Physicochemical and retrogradation properties of modified chestnut starches

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Abstract Physicochemical properties of acetylated (AC), cross-linked (CL), and hydroxypropylated (HP) chestnut starches were investigated. Modified chestnut starch showed low RS and amylose contents. AC revealed the highest solubility and HP showed the highest swelling power at 60 °C. CL showed the lowest solubility and swelling power at both 60 and 90 °C. AC and HP showed a lower pasting temperature and higher peak viscosity than native chestnut starch (NC). Modified chestnut starch formed gels at higher solid content than NC. CL had the lowest freeze–thaw stability, and AC and HP showed the strongest tolerance to freeze–thaw cycles. Amylopectin melting enthalpy of NC dramatically increased over the

first 2 days and continued increasing gradually until day 24. On the other hand, all the modified chestnut starches showed a slight increase in amylopectin melting enthalpy, indicating retarded retrogradation. CL showed the lowest degree of retrogradation, followed by HP, AC, and NC.

Keywords Chestnut starch · Starch modification · Physicochemical properties · Retrogradation

Introduction

A large amount of chestnuts (*Castanea sativa* Mill.) has been produced in Korea. However, its consumption is very limited due to its restricted application, leading many chestnuts to being discarded every year. One of the ways to expand the range of chestnut consumption is isolation of starch which is the main component of chestnut. Chestnut starch has a tendency to form a gel at a low concentration with high viscosity and setback. In addition, its high and fast retrogradation compared to corn starch inhibit industrial application (Lee et al., 2015).

To resolve the shortcomings of native starches, starches can be modified by either chemical or physical methods. Acetylation of starch substitutes the acetyl groups for free hydroxyl groups at C₂, C₃, and C₆ positions of anhydrous glucose units in starch. It is commonly obtained by esterification of native starch with acetic anhydride in an aqueous solution with an alkaline catalyst (Miyazaki et al., 2006). In the food industry, acetylated starch with a low degree of substitution (DS) is used as a thickener, stabilizer, or binder. In general, acetylation of starch increases peak viscosity, water absorption, solubility, and swelling power and decreases initial pasting temperature and setback (Gonzalez and Perez, 2002). These behaviors are the

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result of a substituted acetyl groups substituted on starch interacting with amylose or amylopectin fractions. (Harper, 1981). Hydroxypropylated starch is also a substituted starch and can be obtained by a reaction with propylene oxide under an alkaline condition. Hydroxypropylation weakens the hydrogen bonds among starch molecules, resulting in lower initial pasting and gelatinization temperatures. The hydrophilic hydroxypropyl groups hold water molecules within its swollen granules or pastes and minimize the separation of water from starch networks during freeze–thaw cycles (Miyazaki et al., 2006; Wootton and Manatsathit, 1983). Cross-linked starch involves covalent bonds within and among starch molecules, enhancing the stability and integrity of starch granules. Cross-linked starch can be obtained by treating with multifunctional reagents that can form ester linkages to hydroxyl groups on starch molecules (Wurzburg, 1986). The common cross-linking reagents are sodium trimetaphosphate, sodium tripolyphosphate and phosphorous oxychloride for food products. Cross-linked starch has resistance to swelling and breakdown and is used as a viscosifier for textures in soups, sauces, gravies, and dairy products (Kaur et al., 2006).

Although numerous studies have reported on modification of various commercial starches, limited information is available on modified chestnut starches. Therefore, the objective of this study was to investigate the physico-chemical and retrogradation properties of acetylated (AC), hydroxypropylated (HP), and cross-linked (CL) chestnut starches in comparison with native chestnut starch to consider its functionality as a food ingredient.

Materials and methods

Materials

Acetic anhydride, hydrochloric acid, and sodium hydroxide were purchased from DaeJung Chemical and Metal Co., Ltd. (Siheung, Korea). Propylene oxide, sodium trimetaphosphate (STMP), and sodium tripolyphosphate (STPP) were obtained from Sigma Chemical Co. (Saint Louis, MO, USA).

Chestnut fruits (*tsukuba* cultivar) were purchased from local markets in Hadong, Gyeongsangnam, Korea. From the peeled chestnut fruit, starch was extracted using the alkaline method of Lee et al. (2015).

