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Characterization of Water Chestnut Starch – Xanthan Gum Complexes Influenced by the Addition of Sucrose at Different Levels

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Abstract

Water chestnut starch was extracted under alkaline conditions. It was investigated how the presence of sucrose affected the rheological, functional, and thermal characteristics of both native water chestnut starch (WCS) and the complex of xanthan gum and water chestnut starch (WCS/XG). The levels of sucrose used in the study varied from 10 to 30% due to the frequent concentration ranges employed in desserts prepared in eastern countries. Total polysaccharide concentration employed for the study was 5% (w/w, db) of water chestnut starch–xanthan gum dispersions (at mixing ratio of 9.7/0.3). It was found that swelling power, freeze thaw stability of both WCS and WCS/XG complex increased in the presence of sucrose at concentration below 30% while, water absorption was decreased significantly. Moreover, sucrose addition increased gelatinization temperature from 77°C to 81°C for WCS paste whereas, it increased from 72°C to 75°C for WCS/XG. The addition of increasing level of sucrose improved peak viscosity significantly from (170–326 BU) for WCS/XG while it increased from (72–114 BU) for WCS. The onset, peak, final temperature and enthalpy of gelatinization for all water chestnut starch/xanthan complexes and WCS dispersions with sucrose were found to be increased significantly with increase in level of sucrose addition. The effect of sucrose on freeze thaw stability and pasting properties was found to be more pronounced for WCS/XG when compared to WCS.

Keywords: Water chestnut, Sucrose, Viscoamylograph, DSC, Xanthan gum, Correlation Analysis

1.INTRODUCTION

The features of starch, such as its swelling, pasting, gelatinization, heat stability, and paste clarity, are what primarily determine its addition to food systems. Thus, selection of suitable starch according to the industrial applications depends on its microstructure, freeze thaw stability and textural characteristics. The starch isolated from wheat, corn, rice, potatoes, is broadly used commercially in the food industries worldwide (Srichuwonget al.2005; Lutfi, et al.2017). New and innovative food products are constantly being developed after the incorporation of starches due to their unique properties and low price. A major source of energy among the various carbohydrates found in the human diet is starch, whose digestibility and functioning are largely determined by the ratio of amylopectin to amylose and how these two compounds interact with other additives in the food chain (Majzoobi, et al.2014; Lutfi, et al.2019). Hence, it is very important to understand the mechanism of other food ingredients in modifying the functional properties of starch.

Usually, the starches were used along with gums to modify and improve the textural and functional properties of food foodstuffs (Nagano et al., 2008). A lot of researches have been conducted to observe the effect of different gums (xanthan, guar, CMC or acacia) on the physicochemical properties of starch pastes (Chaisawang and Suphantharika, 2005; Lutfi and Hasnain, 2009; Tischer et al. 2006; Nawab et al.2017). The viscosity of the starch-based system was found to be increased after the addition of xanthan gum (Chaudemanche and Budtova, 2008). Xanthan gum is extensively used by the food industries to improve the stability of a variety of food products against high temperatures, shear applications and freezing (Viturawong et al.2008). Xanthan gum is termed as heteropolysaccharide due to the presence of different monosaccharides (1,4-linked Delta-D-glucose, mannose and glucuronic acid). It has the tendency to withstand against heat, alkali and acids. Moreover, it provides high viscosity when added at low concentration to the system (Zobel and Stephen, 1995; Achayuthakan and Suphantharika, 2008).

The food which contains starch generally form a complex system, and the starch/gum mixtures is usually present along with other constituents in the food product, such as salts, sugars and oil. Among all other ingredients with respect to the taste, sugars are broadly used ingredient in the starch-based products (Aee et al.1998). The retrogradation, swelling and rheological properties of starch could greatly be influenced by the presence of sugars. However, the source from which starch is obtained as well as the concentration of sugar could not be neglected (Acquarone and Rao, 2003; Chang et al.2004). Several researchers observed that the introduction of sugar caused the paste to become more viscous and the starch to take longer to gelatinize (D'appolonia, 1972; R. D. Spies, 1981; Richardson et al.2003; Baek et al.2004; Lutfi and Hasnain, 2009). The demand of starch due to its multiple functionalities has been rapidly increased by the food and non-food industries to facilitate the end users. Conventional sources will not be enough to fulfill their requirements for that reason; isolation of starch from non-conventional sources is of great concern. These sources not only useful to achieve the functional properties that are required and needed for value addition but also increase the shelf life of the product against deterioration (Nawab et al.2016). Among various explored resources water chestnuts is low cost and neglected source of starch (Lutfi et al.2017).

