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Effect of phytochemical extracts on the pasting, thermal, and gelling properties of wheat starch

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ABSTRACT

Pasting, thermal and gel textural properties of wheat starch were studied in the presence of phytochemical extracts from pomegranate peel (C18), green tea (C53), Chinese hawthorn (C54), and Chinese gall (C46). All the four extracts increased the breakdown values and reduced the final viscosity. C18, C46, and C53 increased the peak viscosity. C18 and C46 reduced peak time and hot paste viscosity. All the four extracts reduced gel hardness. C46 increased gel adhesiveness. C46 facilitated the gelatinization of starch with earlier onset of T_o, T_p and T_c and a higher melting enthalpy whereas C18 and C54 prolonged the T_o, T_p and T_c and decreased the melting enthalpy. All phytochemical extracts caused earlier onset of T_o and T_p of amylose inclusion complex melting without altering the enthalpy. Scanning electron microscopy revealed that phytochemical extracts could cause looser gel matrices of dried wheat starch gels. Colour observation showed phytochemical extracts imparted different colours to wheat starch gels.

1. Introduction

Ubiquitous phytochemicals are natural chemicals from various plants (Naczk & Shahidi, 2006; Shahidi, 2000). Major classes of phytochemicals include phenolic compounds (e.g., flavonoids, phenolic acids, tannins, lignans, and stilbenes), carotenoids, vitamins, etc. (Cai, Luo, Sun, & Corke, 2004; Epifano, Genovese, Menghini, & Curini, 2007; Liu, 2004; Shahidi & Ho, 2005). Phytochemicals have gained increasing attention during the last decade due to their biological significance and potential health effects, such as antioxidant, anticancer, anti-aging, antiatherosclerotic, antimicrobial, and anti-inflammatory activities (Shahidi, 2004; Shahidi, McDonald, Chandrasekara, & Zhong, 2008). Experimental and epidemiological studies have suggested that regular intake of some phytochemicals has been associated with reduced risks of chronic diseases, such as cancer, heart disease, and diabetes (Bao & Fenwick, 2004; Fresco, Borges, Diniz, & Marques, 2006; Han, Shen, & Lou, 2007; Liu, 2004; Shahidi, 2004). Because of their ubiquity, abundance and low cost, many phytochemicals have been isolated and identified from natural botanical sources such as fruits, vegetables, spices, cereals, and medicinal herbs (Cai et al., 2004; Han et al., 2007; Shahidi & Ho, 2005).

Many herbs and spices and their extracts are traditionally used in cooking starch-rich foods (e.g., rice, wheat, beans, dietary tubers or roots) in China and other Asian countries, not only as flavouring and colouring agents but also for health-promotion and as food preservatives, due to their antioxidant activity and antimicrobial effect (Nakatani, 1994; Shan, Cai, Brooks, & Corke, 2007). Phytochemicals are important sources of natural food antioxidants, some of them have been developed and processed for popular functional beverages and dietary supplements (Bao & Fenwick, 2004; Shahidi & Ho, 2005). Natural antioxidants from phytochemicals as food additives may have great potential for use in staple food products (starch-based foods), not only to improve food quality and health effects but also to extend shelf life. However, the effect of phytochemicals on physicochemical properties of starch has rarely been studied.

Wheat starch is one of the most consumed food ingredients (Bhattacharya, Jafari-Shabestari, Qualset, & Corke, 1997). Physicochemical properties of wheat starch are affected by amylose and amylopectin molecular structures and any other components present such as phenolic compounds and polysaccharides (Beta & Corke, 2004; Funami et al., 2005; Vandeputte & Delcour, 2004). Phytochemical addition to wheat starch-based foods may affect the properties during processing and the end-use quality. There are few studies on the interaction and association between starch and phytochemicals. Deshpande and Salunkhe (1982) investigated interactions of tannic acid and catechin with legume starches. Beta and Corke (2004) reported that two phenolic compounds (ferulic acid and catechin) affected sorghum and maize starch pasting properties. We have not found any published reports on interactions between wheat starch and phytochemicals.

