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ORIGINAL ARTICLE

Evaluation of different hydrocolloids to improve dough rheological properties and bread quality of potato–wheat flour

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Abstract The aim of study was to investigate the effect of hydroxylpropylmethylcellulose (HPMC), arabic gum (AG), konjac glucomannan (KG) and apple pectin (AP) at 2% (w/w, potato–wheat flour basis) on the potato–wheat dough (the mass ratio was 1:1) rheological, fermentation and bread making properties. The tan δ of potato–wheat dough was significantly increased upon addition of adding HPMC which was close to wheat dough (0.531). Moreover, dough height during fermentation process was significantly improved on addition of hydrocolloids, with the order of HPMC (23.1 mm) > AP (19.3 mm) > AG (18.6 mm) > KG (13.6 mm). Protein bands of potato–wheat dough were pale in the presence of hydrocolloids, suggesting the formation of higher molecular weight aggregates formed between proteins–hydrocolloids or proteins–proteins after fermentation process. Furthermore, HPMC significantly increased specific volume (from 1.45 to 2.22 ml/g), and hydrocolloids restricted the retrogradation of starch in potato–wheat breads.

Keywords Dough property · Hydrocolloid · Protein structure · Specific volume · Texture · Thermal characteristics

Chemical compounds Hydroxylpropylmethylcellulose (PubChem CID: 57503849) · Sodium dodecyl sulfate (PubChem CID: 3423265) · Polyacrylamide (PubChem CID: 3083321) · Coomassie Brilliant Blue G 250 (PubChem CID: 6333920) · Mercaptoethanol (PubChem CID: 1567) · Sodium dihydrogen phosphate (PubChem CID: 1567) · Sodium dihydrogen phosphate (PubChem CID: 23672064) · Disodium hydrogen phosphate (PubChem CID: 24203) · Carbon dioxide (PubChem CID: 280)

Introduction

Nowadays, the use of mixed and wheat-less flours for bread making is a very recent development across the globe owing to some economic, social and health reasons. In some countries, research efforts are devoted to partial substitution of wheat flour for bread baking purposes, in order to reduce the huge expenditure on wheat importation and to increase the utilization of locally available food crops (Hager and Arendt 2013).

Potato is the fourth important food crop in the world after rice, wheat and maize (FAOSAT 2016). Potato protein is characterized by balanced amino acid composition, which repairs the defects of wheat protein. Moreover, potato flour contains several phytochemicals such as

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phenolics, flavonoids, and carotenoids, which play pivotal role in human health and are essential part of our routine diet (Ezekiel et al. 2013). Due to its high nutritional value and low caloric content, potato is supposed to be a better alternate of wheat flour in food industry. Moreover, potato flour addition may influence wheat dough properties, which impact the physicochemical properties of bread. It has been proven that potato flour up to 20% can be mixed with wheat flour to prepare acceptable bread (Ijah et al. 2014). However, higher substitution of wheat flour has a negative impact on dough development during fermentation process and the quality of the products, for example, dough height is reduced, specific volume is decreased, and hardness is increased. Therefore, the addition of additives is a strategy to improve the bread making performance in low gluten or gluten free breads.

Hydrocolloids have a wide application as additives to improve the quality of wheat, low gluten or gluten free breads. The functional effects of hydrocolloids stem from their ability to modify dough rheology and keep qualities of baked products. Hydrocolloids consist of a number of water soluble polysaccharides with different chemical structure, and provide various functional properties by controlling the water molecule's mobility, thus affecting the dough rheology, dough development and gas retention (Peressini et al. 2011; Mancebo et al. 2015; Nicolae et al. 2016). Various hydrocolloids have been applied to improve dough rheology, the rheology of wheat dough can be improved with the use of sodium alginate, k-carrageenan, xanthan gum (XG) and hydroxylpropylmethylcellulose (HPMC), alginate and HPMC showed an exceptional retardation of staling (Guarda et al. 2004). Shittu et al. (2009) found that XG improved the quality of cassava-wheat bread (the mass ratio of cassava flour and wheat flour was 1:9). Moreover, hydrocolloids have also been used extensively as improver in gluten free bread, yielding higher specific volume and softer crumb (Moore et al. 2004; Korus et al. 2009; Nicolae et al. 2016). Peressini et al. (2011) found that propylene glycol alginate showed better improvement than XG when they studied rice-buckwheat dough and bread quality. Conclusively, it's still a challenge to predict the real effect of hydrocolloids on dough properties and bread quality due to different applied ingredients, structure of hydrocolloids, dough preparation and baking procedures. Up to date, a handful of information is available on the application of different hydrocolloids to improve the dough property and quality of potato–wheat bread.

In the present study, the effects of hydroxylpropylmethylcellulose (HPMC), arabic gum (AG), konjac glucomannan (KG) and apple pectin (AP) at 2% level (w/w, potato–wheat flour basis) on rheological, fermentation properties and bread making performance of potato–wheat flour blend (the mass ratio of potato flour and wheat flour was 1:1) were investigated. The effect of these hydrocolloids on the protein structure and staling of the potato–wheat bread at 24 and 48 h of storage were also studied to improve the quality of bread.

