Physicochemical, pasting, rheological, thermal and morphological properties of horse chestnut starch

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Abstract Indian Horse chestnuts contain high content of starch which can be explored to be used in various applications in food industry as encapsulating agent, stabilizer, binder, thickener, gelling agents and many more. Horse chest nut is locally available and can be a boon for food industry if the inherent properties are explored. Hence, horse chest nut starch can be a better option for the replacement of conventional starches to meet the industrial demand of starch. Physicochemical, pasting, rheological, thermal and morphological properties of starch isolated from Indian Horse chestnut (HCN) were determined. Amylose content was found to be 26.10 %. Peak viscosity obtained from RVA profile was 4110 cP. Hardness, cohesiveness, adhesiveness and gumminess were determined by Texture Profile Analyser. Particle size analysis showed a typical Uni modal size distribution profile with particle distribution ranging from 7.52 to 27.44 μm . The shape of starch granules varied from round, irregular, oval, and elliptical with smooth surface. X-ray diffraction revealed that HCN starch showed a typical C-type pattern with characteristic peaks at 5.7, 15.0, 17.3 and 22.3°. The transition temperatures (T_o , T_p , and T_c) and enthalpy of gelatinization (ΔH) values were 53.35, 58.81, 63.57 °C and 8.76 J/g, respectively. The rheological properties were determined in terms of variation of storage modulus (G'), loss modulus (G'') and loss factor ($\tan \delta$) at different temperatures. Peak G' , peak G'' and peak $\tan \delta$ values were observed as 10,400 Pa, 1,710 Pa, and 0.164, respectively.

Keywords Differential scanning calorimeter · Dynamic rheometry · Horse chestnut starch · Rapid visco analyser · Scanning electron microscope · XRD

Introduction

Indian Horse Chestnut or Himalayan Chestnut (*Aesculus indica*), is found in temperate regions of Asia particularly in India, Nepal, Pakistan and Afghanistan. In India, the horse chestnut tree occupies moist and shady ravines of Jammu and Kashmir, Himachal Pradesh and Uttar Pradesh (Singh 2006; Zhang et al. 2010) with an average height of about 22.5 m and has an upright straight cylindrical bole with spreading crown. The tree yields large number of seeds that get ripened in October and each single seed is being present in hard capsule. The seeds are about 3.5 cm in diameter with a hard shiny black rind from outside and lime white cotyledon inside (Parmar and Kaushal 1982). Based on the size of the seed, two types of horse chestnuts are known in Kashmir valley viz., small and large, locally known as *lakut* and *budh handun*. In hilly areas of Kashmir valley, seeds are mainly gobbled up by wild animals while in plains they have no use as such and often go as waste. Moreover, seeds have edible purpose. In Himachal Pradesh, seeds with reduced level of bitterness after being kept in running water are dried and ground into flour called Tattwakhar, used for making *Halwa* (porridge) and also mixed with wheat flour to make *chapattis* (Rajasekaran and Singh 2009). During famine times, the seeds have been used as food by various races of North and North Eastern India (Singh and Kachroo 1976). Seeds also possess medicinal properties, used to cure fevers, piles, wound healing, viral infections, rheumatism, skin diseases and cardiovascular

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diseases (Kaul 1997; Kaur et al. 2011). The seeds constitute moisture: 50.5 %, sugars: 5.85 %, protein: 0.39 %, ash content: 1.93 % (Parmar and Kaushal 1982) and starch: 38.3 % on dry weight basis (Singh et al. 2003a). Due to this satisfactory starch content, horse chestnut seeds can prove as an inexpensive non-conventional source of starch.

Identification of native starch source is required for desired functionality and unique properties (Duxbury 1989). Physicochemical and functional characteristics of starch directly decide its application in food and non-food industries. Much of the research has been conducted on the structural and functional properties of conventional sources of starch such as potato, rice, corn and wheat due to easy availability and their extensive usage in food and non-food applications (Singh et al. 2003b). However, little information is available on starch isolated from horse chestnut. The objective of the present study was to investigate the physicochemical, pasting, rheological, thermal, and morphological properties of starch isolated from Indian Horse Chestnut (HCN).