Preparation of acetylated chestnut starch

Acetylation of chestnut starch was performed using the method described by Wang and Wang (2002) with some modifications. Native chestnut starch slurry (20%, w/w)

was prepared, and the pH was adjusted to 8.0–8.5 with 1 N NaOH. Acetic anhydride (12%, sb) was added drop-wise into the starch slurry while maintaining a pH range of 8.0–8.5 using 1 N NaOH. After addition of acetic anhydride, the reaction was carried out at 30 °C for 1 h with continuous stirring. After the reaction, the pH was adjusted to 5.5 with 1 N HCl, and then the starch suspension was washed three times with distilled water. Finally, the starch suspension was centrifuged and dried at 40 °C.

The acetyl contents and degree of substitution (DS) of AC were determined by a titration method and calculated (Choi et al., 2009).

Preparation of cross-linked chestnut starch

Cross-linked starch was prepared using STMP and STPP according to the method of Woo and Seib (2002). Chestnut starch was dispersed in distilled water (20%, w/w), and sodium sulfate (10%, sb) was added. Using 1 N NaOH, the pH of the mixture was adjusted to 11.5, and 12% (w/w, sb) of STMP and STPP (99:1, w/w) were added and reacted at 45 °C for 3 h. After the reaction, the slurry was neutralized to pH 6.5 using 1 N HCl and washed with distilled water. Drying and sieving were carried out in the same manner as in the previous method.

The degree of cross-linking was determined by the RVA method of Kaur et al. (2006).

Preparation of hydroxypropylated chestnut starch

Hydroxypropylated chestnut starch was obtained using the method of Wootton and Manatsathit (1983). The native chestnut starch (100 g, db) was dispersed in distilled water (400 mL), and sodium sulfate (8%, sb) was added to the suspension. The pH was adjusted to 11.5 using 1 N NaOH followed by addition of propylene oxide (12%, sb). The reaction was carried out at 45 °C for 24 h. To terminate the reaction, the pH was adjusted to 5.5 with 1 N HCl, and the sample was washed with distilled water. Drying and sieving were carried out in the same manner as in the previous method.

The hydroxypropyl contents of the samples were determined using the spectrophotometric method of Johnson (1969) and calculated using the equation of Hwang et al. (2009). Degree of substitution (DS) was calculated from the hydroxypropyl contents (Van Hung and Morita, 2005).

Proximate composition, amylose content, and RS

Korean Food Standards Codex methods were used for proximate analysis (Food and Association, 2005). Amylose

content was determined by the method of Morrison and Laignelet (1983).

The amount of resistant starch (RS) was determined using Megazyme Resistant Starch Assay Kit (Megazyme Inc., Chicago, IL, USA) (McCleary et al., 2002) with some modifications. Uncooked samples were used without boiling during measurement. The fractions based on the rate of hydrolysis were rapidly digestible starch (RDS, within 20 min) and slowly digestible starch (SDS, between 20 and 120 min). The RS content was calculated as $100 - (\text{RDS} + \text{SDS})$ (Kim et al., 2017).

Swelling power and solubility

A starch sample (0.5 g, db) and distilled water (30 mL) were mixed and then heated at 60 °C or 90 °C in a water bath for 30 min. After heating, the samples were centrifuged at $1500\times g$ for 60 min. The supernatant was dried at 105 °C overnight, and the precipitate was weighed. The swelling power and solubility were calculated according to method of Shi et al. (2013).

RVA pasting properties

The pasting properties of the samples were determined using a Rapid visco analyzer (RVA-3D, Newport Scientific Pty. LTD., New South Wales, Australia) by the method of Lee et al. (2015) with some modifications. Starches (3.0 g, db) were dispersed in distilled water (25 mL) and held at 50 °C for 1 min, heated to 95 °C at a rate of 12 °C/min, held at 95 °C for 3.3 min, cooled to 50 °C, and maintained at 50 °C for 2 min.

Gel-forming ability

Gel-forming ability was determined using the method of Lee et al. (2015) with a few modifications. Native and modified chestnut starch slurries (3–15% (w/v) at 2% intervals) were prepared and heated in boiling water bath for 15 min. After heating, the gelatinized starch was stored at 4 °C for 24 h, and then samples were placed on a petri dish. The result was recorded using a digital camera (C-5060 wide Zoom, OLYMPUS, Tokyo, Japan).

