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# Synergistic effect of milk solids and carrot cell wall particles on the rheology and texture of yoghurt gels

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ABSTRACT

There is growing interest to improve texture, flavour and health benefits of manufactured foods, particularly dairy based products, using natural fruit and vegetable fibre. In this study, we aimed to investigate whether cell wall particles (CWP) could be used to replace part of milk solids and still maintain the gel strength and texture of the yoghurt gel. Set yoghurts with total solids of 12% w/w were used as the benchmark. Effects of replacing milk solids with carrot CWP at 1 or 2% on the gelation kinetics, microstructure, rheological and textural properties of yoghurt gels were examined. Replacement of 1% milk solids by CWP produced gels with similar rheological properties to that of the 12% milk solid gel. Confocal images showed that most of the carrot CWP was individually embedded in the casein micelle network providing a 'filler' effect and synergistically contributed to the rheological properties of the yoghurt gel. However, replacement of 2% milk solids by CWP lowered the complex modulus ($G^*$) of the gel. $G^*$ remained low even for the yoghurt prepared with 13% total solids where 2% milk solids were replaced by CWP. This is because CWP can also form a particulate network at 2%, thereby hindering the casein micelles to form a connected colloidal network. This was demonstrated by the delay of the peak in tan δ during fermentation. However, the texture analysis revealed that the substitution of 2% milk solids by CWP improved the firmness of the gel. In addition, whey loss was also reduced considerably when CWP was used to replace milk solids in the formulation, due to the ability of carrot CWP to hold more water than casein micelles.



## 1. Introduction

Yoghurt is a fermented gel made from milk, using a starter culture mix of lactic bacteria (usually *Streptococcus thermophilus* and *Lactobacillus bulgaritus*) (Tamime & Robinson, 1999). The bacterial cultures induce an acidification of milk from pH 6.5 to pH 4.6 by production of lactic acid from lactose, which leads to the aggregation of casein micelles into a 3-dimensional gel network. Before inoculation, heating treatment of milk is a common practice. Heating milk at above 70 °C unfolds the globular whey proteins allowing the denatured whey proteins (mainly β-lactoglobulin) to interact with κ-casein at the surface of the casein micelles via hydrophobic interactions and disulfide bonds (Corredig & Dalgleish, 1996; Lucey & Singh, 1997). The denatured whey proteins provide bridging connections between the casein micelles, thus producing a highly interconnected gel with lower porosity (Lucey, Munro, & Singh, 1999). As a result, heat treatment of milk prior to acidification increases the gel strength and reduces syneresis (e.g. whey loss).

One common approach to enhance the physical properties of yoghurt formulation is to use other functional ingredients such as starches (Considine et al., 2011; Oh, Anema, Wong, Pinder, & Hemar, 2007), polysaccharides and gums (e.g. locust bean gum, xanthan, guar gum, pectin and inulin) (Brennan & Tudorica, 2008; Everett & McLeod, 2005; Fagan, O'Donnell, Cullen, & Brennan, 2006; Guggisberg, Cuthbert-Steven, Piccinah, Butikofer, & Eberhard, 2009; Kip, Meyer, & Jellema, 2006), or by increasing milk protein solids using skim milk powder, sodium caseinate or whey protein concentrates (Keogh & O'Kennedy, 1998; Soukoulis, Panagiotidis, Koureli, & Tzia, 2007). Polysaccharides modify the rheological properties of acidified milk gel networks by trapping aggregated caseins within a viscous polysaccharide solution (Everett & McLeod, 2005). However, chemically refined stabilisers and starches are perceived by consumers as 'unnatural' ingredients.