Materials and methods

Materials

Wheat flour was purchased from Beijing Qijian Food Ltd. (Beijing, P. R. of China). Fresh potato (Shepody) was provided by Institute of Vegetables and Flowers, Chinese Academy of Agricultural Sciences (Beijing, China). Potato tubers were peeled, washed, then steamed for 30 min at 100 °C, dried between 170 and 200 °C, and milled into flour using hammer mill (Beijing kaichuang tonghe Technology Development Co., Ltd. China) and sieved through 100 μm screen. The basic compositions of wheat flour and potato flour are given in supplement Table 1. AP, AG, KG and HPMC were obtained from Henan Zhongxin Chemical Co., Ltd. (Zhengzhou, Henan, P. R. of China). Degree of esterification of pectin was 58.15. The viscosity of KG and AG were 36,000 MPa/min (1% aqueous solution at 25 °C) and 5100 MPa/min (1% aqueous solution at 25 °C), respectively. And the degrees of methoxyl and hydroxypropyl substitution of HPMC were 28.2 and 7.8%, respectively. Instant dry yeast was obtained from Angel Yeast Co. Ltd. (Yichang, Hubei, China). Tap water was used to prepare dough.

Dynamic rheological properties of dough

According to amino acid composition, the equipment adaptability of commercial process, the acceptability of consumers, etc., the mass ratio of potato and wheat flour was 1:1, which was selected throughout the study.

The water absorption of wheat flour was determined according to farinograph (water absorption: 63 ± 0.6%). And for the potato–wheat flour blends (the mass ratio of potato flour and wheat flour was 1:1) was 90%, and the level of hydrocolloids was 2% (w/w, potato–wheat flour basis) (Supplement Table 2). The mixed flour and appropriate water (deprived of yeast) were mixed at the low speed (80 rpm) for 10 min using a Hobart mixer A-120 (Tory, Ohio). Dynamic oscillatory tests were performed using Anton Par Physica MCR 301 equipped with a parallel plate geometry (25 mm diameter) with a 1.0 mm gap between plates. Before measurements, samples were allowed to rest 10 min between plates. Deformation sweeps were performed at a constant frequency in order to determine the linear viscoelastic range of each sample, frequency sweeps (from 1 to 100 rad/s) were performed at a constant stress (0.1%) within the linear viscoelastic range. Experimental data were described by the power law model (Korus et al. 2009):

$$G'(\omega) = K' \cdot \omega^{n'}$$

$$G''(\omega) = K'' \cdot \omega^{n''}$$

G′—storage modulus (Pa), G″—loss modulus (Pa), ω—angular frequency (rad s^{-1}), and K′, K″, n′, n″—experimental constants.

Rheofermentometer measurements

Fermentation property was determined using a Rheofermentometer F3 (Chopin Technologies, France) following the supplier specifications. The yeast content was 3% (flour basis). Dough was mixed according to 2.2, placed (300 g) in the fermentation vat at the temperature of 30 °C for 3 h and a weight constraint of 0.5 kg was applied. Fermentation parameters included: H_m, height under constraint of dough at maximum development time (mm); V_T, total volume of CO_2 (ml) produced during fermentation (Dahir et al. 2015).

Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE)

SDS-PAGE under reducing conditions was performed according to the method described by Laemmli (1970) using an AE-6450 electrophoresis system (Atto Corporation, Tokyo, Japan). 0.2 g dough was transferred into a vial and mixed with 0.5 ml of extraction solution (0.5 M Phosphate buffer at pH 7.4 with 2% SDS), vortex shaking for 30 min, and centrifuged for 20 min at 10,000×*g*. The supernatant was directly dissolved (4:1, v/v) in the sample buffer. After boiling at 100 °C for 2 min, the samples were centrifuged at 10,000×*g* for 20 min. The 15-µl samples and 10-µl marker solutions were placed into wells. Gel electrophoresis was run on 5% loading gels and 15% separating gels. The gels were stained using Coomassie Brilliant Blue R-250 method and distained with methanol wash solution. A marker kit containing bovine serum albumin (66.2 kDa), ovalbumin (45.0 kDa), lactate dehydrogenase (35.0 kDa), REase Bsp98I (25.0 kDa), β-lactoglobulin (18.4 kDa), lysozyme (14.4 kDa) (Sigma) were used for evaluating the apparent molecular mass.

Bread making

The yeast content was 3% (flour basis). Dough was mixed according to 2.2, then covered with a plastic film, and was fermented 1 h at 30 °C and 80% relative humidity (RH). After first fermentation, dough was divided into 50 g portions, rounded, and again kept at 30 °C and 80% RH for 20 min. Baking was performed in an electrical oven ACA model ATO-CF24B (Zhuhai, China) for 35 min at 160 °C. After cooling, the bread samples were packed in bags and stored for 0, 24 and 48 h at room condition (25 °C and 47% RH).

Bread quality analysis

Bread volume was assessed by rapeseed displacement. The height and diameter of breads were measured using a vernier caliper and the shape was determined from the height/diameter ratio. Water content, water activity (a_w), and weight loss were determined according to the method described earlier (Sahraiyan et al. 2013).

Additionally, analysis of crust color in CIE L*a*b* system was performed by reflectance method using Color i5 spectrometer (XRite, USA) set for the following parameters: measuring geometry d/8, illuminant D65, observer 10°, slit width 25 mm.

Texture profile analysis was measured using a TA-XT2i Texture Analyser equipped with a 5 kg load cell (Godalming, London). Pre-test speed 5.0 mm/s, test speed 1 mm/s, post-test speed 5.0 mm/s, 40% compression, 35 mm diameter cylinder probe. The waiting time between the first and second compression cycle was 1 s. Hardness, springiness and chewiness were calculated from the graphic.