Our previous studies characterised a large number of natural phenolic compounds from hundreds of traditional medicinal herbs

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Table 1
Aqueous extracts of phytochemicals from four herbal plants

Code	Common and scientific names	Used part	TPC (g/100 g DW)	Major phenolic compounds
C18	Pomegranate (*Punica granatum* L.)	Peel	20.66	Ellagitannins (punicalin, punicalagin), ellagic acid, gallagic acid, and gallic acid
C46	Chinese gall (*Rhus chinensis* Mill. or *R. potaninii* Maxim.)	Gall	50.20	Gallotannins, gallic acid
C53	Green tea (*Camellia sinensis* (L.) Kuntze)	Young leaf	13.60	Epicatechin gallate, epigallocatechin gallate, epicatechin, condensed tannins, kaempferol and quercetin glycosides, gallic acid
C54	Chinese hawthorn (*Crataegus pinnatifida* Bge.)	Fruit	1.01	Proanthrocyanidins (condensed tannins), flavonoids (epicatechin, hyperoside, isoquercitrin, and rutin), chlorogenic acid

and dietary plants (e.g., spices, fruits, and cereals) (Cai, Sun, Xing, Luo, & Corke, 2006; Cai et al., 2004; Shan, Cai, Sun, & Corke, 2005; Surveswaran, Cai, Corke, & Sun, 2007), some of which are used as dietary foods and traditional beverage ingredients in China and Southeast Asia. Four phytochemical extracts from pomegranate, green tea, Chinese hawthorn, and Chinese galls were selected for use in this study (Table 1), which are rich in polyphenols. Chinese hawthorn, pomegranate, and green tea are common fruits and beverage in China. Our fundamental objective was to investigate the interaction between wheat starch and these four phytochemical extracts in terms of pasting, thermal, and textural properties. This may provide a scientific basis for phytochemical application in wheat products.

2. Materials and methods

2.1. Materials

2.1.1. Wheat starch and herbal materials

Unmodified wheat starch (S5127) was obtained from Sigma (St. Louis, MO, USA). Moisture content of the wheat starch was 12.2% (w/w). Pomegranate peel (C18), Chinese galls (C46), green tea (C53) and Chinese hawthorn (C54) were purchased from Hong Kong supermarkets and drugstores. These materials had been identified in a previous study with significantly different total phenolic contents (Cai et al., 2004). The scientific names, parts used, major phenolic compounds, and total phenolic contents (TPC) of the phytochemical extracts are detailed in Table 1. TPC was estimated using Folin–Ciocalteu method with minor modification (Cai et al., 2004). Major phenolic compounds were identified using HPLC and LC-ESI-MS, according to the UV–vis spectra, retention time and MS data, and by cochromatography with authentic standards as well as by comparison with literature data (Cui et al., 2006; Gao, Xu, & Li, 2000; Sakakibara, Honda, Nakagawa, Ashida, & Kanazawa, 2003). Particularly, pomegranate peel is well-known and useful traditional Chinese medicine, but commonly a waste product of pomegranate processing in Western countries. It was chosen in the present study for use as a test herbal material due to its much higher antioxidant capacity and stronger bioactivity compared to the pulp (Lansky & Newman, 2007).

2.1.2. Preparation of phytochemical extracts

The collected plant samples were further air-dried in a ventilated oven at 40 °C for 24 h to constant weight and then ground to fine powder (710 μm) by a Kenwood Multi-Mill (Kenwood Ltd., Hants, UK) and passed through a sieve (24 mesh). Powdered sample (10 g) was extracted with 100 mL ultra-filtered water at 80 °C for 20 min in a water bath shaker (Shaking Bath 5B-16) (Techne Ltd., Cambridge, UK). After cooling the extract was centrifuged at 4650*g* for 10 min and filtered by a Millipore filter with a 0.45 μm nylon membrane. The filtrate was freeze-dried by a Heto FD3 freeze-dryer (Heto-Holten A/S, Allerod, Denmark), and stored at 4 °C until use.

2.2. Methods

2.2.1. Pasting properties

Pasting properties of wheat starch and their mixtures with herbal extracts were determined at least in duplicate using a Rapid Visco-Analyser (RVA) model 3D (Newport Scientific, Warriewood, Australia). Double deionized water (24.8 g) was added to starch (3 g, dry basis) and phytochemical extracts (0.2 g) with a concentration of 0.7% (w/w) in the RVA canister to obtain a total constant sample weight of 28 g. The slurry was then manually homogenised using the plastic paddle to avoid lump formation and the pH of the starch–water–phytochemical extracts suspension was recorded by a pH meter (Orion model 720A, Boston, MA, USA) before the RVA run. A programmed heating and cooling cycle was set for 22 min, where it was first held at 50 °C for 1 min, heated to 95 °C in 7.5 min, further held at 95 °C for 5 min, cooled to 50 °C within 7.5 min and held at 50 °C for 1 min. The viscosities were presented in Rapid Visco Units (RVU).

