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RESEARCH ARTICLE

Peracetic acid concentration and starch slurry ratio on functional properties of oxidized sweet potato (*Ipomoea batatas* (L.) Lam.) starch

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ABSTRACT
Sweet potato (*Ipomoea batatas* (L.) Lam.) is an important food crop with great source of starch. Sweet potato starch has inferior properties like high swelling power, soft gel texture and low paste clarity. Peracetic acid is an environmentally friendly oxidizing reagent without harmful effects to human health. This research evaluated the feasibility of peracetic acid concentration (2, 4, 6, 8, 10 ppm) and starch slurry ratio (1:8, 1:10, 1:12, 1:14, 1:16 w/w) to functional characteristics of the oxidized sweet potato starch. Results showed that the highest swelling power (57.34%), solubility (2.68%) and peak viscosity (6264 cP) were obtained by peracetic acid 6 ppm and starch slurry ratio 1:12 w/w. Peracetic acid could be successfully applied as a powerful oxidizing agent in starch modification.

Introduction

Sweet potato (*Ipomoea batatas* (L.) Lam.) contains different nutritional and functional advantages ranked after rice, wheat, maize, sorghum and potato (1). It is a rich source of starch, dietary fibers, minerals, vitamins, and antioxidants (2-9). It has a low glycemic index due to low digestibility of the starch making it suitable for diabetic or overweighted people (10). It has specific pulp pigments like cream, deep yellow, orange and purple (11-13). Purple-fleshed sweet potato is rich in anthocyanin contributing to numerous pharmacological activities such as antioxidant, antiinflammatory, antimutagenic, anticarcinogenic, chemopreventive, antihyperglycemic, memory enhancement, free radical scavenging and lower insulin resistance (2, 4, 14-24). Meanwhile, orange-fleshed sweet potato is rich in β-carotene, minerals, vitamins, dietary fiber, and phytochemical components contributing to antioxidant, anticancer, cardiovascular and blindness prevention (6, 25, 26). Sweet potato can be converted into different value added products (27).

Starch is a naturally, readily-available, cheap polymer with extensive applications in the food processing sector due to its safety, biodegradability with specific functional characteristics such as gelling, thickening, film forming and fat mimicking (28-29). Different chemical, physical and enzymatic methods are used to modify starch (30-37). Sweet potato starch has inferior attributes such as high swelling power, soft gel texture and low paste clarity. It has been successfully implemented into noodles, soups, sauces, snacks and breads (38).

Peracetic acid exists in liquid, clear and colorless form with no foaming capability. Peracetic acid has a powerful oxidant capability superior to ozone and chlorine (39). Peracetic acid decomposes rapidly with minimal residue harmless on naturally existing components (40). It includes an aqueous mixture of acetic acid and hydrogen peroxide. Peracetic acid oxidises the outer cell membrane of vegetative bacterial cells, endospores, yeast and mold spores. Its working mechanism penetrated on the cell wall and cell membrane to oxidize the H-S and S-S linkages. Microorganism changes their functional properties (41). Therefore, it is utilized to sanitize recirculated water in washing raw materials. It is also used to modify food starch through mild oxidation. Objective of our study examined the possibility of peracetic acid concentration and starch slurry ratio on swelling

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power, solubility and paste viscosity of the oxidized sweet potato starch.

Materials and Methods

Material

Sweet potato tuber was harvested in Hau Giang province, Vietnam. It was washed thoroughly in water to remove dirt and foreign matter. Chemical reagents were all analytical grade.

Researching method

Sweet potato starch was received from stripping, dissolving, extracting, filtering, settling, and drying. Starch extraction was conducted by the dilution ratio of sweet potato pulp to water to 1: 5 (w/w). The starch sediment was dehydrated at 55 °C for 18 hrs to 10±0.5 % moisture. The dried starch was ground, sieved, packed and stored at ambient condition for experiments.