Materials and methods

Materials

Horse chestnuts were harvested from trees located in rural areas of Anantnag, Jammu & Kashmir, India during the month of October, 2013. The variety chosen for this study was large sized horse chestnut, locally known as *budh handun*. The seeds were oven dried at 60 °C to remove excess moisture and stored at 5 °C till further use. All the reagents and chemicals used in the study were of analytical grade, provided by M/s. Loba Chemie Pvt. Ltd, Mumbai (India).

Starch isolation

Starch was extracted from horse chestnuts, using alkaline steeping method as described by Sun et al. (2014) and Perez & Lares (2004) with slight modification. Dried HCN seeds were manually de-shelled and kernels were cut into pieces (2 cm²), steeped in 0.25 % NaOH solution (w/v) in the ratio of 1:3 and stored at 4 °C for 24 h. The steeped kernels along with alkali were ground with a laboratory grinder and filtered through 100 mesh sieve and kept for settlement followed by 2–3 washings with distilled water. The slurry was again filtered through 300 mesh sieve and centrifuged at 3000 rpm for 15 min. The aqueous phase obtained on centrifugation was discarded. The upper non-white layer was scraped off while white starch layer was re-suspended in distilled water and centrifuged 2–3 times. The starch was then collected and dried in hot air oven at 40 °C. The starch was analysed for physicochemical, pasting, gel texture, thermal, morphological, and rheological properties and the results were compared with the

results on earlier studies on (Singh et al. 2005), water chestnut (Singh et al. 2009), corn (Kaur et al. 2004) and mango kernel starch (Sandhu et al. 2004). Saponins, the bitter compound present in Horse chest nut was removed by continuous washings given to the starch.

Physicochemical properties of starch

Color

Color measurement of HCN starch was carried out in triplicates, using Color Flex Spectrocolorimeter (Hunter Lab Colorimeter D-25, Hunter Associates Laboratory, Ruston, USA). The results were expressed in terms of L*, a* and b* values. The functions chroma [$C^* = (a^{*2} + b^{*2})^{1/2}$] and hue angle [$h^* = \tan^{-1}(b^* / a^*)$] were also calculated.

Compositional analysis

Moisture content, crude protein, fat, and ash content of purified starch was determined according to AOAC (1995) method. Amylose content of isolated starch was determined according to the method described by Williams et al. (1970).

Swelling power and solubility

Swelling power (SP) and solubility of native HCN starch was determined with slight modification to the method described by Adebooye and Singh (2008). Starch (500 mg) was cooked with 20 ml distilled water at different temperatures of 55, 65, 75, 85 and 95 °C, separately for 30 min. Samples were then cooled to room temperature and centrifuged at 3000 rpm (C-24, BL; M/s. Remi Laboratory Industries, Mumbai, India) for 15 min. The supernatant was carefully poured into pre-weighed glass dish, oven dried at 105 °C and weighed for solubility determination while the residue was weighed for swelling power estimation.

All measurements were done in triplicates. Percent solubility and swelling power of HCN starch was calculated as follows:

$$\begin{aligned}\% \text{SOL} &= A/S \times 100 \\ \text{SP} &= (B \times 100)/S (100 - \% \text{SOL})\end{aligned}$$

Where % SOL=Percent solubility; SP=swelling power; A=weight of dissolved solids in supernatant; B=weight of sediment paste; S=weight of sample.