The edible white portion of water chestnuts (Trapa Bispinosa) is covered with thick black skin. It is locally known as “Singhara” in Pakistan (Ahsan et al.2023). It is cultivated in swampy areas of province Sindh and Punjab. The primary component of water chestnuts is starch that is approximately 80-95% dry basis.

It also contains various bioactive components which make it healthier food. The pasting, thermal, and gelation attributes of WCS were thoroughly examined in our previous research, as were the effects of ionic compounds (NaCl) and gums (xanthan, acacia, guar, and CMC) on the physical attributes of sponge cakes and yeast-leavened breads, both before and after chemical and physical modification (acetylation, acid-thinning, and pre-gelatinization) (Chen et al.2014; Lutfi et al. 2019; Lutfi and Hasnain, 2009; Lutfi & Hasnain, 2013; Lutfi et al.2017; Nawab et al.2017).

Up until now, the majority of research has examined the impact of sucrose on starch. A smaller number of studies have been conducted on the consequences of sucrose on starch/hydrocolloid complex, but no research has been done on the effects of sucrose on water chestnut starch/gum complex (WCS/XG). Therefore, the purpose of this study is to explore the physicochemical and thermal characteristics of water chestnut starch (WCS) and xanthan gum (XG) blend with the co-existence of sucrose, so as to provide valuable data for the production of starch-based foods especially Pakistani traditional desserts which tends to have higher sugar concentrations in formulation like kheer, firni and variety of custards.

2. MATERIALS AND METHOD

In Karachi, Pakistan, a local market provided the dried water chestnut fruits (Trapa Bispinosa), and Pakistan Gum and Chemicals Ltd. was the source of xanthan gum. All substances were of analytical quality, even the 99.5% pure sucrose.

2.1. Extraction of water chestnut starch

The water chestnuts were first washed, cleaned, and then dried. The particle size of the dried water chestnuts was reduced to maximize starch extraction. One kilogram of powdered water chestnuts was mixed with 2 liters of distilled water and stirred continuously for 30 minutes at ambient temperature. The pH of the mixture was maintained at 9.0 by dropwise addition of a NaOH (0.2 %) solution. The mixture was stirred, then put through 100 and 170 mesh sieves respectively before being centrifuged at 3000 rpm using a AllergaTM X-22 centrifuge (Beackman Coulter, Inc. USA). To remove the surface protein layer, the residues were rinsed with distilled water. Hot air was then passed over the starch until it contained 13% moisture, as described in the study of Lutfi et al.2017 and Qiaoet al.2019.

2.2. Granular structure

The dried samples of water chestnut starch was mounted on scanning electron microscopy stub and subsequently, they were coated with gold (300 °A) by using a coater (JFC-1500, Jeol Japan). The scanning electron microscope (JSM,6380A, Jeol Japan) was employed to capture the micrographs at an accelerating voltage and magnification of 5 Kv and 1000x, respectively (Moin et al.2017).

2.3. Sample preparation

Water chestnut starch (9.70%) and xanthan gum (0.3% w/w) were added to deionized water while stirring continuously to completely dissolve the gum, resulting in the mixture (5%) WCS/XG. Afterwards, pre-calculated amount of sucrose 10%, 20% and 30% (w/v) was added with continuous stirring for 15 min to avoid any lump formation (Sudhakar et al.1995).

2.4. Swelling factor

Swelling factor of WCS and WCS/XG samples was determined according to the methodology outlined by Lutfiet al., (2019).