Sweet potato starch was diluted with water (1:8, 1:10, 1:12, 1:14, 1:16 w/w) combined with peracetic acid concentrations (2, 4, 6, 8, 10 ppm). The oxidation process was set for 15 min. The obtained starch was precipitated out and dehydrated at 55 °C for 18 hrs. The treated starch was finally analyzed swelling power (%), solubility (%) and peak viscosity (cP) to define the optimal parameters.

Physicochemical determination

Swelling power was estimated according to the standard method (42). A starch sample (2.0 gm) was inserted into test tube. The weight of sample and test tube was considered as M1. Distilled water (100 ml) was supplemented into the sample to create a slurry paste. The composition was mixed thoroughly and denatured at 100 °C for 20 min. The gellation was set by cooling at ambient temperature and separated the gel and aliquot by centrifugator at 3500 rpm in 5 min. Aliquot (10 ml) was dehydrated at 105 °C to constant weight. The achieved residue from dehydration of supernatant could be counted as solubility (%) of starch. The remained weight of gel and test tube after centrifugation was considered as M2. Swelling power (%) = M2–M1/weight of starch. Peak viscosity (cP) or maximum viscosity between the heating and holding cycles was determined through a quick viscometer (43) by holding at 50 °C for 1 min heating from 50 to 95 °C in 3.7 min, holding at 95 °C for 2.5 min and then cooling down to 50 °C in 3.8 min. The gel was then maintained for 2 min at 50 °C with continuous stirring at 160 rpm.

Statistical analysis

The experiments were run in triplicate with different groups of samples. The data were presented as mean±standard deviation. Statistical analysis was performed by the Statgraphics Centurion version XVI.

Results and Discussion

Starch is a naturally available foodstuff consisting of glucose polymers accumulated in free and independent granules (43, 44). Native starch had limited functional characteristics (45). The swelling powers of bare and oxidized starches were presented in Table 1. Swelling power obtained from all treatments were higher than bare starch (control). The starch slurry ratio 1:12 incorporated with a 6 ppm peracetic acid showed the highest swelling power (57.34%). The slurry ratio had a significant impact to swelling power, the starch slurry ratio started from 1:8 to 1:12 w/w, the swelling power increased. However, if the starch slurry continued increasing (1: 14 and 1:16), the swelling power went down. The swelling power can be correlated to the degree of depolymerization of starch polymers to create carbonyl groups of which much more oxidation induced the appearance of the carboxyl group. The acceleration in swelling power of starch oxidation could be explained by the occurrence of a hydrophilic carboxyl group and the existing of a repulsive force between negative charges (46). Swelling power also can be associated with water absorption capacity of the sweet potato starch. Swelling power is affected by the ability of starch to bind water molecules through hydrogen bond formation. After gelatinization, hydrogen bonding between starch molecules was cut-off and replaced by hydrogen bonding with water (47). Meanwhile, a decrease in swelling power of modified starch granules caused a decrease in stability due to the release of the double helix bonds contained in the crystalline starch granules (48). Acetyl group was much bulkier than a hydroxyl group (49). It prevented the structural organization of starch chains (49). Studies revealed an increase of the swelling power after succinylation of sorghum starch (50). The swelling power of modified corn and potato

Table 1. Swelling power (%) of the oxidized sweet potato starch

Starch slurry ratio (w/w)	Peracetic acid (ppm)					
	Control	2	4	6	8	10
1:8	36.15±0.04^{d}	41.81±0.00^{c}	44.74±0.02^{b}	49.17±0.01^{a}	46.35±0.02^{ab}	43.14±0.03^{bc}
1:10	37.25±0.03^{d}	43.09±0.07^{c}	46.63±0.04^{b}	51.66±0.02^{a}	48.50±0.01^{ab}	45.37±0.05^{bc}
1:12	43.16±0.05^{d}	49.62±0.01^{c}	52.74±0.03^{b}	57.34±0.00^{a}	54.31±0.02^{ab}	51.23±0.01^{bc}
1:14	41.35±0.02^{d}	47.59±0.04^{c}	50.41±0.01^{b}	55.48±0.04^{a}	52.29±0.03^{ab}	49.34±0.03^{bc}
1:16	39.20±0.06^{d}	45.38±0.02^{c}	48.53±0.03^{b}	53.29±0.02^{a}	50.63±0.04^{ab}	47.21±0.02^{c}