2.2.2. Texture analysis

Gel textural properties were determined on the starch gels made from the RVA testing using a TA-XT2 Texture Analyzer (Stable Micro Systems, Godalming, Surrey, England) under TPA (Texture Profile Analysis) mode. After RVA testing, the paddle was removed immediately and the starch paste in the canister was covered by Parafilm and stored at room temperature (23–26 °C) for 48 h. The gel was compressed at a speed of 1 mm/s to a distance of 10 mm with a 5 mm cylindrical probe. The maximum force peak in the TPA profile represented the gel hardness and the negative area of the curve during the first retraction of the crosshead was termed adhesiveness. Springiness was measured by the distance of the detected height of the product on the second compression divided by the original compression distance. Cohesiveness was defined as the ratio of the positive force areas during the second compression to that during the first compression.

2.2.3. Thermal properties

Thermal analysis was performed at least in triplicate with a Differential Scanning Calorimeter 2920 thermal analyzer equipped with a thermal analysis data station (TA Instruments, Newcastle, DE, USA) following Gunaratne & Corke, 2007 with some modification. Starch (2.5 mg, dry basis) and herbal extracts (0.25 mg) were directly weighed into an aluminum DSC pan and double deionized water (7.5 μL) was added with a microsyringe. Pans were sealed, and allowed to stand for 24 h at 4 °C for even distribution of water. The scanning temperature and the heating rates were 30–130 °C and 10 °C/min, respectively. An empty pan was used as reference for all measurements.

2.2.4. Colour measurement

Colour on the surface of wheat starch gel samples from the RVA tests was measured by a chroma meter Minolta CR-300 (Minolta Camera Co., Osaka, Japan). Lightness (L^*, 100 = white and 0 = black),

redness–greenness (a^*, positive = red), and yellowness–blueness (b^*, positive = yellow) of the CIE LAB colour space (CIE 1986) were analyzed. Measurements were conducted after storage for both 2 h and 7 days after the RVA test on four different locations of the gel surface. The mean values from each sample were used for data analysis. Chroma ($C^* = (a^{*2} + b^{*2})^{1/2}$, and hue angle ($H^* = \tan^{-1}(b^*/a^*)$) were calculated.

2.2.5. Scanning electron microscopy (SEM)

Morphology of naturally dried wheat starch gels was investigated by a Scanning Electron Microscope Cambridge S440 (Cambridge, UK). The wheat starch gels made from the RVA pasting were put open in the air at room temperature (23–26 °C) for 14 days. Then they were rapidly frozen in the liquid nitrogen and freeze-dried by a Heto FD3 freeze-dryer (Heto-Holten A/S, Allerod, Denmark). The fractures of the dried wheat starch gels were mounted on a silver specimen holder, then coated with gold in a vacuum evaporator with a coating time of 50 s. The images were obtained at an accelerating voltage of 10 kV.

2.2.6. Statistical analysis

Significant differences between means of data were compared by Fisher's least significant difference (LSD) calculated using the Statistical Analysis System (SAS Institute Inc., Cary, NC).

3. Results and discussion

3.1. Effect of phytochemical extracts on pasting properties of wheat starch

During the heating and holding process, addition of three phytochemical extracts significantly affected peak viscosity (PV), peak time (PT) and hot paste viscosity (HPV) (Table 2). C18, C46 and C53 considerably increased the PV values by 31 RVU, 19 RVU and 8 RVU, respectively. C18 and C46 significantly reduced HPV (up to 31 RVU) and PT (up to 1 min), respectively, whereas C54 hardly changed both PV and PT but decreased HPV by 18 RVU. All the phytochemical additives significantly increased breakdown (BD) with a maximal effect caused by C18 (up by 54 RVU) and minimal by C54 (up by 16 RVU).