Thermal properties

Thermal properties were characterized by differential scanning calorimeter (DSC) Q100 (New Castle, Delaware, USA). 6–15 mg bread samples were placed into aluminum hermetic pans and analyzed at 0, 24 and 48 h at room condition (25 °C and 47% RH). An empty pan was used as reference. Sample and reference were heated between 0 and 140 °C at a heating rate of 10 °C/min. The endothermic transition temperature (T_p), and enthalpy (ΔH) for starch gelatinization were computed from the endothermic peaks. Enthalpies were expressed as J/g DW.

Statistical analysis

To establish the statistical differences between means, the data were subjected to one-factor analysis of variance, and the least significant difference (LSD) at significance level 0.05 was calculated using Fisher post hoc test. Statistical analysis was performed using the Statistical Analysis System version 8.1 software (SAS Institute Inc., Cary, NC, USA).

Results and discussion

Chemical composition of wheat and potato flour

The composition of wheat and potato flour is shown in supplementary Table 1. Protein, ash, fat, dietary fiber and starch content of wheat flour was 13.22 ± 0.21, 0.48 ± 0.02, 1.23 ± 0.01, 1.88 ± 0.08, 60.58 ± 0.14%, respectively, and of potato flour was 9.87 ± 0.11, 1.86 ± 0.01, 0.26 ± 0.01, 6.28 ± 0.06, 68.78 ± 0.32%, respectively. Moreover, the dietary fiber content of potato flour was 3.34-fold than that of wheat flour. K, P and vitamin C content of potato flour was significantly higher than wheat flour. The addition of potato flour in wheat flour would enhance bread nutritional and functional qualities.

Dynamic rheological properties of dough

The storage modulus (G'), loss modulus (G''), and phase shift tangent (tan δ) of the samples are represented in supplementary Fig. 1. Table 1 shows the parameters of power law model. Storage modulus were larger than those of loss modulus ($G' > G''$) in all samples, which indicated that elastic properties predominated viscous features, and solid like behavior of all tested samples. However, concrete viscoelastic properties were different between samples. The G', G'' and tan δ values of PW dough were lower than wheat dough. Therefore, hydrocolloids with thickening effects in PW dough might be more suitable for making bread. Compared to PW dough, the addition of AG, KG and AP increased G' and G'' values significantly (supplement Fig. 1), which was also confirmed by the values of K' and K'' (Table 1). However, HPMC addition decreased the G' accompanied with increasing G''. Furthermore, AG and KG addition had an increase in K' and K'' accompanied by the lower in n' and n'' values, which suggested an increase in gel stability (Witczak et al. 2014). Studies also found that addition of xanthan gum to rice-buckwheat dough increased G' and G'' (Peressini et al. 2011). Because of the tendency of AG and KG for aggregation or self-association, which may exhibit a wide range of conformations in solution as the links along the polymeric chains, thus encourage extensive structuring in the surrounding water, this hydrocolloid may have contributed to batter strength with the formation of weakly associated aggregates (Anton and Artfield 2008). Another contribution of AG and KG to dough elasticity could be due to starch granule or protein-hydrocolloid interaction. Peressini et al. (2011) found that some starch granules appeared to be glued together by the hydrocolloids and enveloped in a coating suggesting a close association of hydrocolloids with starch granule.

In order to compare the difference of samples, tan δ values at 1 Hz (within the linear region) was conducted. Potato flour addition significantly reduced tan δ value compared to wheat dough (from 0.531 to 0.337). Tan δ of HPMC-PW dough (0.425) was close to the wheat flour dough (0.531), and significantly higher than PW dough (0.337) (Table 1). HPMC addition increased tan δ and decreased the storage modulus of the PW dough, which was similar to the influence of propylene glycol alginate on the rice-buckwheat batters (Peressini et al. 2011). Hydrophobic groups of HPMC introduced a bump on the chain that prevents close association of chains resulting in quite stable polymer solution (Nammakuna et al. 2016). Although AP addition resulted in a significant growth of G' and G'' values, tan δ only had a slight shift (0.348), which might be attributed to that AP enhanced the elasticity and viscosity of dough in the similar degree. The reason could be explained that pectin is a hetero-polysaccharide, which contains at least 65% (w/w) units of galacturonic acid, which is significant from the other hydrocolloids. Our result agrees with the finding that the pectin had contributed to the overall elasticity and viscosity of bread dough or potato starch paste (Witczak et al. 2014). AG and KG addition caused noticeable reduction of tan δ and loss of the relation between moduli and oscillation frequency,

Table 1 Parameters of the power-law functions describing dependence of storage and loss moduli on angular frequency