Freeze–thaw stability

Freeze–thaw stability was determined using the methodology of Demiate et al. (2001). The freeze–thaw stability of the sample was determined in two ways: (1) at the lowest gelation concentration (LGC, w/v) and (2) at the 15% (w/v) concentration where all the starch samples formed a gel. The starch slurry was heated in a conical tube in a boiling water bath for 10 min and then cooled at room temperature

for 1 h. The sample tubes were frozen at -20 °C for 20 h and thawed at room temperature for 4 h. After each freeze–thaw cycle, the samples were centrifuged at $1500\times g$ for 15 min, and the separated water was removed from the top of the gel. The freeze–thaw cycle was conducted for up to 5 cycles. From the weight of separated water in each freeze–thaw cycle, syneresis was calculated (Eliasson and Kim, 1992).

Gelatinization and retrogradation properties

Gelatinization and retrogradation properties were determined using differential scanning calorimetry (DSC 4000, PerkinElmer Inc., Waltham, MA, US). For gelatinization properties, 67% starch slurry (w/w, db) in an aluminum pan was hermetically sealed, and an empty pan was used as a reference. All samples were heated from 25 to 120 °C at a heating rate of 5 °C/min. Indium and zinc were used for calibration. The onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c), and gelatinization enthalpy (ΔH_g) were obtained from the DSC thermogram.

For retrogradation properties, the first scanned sample pans were stored at 4 °C for 24 days. After storage, sample pans were cooled to -70 °C using liquid nitrogen and reheated from -70 to 120 °C at a heating rate of 5 °C/min. Glass transition temperature (T_g'), ice melting enthalpy (ΔH_i), and retrogradation enthalpy (ΔH_r) were obtained from the DSC thermogram. The degree of retrogradation (DR) was calculated as the ratio of gelatinization enthalpy and retrogradation enthalpy.

Statistical analysis

All experiments were repeated three times. Experimental data were analyzed using Analysis of Variance (ANOVA) and expressed as mean $\pm$ standard deviation. Duncan's multiple range test was conducted to assess significant differences among experimental mean values ($p < 0.05$). All statistical computations and analyses were conducted using SAS version 8.02 for Windows (SAS Institute, Inc., Cary, NC, USA).

Results and discussion

Proximate composition and amylose content

Degree of substitution (DS) of AC, CL, and HP was 0.09%, 92.1%, and 0.05%, respectively. NC revealed the highest amylose content (18.33%) followed by HP (7.77%), AC, (6.83%) and CL (4.02%). These reductions may be caused by elution of amylose during modification reactions. Moreover, the presence of acetyl groups within and

between molecules impedes formation of the helical structure of amylose, resulting in inhibition of amylose-iodine interactions and a decrease of apparent amylose content (Gonzalez and Perez, 2002; Shubeena et al., 2015). Similarly, HP also revealed a reduction in apparent amylose content because the introduction of hydroxypropyl groups to the starch chain decreased the affinity of amylose and iodine (Park et al., 1999). Therefore, a reduction of amylose content in the modified starch is due to elution during the reaction and inhibition of amylose-iodine interactions by substituted functional groups.

Digestibility

The digestibility of native and modified chestnut starches is shown in Table 1. Modified starches showed a larger amount of RDS than that of NC. On the other hand, SDS decreased with modification, except in AC, and RS decreased with modification in all types except CL. Substituted starches, i.e., AC and HP, revealed relatively lower RS, suggesting an increase in digestibility. The increase in digestibility in AC and HP may be due to the substitution of acetyl or hydroxypropyl groups, which impedes the strong interaction between starch chains and results in easy access for the amylolytic enzymes. It has been reported that acetylation and hydroxypropylation induce granules to open their structure and expand the extent of enzymatic hydrolysis (Wootton and Chaudhry, 1981). It is interesting to note that the RS content of CL did not show a significant difference from that of NC. It is generally known that chemically modified starch had higher RS content than native starch. However, the digestibility measurement of this study showed the different result because uncooked starch was used, and may show another tendency when cooked samples were used. According to Woo and Seib (2002), cross-linked starch prepared by STMP and STPP was protected from enzymatic attack, and this property was associated with a higher degree of substitution. On the other hand, the RS content was determined with an

approved method and was not the same in chemically modified starch and RS type 4 (Hwang et al., 2009; Kim et al., 2017). Therefore, the difference between our study and the other research is attributed to be due to the difference between cooked or uncooked starches.