Early onset of PV is an indicator of early and rapid swelling of starch granules with amylose leaching out of granules (Gunaratne, Ranaweera, & Corke, 2007). The phytochemical extracts used in this study were rich in phenolic compounds with different total phenolic contents (TPC) as shown in Table 1. C46 contains very high levels of gallotannins (TPC = 50.2 g/100 gDW) while C18 contains high levels of ellagitannins (TPC = 20.7 g/100 gDW) and C53 is rich in tea polyphenols (catechin derivatives), and C54 mainly contains condensed tannins (proanthocyanidins) and flavonoids. These phenolic compounds in the extracts often structurally possess several hydroxyl and carboxyl groups per molecule. Polyhydroxy compounds could alter the functional properties of starches by competing for water with starch through hydration. Interaction between hydroxyl groups and water molecules alters the water activities and ionic strength of the aqueous solution (starch is usually electronegative in nature) (Gunaratne et al., 2007). On the other hand, addition of all phytochemical extracts significantly lowered the pH of the starch–water suspension (Table 2). This is mainly due to the phenolic acids like gallic acid and chlorogenic acid in the extracts (Table 1). C18 had the greatest pH reduction by 2.8, whereas C53 had the least by 0.7. Correlation analysis showed that the pH of the suspensions correlated positively with final viscosity (CPV) ($R^2 = 0.84$) whereas the pH versus other pasting parameters did not have such obvious trends ($R^2 = 0.19-0.67$), suggesting that the altered pH of the suspension by adding phytochemical extracts would partially contribute to the alteration of wheat starch pasting properties. Bao and Corke (2002) reported that the pasting properties of gamma-irradiated rice starches in different pH solutions were pH dependent to some extent.

During cooling, the increase of final viscosity (CPV) and setback (SB) are mainly due to some degree of re-ordering of leached amylose chains, which is often termed short-term retrogradation (Funami et al., 2005). All phytochemical extracts significantly reduced the CPV values. C46 had greatest effect (up by 40 RVU) and C53 had least effect (up by 13 RVU). CPV of native starch gel was higher than those with phytochemical extracts. The setback (SB) also varied between the native starch and those with extracts. C53 increased the SB by 7 RVU whereas C54 decreased it by 10 RVU. In addition to the differing pH, another possible reason might be the interaction between the phytochemicals and leached amylose at the hydrophobic regions and binding to the side chains of amylopectin through hydrogen bonding and van der Waals force, which might change the short-term retrogradation and reassociation during RVA cooling phase. In general, different phytochemical extracts affected the pasting properties of wheat starch to different extents, probably due to their varied concentrations, chemical compositions, structural diversities and molecular weights.

3.2. Effect of phytochemical extracts on gel textural properties of wheat starch

For RVA gels stored for 48 h, gelatinized starch gels went through ageing. All the phytochemical extracts considerably reduced the gel hardness with the greatest effect by C46 and the least by C18 (up to 15.7 and 10.4, respectively) (Table 3). Compared with native starch (control), only C46 significantly increased the adhesiveness with the greatest effect by C46 (up to 12.3) whereas C18, C53 and C54 maintained it. C46 decreased the springiness only by 0.04, suggesting that it had little influence on the wheat

Table 2
RVA parameters of wheat starch treated with four phytochemical extracts as compared with native starch[a]

Samples	PT (min)	PV (RVU)	HPV (RVU)	BD (RVU)	CPV (RVU)	SB (RVU)	pH
Starch (control)	9.9^{A}	230^{A}	163^{A}	67^{A}	312^{A}	149^{A}	6.8^{A}
Starch + C18	9.5^{B}	261^{B}	140^{B}	121^{B}	282^{B}	142^{B}	4.0^{B}
Starch + C46	8.9^{C}	249^{C}	132^{C}	117^{C}	272^{C}	140^{C}	4.4^{C}
Starch + C53	9.3^{D}	238^{D}	143^{B}	96^{D}	299^{D}	156^{D}	6.1^{D}
Starch + C54	9.8^{A}	229^{A}	145^{B}	83^{E}	276^{C}	130^{E}	4.8^{E}
$LSD_{0.05}$	0.15	4.9	5.0	2.9	5.4	0.9	0.2

[a] All determined values were expressed as mean. $LSD_{0.05}$, least significant difference ($p < 0.05$). Means with the different letters (i.e., A–E) as superscript were significantly different. PT, time from the initial to the peak viscosity; PV, peak viscosity; HPV, hot paste viscosity; BD, breakdown (PV–HPV); CPV, final viscosity; SB, setback (CPV–HPV).