Samples	$G' = K' \cdot \omega^{n'}$		$G'' = K'' \cdot \omega^{n''}$		tanδ
	$K' \times 10^{-3}$ (Pa $s^{n'}$)	n'	$K'' \times 10^{-3}$ (Pa $s^{n''}$)	n''	At 1 Hz
Wheat	11.42 ± 0.52d	0.191 ± 0.002b	6.86 ± 0.21c	0.192 ± 0.006b	0.531 ± 0.001a
PW	8.74 ± 0.23e	0.148 ± 0.003d	3.17 ± 0.19e	0.188 ± 0.004c	0.337 ± 0.006c
HPMC-PW	8.04 ± 0.12f	0.218 ± 0.006a	3.81 ± 0.08d	0.252 ± 0.005a	0.425 ± 0.005b
AG-PW	34.59 ± 1.59a	0.114 ± 0.001f	8.16 ± 0.27a	0.152 ± 0.008d	0.222 ± 0.001e
KG-PW	24.46 ± 0.67b	0.132 ± 0.004e	7.28 ± 0.19b	0.160 ± 0.005d	0.283 ± 0.004d
AP-PW	20.43 ± 0.42c	0.172 ± 0.006c	7.52 ± 0.09b	0.196 ± 0.009c	0.348 ± 0.002c

PW potato flour-wheat flour, *HPMC* hydroxylpropylmethylcellulose, *AP* apple pectin, *AG* arabic gum, *KG* konjacglucomannan which was illustrated by the lowest values of n′ and n″ (Table 1). Therefore, AG and KG had a gelling effect than the thickening effect. Similar results found when agar, HPMC and xanthan gum were added to chestnut dough (Moreira et al. 2011).

Fermentation properties of dough

Effect of hydrocolloids on dough development and total amount of gas (CO_2) is shown in Table 2. Dough development was characterized by dough height at maximum development time (H_m), higher H_m suggested the condition of dough was more favorable to produce larger volume (Huang et al. 2008). H_m was significantly and negatively influenced by potato flour addition (from 58.7 to 10.8 mm). This was in agreement with the finding of Wang et al. (2002), who observed that bran addition decreased the dough height by preventing the free expansion of wheat dough during fermentation. Compared to PW dough, hydrocolloids addition increased the H_m significantly, especially HPMC (23.1 mm) and AP (19.3 mm), which agreed with that HPMC inclusion in the biscuit and whole meal flour formulations improved dough development (Zannini et al. 2014). Mudgil et al. (2016) also found that partially hydrolyzed guar gum addition increased the peak dough height and stability of wheat dough. Similar results were also reported by Dahir et al. (2015). They reported that carboxymethylcellulose improved the Hm of sorghum-wheat dough. The reason might be due to that the hydrocolloids interact with protein and starch, thus influences dough stability during proofing and confers additional strength to increase the gas retention leading to greater volume. The results of Ribotta et al. (2005) and Correa et al. (2014) confirmed the explanation, they found that hydrocolloids could form hydrophilic complexes with protein or starch, which moreover changed the viscoelasticity and influenced the fermentation character.

Table 2 Fermentation properties of potato–wheat dough obtained using different hydrocolloids

Samples	Dough development H_m (mm)	Gas behavior V_T (ml)
Wheat	58.7 ± 0.2a	1713 ± 20e
PW	10.8 ± 0.1f	2553 ± 25c
HPMC-PW	23.1 ± 0.1b	2368 ± 38d
AP-PW	19.3 ± 0.2c	2614 ± 12b
AG-PW	18.6 ± 0.1d	2671 ± 31a
KG-PW	13.6 ± 0.1e	2714 ± 29a

PW potato flour-wheat flour, *HPMC* hydroxylpropylmethylcellulose, *AP* apple pectin, *AG* arabic gum, *KG* konjacglucomannan, H_m dough height at maximum development time, V_T total volume of CO_2 (ml)

Regardless to the retarded dough development, compared to wheat dough, the gas behavior (total volume of CO_2, V_T) was improved with potato flour addition (from 1713 to 2553 ml). The reason might be the processing way of potato flour caused the gelatinization of starch and the break of structure, an easier access of the enzyme to the active sites in starch and then yield sugars metabolized by the commercial yeast addition. However, hydrocolloids addition did not have prominent effect on V_T of PW dough, which might be due to that hydrocolloids had no significant influence on the enzymatic activity and sugar content pivotal for yeast growth.

SDS-PAGE

The typical protein electrophoretic profiles obtained by SDS-PAGE are shown in Fig. 1. Wheat dough protein extract showed the presence of very faint bands at 61, 56 and 48.8 kDa that corresponded to ω-gliadins, followed by other polypeptides species of 41, 37, 35, 32 kDa which could be assigned to α, β-and γ gliadins and low molecular weight glutenin subunits (LMW-GS), and bands at 26, 17 and 14 kDa corresponded to albumin and globulins (Correa et al. 2014; Wang et al. 2016). The profile of potato protein showed the presence of 40 and 18.4 kDa bands, which were assigned to patatin and protease inhibitor, respectively (Koningsveld 2001). Compared to the wheat and PW dough, the protein bands of PW dough turned pale in the presence of hydrocolloids, especially for patatin and protease inhibitor sites, which indicated a difficult extraction of protein subunits. This may be attributed to the formation of higher molecular weight complexes between proteins–hydrocolloids or proteins–proteins during fermentation process, thus changed the protein solubility, and the capacity of complexation appears to be related to the type of hydrocolloid. These results were demonstrated by Ribotta et al. (2005), who found that carrageenan and pectin decreased the density of wheat protein bands because of forming hydrophilic complexes with gluten proteins. However, the result was different with that high molecular weight aggregates were observed at the top of the gel when hydrocolloids added into wheat dough (Correa et al. 2014). However, occurrence of other types of interactions, such as electrostatic and hydrophobic interactions in the aggregates present in the dough cannot be ruled out. The hydrocolloids addition also could affect the protein properties through the change of secondary structure or forming non-covalent links, which were confirmed by the results of Correa et al. (2014). They observed microcrystalline cellulose and HPMC changed the α-helix conformation percentage of wheat protein.