Note: the values were expressed as the mean of twenty two samples; the same characters (denoted above), the difference between them was not significant (α = 5%).

starch decreased with an increase of malonic acid content due to the higher extent of cross-linking. The swelling power of corn and potato starch decreased with an increase of malonic acid content used for modification due to the higher extent of cross-linking (51). Modification of wheat starch with mixtures of acetic anhydride with succinic and azelaic acid showed the increased swelling power (52).

Solubility of starch increases resulting in a lower gelatinization temperature and enthalpy (52). The solubilities of bare and oxidized starches were presented in Table 2. Solubilities obtained from all treatments were higher than bare starch (control). The starch slurry ratio 1:12 incorporated with a 6 ppm peracetic acid showed the highest solubility (2.68%). The slurry ratio had a significant impact to solubility, the starch slurry ratio started from 1:8 to 1:12 w/w, the solubility increased. However, if the starch slurry continued accelerating (1: 14 and 1:16), the solubility decreased. Solubility reflects the percentage of dissolved starch particles at a specific temperature (53). The high solubility can be explained by the depolymerization and structural hurting of starch granule by oxidation process (42). The decreased solubility can be due to the existing of cross-linking that retarded amylopectin from leaching out as well as the inefficient oxidation (54). A decrease in solubility of sweet potato starch can also be caused by the decrease in the number of molecules of amylopectin and increase of amylose due to the increasing number of degraded amylopectin molecules (55). There are reports that elaborated the decline in the starch swelling power caused by changing in annealing amorphous amylose forming helix structure; this increased interaction between amylose chains and changed in the interaction between crystalline and amorphous regions during the annealing process (56). The increase in swelling power and solubility might be created by disorganization macromolecular level and type of starch degradation (57). The higher the degree of gelatinization sweet potato starch, the higher the level of disorganization so increase the molecular starch swelling power and solubility of the sweet potato flour. Tapioca, barley and wheat starches modified with a mixture of adipic acid and acetic anhydride had lower solubility than their native counterparts (58). A decrease of solubility adley starch glutarate by reacting the starch with glutaric acid (59). Modified cassava starch with oxalic, malonic and succinic acid (60). Compared to the native starch, oxalic and malonic starch complexes had higher solubility due to the huge number of carboxylic groups.

Peak viscosity was the viscosity of the batter during the heating process or condition in which the starch granules reached the maximum so that the next development would be broken. This variable could be utilized as an indicator of ease when cooked, and also showed the strength of the dough that was created of gelatinization during processing in food applications. The decrease in the peak viscosity implied that there was also a decrease in the ability to inflate, and polymer was separated during heating. Peak viscosity decreased as peracetic acid concentration increased (Table 3). The insignificant difference was not clearly noticed at peracetic acid below 6 ppm as well as starch slurry ratio from 1:8 to 1:12. At peracetic acid from 8 to 10 ppm as well as starch slurry ratio from 1:14 to 1:16, the peak viscosity reduced dramatically. Sweet potato starch should be treated by peracetic acid 6 ppm or starch slurry ratio 1:12 to maintain the functional peak viscosity. During starch slurry dilution and oxidization, the modified starch granules became ruptured revealing poor holding capacity. Carbonyl and carboxyl group occurrence during oxidation could be explained as the reason for the weakening of the starch granule (61). The decreased viscosity is strongly related to oxidation duration (62-64). The low peak viscosity of starch was caused by amylose starch molecules bound very strongly (65). It was also observed that increase of the peak viscosity after acetylation of rice starch (66). It was also verified that the viscosity of acetylated starches was influenced by two factors: a weakening starch granule due to disruption of the inter and intra- molecular bonds and reduced bonding with water molecules due to the hydrophobicity of acetyl groups (67). Depending on the interplay between these two factors, the viscosity could be decreased or increased by acetylation. It was showed that starch treated by succinate induced high viscosity (50). The peak viscosity went up after succinylation of maize starch (68). Modification of wheat starch with mixtures of acetic anhydride with succinic and azelaic acid, respectively increased the peak viscosity (58). It was proved that the succinylation of both native sorghum and acid-thinned starches induced a sharp rise in peak viscosity (69). Studies are on the esterification of retrograded potato starch with acetic and adipic acid (70). The resistance of modified starches to the action of amyloglucosidases increased along with the