Table 3
Gel textural properties of wheat starch treated with four phytochemical extracts as compared with native starch[a]

Samples	Hardness (g)	Adhesiveness (g s)	Springiness	Cohesiveness
Starch (control)	39.6^{A}	68.3^{AB}	0.98^{A}	0.57^{A}
Starch + C18	29.2^{B}	77.1^{BC}	0.97^{A}	0.61^{B}
Starch + C46	23.9^{C}	80.6^{C}	0.94^{B}	0.57^{A}
Starch + C53	28.1^{B}	67.8^{AB}	0.97^{A}	0.59^{A}
Starch + C54	27.8^{B}	64.9^{A}	0.97^{A}	0.59^{A}
$LSD_{0.05}$	2.6	11.2	0.01	0.02

[a] All determined values were expressed as mean. $LSD_{0.05}$, least significant difference ($p < 0.05$). Means with the different letters Means with the different letters (i.e., A–E) as superscript were significantly different.

starch gel's "rubbery" feeling in the mouth (Otegbayo et al., 2007). C18 increased the cohesiveness by 0.04 which is a measure of the degree of difficulty in breaking down the gel's internal structure (Lau, Tang, & Paulson, 2000). The addition of other phytochemical extracts hardly changed the cohesiveness of starch gels except C18. Ring (1985) proposed that the starch gel is formed by an interpenetrating amylose gel in the swollen gelatinized starch granules. The interaction between the dispersed amylose and continuous phases thus could influence the textural properties of wheat starch gels. The introduction of different phytochemical extracts changed properties of continuous phases and interacted with amylose through hydrogen bonding and van der Waals force to various extents, which might weaken the intermolecular interactions between the amylose by inhibiting the junction zone formation, thus altering the gel texture.

3.3. Effect of phytochemical extracts on thermal properties of wheat starch

Introduction of phytochemical extracts considerably affected the gelatinization properties of wheat starch (Table 4). During the first endothermic transition, compared with native starch (control), C46 significantly facilitated the gelatinization of wheat starch with earlier onset of T_o and T_p (1.9 °C and 0.6 °C, respectively) and a higher enthalpy of melting by 1.0 J/g, whereas C18 and C54 prolonged the inception of T_o (by 1.0 °C and 1.2 °C, respectively) and T_p (by 0.9 °C and 1.3 °C, respectively) and hardly decreased the melting enthalpies. The additions of all the phytochemical extracts had no significant influence on T_c.

Thermal properties of starch have been reported to be influenced by the degree of crystallinity of starch, granule size and shape, amylose and phosphorus contents, amylopectin chain length and size of crystalline regions as well as other component present (Cardoso, Putaux, Samios, Samios, & Silveira, 2007). As previously discussed in the RVA test session, the effects of the phytochemical extracts on the gelatinization of wheat starch might be explained on the basis of two factors. Firstly, phytochemicals could interact with the water molecules and change the pH and ionic strength of the aqueous solution, thus altering the "surrounding environment" of starch granules. It was reported that pH could significantly affect the gelatinization of starch (Bao & Corke, 2002). Furthermore, acid molecules might cause erosion to the amorphous region of granules during the 24 h storage (Hoover, 2000) period before DSC test. Secondly, the hydroxyl groups of phytochemicals with different conformational flexibilities might interact with side chains of amylopectin and bind to the amorphous region of starch granules to various degrees and thus change the coupling forces between the crystallites and the amorphous matrix (Cardoso et al., 2007; Funami et al., 2005; Gunaratne et al., 2007). All these aspects could contribute to the modification of the granules and thus lead to the alteration of T_o, T_p, T_c and ΔH of the native starch to certain extents.

During the phase of amylose inclusion complex transition, presence of all the four phytochemical extracts caused an early onset of melting (T_o and T_p) with the greatest effect by C46 (T_o and T_p up by 7.9 °C and 6.4 °C, respectively) without changing their enthalpies (ΔH), indicating that phytochemical extracts could facilitate the collapse of amylose–lipid complex.

3.4. Colour observation

Introduction of phytochemical extracts changed the colour parameters (L^*, a^*, b^*, C^* and H^*) of native starch gel stored for 2 h under exposure to the air after the pasting (Table 5). Compared with control (native starch), C46 increased L^* (lightness) by 5.3, whereas both C54 and C18 decreased it by 8.3. C18 increased a^* (redness) by 4.1 and C53 decreased it by 1.6, whereas C46 had no effect. All four extracts considerably increased b^* (yellowness), especially C18 (increased 30.3). C18, C53, and C54 increased C^* (colour purity) by 16.4, 4.9 and 7.4, respectively and H^* (hue value) by 28.6, 7.2 and 30.4, respectively, but C46 had no effect. In addition, colour development of the starch gel samples after 7 days storage at room temperature (23 °C) was observed (Table 5). During storage, C18 and C46, like control, changed L^*, while C53 and C54 stabilized L^*. C46 and C53 altered H^*, as compared with control and other two extracts. This indicated that different phytochemical extracts contributed varied colours to the starch gels. Because the colour of the starch gels was from natural extracts and the synthetic pigments are under much scrutiny for safety and preference concerns, it should be easily accepted by consumers. Spice and herb extracts are traditionally used for cooking and colouring starch-based foods (e.g., rice and flat bread) and also as ingredients to develop functional foods in many Asian countries.