Swelling power and solubility

The solubility and swelling power of native and modified chestnut starches are presented in Fig. 1. Both solubility and swelling power increased as temperature increased in all samples. At 60 °C, AC showed the highest solubility, and HP revealed similar solubility to that of NC. However, NC showed the highest solubility at 90 °C, and there was no significant difference between AC and HP. CL showed the lowest solubility at both 60 °C and 90 °C, which is a typical characteristic of cross-linked starch (Fig. 1A). Starch solubility is associated with leached amylose molecules during hydration and swelling. It has been reported that acetylated rice starch showed higher solubility than native starch at all measured temperatures due to the substituted group, which decreased the starch bonding density and facilitated the introduction of water molecules to amorphous areas, resulting in a more soluble fraction to leach out with hydration and heating (Gonzalez and Perez, 2002). On the other hand, in our study, NC showed higher solubility than those of modified starches at 90 °C. This result corresponded with that of amylose content (NC > HP > AC > CL). It has been reported that the solubility of rice starch is proportional to amylose content during hydration and heating (Colussi et al., 2014). Therefore, in native and modified chestnut starches, the solubility was greatly affected by amylose content but not by presence of substituted groups such as acetyl and hydroxypropyl groups.

The swelling power of native and modified chestnut starches showed a similar pattern to solubility (Fig. 1B). The introduction of acetyl or hydroxypropyl groups contributed to rearrangement of starch molecules during

Table 1 Digestibility and DSC thermal properties of native and modified chestnut starches

	Digestibility			DSC thermal properties			
	RS (%)	RDS (%)	SDS (%)	T _o (°C)	T _p (°C)	T _c (°C)	ΔH _g (J/g dried sample)
NC	72.8 ± 0.9 ^a	18.8 ± 0.2 ^c	8.4 ± 1.1 ^b	59.9 ± 0.1 ^a	64.7 ± 0.0 ^a	71.0 ± 0.0 ^a	12.1 ± 0.1 ^b
AC	52.3 ± 0.2 ^c	31.3 ± 0.5 ^a	16.4 ± 0.7 ^a	50.3 ± 0.1 ^c	57.5 ± 0.2 ^d	65.6 ± 0.5 ^b	9.5 ± 0.4 ^c
CL	71.9 ± 0.2 ^a	24.6 ± 0.1 ^b	3.5 ± 0.2 ^d	58.5 ± 0.1 ^a	63.6 ± 0.1 ^b	69.5 ± 0.2 ^a	12.5 ± 0.3 ^a
HP	63.7 ± 0.5 ^b	29.8 ± 0.1 ^a	6.5 ± 0.6 ^c	55.9 ± 1.4 ^b	60.2 ± 1.8 ^c	66.3 ± 2.5 ^b	9.5 ± 0.4 ^c

Same letters in the same column are not significantly different ($p < 0.05$)

RS resistant starch, RDS rapidly digestible starch, SDS slowly digestible starch, T_o onset temperature, T_p peak temperature, T_c conclusion temperature, ΔH_g gelatinization enthalpy

Fig. 1 Solubility (A) and swelling power (B) of native and modified chestnut starches

modification in the amorphous area, leading to the increase in water penetration and swelling capacity (Lawal, 2004). These physicochemical properties have been reported to be dependent on the type of reagent, degree of substitution, and botanical source (Lawal, 2004). Similar to solubility, CL revealed the lowest swelling power at both temperatures. Cross-linking reagents increase the density around the starch chain and inhibit water penetration for swelling (Carmona-Garcia et al., 2009). Moreover, solubility and swelling power of cross-linked starches are affected only by short amylose chains around the outside of the granule or the relatively low degree of cross-linking in the amorphous region (Carmona-Garcia et al., 2009). Therefore, the smallest amount of amylose content in CL (4.02%) presented the lowest swelling power in this case.

Rapid Visco Analyzer (RVA) analysis

The RVA pasting properties of native and modified chestnut starches are shown in Fig. 2. Starches have specific viscosity profiles depending on temperature, and chemical modifications are generally used to change or improve these inherent properties. In the RVA curve,

Fig. 2 RVA pasting curves of native and modified chestnut starches

pasting temperature and peak viscosity of AC and HP were lower and higher than those of NC, respectively. Starch derivatives such as acetylated starch and hydroxypropylated starch were influenced by steric hindrance, which alters the hydrogen bonds, resulting in a lower pasting temperature and an increase in peak viscosity due to the hydrophilic molecules (Kaur et al., 2004).