2.5. Water absorption capacity

Water absorption capacity of WCS and WCS/XG samples were evaluated with slight modification according to the method reported by Lutfi et al., (2017). The samples prepared by aforementioned methodology were kept at room temperature for 30 min without stirring followed by the centrifugation at 5000 rpm for 5 min using a AllergaTM X-22 centrifuge (Beackman Coulter, Inc. USA). The amount of water absorbed was evaluated by subtracting the volume of supernatant from the initial volume of water (Lutfi, et al., 2021).

2.6. Freeze-thaw stability

The WCS and WCS/XG samples were heated at boiling temperature (100°C) for 30 min with constant swirling. After that, the samples were cooled to room temperature. Afterwards, samples were kept at -10 °C for 1 week. The thawing was carried out at room temperature for 30 min followed by centrifugation at 8000 rpm for 20 min using a AllergaTM X-22 centrifuge (Beackman Coulter, Inc. USA). The gel stability (%) was determined by measuring the volume of separated water. This analysis was conducted in 5 cycles and the duration of each cycle was 24 hours (Lutfi and Hasnain, 2013).

2.7. Micro-Viscoamylography

The pasting profile was analyzed by Brabender Microviscoamylgraph (Model D- 47055, Germany). Water chestnut starch at 5% (w/v) level was mixed with (0.3%) xanthan gum in sucrose solutions (0-30%, w/v). The protocol and specifications of Moin et al. (2016) were followed. Gelatinization temperature (°C) and maximum viscosity (BU) was recorded.

2.8. Differential scanning calorimetry measurements

Using (DSC Q10, TA Instruments, USA) the gelatinization of WCS in the presence and absence of XG and sucrose was studied. Aliquots of 20 µL of the homogeneous systems prepared using the aforementioned methodology were added to aluminum DSC pans, sealed, and equilibrated for 1 hour before thermal scanning. Starting at 30 °C and continuing until 120 °C, the heating rate was 10 °C/min. As a reference, an empty aluminum pan was used. The equipment's built-in software (Universal Analysis) was used to calculate the temperatures at the beginning (To), peak (Tp), and end (Tf) of gelatinization., gelatinization temperature range (Tf-To) and the enthalpy change (ΔH) (Lutfi, et al., 2021).

2.9. Differential scanning calorimetry measurements

Variance Analysis (ANOVA) was used to calculate significant differences between the means (n=3) and Duncan's test at P ≤ 0.05 was employed. Pearson correlation was studied at P< 0.05 and P< 0.01 between sucrose addition on WCS and WCS/XG gels physicochemical properties. The SPSS software (version17, 263 SPSS Inc., USA) was employed.

3. RESULTS AND DISCUSSION

3.1. Granular structure

The structure of untreated water chestnut starch is shown in SEM mircograph (Figure 1). Intact, smooth and ovoid granules with protruding horns could be observed. This feature is unique to water chestnut starches and is in accordance with study on Thai variety of water chestnut starch (Tulyathan et al., 2005) and our previous work on Pakistani water chestnut (Lutfi et al., 2017). However, tea seeds (Huanget al.,2019) and Pongamiapinnata (legume)(Siroha et al.,2020) starches are reported to have flat spherical or oval with smooth surface

3.2. Effect of sucrose on swelling factor

In order to study the effect of sucrose addition at different levels on the physicochemical change of starch granules at the temperature 90 °C, the swelling factor (SF) was calculated. The results are presented in Table 1. For WCS and WCS/XG gels, addition of sucrose resulted in a significant increase in swelling factor at a concentration below 30% however, decline in swelling factor was observed at 30% sucrose concentration. Chen et al., (2014) also studied a comparable effect on the swelling of potato starch with and without flaxseed polysaccharide in the presence of sucrose at different concentrations. It was found in the study of Ahmad et al., (1999) that due to the least disintegration of starch granule by the sugar when added (below 20%) the swelling factor was increased whereas presence of sucrose at high concentration (>20%), exerted the osmotic pressure which ultimately restricted starch granule form further swelling. The sucrose also prohibited the release of amylose from the granule. They further added that swelling factor and amylose leaching is greatly depends on the type and concentration of sugars. The reduction of leached amylose was probably due to the strong interaction of sucrose molecules with amylose chain in the amorphous region of the granule. The penetration of sugar molecules dependent on granule swelling, the reduction in swelling at high concentration of sucrose can be attributed to competition between sugar and starch for water which finally restricted the hydration of starch. The effect of sugars at higher concentration on swelling property of starch was further elaborated by Slade et al. (1989). According to them, swelling factor was decreased because of low mobility of water molecules due to the presence of high molecular weight sugar molecules. The slower increase in rate of consistency at high concentration of sugar was also observed. This explanation was also supported by Sudhakaretet. al., (1995) and Gunaratne et al., (2007). The concentration dependent decline observed in the swelling capaciy of water chestnut starch would help recipe formulation of local sweet declicacies.

