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Physicochemical properties of potato, sweet potato and quinoa starch blends

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ABSTRACT

Blends of different native starches may have properties different from those of the individual starches. Physicochemical properties of blends of three different starches were studied. Potato, sweet potato and quinoa starches were selected as model starches as they are different in the polymorph type and granule size. Simplex-centroid design was used and the ratio of each starch in the blends ranged from 0 to 100%. Rheological and thermal properties, swelling, digestibility, and retrogradation of the blends were studied using various techniques. The interactions among the starches in the blends were studied by plotting and comparing the surface response graphs of the experimental and theoretical values. The results showed that the interactions of the starches were additive or non-additive, depending on the processing and analytical methods. By selecting the type and proportions of individual starches, a range of functionalities significantly different from the individual starches could be precisely obtained using mathematical models.

1. Introduction

Starch is a major component of our diet. It is also an important industrial ingredient with diverse applications. Amylose and amylopectin are the two major components of starch. The former is largely linear and smaller, and the latter is highly branched and larger (Pérez & Bertoft, 2010). Starch granules are found in nature with sizes ranging from 1 to 100 μm. There is a great diversity in the composition, structure, and functional properties of different starches from different plants (Pérez & Bertoft, 2010).

However, such a diversity usually does not meet the industrial needs using any type of native starches. To increase the diversity to meet the requirements from different applications, native starches are modified with chemical, physical, and/or enzymatic methods (Zhu & Corke, 2011). Physical means of modifications have attracted research focus because they are considered green and present a “healthy” and “clean” image to the consumers (BeMiller & Huber, 2015). Among the physical modifications, blending different starches to create a range of functionalities has gained research attention (Waterschoot, Gomand, Fierens, & Delcour, 2015; Zhu & Corke, 2011). Starch mixtures have been useful for food formulations. For example, noodles made from potato/mung bean and rice starch blends had improved quality compared to those from individual starches (Sandhu, Kaur, & Mukesh, 2010; Wu, Meng, Yang, Tao, & Xu, 2015). Understanding the interactions of starches in their mixtures is critical for the food and non-food applications.

Previous studies mostly focused on the physicochemical properties of mixtures of two starches from different plants (Waterschoot, Gomand, Fierens, et al., 2015). Both additive and non-additive behaviours in various physicochemical properties of starch mixtures were reported (Li, Ye, Zhou, Lei, & Zhao, 2019; Puncha-arnon, Pathipanawat, Puttanlek, Rungsardthong, & Uttapap, 2008; Waterschoot, Gomand, Fierens et al., 2015; Waterschoot, Gomand, & Delcour, 2016; Wu, Dai, Gan, Corke, & Zhu, 2016; Zhu & Corke, 2011). In the presence of a limited amount of water, non-additive behaviours in gelatinization of binary starch mixtures were obtained (Waterschoot, Gomand, Delcour, & Goderis, 2015). This has been largely attributed to the competition for available water between the starches. In the presence of an excessive amount of water, the gelatinization behaviours measured using differential scanning calorimetry (DSC) were seen to be mostly additive, whereas the pasting properties measured using a viscometer with shearing were largely non-additive (Waterschoot, Gomand, Fierens, et al., 2015; Wu et al., 2016; Zhu & Corke, 2011). Overall, the physicochemical properties of starch blends depend on the type of starches used, mixing ratios, water content, and the type of testing techniques and the parameters. It has been shown that larger differences in the composition and structure of the individual starches tend to give more pronounced non-additive behaviours (Puncha-arnon et al., 2008; Waterschoot et al., 2016). Most of the previous studies focused on mixtures of two starches. There have been few studies on starch mixture systems with three or more starch types (Karam, Grossmann, Silva, Ferrero, & Zaritzky, 2005 and 2006). Karam et al. (2005 and 2006)

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analysed the properties of maize, cassava and yam starch mixtures. The results showed that certain properties such as those of exudate of individual starches may be improved using three-starch blends. The interactions of starches in a three-starch mixture systems remain to be better understood. The hypothesis is that using starches with significant differences in structure and properties may lead to a range of physicochemical properties of a three-starch mixture system. It should also be pointed out that starch gelatinization is a complex process (Schirmer, Jekle, & Becker, 2015). This process may be measured using a range of different techniques targeting different aspects of gelatinization. Differential scanning calorimetry (DSC) and pasting analysis are commonly used to study the starch gelatinization for very different aspects.

In this study, three different starches from potato, sweet potato, and quinoa were used to obtain different starch blends of different mixing ratios. These three starches differ greatly in the composition, granular and molecular structure. Potato starch has B-type polymorph with a relatively large granule size. Quinoa starch has A-type polymorph with a very small granule size. Sweet potato starch has C-type polymorph with an intermediate granule size. Simplex-centroid design was used to obtain starch mixtures at different mixing ratios. Swelling factor, amylose leaching, pasting, gel textural, thermal properties and enzyme hydrolysis of the starch mixtures were measured. This study may stimulate more interest in using starch blends to obtain a range of functional properties.