Pasting properties of CL could not be determined. This result corresponds to the solubility and swelling power results. Due to limited water penetration, the amount of water entering the starch is not sufficient for pasting to occur. It has been reported that cross-linked pea starch traced a straight line in its RVA pasting curve, indicating granule stability against heating; this stability was attributed to an additional covalent bond (Shi et al., 2013).

During holding at high temperature (95 °C), the starch structure completely collapsed, and the viscosity decreased rapidly. Thereafter, polymer in the continuous phase during the cooling process began to reassociate, and the difference in viscosity at this time is called setback. In general, setback is associated with reassociation of solubilized amylose and amylopectin molecules, particularly with rapid recrystallization of amylose. AC and HP showed a relatively lower setback compared to NC, possibly due to substituted groups in modified starch molecules, which reduced the ordered-structure formation of starch fragments.

Gel-forming ability

Gel forming abilities of native and modified chestnut starches are shown in Fig. 3. Chemical modifications greatly influenced the gel forming ability of chestnut starch. The lowest gelation concentration of NC was 5% (w/v), while those of AC, CL, and HP were 15% (w/v), 13% (w/v), and 11% (w/v), respectively. It has been

Fig. 3 Gel forming abilities of native and modified chestnut starches

reported that native chestnut starch had gel-forming ability when the slurry concentration was 5–7% (w/v) (Demiate et al., 2001; Lee et al., 2015). However, no modified starches formed a gel at that concentration, possibly due to substituted groups. Those substituted groups interfered with the rearrangement of starch molecules (Han and Kim, 2002). It is suggested that different modifications led to distinctive gel forming ability of chestnut starch. Moreover, because of the low degrees of hydration and swelling of the CL, higher amounts of starch were required to form gels.

HP gel appeared more transparent than other samples, attributed to hydration of hydroxypropyl groups substituted into starch chains. Likely, the bulky hydroxypropyl group suppressed amylose aggregation, resulting in increasing paste clarity (Park et al., 1999). In our study, the gel clarity of CL did not seem to be significantly different from that of NC; however, other studies have reported that the higher is the degree of cross-linking, the lower is the clarity due to incomplete gelatinization and the lower degree of swelling (Singh et al., 2007). Acetylated starch also has been reported to have improved paste clarity because the acetyl groups within the granules impede agglomeration of molecular segments (Leach, 1959), but there is no difference between AC and NC in this case.

Freeze–thaw stability

Figure 4 shows the freeze–thaw stability of native and modified chestnut starches at the lowest gel forming concentration (Fig. 4A) and at the same concentration (Fig. 4B). In both cases, CL showed the lowest freeze–thaw stability. The highest syneresis of CL can be explained by restriction of granule swelling. Limited swelling of CL led to separation of a relatively large amount of free water. On the contrary, freeze–thaw stabilities of AC and HP were improved at the lowest gel forming concentration (Fig. 4A). The improvement of freeze–thaw stability of AC and HP was attributed to the presence of hydrophilic groups in the starch molecules. Consequentially, substitution increased the water holding capacity of water under the freeze–thaw cycle (Van Hung and Morita, 2005). However, this is not always true. At the same concentration, the freeze–thaw stability of AC and

Fig. 4 Freeze–thaw stability of native and modified chestnut starches; the lowest gel forming concentration (w/v) (A) and 15% starch (w/v) (B)

HP was not improved compared to that of NC (Fig. 4B). It is interesting to note that the freeze–thaw stability of native and modified chestnut starches improved with increasing starch concentration, but their concentration effect was not consistent. Starch concentration greatly influenced freeze–thaw stability of NC. Syneresis of 5% (w/v) NC gradually increased from 8.59 to 29.29% as the freeze–thaw cycle increased, whereas that of NC at 15% (w/v) did not change with increasing freeze–thaw cycles. This result suggests that both modification and starch concentration play a key role in freeze–thaw stability of chestnut starch. The high syneresis indicated the association between leached amylose and amylopectin, causing release of water (Shubeena et al., 2015). The ice crystals were formed in starch gel during freezing and became larger throughout the freeze–thaw cycles. When ice crystals melted, a rough and porous gel was obtained, and the rough pores may have acted as a

sponge, influencing the retention capacity for water (Deetae et al., 2008). The high concentrations of starch and substituted groups in starch may contribute to the formation of a sponge-like structure, resulting in low syneresis and high freeze–thaw stability.