3.5. SEM observation

SEM micrographs (Fig. 1) of the freeze-dried gels gelatinized and stored under exposure to air at room temperature for 14 days show that wheat starch treated with C18 formed a looser gel matrix, while the control showed a more compact micro-structure. During storage, the water holding capacity of the phytochemical extract dispersed in the starch gels inhibited water evaporation and helped to maintain the micro-structure. The control gel shrank because of greater evaporation. C18 might perform better in water holding than other phytochemicals, thus the dried starch gels exhibited a looser internal matrix, compared with that of other

Table 4
Thermal properties of wheat starch treated with four phytochemical extracts as compared with native starch[a]

Samples	Melting endotherm				Amylose inclusion complex endotherm			
	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)
Starch (control)	58.6^A	63.8^A	72.1^A	9.6^A	92.4^A	98.6^A	103.5^A	1.0^A
Starch + C18	59.6^B	64.7^B	72.4^A	9.5^A	87.6^B	95.9^B	102.2^A	1.3^A
Starch + C46	56.7^C	63.2^C	70.9^A	10.6^B	84.5^C	92.2^C	98.0^A	1.2^A
starch + C53	58.3^A	64.1^A	71.8^A	9.2^A	87.6^B	96.2^B	102.4^A	1.1^A
Starch + C54	59.8^B	65.1^B	73.2^A	9.6^A	90.4^D	97.3^{AB}	102.8^A	0.9^A
$LSD_{0.05}$	0.5	0.4	2.3	0.8	1.9	1.9	4.3	0.7

[a] All determined values were expressed as mean. $LSD_{0.05}$, least significant difference ($p < 0.05$). Means with the different letters Means with the different letters (i.e., A–E) as superscript were significantly different.

Table 5
Colour of wheat starch gels treated with four phytochemical extracts as compared with native starch[a]

Storage	Samples	L^*	a^*	b^*	C^*	H^* (°C)
0 day	Control	50.0^A	-4.5^A	-6.3^A	7.8^A	54.3^A
	Starch + C18	41.7^B	-3.0^B	24.0^B	24.2^B	82.9^B
	Starch + C46	55.3^C	-4.7^A	6.5^C	8.1^A	53.8^A
	Starch + C53	47.8^D	-6.1^C	11.2^D	12.7^C	61.5^C
	Starch + C54	41.7^E	-1.4^D	15.1^E	15.2^D	84.7^D
	$LSD_{0.05}$	2.1	0.2	0.5	0.5	1.4
7 days	Control	54.5^A	-5.0^A	-7.1^A	8.7^A	54.5^A
	Starch + C18	45.8^B	-3.7^B	23.4^B	23.7^B	81.0^B
	Starch + C46	60.1^C	-5.0^A	5.5^C	7.5^C	47.7^C
	Starch + C53	49.2^D	-4.5^C	12.1^D	12.9^D	69.7^D
	Starch + C54	43.7^E	1.3^D	14.5^E	14.6^E	85.0^E
	$LSD_{0.05}$	1.2	0.1	0.5	0.5	1.0

[a] All determined values were expressed as mean. $LSD_{0.05}$, least significant difference ($p < 0.05$). Means with the different letters Means with the different letters (i.e., A–E) as superscript were significantly different.