The use of natural fibres from fruits, vegetables and cereal sources in yoghurt formulations has also gained considerable interest. Natural fibres exhibit benefits of enhanced texture and firmness in yoghurt, reduced whey separation (i.e. syneresis) and achieving sensory properties such as texture and flavour that have positive consumer acceptance (Aportela-Palacios, Sosa-Morales, & Velez-Ruiz, 2005; Dello Staffolo, Bertola, Martino, & Bevilacqua, 2004; Espirito-Santo et al., 2013; Garcia-Perez et al., 2006; Hashim, Khalil, & Afifi, 2009; Sendra et al., 2008, 2010). Our previous study showed that natural cell wall particles (CWP) can be used as new potential alternatives to structure dairy gels (McCann, Fabre, & Day, 2011). Natural cell wall materials contain heterogeneous particles forming an intact cell wall structured by polysaccharides (cellulose, hemicelluloses, pectin, etc.). In addition, the

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inclusion of natural fibre from fruit and vegetables can also provide natural antioxidant properties and has been shown to reduce peroxidise activity during yoghurt storage (Tseng & Zhao, 2013).

Plant cell wall materials derived from fruit and vegetables are an excellent source of dietary fibre. They are resistant to digestion and absorption in the human small intestine, with complete or partial fermentation taking place in the large intestine (Day, Gomez, Oiseth, Gidley, & Williams, 2012; Slavin & Lloyd, 2012). The use of less refined natural cell wall materials in foods has a number of benefits. Apart from their positive health benefit, they also possess unique functional properties such as their ability to hold a large amount of water. Their unique rheological properties such as visco-elastic response and high yield stress at low solid content make them the ideal candidates for increasing gel strength and viscosity building (Day, Xu, Oiseth, Hemar, & Lundin, 2010; Day, Xu, Oiseth, Lundin, & Hemar, 2010). In practice, they are most likely produced from by-products of industrial fruit and vegetable processing, with additional processes carried out to reduce particle sizes (Chantaro, Devahastin, & Chiewchan, 2008; Figuerola, Hurtado, Estevez, Chiffelle, & Asenjo, 2005; Hemar, Lebreton, Xu, & Day, 2011; Larrauri, 1999; Redgwell, Curti, & Gehin-Delval, 2008). These particles differ from chemically extracted and modified hydrocolloids in that they are heterogeneous particles comprising an intact cell wall matrix structure made up of mixed polysaccharides: cellulose, hemi-cellulose and pectin (Harris & Smith, 2006; Waldron, Parker, & Smith, 2003). Cell wall particle dispersions can form particulate networks at relatively low particle concentrations (1–2% w/v depending on particle sizes) to provide gel strength similar to that of soft elastic particles (Adams, Frith, & Stokes, 2004; Day, Xu, Oiseth, Hemar, et al., 2010; Genovese, Lozano, & Rao, 2007).

In our previous study, we investigated the effect of CWP, produced from an industrial carrot pomace, on the gelation kinetics, viscoelastic properties, microstructure, texture and whey loss of the set yoghurt gels as a function of CWP concentration, particle size and storage time (McCann et al., 2011). The addition of carrot CWP accelerated the rate of pH reduction and induced earlier gelation. The carrot CWP occupied the void space within the casein particle networks, and thus resulted in an increase in the gel viscoelastic properties and reduction in the whey loss with increasing CWP concentration. The small particles ($d_{0.5} = 34$ μm) gave better gel strength and lower whey loss compared to the larger CWP ($d_{0.5} = 80$ μm), attributed to higher contact between the small CWP and casein micelles. The study demonstrated that CWP enrichment could lead to a shorter gelation time due to the acceleration of the acidification by charged CWP and could produce a firmer gel with enhanced viscoelastic properties (higher $G^*$).

The question is whether the enhanced gelation properties contributed by the addition of CWP in the milk protein matrix could be utilised to replace a portion of milk solids without having negative effects on the gelation and textural properties of milk-CWP gels. Such an approach could reduce the raw material cost (e.g. use of less milk powder), and yet fabricate a milk gel based product with higher fibre content without deviating from the product characteristic and quality that consumers are familiar with. Thus, the aim of the work was to investigate whether a synergistic effect on the rheology and texture of yoghurt gels could be achieved by replacing a portion of milk (up to ~2% of total milk solids) with carrot CWP.

