 2010). This was highlighted in studies of food models containing high amylose starch granules with a particle size of ~15 μm which were thought to be responsible for the roughness and rough afterfeel perceived in a milk dessert (Ares, Baixauli, Sanz, Varela, & Salvador, 2009). Vaiseygenser, Vane, and Johnson (1989) have shown that fat crystals in margarine or chocolate could be detected in mouth when the size of fat crystals exceeded ~22 μm and above 30 μm they were perceived as 'gritty' or 'coarse'. Chocolate containing fat crystals <20 μm were perceived as creamy and considered to have reached optimum smoothness (Afoakwa, Paterson, & Fowler, 2007; Tyle, 1993). The textural perception of particles is strongly influenced by not only the size, but also the shape and deformability of the particles. Particles up to about 80 μm were not perceived as gritty if they were soft and rounded such as polyethylene particles while hard and angular particles were detected as being gritty at a particle size range of about 11–22 μm.

The objective of the current study was to describe the sensory textural perception of plant cell wall dispersions in relation to their particle morphology and rheology (soft deformable particles) and to determine the effect of the particle network (particle–particle interaction) and their inherent viscosity on the perceived textural sensory attributes. It has been suggested that particle concentration (volume) and aqueous phase viscosity may influence the sensory perception of particles (Imai, Hatae, & Shimada, 1995; Imai, Saito, Hatakeyama, Hatae, & Shimada, 1999; Tyle, 1993). In order to investigate these effects the particle solid content and viscosity of the cell wall dispersions were varied by the addition of water or polysaccharides. The use of sensory descriptive analysis by a trained panel to describe the sensory properties of rheologically and structurally characterised plant cell wall dispersions should contribute to a better understanding of the potential use of plant cell wall materials in the food industry as a natural and nutritious alternative to current bulking or texturing agents such as starch.

2. Materials and methods

2.1. Materials

Carrots were purchased from a local supermarket. Xanthan gum (Keltrol®) was generously donated by CP Kelco (CP Kelco Australia ApS, Cheltenham, VIC, Australia), and Pectin (high methoxyl) (Grindsted® RS 450) by Danisco USA Inc (Madison, USA).

2.2. Preparation of cell wall particle dispersions

Three dispersions containing cell wall particles of different size and morphologies were prepared from carrots by applying various conditions of heating and homogenisation treatments. Carrots were peeled and cut into approx. 2 cm pieces. Two separate batches of water (200 g) were prepared. One batch was pre-heated to 80 °C and the other to 100 °C. Carrot pieces (200 g) were added into each batch of the pre-heated water (200 g) and cooked either for 10 min at 80 °C or 30 min at 100 °C. The cooked carrots were cooled immediately on an ice bath. After cooling, an additional amount of pre-heated water was added to make up for the evaporated volume. Two stock dispersion samples (400 g) were produced based on their heat treatment by homogenising the carrots using a kitchen blender (Sunbeam PB9500, 1200 W, 7000 rpm) for a total of 8 min. The cell wall fragment dispersion was produced by subjecting another batch of carrot which had been cooked at 100 °C for 30 min and blended with a kitchen blender for 8 min to a further high shear homogenisation treatment using microfluidisation, (60 MPa, 3 passes).

2.3. Physico-chemical characterisation

2.3.1. Particle size determination

Apparent particle size distribution was measured by laser light scattering using a Malvern Mastersizer 2000 instrument (Malvern Instruments Ltd, Worcestershire, UK). A differential refractive index of 1.173 (1.560 for particle/1.33 for water) absorption of 0.1 were used as the optical properties of the dispersion. The particle calculation was set for irregular particles. Volume median diameter value $d(0.5)$ was used as the average particle size. Each sample was measured in duplicate.

2.3.2. Microstructure

Particle morphologies of the dispersions were characterised using Confocal Laser Scanning Microscopy (CLSM). Particle dispersions were diluted with deionised water at a ratio of 1:1 to 1:2 to refrain from imaging close packed particles. Samples were stained with the fluorescent dye Congo red (0.005%, Ajax Chemicals, Sydney, Australia), then observed at room temperature under a HC PL APO 20× or a HCX PL APO 63× objective using a Leica TCS SP5 confocal laser scanning microscope (Leica Microsystems, Wetzlar, Germany). The fluorescent dye was excited by an Argon 488 nm laser and the emitted light was collected at 544–663 nm.

2.3.3. Total solid content

The total solid contents of the dispersions were determined in duplicate according to the AOAC Official Method 964.22. About 15 g (1 tablespoon) of washed sand was added to a flat bottom metal dish and dried at 102 °C for a minimum of 30 min in a conventional Contherm oven. The dish was then allowed to cool down in a desiccator before the sample (about 10 g suspension) was added to each dish, and mixed using a glass rod to ensure an even distribution of the sample over the base of the dish. A small amount of deionised water was added to the samples that were difficult to mix. The dish was then placed on a water bath containing boiling water to remove most of the moisture, followed by drying in a vacuum oven, set at 70 °C for 2–3 h with a dry air flow (through silica gel) at a maximum pressure of 70 kPa. After drying, the dish was transferred to a desiccator and weighed as soon as the sample reached room temperature to minimize moisture uptake.

2.3.4. Viscosity measurement

All viscosity measurements were carried out using a Paar Physica controlled-stress rheometer (Model MCR 300, PHYSICA