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Impact of swelling power and granule size on pasting of blends of potato, waxy rice and maize starches

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ABSTRACT

This study investigated the impact of swelling power and granule size on pasting of blends of potato starch (PS) and maize (MS) or waxy rice (WRS) starch. First, viscosity development of one starch in the blend was reduced by cross-linking it to such extent that no viscosity development was recorded with Rapid Visco Analyser at the used concentrations. This way the difference in swelling power between the starches in a blend was changed. Comparison of the pasting profiles of blends of cross-linked PS and WRS or MS with those of blends of only native starch, showed that cross-linked PS contributes to viscosity development when another starch is present by increasing the total solid content and binding some of the available water. This was also observed for blends of PS and cross-linked WRS and MS. In a second approach, the impact of granule size was investigated by size fractionation of PS into PS_{small}, PS_{medium} and PS_{large} and by blending these fractions with WRS. PS_{small} had lower amylose and higher phosphorus contents, a higher swelling power and lower carbohydrate leaching than PS_{medium} and PS_{large}. All fractions had similar pasting properties. Peak, minimum and end viscosities were higher for blends of WRS with PS_{small} than for those with PS_{medium} or PS_{large}. This is probably due to the higher swelling power and higher rigidity (due to its lower granule size) of PS_{small}.

1. Introduction

Starch is an important plant polysaccharide with numerous applications in the food industry because of its gelling, thickening and food system stabilizing capacities. Chemical modification of starches (*e.g.* cross-linking and substitution) is often applied to meet the process and product requirements (*e.g.* resistance to shear, acid and high temperatures) in a way that native starches cannot. Cross-linking introduces intra- and intermolecular bonds, which reduce swelling of the granules during heating in excess water and increase the overall granule stability and strength (Choi & Kerr, 2004; Koo, Lee, & Lee, 2010). Cross-linked (CL) starches resist high temperatures, acid and shear better than their native counterparts and consequently show less breakdown and a high viscosity under these circumstances (Hirsch & Kokini, 2002; Reddy & Seib, 1999, 2000; Wu & Seib, 1990).

The food industry increasingly searches alternative natural ways to alter starch properties. One way to generate new properties is by blending different starches. Starches in a blend can indeed influence each other's gelatinisation and pasting and display unexpected physical properties (Waterschoot, Gomand, Fierens, & Delcour, 2014a). Pasting involves post-gelatinisation granule swelling, leaching of carbohydrates, formation of a three-dimensional network of leached molecules and interactions between granule remnants and leached material (Atwell, Hood, Lineback, Varriano-Marston, & Zobel, 1988). For starch blends, pasting characteristics are (non-)additive when the properties of the blend can(not) be predicted from those of the individual starches (Puncha-arnon, Pathipanawat, Puttanlek, Rungsardthong, & Uttapap, 2008; Yao, Zhang, & Ding, 2003). In literature, the non-additive behaviour of starches in a blend has been attributed to differences in their granule size distribution, swelling power (SP), amylose content and concentration. Each of these factors is discussed in the following paragraphs.

Puncha-arnon et al. (2008) studied the impact of granule size on pasting of starch blends. They analysed blends of canna starch (granule size range 10–152 μm) with potato starch (PS) (8–131 μm), mung bean (6–61 μm) or rice (2–24 μm) starch at a total starch concentration of 6% and concluded that the difference

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in granule size between two starches in a blend is the main factor influencing gelatinisation and pasting of the blend. For the canna-rice starch blends (with a large difference in granule size), peak viscosity was lower than expected due to reduced swelling of canna starch in the blend, while for blends of canna starch with PS or mung bean starch, peak viscosities were as expected based on pasting of the individual starches (Puncha-arnon et al., 2008).

Another important factor is the SP of the starches and competition for water. Pasting of blends of starches that significantly differ in SP is not fully understood. A lower than expected peak viscosity has been observed for blends of waxy maize starch and PS (Park, Kim, Kim, & Lim, 2009), regular and high amylose maize starches (Juhasz & Salgo, 2008), different regular rice starches (Hagenimana & Ding, 2005), PS and maize starch (MS) (Obanni & BeMiller, 1997), PS and wheat starch (Obanni & BeMiller, 1997), PS and rice starch (Sandhu, Kaur, & Mukesh, 2010), PS and amaranth starch (Gunaratne & Corke, 2007), cassava and lima bean starches (Novelo-Cen & Betancur-Ancona, 2005), (PS) and waxy rice starch (WRS) or waxy maize starch (Lin, Kao, Tsai, & Chang, 2013). Several of these blends contain PS which has a high SP. PS carries negatively charged phosphate monoesters which induce repulsion between adjacent starch chains. This facilitates water absorption and contributes to the high SP (Lim, Kasemsuwan, & Jane, 1994; Singh, Singh, Kaur, Sodhi, & Gill, 2003). A lower than expected peak viscosity of starch blends containing PS may be due to reduced swelling of PS in the blend as a result of the other starch competing for water because of the large difference in SP of the starches in the blend (Lin et al., 2013; Puncha-arnon et al., 2008; Zhang, Gu, Hong, Li, & Cheng, 2011).