Water binding capacity (WBC) and oil binding capacity (OBC)

Water binding capacity and Oil binding capacity of the starch sample was determined by a modified method described by Medcalf and Gilles (1965). Suspensions, 5 g (dry weight) of starch in 75 ml distilled water and oil, respectively were agitated for 1 h and centrifuged at 3000 rpm for 10 min. The free water and oil was removed from the wet starch sample and then drained for 10 min. The wet starch was then weighed.

$$\text{WBC/OBC (\%)} = \frac{\text{Weight of residual starch} \times 100}{\text{Weight of sample}}$$

Turbidity

Turbidity of HCN starch was determined using the method of Peera and Hoover (1999) with slight modification. Aqueous starch suspension of 1 % was heated in a boiling water bath for 1 h with constant stirring. The suspension was then cooled to room temperature, stored for 5 days at 4 °C. Turbidity was determined every 24 h by measuring the absorbance at 640 nm against water (blank) with a UV Spectrophotometer (ID 5000 HACH, USA).

Pasting properties

Pasting properties were performed using Rapid Visco-Analyser (RVA Starch Master TM 17133; Newport Scientific Pvt. Ltd., Warriewood, Australia). Pasting profile was calculated as per standard protocol. Starch sample (3 g) was weighed directly in RVA canister and distilled water (25 g) was added to it. A programmed heating and cooling cycle was followed, where the sample was held at 50 °C for 1 min, heated to 95 °C for 7.5 min and held at 95 °C for 2 min. It was then cooled to 50 °C in 7 min and held at 50 °C for 2 min. The centrifuge rotating speed was initially at 960 rpm for 10s and maintained at 160 rpm during the process. The experiments were done in triplicates.

Textural properties of starch gel

After RVA measurement, gelatinized starch sample in canister was kept at 4 °C for 24 h for solid gel formation. The gel was then evaluated for textural properties using TA-XT2 texture analyzer (M/s. Stable Microsystems, Surrey, UK). The gel sample was compressed at a speed of 0.5 mm/s to a distance of 10.0 mm using cylindrical plunger (P/5, diameter=5 mm). Compression was repeated twice to generate a force–time curve from which hardness (height of first peak), adhesiveness (negative area of the curve during retraction of the probe),

cohesiveness (ratio between the area under the second peak and the area under the first peak) and gumminess (product of hardness and cohesiveness) were calculated. Measurements in triplicates were performed and average was taken.

Morphological properties

Scanning electron microscopy

Scanning electron microscopy of starch sample was done by using a Scanning Electron Microscope (Jeol JSM-7500, Joel Ltd, Tokyo, Japan) as per the method described by Gul et al. (2014). The sample was mounted on SEM stub using double sided adhesive tape and was coated with platinum. An accelerating potential of 5 kV and 1000x magnification was used during micrography.

Granule size analysis

The granule size distribution of HCN starch was determined with laser light diffraction particle size analyzer (Shimadzu SALD-2300, M/s. Shimadzu Corporation, Kyoto, Japan). The percentage number of granules with different sizes was evaluated and the median granule diameter, equal to particle diameter for 50 % of normalized particle amount was calculated as given by the software.

XRD

X-ray diffraction analysis of the starch sample was carried out by using an X-ray diffraction meter (Shimadzu XRD-7000, M/s. Shimadzu Corporation, Japan). The diffractometer with Cu K α ($\lambda=1.54060$ Å) radiation was operated at a voltage of 40 kV and 30 mA. The sample was scanned between $2\theta=5$ - 50° with a scanning speed of $2^\circ/\text{min}$. The total area under the curve and the area under each prominent peak was determined using Origin Pro software package and percentage crystallinity was calculated using formula below:

$$\% \text{ Crystallinity} = (\text{Area under peaks} / \text{Total area}) \times 100$$

Thermal properties

The thermal behavior of starch gelatinization was determined using Differential Scanning Calorimeter (DSC, model 821e, M/s. Mettler Toledo, Switzerland). Sample (3 mg, dwb) was mixed with 7 mg of distilled water, hermetically sealed in aluminium pan and allowed to stand for 1 h at room temperature before heating in DSC. The instrument was calibrated using indium and an empty aluminium pan was used as reference. Sample was heated at $10^\circ\text{C}/\text{min}$ from 20 to

120 °C. Thermal transitions of sample for gelatinization characterized by T_O (onset temperature), T_P (peak temperature), T_C (conclusion temperature), and ΔH (enthalpy of gelatinization) were calculated automatically (Sandhu and Singh 2007). The gelatinization temperature range (R) and peak height index (PHI) were calculated as $2(T_P - T_O)$ and $\Delta H/(T_P - T_O)$ described by Krueger et al. (1987).