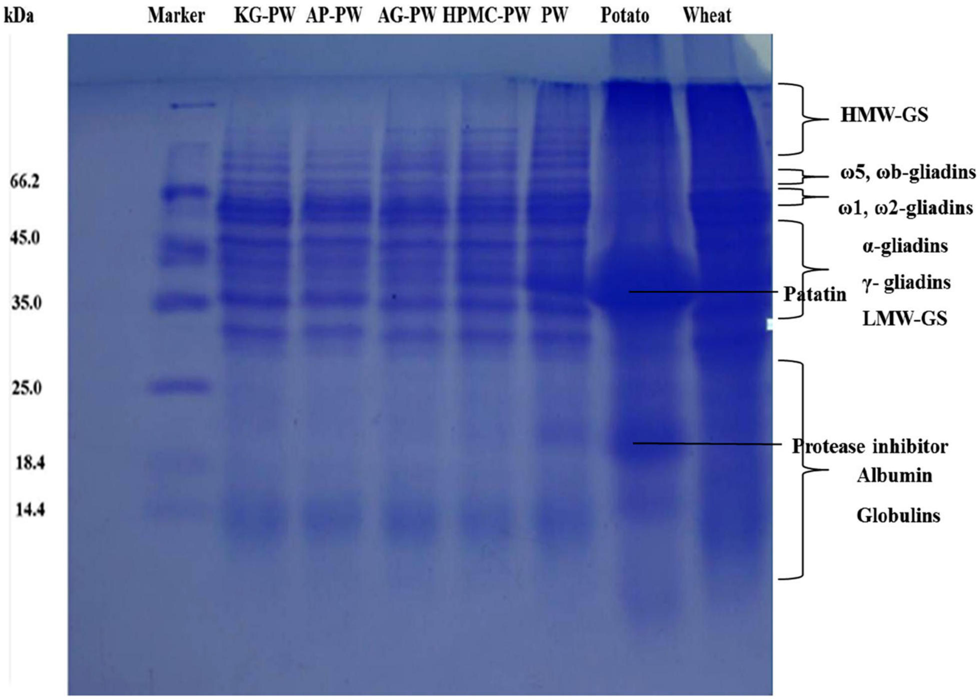


Fig. 1 SDS-PAGE micrographs of the dough obtained using different hydrocolloids. *PW* potato flour–wheat flour, *HPMC* hydroxylpropylmethylcellulose, *AP* apple pectin, *AG* arabic gum, *KG* konjacglucomannan

Bread quality analysis

Specific volume and height/diameter ratio

The photographs of breads are shown in supplement Fig. 2. The bread prepared with 100% wheat flour had the biggest specific volume (3.08 ml/g, Table 3), accompanied by a good distribution of pores on the crumb surface. The smallest specific volume of bread (1.45 ml/g, Table 3) was found in PW. It was well known that gluten (gliadins and glutenins) was responsible for the protein starch interaction which is related to gas cell formation, including stabilization and retention of the gas cells during the proofing and baking process (Khatkar et al. 2013), and potato flour addition destructed the gluten structure. Therefore, the lowest specific volume of PW bread might be due to the "dilution effect" of the gluten proteins and different starch granule, amylose/amylopectin, particle size between potato and wheat flour. Hydrocolloids addition significantly increased the specific volume of bread, which was in agreement with the result that 0.5 and 1.0 g/100 g guar and all concentrations of locust bean gum-flour blends gave higher loaf volume compared to control (Hammed, Ozsisli and Simsek 2016), 1% sodium carboxymethyl cellulose increased volume of rice bread (Nicolae et al. 2016), xanthan gum, guar gum, and locust bean gum increased the specific volume of gluten-free bread based on small broken rice berry flour (Numfon 2017). The reason could be attributed to that hydrocolloids improved dough rheological properties (Table 1) and fermentation capability (Table 2), and the increased extent appeared to be related to the type of hydrocolloid. This might be because too high or low viscosity and elasticity caused a limited gas cell expansion during fermentation, which was in agreement with the results of Lazaridou et al. (2007), who observed that viscosity and elasticity up to a certain level have the advantage to allow for a larger increase in volume. HPMC-PW bread had the biggest specific volume (2.22 ml/g), which was 1.53-folds of PW bread, this could be confirmed by the result that HPMC increased the $\tan \delta$ (near to wheat dough) (Table 1) and maximum dough height (H_m) of PW dough (Table 2). HPMC contains hydrophobic groups, which increase the interfacial activity within the dough system during fermentation, and form gel networks on heating during bread making process (Mancebo et al. 2015). Such network structures serve to further strengthen the boundaries of the expanding cells in the dough, thus increase gas retention and lead to a better bread specific volume consequently (Lazaridou et al. 2007). AP addition also increased the specific volume of bread from 1.45 to 2.04 ml/g, coinciding with the results of Correa et al. (2012) and Lazaridou et al. (2007), who found that pectin increased the specific volume of gluten free rice bread. These height/diameters of all the samples were higher than 0.5, suggesting a spherical shape was formed. AG had the highest value (0.74), even more than the sample with only wheat flour (0.67). On the other hand, PW showed the lowest height/diameter (0.58), which showed that the shape was close to round.