## 2. Materials and methods

### 2.1. Materials

Carrot cell wall powder was manufactured at the pilot plant of CSIRO Animal, Food and Health Sciences, Werribee (McCann et al., 2011). The CWP had a median size ($d_{0.5}$) of 34 μm (dry) or 49.3 μm (rehydrated) determined by the laser light scattering method using a Mastersizer 2000 (Malvern Instruments Ltd, Worcestershire, United Kingdom) and a moisture content of 10.6 wt.% (McCann et al., 2011).

Low heat skim milk powder (LHSMP) with 4.2 wt.% moisture content was obtained from Fonterra Australia Pty Ltd (Melbourne, Australia). A freeze-dried lactic culture ABT-5 containing a mixture of *S. thermophilus* and *L. bulgaritus* was obtained from CHR Hansen Pty Ltd (Bayswater, Victoria, Australia).

### 2.2. Preparation of milks and carrot cell wall particle dispersions

Milk solutions containing 10, 11, 12, 20 or 22% w/w total solids were prepared by reconstituting milk powder in deionised water using an over-head stirrer (Heidolph RZR 2050 mixer, John Morris Scientific Pty Ltd) with a Cowles blade (4.5 cm in diameter, 8 teeth) at a speed of 600 rpm for 30 min. In the same way, dispersions containing 2% and 4% w/w CWP were also prepared by reconstituting CWP in deionised water. All solutions were left overnight at 4 °C to ensure complete hydration of milk powder and CWP. All milk solutions and CWP dispersions were then allowed to equilibrate at room temperature and the pH of the solutions was measured and adjusted where necessary to pH 6.5 using 1 M NaOH solution. Weights of all solutions were also re-checked and appropriate quantity of deionised water was added to compensate for any loss through evaporation overnight.

### 2.3. Lactic culture preparation

The lactic culture solution was prepared by hydrating 1 g of ABT-5 culture granules in 50 g of unheated milk for 15 min at 4 °C with stirring. This solution (10 mL) was then used to incubate 1 L of yoghurt milks with or without CWP.

### 2.4. Yoghurt gel preparation

Milks for manufacture of yoghurts with added CWP were prepared by mixing more concentrated solutions of skim milk powder (20 or 22% w/w) and CWP (2 or 4% w/w) to achieve the required final concentrations. To study the combined effect of total solids and addition of CWP, solution containing 11% milk solids and 2% CWP (total solids 13% w/w) was also prepared. The CWP dispersions (2 or 4% solids) were heated at 85 °C for 10 min with stirring, and then mixed with an equal quantity of milks (22% or 20% milk solids) to obtain milk solutions with total solids of 12% in which 1 or 2% milk solids was replaced with CWP, and the milk solution with 13% w/w total solids in which 2% milk solids was replaced with CWP. The above milk-CWP mixtures and milks with 10, 11 or 12% milk solids without CWP were heated for a further 30 min at 85 °C. The solutions were cooled to 43 °C on an ice bath and weighed. A small amount of deionised water was added to compensate for any loss through evaporation. The lactic culture solution was then added to the yoghurt milk mixture and mixed thoroughly before sub-sampling for yoghurt setting.

Yoghurt milks were sub-sampled into plastic jars (volume 50 mL; 43 mm in diameter and 53 mm in height) and incubated in a water bath at 43 °C. The pH of the yoghurt milks was monitored until they reached 4.6 and the yoghurt gels were allowed to set overnight at 4 °C.

### 2.5. pH measurement

pH was recorded every 5 min during gelation using a WP-81 pH meter (TPS Pty Ltd, 4, Jamberoo St., Springwood, Brisbane, Australia 4127).

### 2.6. Oscillatory rheology

An Anton Paar-Physica stress control rheometer (MCR 300, Anton Paar Physica, Physica Meßtechnik GmbH, Stuttgart, Germany) with a vane geometry (the cup has an inner diameter of 28.9 mm, the vane is 10 mm and length 16 mm, a total of 6 blades) was used to study the rheological properties of yoghurt during gelation and the viscoelastic