Rheological properties

Dynamic rheology of horse chestnut starch was analyzed wherein temperature sweep oscillatory test was performed with Modular Compact Rheometer (MCR-102, M/s. Anton Paar, Austria), equipped with parallel plate system (50 mm diameter) and PP50-SN32770 [$d=0.5$ mm] was used as a probe. The gap size was set at 0.5 mm; strain and frequency were set at 0.5 % and 1 Hz, respectively. About 2 ml of starch suspension (20 % (w/w)) was loaded on the ram of rheometer and the edge of sample was covered with a thin layer of low-density silicon oil to minimize evaporation losses. The starch sample was subjected to temperature sweep test with a temperature ramp from 50 to 90 °C at a heating rate of 2 °C/min. The dynamic rheological properties of native HCN starch in terms of storage modulus (G'), loss modulus (G'') and loss factor ($\tan \delta$) were determined as a function of temperature.

Statistical analysis

The data reported in the tables represent average of triplicate observations $\pm$ standard deviation. Statistical analysis was performed using Statistica-log software package version 7 (M/s. StatSoft Inc., OK, USA). The significant differences were obtained by a one-way analysis of variance (ANOVA) followed by Duncan's multiple range test (DMRT) ($P<0.05$).

Results and discussion

Physicochemical properties of HCN starch

Color measurement

A high degree of whiteness was observed for HCN starch with L^* value of 96.2. The L^* value was higher than the starch extracted from white sorghum and Alphine as reported by Perez & Lares (2004) and Doporto et al. (2011). Boudries et al. (2009) have concluded that L^* values greater than 90 give a satisfactory whiteness for starch purity. The chroma (c^*) and hue (h^*) values of starch sample was 96.23 and 84.30, respectively. The values for a^* (red/green) and b^* (yellow/blue) were -2.43 and 2.77 , respectively.

Proximate composition and amylose content

The proximate analysis (Table 1) of HCN starch revealed 10.97 ± 0.23 % moisture, 0.31 ± 0.14 % protein, 0 % fat and 0.29 ± 0.9 % ash, and the results were compared with that of water chestnut and sweet potato. The native HCN starch showed amylose content of 26.10 ± 2.64 % The observed amylose content of HCN starch was more than that of Indian water chestnut (Singh et al. 2009) and Sweet potato (Singh et al. 2005). The variation in amylose content of starch is due to the botanical origin (Singh et al. 2003a) and is also affected by climatic conditions and soil type during growth (Asaoka et al. 1985).

Swelling power (g/g) and Solubility (%)

Swelling power and solubility of native HCN starch as a function of temperature is presented in Fig. 1. The swelling power and solubility showed a continuous increase with increase in temperature, probably due to starch gelatinization, which leads to irreversible changes in properties like granular swelling, native crystallite melting, loss of birefringence and starch solubilisation (Collado and Corke 2003). When aqueous suspension of starch is heated above gelatinization temperature, the crystalline structure of starch is disrupted and water molecules become linked with exposed hydroxyl groups of amylose and amylopectin through hydrogen bonding, resulting in swelling of starch molecules, and increase in solubility as leaching of some soluble starch into liquid occurs. The highest swelling power and solubility for HCN starch was obtained at 95 °C, where most of the granules were gelatinized or swollen. As compared with the results obtained

Table 1 Chemical composition of Horse chestnut, Sweet potato and Water chestnut starches