Table 3 Technological parameter of potato–wheat breads obtained using different hydrocolloids

Samples	Weight loss (%)	Height/diameter	Water activity	Specific volume (ml/g)	Water content (%)			L*	a*	b*
					0 (h)	24 (h)	48 (h)			
Wheat	22.65 ± 0.21a	0.67 ± 0.04bc	0.9645 ± 0.001a	3.08 ± 0.01a	42.17 ± 0.12 l	37.49 ± 0.11m	36.85 ± 0.02n	67.9 ± 0.2a	6.9 ± 0.1e	35.1 ± 0.3e
PW	19.69 ± 0.14b	0.58 ± 0.02d	0.9646 ± 0.002a	1.45 ± 0.02f	49.07 ± 0.17c	46.28 ± 0.07h	45.24 ± 0.06i	64.9 ± 0.4c	8.2 ± 0.2c	38.7 ± 0.2d
HPMC-PW	18.30 ± 0.13c	0.63 ± 0.03cd	0.9650 ± 0.008a	2.22 ± 0.03b	49.74 ± 0.21b	47.44 ± 0.02e	45.02 ± 0.12j	60.9 ± 0.5d	10.5 ± 0.1b	42.0 ± 0.4a
AP-PW	18.30 ± 0.20c	0.61 ± 0.03cd	0.9650 ± 0.007a	2.04 ± 0.01c	49.15 ± 0.08c	46.77 ± 0.15g	43.65 ± 0.11k	58.6 ± 0.1e	13.4 ± 0.2a	41.2 ± 0.1b
AG-PW	18.20 ± 0.08c	0.74 ± 0.06a	0.9652 ± 0.004a	1.70 ± 0.02e	49.15 ± 0.08c	48.66 ± 0.21d	47.08 ± 0.02f	66.6 ± 0.1b	5.8 ± 0.1f	38.7 ± 0.1d
KG-PW	16.94 ± 0.11c	0.69 ± 0.02ab	0.9649 ± 0.006a	1.82 ± 0.01d	51.31 ± 0.09a	48.67 ± 0.03d	47.51 ± 0.08e	64.4 ± 0.2c	7.7 ± 0.1d	39.8 ± 0.2c

PW potato flour-wheat flour, *HPMC* hydroxylpropylmethylcellulose, *AP* apple pectin, *AG* arabic gum, *KG* konjacglucomannan

Crust colour

The Hunter parameters of the crust are reported in Table 3. Compared to wheat bread, the addition of potato flour and hydrocolloids decreased L*, the one reason might be that L* of potato flour was lower than wheat flour, and the other reason might be that the L* was affected by the making process of bread. The parameter a* denotes the balance between green (negative values) and red (positive values). The a* of PW bread was significantly increased by AP and HPMC addition, suggesting an increase in the red colour of these samples, while the opposite trend was found for breads with AG and KG addition. In the case of parameter b*, all tested sample showed evidence of the dominance of yellow ($b^* > 0$). The lowest value of b* was observed in the wheat bread (35.1). Hydrocolloids addition significantly increased the value of the parameter b*, especially AP (41.2) and HPMC (42.0), which was different to the result of Lazaridou et al. (2007), who obtained bluer gluten free breads supplemented with different hydrocolloids compared to control, the reason might be different material composition and making process of the researchers.

Water activity, weight loss and water content

Water properties of bread are important for bread quality, especially for the retrogradation during storage. The water activity (a_w) values of the bread of all potato–wheat flour recipes are presented in Table 3. The results demonstrated that the values of a_w varied within the ranges of 0.9645 (Wheat)–0.9652 (AG-PW). The a_w value was not affected by hydrocolloids addition, which was in accordance with the result of Sahraiyan et al. (2013), who found the *Lepidium sativum* seed and guar gum had no significant influence on the a_w of rice–wheat bread. In contrast, Rosell et al. (2001) reported an increase of a_w as well of moisture retention due to the higher water holding capacity of the gum. Correa et al. (2014) reported that significantly higher relaxation times were observed when modified celluloses were added. Moreover, hydrocolloids addition significantly decreased the weight loss during the baking process because of the higher water holding capacity, the better dough stability, or the gas cells with a more continuous surface and a thicker appearance with respect to the control (Fadda et al. 2014).

The weight loss of all the PW bread were lower than the wheat bread may be attributed to higher water holding capacity of potato flour than wheat flour because of difference in composition, such as protein, starch, dietary fiber and phosphorus content. Besides, hydrocolloids addition significantly affected the water content of PW bread during storage. After the 24 and 48 h of storage, a trend of decreasing water content of all the bread was found, while the degree of reduction was inhibited by hydrocolloids with the exception of AP (Table 3).

Texture properties

Table 4 shows selected texture parameters of bread. The interactions between starch and other macromolecular constituents are especially important for structural changes occurring in bread. In traditional wheat based bakery products, the primary role is played by gluten and starch. Polysaccharide constituents are generally more important in establishing bread structure than protein in the case of wheat-less products. Moreover, the presence of polysaccharide significantly influence on bread staling, which occurs due to the changes in water binding and starch retrogradation. Initial hardness of wheat bread was 19.23 N and increased to 31.02 and 46.58 N after the 24 and 48 h of storage, respectively. As for the PW, the hardness was 19.24, 30.19, and 38.56 N on the 0, 24, and 48 h, respectively. These hydrocolloids addition did not affect the hardness of the fresh bread (Table 4). There was a report on correlation between loaf volume and hardness (Moore et al. 2004). However, this result was not certified by the study, as the Wheat and PW had the different specific volume, and the hardness of them was almost similar at the same time.