Table 2. Solubility (%) of the oxidized sweet potato starch

Starch slurry ratio (w/w)	Peracetic acid (ppm)					
	Control	2	4	6	8	10
1:8	0.13 ± 0.01^{d}	0.59 ± 0.00^{c}	0.94 ± 0.02^{b}	1.17 ± 0.03^{a}	1.04 ± 0.02^{ab}	0.73 ± 0.00^{bc}
1:10	0.29 ± 0.00^{d}	0.76 ± 0.01^{c}	1.25 ± 0.03^{b}	1.59 ± 0.00^{a}	1.33 ± 0.03^{ab}	0.91 ± 0.01^{bc}
1:12	0.99 ± 0.03^{d}	1.13 ± 0.00^{c}	2.10 ± 0.01^{b}	2.68 ± 0.01^{a}	2.32 ± 0.01^{ab}	1.72 ± 0.02^{bc}
1:14	0.82 ± 0.01^{d}	0.97 ± 0.03^{c}	1.91 ± 0.02^{b}	2.12 ± 0.03^{a}	2.01 ± 0.00^{ab}	1.36 ± 0.03^{bc}
1:16	0.58 ± 0.02^{d}	0.89 ± 0.01^{c}	1.69 ± 0.00^{b}	1.97 ± 0.01^{a}	1.80 ± 0.02^{ab}	1.25 ± 0.01^{c}

Note: the values were expressed as the mean of twenty two samples; the same characters (denoted above), the difference between them was not significant (α = 5%).

Table 3. Peak viscosity (%) of the oxidized sweet potato starch

Starch slurry ratio (w/w)	Peracetic acid (ppm)					
	Control	2	4	6	8	10
1:8	6425±11[a]	6397±13[a]	6374±14[a]	6353±12[a]	5130±19[ab]	4453±17[b]
1:10	6389±10[a]	6360±16[a]	6321±11[a]	6299±10[a]	5086±11[ab]	4301±14[b]
1:12	6357±17[a]	6328±11[a]	6293±19[a]	6264±16[a]	5039±10[ab]	4122±11[b]
1:14	5072±16[a]	5036±14[a]	5004±10[a]	4975±13[a]	3807±15[ab]	3029±13[b]
1:16	4136±13[a]	4103±12[a]	4066±13[a]	4030±15[a]	2914±16[ab]	2205±10[b]

Note: the values were expressed as the mean of twenty two samples; the same characters (denoted above), the difference between them was not significant (α = 5%).

increase of peak viscosity of the starch paste. Starch modification by OSA showed an increase of paste viscosity (71). It was verified that the oxidation of cassava starch at different dissolved ozone concentration on functional properties (46). It was concluded that oxidized starch with an incorporation of 1.4 ppm dissolved ozone and a starch slurry ratio of 1:10 gave high swelling power (44.31%), solubility (0.88%) and low paste viscosity (6082.5 cP).

Conclusion

Sweet potato (*Ipomoea batatas* (L.) Lam.) is an important food crop of local villages. It contains various nutritional and phytochemical elements with a great positive effect on human health. Among chemical modification of starch, peracetic acid was drawn the greatest attention. This research was successfully indicated the effectiveness of peracetic acid concentration and starch slurry ratio on the swelling power, solubility and peak viscosity of the modified sweet potato starch. Oxidation by peracetic acid created significant impact to functional properties of this oxidized starch.

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Authors' contributions

Nguyen Phuoc Minh arranged the experiments and also wrote the manuscript.

Conflict of interests

The author declared that the present study was performed in the absence of any conflict of interest.

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