Thermal and retrogradation properties

Table 1 shows the DSC thermal properties of native and modified chestnut starches. The onset temperature (T_o) of modified chestnut starches was lower than that of native chestnut starch. The introduction of acetyl and hydroxypropyl groups decreased and weakened the interaction between starch chains, resulting in a relatively low T_o . Meanwhile, the gelatinization enthalpy (ΔH_g) indicates the energy needed to disrupt the ordered structure in the starch. NC and CL showed relatively higher ΔH_g than those of AC

Fig. 5 Changes in glass transition temperature (A), ice melting enthalpy (B), amylopectin melting enthalpy (C), and degree of retrogradation (D) of native and modified chestnut starches during storage at 4 °C

and HP. Slightly higher ΔH_g of cross-linked starch than that of native starch has been reported; the covalent bond acts as a bridge to reinforce granule stability and integrity (Wongsagonsup et al., 2014). Substituted starches generally reveal relatively lower ΔH_g due to disintegration of ordered structure during the modification reaction (Wurzburg, 1986).

Retrogradation properties of native and modified chestnut starches are presented in Fig. 5. The T_g' is the temperature where the glassy state changes into the rubbery state; rubbery regions are typically amorphous with respect to the chemical structure and can be adopted after heating or upon addition of a plasticizer (Slade and Levine, 1995). The T_g' of samples increased during storage, and the modified starches revealed a relatively higher T_g' than the native starch (Fig. 5A). In case of cross-linked starch, phosphate groups or cross-links in the starch amorphous region reduce the chain mobility, and thus increases the glass transition temperature in freeze-concentrated system. The introduction of starch molecules into the amorphous regions of starch molecules of acetyl and hydroxypropyl groups interfere the interaction between starch and water molecules and decrease the water mobility, which resulted in increased T_g' .

An increase in T_g' during storage has been reported as an indicator of retrogradation properties. During storage of starch gel, water molecules are incorporated into the starch crystal lattices, resulting in an increase of T_g' (Baik et al., 1997). Trends in ΔH_i (Fig. 5B) tend to be opposite those for T_g' . Generally, ΔH_i reflects the amount of freezable water in starch gel. Changes in T_g' and ΔH_i are strongly related to the amount of water present in the starch gel system. As the amount of freezable water increases, T_g' decreases and ΔH_i increases. However, freezable water enters the starch crystals through the retrogradation process and changes into unfreezable water, resulting in a decrease in ΔH_i and an increase in T_g' (Oh et al., 2017).

There were noticeable effects of modification on starch retrogradation via amylopectin melting enthalpy (ΔH_r) and degree of retrogradation (DR) (Fig. 5C, D). NC showed a drastic increase in both ΔH_r and DR during storage, especially during the first 2 days. On the other hand, modified chestnut starches revealed a relatively slow increase in both ΔH_r and DR during storage. This kind of retardation of retrogradation can be explained by the substituted moieties in the starch chains, which interrupt the reassociation of starch chains.

Chemically modified chestnut starches revealed novel physicochemical properties that were different from those of NC. Solubility and swelling power of modified chestnut starches at 90 °C were much lower than those of NC, indicating less water holding capacity at high temperature. RVA pasting properties were also greatly influenced by modification. AC and HP revealed relatively low pasting temperature and high peak viscosity, while CL did not show pasting properties. Chemical modifications also

greatly influenced the gel forming ability of chestnut starch, which is an important factor in the food industry. Acetylation and hydroxypropylation provided freeze thaw stability. Consequently, chemically modified chestnut starches showed very slow retrogradation that might be helpful for application of chestnut starch in bakery and confectionary industries. Unfortunately, only one concentration of each chemical reagent was studied in this study. However, we have conducted the starch modification to the extent that it is available in the food grade, and those reagents, concentration and conditions used in this study are commonly used in many other applications. Therefore, this study focused on the potential availability of modified chestnut starches in various industries.

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Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

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