Table 4 Texture of potato–wheat from breads prepared using different hydrocolloids

Samples	Hardness (N)	Springiness	Chewinness (N)
Wheat (h)			
0	19.23 ± 1.25de	0.90 ± 0.01a	7.84 ± 1.34f
24	31.02 ± 1.44c	0.93 ± 0.01a	13.71 ± 0.73d
48	46.58 ± 3.04a	0.94 ± 0.01a	19.44 ± 2.36abc
PW (h)			
0	19.24 ± 2.20de	0.90 ± 0.01a	8.82 ± 0.80ef
24	30.19 ± 3.05c	0.94 ± 0.01a	14.75 ± 0.90d
48	38.56 ± 2.35b	0.93 ± 0.01a	17.43 ± 1.14c
HPMC-PW (h)			
0	16.76 ± 1.40e	0.90 ± 0.01a	8.61 ± 0.43ef
24	31.02 ± 1.44c	0.91 ± 0.01a	13.99 ± 0.54d
48	46.58 ± 3.04a	0.91 ± 0.01a	19.84 ± 1.10ab
AP-PW (h)			
0	17.65 ± 1.70de	0.92 ± 0.01a	8.89 ± 0.76ef
24	20.73 ± 1.72d	0.91 ± 0.02a	9.56 ± 1.20ef
48	33.48 ± 1.35c	0.93 ± 0.01a	14.75 ± 0.48d
AG-PW (h)			
0	16.56 ± 0.92e	0.91 ± 0.02a	9.09 ± 2.28ef
24	20.54 ± 0.64d	0.93 ± 0.01a	10.02 ± 0.21e
48	30.08 ± 0.39c	0.94 ± 0.01a	13.42 ± 0.23d
KG-PW (h)			
0	20.33 ± 3.78d	0.91 ± 0.02a	9.77 ± 2.37ef
24	40.54 ± 1.39b	0.93 ± 0.01a	17.95 ± 0.65bc
48	50.06 ± 2.44a	0.91 ± 0.01a	21.00 ± 1.20a

PW potato flour-wheat flour, *HPMC* hydroxylpropylmethylcellulose, *AP* apple pectin, *AG* arabic gum, *KG* konjacglucomannan

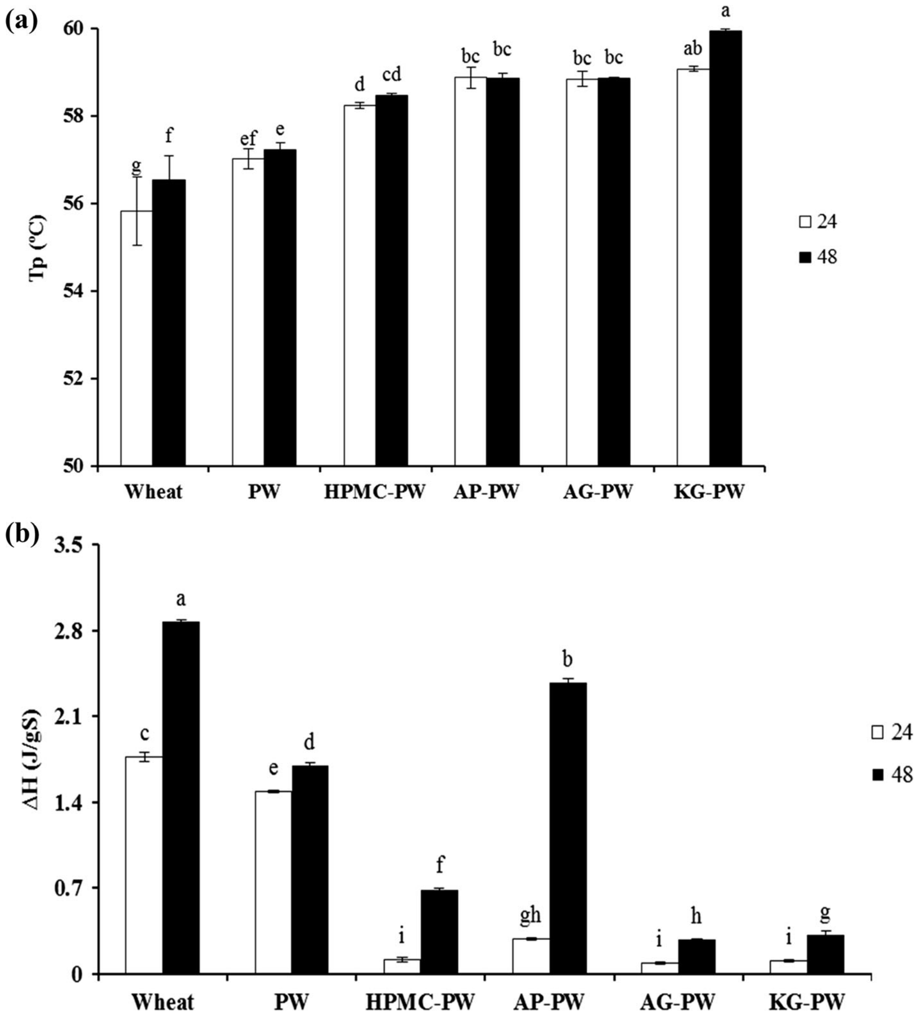
HPMC addition inhibited a significant reduction of hardness during storage, which was in agreement with the results observed earlier by Hager and Arendt (2013). Similar result was also reported by Burešová et al. (2016), who found that the hardness of rice-buckwheat crumb without hydrocolloids (12.2 N) was decreased by calcium caseinate (4.3 N), xanthan gum (9.1 N) and carboxymethyl cellulose (9.3 N). The hardness of PW bread with AG and AP addition were less than PW bread after 24 h of storage. Similarly, the lower hardness was measured for bread supplemented with AG (30.08 N) and AP (33.48 N) after 48 h of storage. Hydrocolloids significantly limited the hardening of the PW bread. These results could be confirmed by the results that ΔH of starch retrogradation was restrained by hydrocolloids addition (Fig. 2b). Hydrocolloids addition delayed the hardening of the bread probably by preventing water migration, which was confirmed by the higher water content after the 24 and 48 h of storage (Table 3). The other possible reason might be that hydrocolloids addition affected the viscosity of the host product interfering with the water diffusion phenomena (Guarda et al. 2004). Conversely, the addition of KG increased the hardness of the bread that could be the consequence of the thickening effect on the bread walls surrounding air spaces as proposed by Rosell et al. (2001). This finding was in agreement with Sim et al. (2011), who reported that the hardness of steamed bread added with KG became firmer when compared with the control counterpart.