Table 1: Swelling factor (g/g) and water absorption (%) of WCS and WCS/XG dispersions at different concentrations of Sucrose[a].

	Sucrose concentration (%)	Swelling factor (g/g)	Water absorption (%)
WCS	0	2.62 ± 0.12[d]	97.82 ± 0.21[a]
	10	4.56 ± 0.11b	65.91 ± 0.11[b]
	20	5.15 ± 0.43[a]	58.75 ± 0.16[c]
	30	3.25 ± 0.34[c]	55.66 ± 0.21[d]
WCS/XG	0	4.12 ± 0.18[b]	107.23 ± 1.31[a]
	10	4.56 ± 0.87[b]	98.21 ± 1.21[b]
	20	5.23 ± 0.76[a]	88.14 ± 0.98[c]
	30	2.87 ± 0.56[c]	87.23 ± 0.78[d]

[a]*Values are means ± SD of triplicates. Values in the same column with different superscript are significantly different (P<0.05). WCS; water chestnut starch and WCS/XG; water chestnut starch-xanthan complex.*

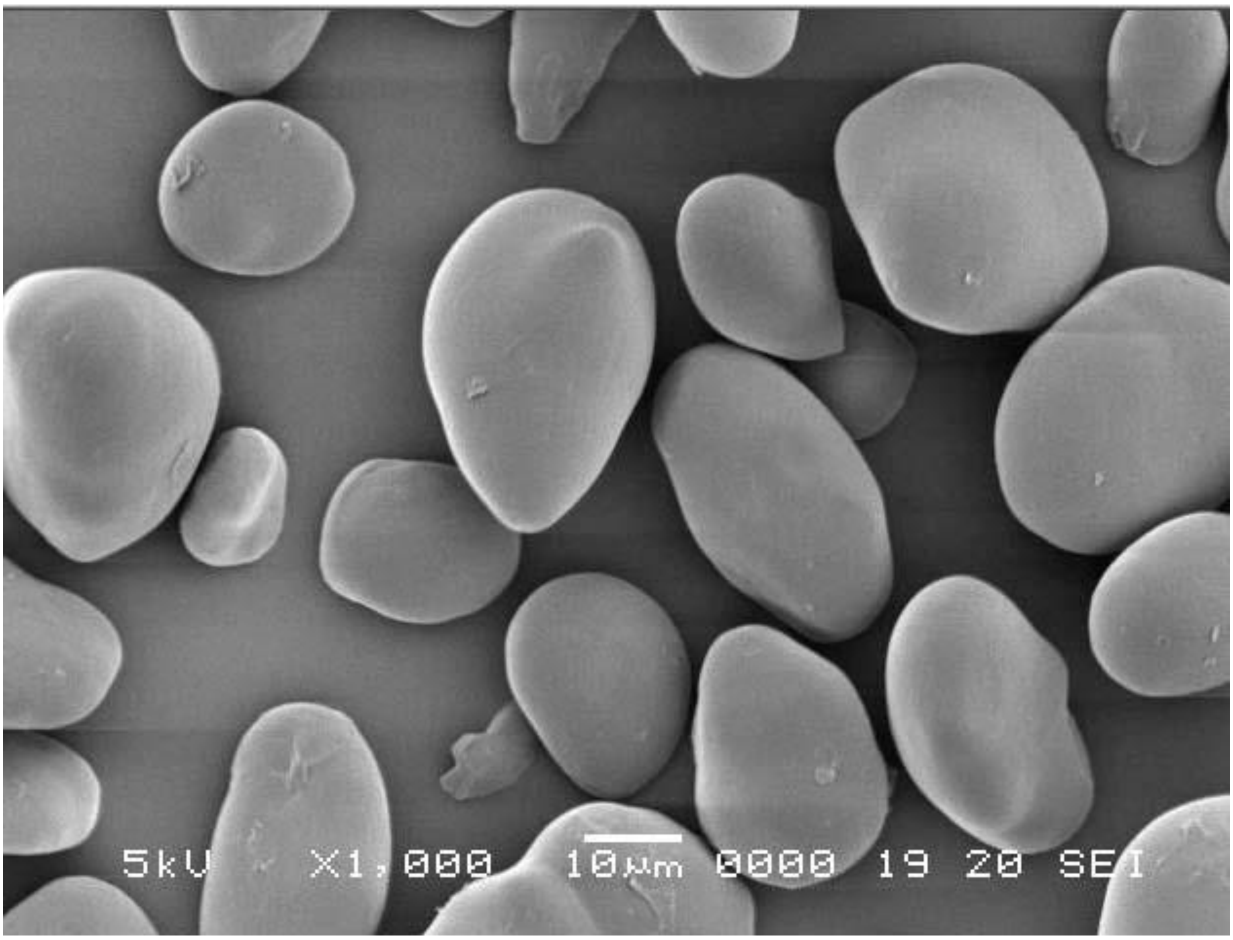

Figure 1. Scanning electron micrograph of water chestnut starch at 5 Kv voltage and 1000x magnification.

To make it easier to formulate traditional desserts, however, it is necessary to thoroughly investigate the information regarding the variation in trend regarding raising the sugar concentration to 50% with WCS.Results showing the effect of sucrose on WCS/XG complexes are also presented in Table 1. When the concentration of sugar increased from 10 to 20%, significant increase in SF of WCS/XG complex was observed. The swelling factor was increased from 4.56 g/g at 10% sucrose to 5.23 g/g at 20% sucrose. However, SF was significantly decreased to 2.87g/g at 30% sucrose. The pronounced reduction in SF observed in WCS/XG-sucrose complexes could be due to the formation of a film around the WCS granules by XG. This can be described by assuming that for effective interaction between WCS and XG, the XG should be completely hydrated first. It was