Parameters (%)	Starch from different sources		
	Horse chestnut	Sweet potato	Water chestnut
Moisture	10.97 ± 0.23^a	9.6 ± 0.11^b	7.85^c
Protein	0.31 ± 0.14^a	0.25 ± 0.02^a	0.20^a
Fat	0.0	0.19 ± 0.01^a	0.10^b
Ash	0.29 ± 0.9^a	0.21 ± 0.02^a	0.20^a
Solubility	$7.24-26.8^*$	13.8	12.5
Water absorption capacity	85.33 ± 0.13^b	57.0^c	88.5^a
Oil absorption capacity	64.67 ± 0.28^a	Not determined	48.54^b
Swelling power	$2.49-17.12^*$	26.4	9.72
Amylose	26.10 ± 2.64^a	20.5^b	22.3^b

Results are expressed as mean values $\pm$ standard deviations. Means in a row with different superscripts are significantly different ($P<0.05$)

*The range is being given as the solubility and swelling power have been determined at different temperature from 55 to 95 °C

Fig. 1 Effect of temperature on solubility and swelling power of Horse chestnut starch

for sweet potato (Singh et al. 2005) and water chestnut (Singh et al. 2009), it was found that HCN starch showed lower swelling power (17.12 % at 95 °C) than sweet potato starch (26.4 % at 92 °C) but more than that of water chestnut starch (9.72 %). The solubility results revealed that HCN starch is having high solubility (27 %) as compared to sweet potato (13.8 %) and water chestnut starch (12.5 %).

Turbidity

The turbidity of gelatinized starch suspension as a function of storage period was found to be increasing progressively with storage period. On day first, it was found to be 1.24, followed by 1.49, 1.62, 1.74, 1.82, 1.86 and 1.90 % on successive days. This increase can be attributed to the interaction between leached amylose and amylopectin chains, resulting in the development of function zones, reflecting or scattering a significant amount of light (Yu et al. 2012). The turbidity showed a progressive increase up to storage period of 4 days and further storage caused no significant change in turbidity. This may be due to aggregation and crystallization of amylose, which increased during first 4 days of storage and was near completion during that period.

Water binding capacity (WBC) and oil binding capacity (OBC)

Water binding and oil binding capacity of native HCN starch were 85.33 ± 0.13 % and 64.67 ± 0.28 %, respectively. Water binding capacity of starch granule is the tendency to absorb water and the degree of association of water molecules within starch granule (Leach et al. 1959; Medcalf & Gilles 1965). When compared with previous findings of sweet potato by

Fig. 2 Rapid visco analyzer pasting profile of native Horse chestnut starch

Singh et al. (2005) and water chestnut starch by Singh et al. (2009), HCN starch was having more WBC than sweet potato while less WBC as compared to water chestnut starch. The degree of association between amylose and amylopectin molecules and availability of water binding sites among the starches affects the water binding capacity (Wotton and Bamunuarachchi 1978). WBC and OBC depend on the availability of hydrophilic and hydrophobic sites in starch molecules.

Pasting properties

Viscosity changes of starch suspension as a function of temperature were analyzed with RVA. RVA Profile for native HCN starch is presented in Fig. 2 and corresponding pasting parameters including peak viscosity (PV), trough viscosity (TV), breakdown viscosity (BV), final viscosity (FV), setback

Table 2 Pasting characteristics of Horse chestnut, Sweet potato and Water chestnut starches using rapid visco analyzer

Pasting parameters	Starch from different sources		
	Horse chestnut	Sweet potato	Water chestnut
Pasting temperature (°C)	65.35±0.4 ^c	71.8±0.0 ^b	75.05 ^a
Peak viscosity (cP)	4110±18.0 ^b	741.5±3.8 ^c	5554 ^a
Trough viscosity (cP)	2458±11.6 ^b	362.7±0.2 ^c	3338 ^a
Breakdown viscosity (cP)	1652±15.2 ^b	378.8±4.1 ^c	2216 ^a
Setback viscosity (cP)	1369±2.3 ^b	54.9±1.6 ^c	2286 ^a
Final viscosity (cP)	3827±7.07 ^b	417.6±1.8 ^c	5624 ^a