Springiness didn't show any notable difference between samples. Chewiness is the energy required to masticate a solid food to a state ready for swallowing and significantly related to hardness, there was no significant difference of fresh samples. The most pronounced reduction of chewiness was caused by the addition of AG at the same storage time, the reason might be due to that the AG had the highest influence on storage modulus (G′) and loss modulus (G″) (Table 1), this viscoelastic character might inhibition of the retrogradation. Similar data was found by Shalini and Laxmi (2007), who observed that the addition of guar gum might affect the amylose network avoiding the formation of spongy matrix.

Thermal properties analysis

Thermal properties of breads using different hydrocolloids are shown in Fig. 2. All fresh breads did not show any endothermic transition, which suggested that the starch was completely gelatinized after baking (data not shown).

Fig. 2 Thermal characteristics of breads obtained using different hydrocolloids, **a** Tp, **b** ΔH. *Tp* peak temperature, *ΔH* retrogradation enthalpy, *PW* potato flour–wheat flour, *HPMC* hydroxylpropylmethylcellulose, *AP* apple pectin, *AG* arabic gum, *KG* konjacglucomannan



Kim et al. (2003) postulated that gluten absorbs 30% of the water in dough, but gluten denatures and transfers the water to the starch granules for gelatinization during baking. The hydrophilic hydrocolloids used in this work probably have a similar mechanism of water transfer. After storage of 24 or 48 h, supplementation of bread with potato flour resulted in an increase in peak temperature (Tp) of about 1 °C compared to wheat bread, and the addition of hydrocolloids increased the peak temperature in different extents (Fig. 2a). The increase in Tp could be caused by the interaction between added hydrocolloids and starch polymers, which in turn might limit the retrogradation and aging of bread. It is in a general accordance with earlier observation on significant decrease in hardness with hydrocolloids addition (Table 4). The result of Rosell and Santos (2010) showed that dietary fiber at medium–high levels (6–34%) increased the higher initial and peak gelatinization temperatures, lower gelatinization enthalpy (ΔH), the reason can be attributed to that fibers would restrict starch swelling by restricting the availability of water for the remaining ungelatinized granules.

As expected, ΔH increased with increase in storage time due to starch retrogradation and the loss of water, but was significantly lower compared to the PW in the presence of hydrocolloids with the exception of AP (Fig. 2b), which attributed to controlling and maintaining the moisture content, stabilizing the dough, and influencing the crust structure (Rosell and Gomez 2007). Yeh et al. (2009) observed that hydrocolloids increased water retention of bread. Therefore, the retained water may have utilized during starch gelatinization. The results of both hardness changes and enthalpy of melting of retrograded amylopectin clearly showed that the used hydrocolloids except AP could act as an antistaling agent. The ΔH was lower in cassava–maize–wheat bread with hydrocolloids and emulsifiers, 6.7–11.0 J/g compared to 20.0 J/g for the reference bread (Eduardo et al. 2016).

Conclusion

The results of the present study showed that the functionality of potato–wheat flour in terms of dough rheology and bread making performance can be successfully improved by the addition of hydrocolloids. SDS-PAGE indicated that hydrocolloids form higher molecular weight aggregation between proteins–hydrocolloids or proteins–proteins after the fermentation process, and which were closely related to the type of hydrocolloids. Specific volume and crumb structure results suggested that HPMC addition provided higher quality potato–wheat bread than AP, AG and KG addition. Furthermore, all the evaluated hydrocolloids with the exception of AP showed antistaling effect on potato–wheat based bread. Considering the dough rheology, specific volume, texture, and thermal properties comprehensively, HPMC addition gave promising results for the production of high quality potato–wheat bread that can provides a potential possibility for replacing wheat flour with potato flour for making bread.

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