In two of the above mentioned studies (Gunaratne & Corke, 2007; Zhu & Corke, 2011) the impact of SP was further investigated by changing the SP of one starch in the blend by physical or chemical modification. Modifying the SP of wheat starch by hydroxypropylation changed the impact of wheat and sweet potato starch on one another and resulted in non-additive pasting which was different from that of blends of sweet potato starch with native wheat starch (Zhu & Corke, 2011). For blends of PS and amaranth starch, SP in the blend was changed by modifying one or both starches in the blend by heat-moisture treatment or cross-linking. When both starches in the blend were modified, the difference in SP was reduced and more additive peak viscosities were observed (Gunaratne & Corke, 2007).

Nevertheless, in blends containing starches with a much smaller difference in SP, other factors may well be responsible for the non-additive effects. In addition, some studies observed that peak viscosity is linearly related to blend composition for blends of starches with a large difference in SP. This was the case for blends of waxy maize and high amylose maize starches (Juhasz & Salgo, 2008), wheat and sweet potato starches (Zhu & Corke, 2011) and PS and MS (Zhang et al., 2011). Taken together, the role of SP in viscosity development is not fully clear and an interplay of different factors probably determines the pasting behaviour.

Additionally, the amylose content impacts pasting of starches and starch blends and especially the network formation during cooling of the starch suspension. A higher than expected end viscosity has been observed for blends of waxy maize and high amylose maize starches (Juhasz & Salgo, 2008), PS and heat-moisture treated amaranth starch (Gunaratne & Corke, 2007), PS and waxy maize starch (Park et al., 2009), PS and MS (Zhang et al., 2011), canna and mung bean starches (Puncha-arnon et al., 2008), PS and canna starch (Puncha-arnon et al., 2008), regular rice starch and WRS (Hagenimana & Ding, 2005) and wheat and sweet potato starches (Zhu & Corke, 2011).

Besides granule size, SP and amylose content, also starch concentration impacts pasting of starch blends. However, this aspect is underdeveloped in literature, as often only one concentration is evaluated. In this context, it is important to introduce the concept of the close packing concentration of starch (C^*). This is the concentration at which the swollen granules fully fill up the available space at a given temperature. At concentrations below C^*, the viscosity of the system is mainly determined by the volume fraction of the granules and thus their SP, while at concentrations exceeding C^*, the viscosity of the system is mainly determined by the rigidity of the granules (Eerlingen, Jacobs, Block, & Delcour, 1997; Steeneken, 1989). Previous work by this group investigated the role of starch concentration on pasting using blends of PS, MS and rice starch (Waterschoot, Gomand, Willebrords, Fierens, & Delcour, 2014). Pasting of blends of PS with (waxy) MS or (waxy) rice starch was different from expectations based on pasting of the individual starches. At lower total starch concentrations (<6.0%), a relatively low peak viscosity was observed for all blends due to reduced swelling in the blend. At higher total starch concentrations (>6.0%), close packing is reached relatively early during the temperature-time profile which means that viscosity development is then determined by granule rigidity rather than by SP. This was shown by the linear relation between peak viscosity and blend composition at 8.0% total starch concentration. In general, minimum and end viscosities of the blends were higher than expected especially at higher total starch concentrations. For blends of PS with waxy maize starch or WRS, end viscosity was as high as that of PS, while for blends of PS and regular MS or rice starch, end viscosity was even higher than that of PS. The latter blends have a higher amylose content than the former blends which results in more network formation (Waterschoot, Gomand, Willebrords, et al., 2014).

Although several studies have investigated pasting of starch blends, the underlying principles of pasting of blends with different granule size and SP at different concentrations are still not fully understood. Microscopy studies have suggested that swelling of the starch with the largest granules is reduced in the presence of a starch with smaller granules (Karam, Ferrero, Martino, Zaritzky, & Grossmann, 2006; Lin et al., 2013; Park et al., 2009; Puncha-arnon et al., 2008). However, it is still not clear which factors lead to this reduction. We here investigated the impact of granule size and swelling power on pasting of starch blends with two approaches. First, SP of one starch in the blend was reduced by cross-linking it to such an extent that with the concentrations used, no viscosity development was detectable with Rapid Visco Analysis (RVA). Full reduction of the viscosity development of one starch will allow further unravelling the role of SP when blending starches. Secondly, PS was fractionated in three fractions with different granule sizes. These fractions were each blended with WRS. To the best of our knowledge, these approaches have not been reported on before.

2. Materials and methods

2.1. Materials

PS and MS were obtained from Cargill (Vilvoorde, Belgium). WRS was from Beneo Remy (Wijgmaal, Belgium). Blends of two starches were made in five different concentration ratios (0–100, 25–75, 50–50, 75–25 and 100–0). Amylose content of PS, MS and WRS was respectively 18.2% (±0.4), 22.4% (±0.2) and 2.6% (±0.6), as determined with the procedure from Megazyme (Bray, Ireland) (cf 2.3).

2.2. Fractionation of potato starch

PS was successively sieved with a 50 μm and a 38 μm sieve. Three fractions were obtained: PS large granules (PS_{large}), medium