Results are expressed as mean values±standard deviations. Means in a row with same superscripts are not significantly different ($P < 0.05$)

Table 3 Gel texture characteristics of Horse chestnut, Sweet potato and Water chestnut starches using texture analyzer

Gel texture parameters	Starch from different sources		
	Horse chestnut	Sweet potato	Water chestnut
Hardness (g)	86.93±2.03 ^a	23.24 ^b	0.448 ^c
Adhesiveness (gs)	89.43±2.10 ^a	5.542 ^b	0.388 ^c
Cohesiveness	0.53±1.75	ND	ND
Gumminess (g)	46.07±2.01	ND	ND

Results are expressed as mean values±standard deviations. Means in a row with same superscripts are not significantly different ($P<0.05$). ND: Not Determined

viscosity (SV) and pasting temperature are summarized in Table 2. RVA profile of the starch suspension reflects the molecular events occurring in starch granules during heating cycle (Majzoobi et al. 2011). The peak viscosity of starch sample was 4110 ± 18.0 cP, reflecting the tendency of starch granules to swell freely before physical breakdown. Trough viscosity of starch sample was 2458 ± 11.6 cP, depending on the extent of amylose leaching and granule swelling. Break-down viscosity, measure of resistance of starch paste to heat and shear was 1652 ± 15.2 cP. Setback viscosity, reflecting the tendency of starch paste to retrograde was 1369 ± 2.3 cP. The final viscosity, giving an insight of stability of cooled-cooked starch paste under low shear was 3827 ± 7.0 cP. Pasting

temperature, the temperature at onset of rise in viscosity was 65.35 ± 0.4 °C.

The RVA profile of horse chestnut starch revealed Type-A viscosity pattern. Viscosity patterns of starch are categorized into four types; Type-A includes high swelling starches like potato, tapioca and waxy cereals, Type-B includes moderate swelling starch like cereal starches, Type-C includes restricted swelling starch and Type-D includes highly restricted starch Schoch and Maywald (1968). Compared with pasting parameters for sweet potato (Singh et al. 2005) and water chestnut starch (Singh et al. 2009), it was concluded that HCN starch was having low pasting temperature and high TV, BD, SB and FV, with PV higher than sweet potato but lower than water chestnut starch. Granular size and rigidity, amylose to amylopectin ratio and swelling power of starch play a key role in determining the pasting properties of starches (Kaur et al. 2006; Kim et al. 1996).

Gel Textural properties

Textural properties of starch gels with their corresponding values are presented in Table 3. A typical TPA curve of HCN starch gel is shown in Fig. 3. Textural parameters of HCN starch gel including hardness (HA), adhesiveness (AD), cohesiveness (CO), gumminess (GU) were 86.93 g, 89.43 gs, 0.53, 46.07 g, respectively. On comparison of HCN starch gel with sweet potato and water chestnut, it was observed that

Fig. 3 A typical texture profile analysis (TPA) curve of native Horse chestnut starch gel

HCN gel was having more hardness, adhesiveness, gumminess which may be due to high amylose content. Retrogradation of starch gel is responsible for gel firmness, which is associated with syneresis of water and crystallization of amylopectin, thus leading to formation of harder gels (Miles et al. 1985). Higher amylose content and longer amylopectin chains of starch, results in formation of harder gels (Mua and Jackson 1997).

Morphological characteristics

The particle size distribution of native HCN starch is shown in Fig. 4. The starch granules showed unimodal distribution profile for granular size. The results showed that granule diameter of native HCN starch showed widest size distribution from 7.52 to 27.439 μm and the median granule diameter was 15.763 μm . The scanning electron micrograph of native HCN starch is shown in Fig. 5. The starch granules were round, irregular, oval, and elliptical in shape with smooth surface. Native HCN starch consisted of mixed population of large, medium and small granules with an average granule size of 1.21 μm . The morphology of granule depends on the

biochemistry of chloroplast or amyloplast, as well as the physiology of plant (Badenhuizen 1969). Moreover, Svegmarm & Hermansson (1993) suggested that the variation in size and shape of starch granules of different plant sources is attributed to biological origin.