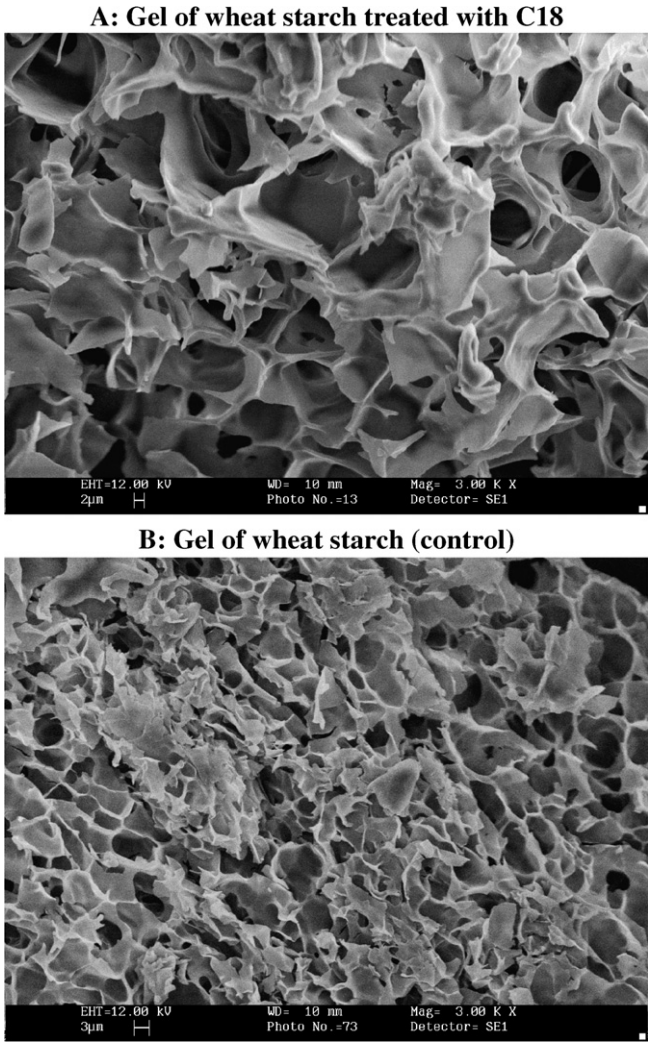

Fig. 1. SEM micrographs of wheat starch treated C18 extract as compared with native starch (control).

phytochemical extracts. This observation was in accordance with cohesiveness results shown by the textural analysis that C18 significantly altered gel's cohesiveness.

4. Conclusions

Addition of phytochemical extracts strongly affected various properties of wheat starch to different extents. The extracts facilitated the pasting of wheat starch, lowered the firmness of starch gel and altered the gelatinization properties. Variation in the types and concentrations of the phytochemicals in the extracts contributed to the different behavior of wheat starch–water systems under various treatments. Introduction of phytochemical extracts significantly modified the colour characteristics of starch gels. Since phytochemicals can benefit human health, this study may provide a scientific basis for the use of phytochemicals in functional and starch-based staple foods. Further studies on the interaction between starch and specific phytochemical compounds are under way.