assumed that before the addition of sucrose, the XG and WCS was completely hydrated and then interacted efficiently resulting in the high swelling factor. Similar results were also reported in our previous study on mango kernel starch and xanthan complex (Nawab et al.,2017). However, after the addition of sucrose at 30% concentration, the XG could not get the chance for complete hydration due to the restriction of available water by sucrose. *3.3. Effect of sucrose on water absorption*

Water absorption of starches is an important parameter to understand the interaction of starches with water during processing of food products to further stabilize and modify the textural attributes of the food according to the requirement of the consumer. The reduced water absorption of WCS and WCS/XG complexes was found in the presence of (10 - 30%) sucrose (Table 1).

Table 2. (%) Syneresis of WCS and WCS/ XG dispersions at different concentration of Sucrose[a].

	Sucrose (%)	1 Cycle	2 Cycle	3 Cycle	4 Cycle	5 Cycle
without XG	0	40.12 ± 0.68[a]	42.34 ± 0.40[a]	42.31 ± 0.51[a]	41.87 ± 0.78[a]	40.16 ± 2.11[a]
	10	12.61 ± 0.25[b]	24.60 ± 0.71[b]	26.38 ± 0.44[c]	29.8 ± 0.65[c]	32.78 ± 0.23[c]
	20	6.98 ± 0.43[c]	7.87 ± 0.91[d]	25.78 ± 0.30[d]	26.56 ± 0.45[d]	30.87 ± 0.11[d]
	30	1.20 ± 0.37[d]	20.87 ± 0.22[c]	30.89 ± 0.76[b]	31.87 ± 1.67[b]	38.78 ± 0.56[b]
with XG	0	20.12 ± 0.65[a]	21.34 ± 0.40[a]	20.31 ± 0.53[a]	21.87 ± 0.77[a]	23.16 ± 2.13[a]
	10	10.61 ± 0.21[b]	9.60 ± 0.71[c]	11.38 ± 0.44[c]	15.83 ± 0.65[b]	18.78 ± 0.23[c]
	20	6.98 ± 0.43[c]	6.87 ± 0.91[d]	10.78 ± 0.37[d]	11.56 ± 0.45[d]	17.98 ± 0.12[d]
	30	10.20 ± 0.37[b]	12.87 ± 0.29[b]	13.89 ± 0.71[b]	14.87 ± 1.67[c]	20.78 ± 0.54[b]