Thermal properties

DSC analysed results of native horse chestnut starch are presented in Table 4. On comparison with thermal characteristics of sweet potato and water chestnut starch, the transition Temperatures (T_o , T_p , T_c) observed for HCN starch were lower than that of sweet potato and water chestnut starch. Gelatinization temperatures and enthalpy of gelatinization of starch may be related to degree of crystallinity of starch granules (Krueger et al. 1987). Higher transition temperatures are consequence of high degree of crystallinity, which enhances the structural stability and makes the granule more resistant towards gelatinization (Barichello et al. 1990). Starches from various botanical sources differ in composition, exhibit different transition temperatures and gelatinization enthalpies (Singh et al. 2003b).

Fig. 4 Particle size distribution curve of native Horse chestnut starch

Fig. 5 Scanning electron micrograph of native horse chestnut starch

X-ray pattern and crystallinity

The X-ray diffraction pattern of native HCN starch is shown in Fig. 6. The XRD results of HCN starch showed the typical C-type, X-ray pattern with characteristics peaks at 5.7, 15, 17.3, and 22.3°. The commonly occurring X-ray diffraction patterns in starch are A, B and C type. A-type is characteristic of cereal starches and has characteristic peaks at 15, 17, 18, and 23°; B-type is shown by tuber starches, characterized by peaks at diffraction angles around 5.8, 15, 17, 20° and double peak at 22–24° and C-type, X-ray pattern exhibited by legume starches is a mixture of 'A' and 'B' unit cells. Diffraction peaks at 5.5°, 15°, 17°, and 22° or 23° has been reported to be characteristic of C-type starch (Hizukuri 1996).

The percentage crystallinity of HCN starch was 32.78 %. The crystallinity of starch depends on crystal size, amount of crystalline region (influenced by amylopectin content and

Fig. 6 X-ray diffraction pattern of native Horse chestnut starch

chain length), and orientation of double helices within the crystalline domain and extent of interaction between double helices (Hoover & Ratnayake 2002).

Rheological properties

The rheological property of starch depends mainly on interaction among starch granules and their rigidity during heating process. The rheological properties of horse chestnut starch during heating are shown in Table 5. It was observed that the rheological properties of horse chestnut starch including storage (G') and loss modulus (G'') were (G' peak=10,400 Pa) and (G'' peak=1,710 Pa) and $\tan \delta$ value (G''/G') was found to be 0.164. The changes in storage modulus (G') and loss modulus (G'') with temperature during heating of the starch suspension in a dynamic rheometer are shown in Fig. 7a and b. G' was maximum (TG') at 65.3 °C. The initial increase of G' is due to granular swelling that fill the entire available volume (Eliasson 1986; Keetels and Van Vliet 1994). Both G' and

Table 4 Thermal characteristics of Horse chestnut, Sweet potato and Water chestnut starch using differential scanning calorimeter

Thermal characteristics	Starch from different sources		
	Horse chestnut	Sweet potato	Water chestnut
Onset temperature (°C)	53.35±0.1 ^c	55.87 ^b	69.58±0.57 ^a
Peak temperature (°C)	58.81±0.7 ^c	71.39 ^b	73.31±0.87 ^a
Conclusion temperature (°C)	63.57±0.1 ^c	82.43 ^a	75.16±0.77 ^b
Enthalpy of gelatinization (J/g)	8.76±0.6 ^b	15.98 ^a	7.29±0.26 ^b
Peak height index= $\Delta H_{gel} / (T_p - T_o)$	1.6±0.2 ^b	2.93 ^a	1.97±0.4 ^b
$T_c - T_o$ =Gelatinization temperature range	10. 22±0.10 ^b	26.56 ^a	5.6±0.2 ^c