2. Materials and methods

2.1. Materials

Red-skinned potato tubers and white quinoa seeds (brand, Fresh Produce Be Fresh Quinoa; country of origin: Peru) were obtained from Countdown Supermarket (Auckland, New Zealand). Sweet potato (variety: Kokei) roots were obtained from Kaipara Kumara (Ruawai, New Zealand). Starches were isolated from potato tubers and sweet potato roots using the method of Zhu, Corke, and Bertoft (2011) and Zhu, Yang, Cai, Bertoft, and Corke, (2011). Starch from quinoa seeds was isolated using the method of Li, Wang, and Zhu (2016). The amylose contents of potato, sweet potato and quinoa starches were 26.3, 16.3, and 6.3%, respectively, according to concanavalin A precipitation based method using a Megazyme amylose/amylopectin assay kit (Wicklow, Ireland). The particle sizes (D [4,3]) of potato, sweet potato and quinoa starches were 44.5, 18.6, and 2.41 μm, respectively, according to the analysis using a Mastersizer 2000 (Malvern Instruments, Worcestershire, UK). The polymorph types of potato, sweet potato and quinoa starches were determined as B, C, and A-type, respectively, using wide-angle X-ray diffraction on a PANalytical Empyrean Xray Diffractometer (Almelo, the Netherlands) (Zhu & Xie, 2018). The phosphorus contents of the potato, sweet potato and quinoa starches were obtained as 7.1, 1.9 and 1.1 mg/100 g, respectively, using a 7700 inductively coupled plasma mass spectrometry (ICP-MS) (Agilent Technologies, Santa Clara, CA, USA). The composition of lipids and proteins and the molecular structure of the 3 different starches were studied previously (Jan, Panesar, Rana, & Singh, 2017; Li & Zhu, 2017; Tian, Rickard, & Blanshard, 1991; Zhu & Xie, 2018; Hoover, 2001). These characteristics of the starches from previous studies were summarized in Supplementary Table 1. It was seen that the tuber and root starches (potato and sweet potato) had less proteins and lipids than quinoa starch, although these non-starch components were minor. The chain lengths of amylopectin unit chains (CL_{ap}), external chain length (ECL), and internal chain length (ICL) were lowest for quinoa amylopectin, and were highest for potato amylopectin. Similar comparative patterns were obtained for the composition of different B-chain categories (B1-chains and BL-chains). Sweet potato amylopectin was seen to have more fingerprint A-chains than quinoa and potato amylopectins (Supplementary Table 1).

Table 1
Sample codes and experimental design.

Sample code	Starch components and composition (ratio)		
	Potato	Sweet potato	Quinoa
A	1	0	0
B	0	1	0
C	0	0	1
D	2/3	1/3	0
E	2/3	0	1/3
F	1/3	2/3	0
G	1/3	0	2/3
H	0	2/3	1/3
I	0	1/3	2/3
1	5/9	2/9	2/9
2	4/9	4/9	1/9
3	4/9	1/9	4/9
4	2/9	5/9	2/9
5	2/9	2/9	5/9
6	1/9	4/9	4/9
7	1/3	1/3	1/3

Pancreatin (30,000 BPU/g) and invertase (≥300 units/mg) were obtained from Sigma-Aldrich Chemical Co. (St. Louis, USA) and amyloglucosidase (200 U/mL) from Megazyme (Wicklow, Ireland). All the other chemicals were of analytical grade.

2.2. Simplex-centroid design

The experiment was designed according to a simplex-centroid and consisted of three groups of individual starches and thirteen groups of starch blends (Box, Hunter, & Hunter, 2005) (Table 1). Triaxial diagrams were established using the canonical equation of Scheffé (1958):

$$Y = \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 12X1X2 + \beta 13X1X3 + \beta 23X2X3 + \beta 123X1X2X3$$

where Y is the experimental result, $\beta 1$, $\beta 2$, $\beta 3$, $\beta 12$, $\beta 13$, $\beta 23$ and $\beta 123$ are the regression coefficients, $X1$, $X2$ and $X3$ are the percentages of potato, sweet potato and quinoa starches in the mixtures, respectively. The experimental values obtained were made into contour graphs using the Origin software (version 9.0, OriginLab Corporation, Northampton, MA, USA). The values of the three individual starches were also plotted as response surface graphs according to the additive effect.

2.3. Swelling factor (SF) and amylose leaching (AML)

Swelling factors (SF) of starch and starch blends at 85 °C were measured using the method of Tester and Morrison (1990). Briefly, starch (100 mg, dry basis) and water (5.0 mL) were mixed in centrifuge tubes before heating in a water bath (85 °C) for 30 min with intermittent vortex shaking. The tubes were then cooled to room temperature before blue dextran solution (0.5 mL, 5 mg/mL) was added and mixed. The tubes were centrifuged at 3000 × g for 5 min and the absorbance of the supernatant was measured at 620 nm. The SF was calculated using the method of Tester and Morrison (1990).

The amylose leaching (AML) of starch and starch blends at 85 °C was measured using the method of Gunaratne and Hoover (2002). Briefly, starch (20 mg) and 10 mL water in the centrifuge tubes were heated in a water bath (85 °C) for 30 min with intermittent shaking. Then the tubes were cooled to room temperature and centrifuged (3000 × g, 30 min). The amylose content of the supernatants was determined using an iodine binding-spectrophotometry based method (Gunaratne & Hoover, 2002).

2.4. Differential scanning calorimetry

Starch gelatinization was measured using a differential scanning