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References

Bao, J. S., & Corke, H. (2002). Pasting properties of γ-irradiated rice starches as affected by pH. *Journal of Agricultural and Food Chemistry, 50*, 336–341.
Bao, Y. P., & Fenwick, R. (2004). *Phytochemicals in health and disease*. Marcel Dekker: New York.
Beta, T., & Corke, H. (2004). Effect of ferulic acid and catechin on sorghum and maize starch pasting properties. *Cereal Chemistry, 81*, 418–422.
Bhattacharya, M., Jafari-Shabestari, J., Qualset, C. O., & Corke, H. (1997). Diversity of starch pasting properties in Iranian hexaploid wheat landraces. *Cereal Chemistry, 74*, 417–423.
Cai, Y. Z., Luo, Q., Sun, M., & Corke, H. (2004). Antioxidant activity and phenolic compounds of 112 traditional Chinese medicinal plants associated with anticancer. *Life Sciences, 74*, 2157–2184.
Cai, Y. Z., Sun, M., Xing, J., Luo, Q., & Corke, H. (2006). Structure-radical scavenging activity relationships of phenolic compounds from traditional Chinese medicinal plants. *Life Sciences, 78*, 2872–2888.
Cardoso, M. B., Putaux, J. L., Samios, D., Samios, D., & Silveira, N. P. (2007). Influence of alkali concentration on the deproteinization and/or gelatinization of rice starch. *Carbohydrate Polymers, 70*, 160–165.
Cui, T., Li, J. Z., Kayahara, H., Ma, L., Wu, L. X., & Nakamura, K. (2006). Quantification of the polyphenols and triterpene acids in Chinese hawthorn fruit by high-performance liquid chromatography. *Journal of Agricultural and Food Chemistry, 54*, 4574–4581.
Deshpande, S. S., & Salunkhe, D. K. (1982). Interactions of tannic acid and catechin with legume starches. *Journal of Food Science, 47*, 2080–2081.
Epifano, F., Genovese, S., Menghini, L., & Curini, M. (2007). Chemistry and pharmacology of oxyprenylated secondary plant metabolites. *Phytochemistry, 68*, 939–953.
Fresco, P., Borges, F., Diniz, C., & Marques, M. P. M. (2006). New insight on the anticancer properties of dietary polyphenols. *Medicinal Research Reviews, 26*, 747–766.
Funami, T., Kataoka, Y., Omoto, T., Goto, Y., Asai, I., & Nishinari, K. (2005). Effects of non-ionic polysaccharides on the gelatinization and retrogradation behavior of wheat starch. *Food Hydrocolloids, 19*, 1–13.
Gao, X. M., Xu, Z. M., & Li, Z. W. (2000). *Traditional Chinese medicines*. Beijing, China: People's Health Publishing House.
Gunaratne, A., & Corke, H. (2007). Influence of prior acid treatment on acetylation of wheat, potato and maize starches. *Food Chemistry, 105*, 917–925.
Gunaratne, A., Ranaweera, S., & Corke, H. (2007). Thermal, pasting, and gelling properties of wheat and potato starches in the presence of sucrose, glucose, glycerol, and hydroxypropyl beta-cyclodextrin. *Carbohydrate Polymers, 70*, 112–122.
Han, X. Z., Shen, T., & Lou, H. X. (2007). Dietary polyphenols and their biological significance. *International Journal of Molecular Sciences, 8*, 950–988.
Hoover, R. (2000). Acid-treated starches. *Food Reviews International, 16*, 369–392.
Lansky, E. P., & Newman, R. A. (2007). *Punica granatum* (pomegranate) and its potential for prevention and treatment of inflammation and cancer. *Journal of Ethnopharmacology, 109*, 177–206.
Lau, M. H., Tang, J., & Paulson, A. T. (2000). Texture profile and turbidity of gellangelatin mixed gels. *Food Research International, 33*, 665–671.
Liu, R. H. (2004). Potential synergy of phytochemicals in cancer prevention: Mechanism of action. *Journal of Nutrition, 34*, 79S–3485S.
Naczk, M., & Shahidi, F. (2006). Phenolics in cereals, fruits and vegetables: Occurrence, extraction and analysis. *Journal of Pharmaceutical and Biomedical Analysis, 41*, 1523–1542.
Nakatani, N. (1994). Antioxidant and antimicrobial constituents of herbs and spices. In G. Charalambous (Ed.), *Spices, herbs and edible fungi* (pp. 251–271). New York: Elsevier.
Otegbayo, B., Aina, J., Abbey, L., Sakyi-Dawson, E., Bokagna, M., & Asiedu, R. (2007). Texture profile analysis applied to pounded yam. *Journal of Texture Studies, 38*, 355–372.
Ring, S. G. (1985). Some studies on starch gelation. *Starch/Stärke, 37*, 80–83.
Sakakibara, H., Honda, Y., Nakagawa, S., Ashida, H., & Kanazawa, K. (2003). Simultaneous determination of all polyphenols in vegetables, fruits, and teas. *Journal of Agricultural and Food Chemistry, 51*, 571–581.
Shahidi, F. (2000). Antioxidants in food and food antioxidants. *Nahrung-Food, 44*, 158–163.
Shahidi, F. (2004). Functional foods: Their role in health promotion and disease prevention. *Journal of Food Science, 69*, R146–R149.
Shahidi, F., & Ho, C. T. (2005). *Phenolic compounds in foods and natural health products*. Washington, DC: American Chemical Society.
Shahidi, F., McDonald, J., Chandrasekara, A., & Zhong, Y. (2008). Phytochemicals of foods, beverages and fruit vinegars: Chemistry and health effects. *Asia Pacific Journal of Clinical Nutrition, 17*, 380S–382S.
Shan, B., Cai, Y. Z., Brooks, J. D., & Corke, H. (2007). The in vitro antibacterial activity of dietary spice and medicinal herb extracts. *International Journal of Food Microbiology, 117*, 112–119.
Shan, B., Cai, Y. Z., Sun, M., & Corke, H. (2005). Antioxidant capacity of 26 spice extracts and characterization of their phenolic constituents. *Journal of Agricultural and Food Chemistry, 53*, 7749–7759.
Surveswaran, S., Cai, Y. Z., Corke, H., & Sun, M. (2007). Systematic evaluation of natural phenolic antioxidants from 133 Indian medicinal plants. *Food Chemistry, 102*, 938–953.
Vandeputte, G. E., & Delcour, J. A. (2004). From sucrose to starch granule to starch physical behaviour: A focus on rice starch. *Carbohydrate Polymers, 58*, 245–266.