Results are expressed as mean values±standard deviations. Means in a row with same superscripts are not significantly different ($P < 0.05$)

Table 5 Rheological characteristics of starch gels from Horse chestnut, Corn and Mango kernel starch during heating using Rheo Optic Analyzer

Starch		TG/ (°C)	Peak G' (Pa)	Peak G'' (Pa)	Breakdown G' (Pa)	Peak $\tan \delta$
Horse chestnut		65.3	10,400	1,710	4,690	0.164
Types of Corn	Dent corn	73.7	2919	427	1177	0.146
	Bold					
	Dent corn	73.4	2463	383	1393	0.155
	Long Pop corn	73.4	3620	438	2020	0.122
Types of Mango Kernel	Chausa	89.4	29,003	11,231	15,500	0.387
	Totapuri	86.9	44,502	14,920	39,502	0.335
	Kuppi	87.4	33,209	11,600	26,509	0.349
	Langra	87.8	42,701	14,500	34,663	0.339
	Dashehari	87.5	30,240	11,753	17,140	0.388

Fig. 7 a. Effect of storage modulus of Horse chestnut starch with temperature, b. Effect of loss modulus of Horse chestnut starch with temperature

G'' after attaining maximum value started declining and reached to a minimum value of 5,710 and 339 Pa, respectively. The decrease in G' with increase in temperature is due to melting of remaining crystallites, resulting in softening of swollen starch granule (Tsai et al. 1997). During heating cycle, G' was higher than G'' in horse chestnut starch. The destruction in gel structure was observed from the breakdown in G' and is defined as the difference between G' peak at TG' and minimum G' at 90 °C (Singh et al. 2002). The variation in G' , G'' and $\tan \delta$ during heating cycle may be due to the difference in starch granule structure and amylose content, which in turn depends on biological origin (Svegmark and Hermansson 1993). Similar reports were observed by Sandhu et al. (2004) and Kaur et al. (2004) for mango kernel and baby corn starch. On comparison with the results for baby corn and mango cultivars it was revealed that HCN was having lowest TG' value but peak G' , peak G'' , breakdown in G' and peak $\tan \delta$ were more than baby corn varieties but less than mango cultivars. The difference in rheological properties among different starches depends on the biological integrity and origin of crop.

Conclusion

Horse chestnuts have high content of starch, presently go as waste and can have a great potential to be used in food industry either for the purpose of formulating newer products or can be used for replacement of conventional starches in food products. Horse chest nut starch finds its way to be used in various food industries due to its potential applications like in food industry for development of various products e.g., in high viscous foods, desert and other food formulations. Horse chest nut starch requires low temperature for gelling and due

to its mechanical strength it can be used as encapsulating agent in various applications. It was also observed from the above study that Horsechest nut starch has low swelling power hence best suited to maintain the texture of foods. The physicochemical, pasting, gel texture and thermal properties of Horse chestnut starch showed significant difference when compared with sweet potato, water chestnut, corn and mango kernel starches. At 95 °C, swelling power of HCN starch was higher than that of water chestnut starch but lower than sweet potato starch. Compared to sweet potato and water chestnut starch, horse chestnut starch was having high amylose content and peak viscosity but low pasting temperature. High amylose may be responsible for increased hardness and adhesiveness of HCN starch gels than sweet potato and corn starch. Transition temperatures of HCN starch including onset, peak and conclusion temperature were low to those of Sweet potato and water chestnut. The starch granules were spherical, oval or elliptical with smooth surface. HCN starch showed a typical C-type X-ray diffraction pattern having crystallinity of 32.78 %. Peak G' , G'' , observed for HCN starch were higher than those of corn starches and lower than those of mango kernel starches. The analysis of various properties of HCN starch will provide valuable information associated with the functional properties of starch.

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