[a]*Values are means ± SD of triplicates. Values in the same column with different superscript are significantly different (P<0.05). WCS; water chestnut starch and WCS/XG; water chestnut starch-xanthan complex.*

The results are in agreement with previous studies on the cassava and potato starches in the presence of sucrose (Teixeiraet al., 2007; Chen et al.,2014). This could be due to the limited availability of water for starch molecule. After the addition of sucrose, the majority of water was attracted by sugar molecule due to the presence of large number of OH groups which subsequently make it more hydrophilic, therefore the formation of more sucrose bounded water took place hence, reduced water absorption by WCS and WCS/XG was observed (Ma et al., 2017).

3.4. Effect of sucrose on freeze thaw stability

During storage of food products at freezing temperatures, the strengthening of starch gel and freeze thaw stability is an important feature to consider. It indicates the retrogradation tendency of starch gels and also governs gel appearance, texture and mouth feel. The stability of starch gels could be enhanced by the addition of different hydrocolloids and food ingredients (Ferrero and Zaritzky, 2000). Freeze–thaw stabilization of WCS and WCS/XG complexes were evaluated by determining liquid separated after freezing/thawing (1–5) cycles. The effect of sucrose on % syneresis of WCS gels is presented in Table 2. During the first to fifth cycle results showed that the addition of (10, 20 and 30) % sucrose significantly reduced the expelled water from WCS-sucrose gels when compared to WCS gel. However, increment in exudation of water in WCS and WCS-sucrose gels upon frozen storage was observed from cycle 1 to cycle 5 as WCS>WSC-10%sucrose >WCS-20%sucrose >WCS-30%sucrose. This could be due to the speeding process of re-association of amylose chains, resulting in the formation of bigger ice crystals by frequent freezing and thawing lowered the impact of sucrose on the stability of starch gels against freezing.

Table 3. Pasting behavior of WCS and WCS/XG dispersions at different concentrations of Sucrose[a].

	Sucrose concentration (%)	**Pv (BU)**	**Tg (°C)**
without XG	0	72 ± 0.21[d]	77.2 ± 0.33[d]
	10	95 ± 0.14[c]	78.8 ± 0.0[c]
	20	103 ± 0.11[b]	80.2 ± 0.0[b]
	30	114 ± 0.23[a]	81.7 ± 0.16[a]
with XG	0	170 ± 0.31[d]	72.6 ± 0.0[c]
	10	259 ± 0.54[c]	71.5 ± 0.14[d]
	20	325 ± 0.47[b]	73.1 ± 0.37[b]
	30	326 ± 0.34[a]	75.6 ± 0.19[a]

[a]Values are means ± SD of triplicates. Values in the same column with different superscript are significantly different (P<0.05). WCS; water chestnut starch and WCS/XG; water chestnut starch-xanthan complex, Pv; Peak viscosity (BU); Tg; Gelatinization temperature (°C).

Our results were in agreement with previous study on the freeze thaw stability of rice starches in the presence of sucrose (Arunyanart and Charoenrein, 2008). It has been already studied that when a starch gel is kept at freezing temperature, it forms a concentrated matrix, leaving behind some unfrozen water. The re-association of amylose chains occurred in the matrix and displaced the water molecules which ultimately formed a separate phase. At room temperature, the separated water was released from the spongy structure and measured (Ferrero et al., 1993; Leeet al., 2002), which can be lowered after the addition of sucrose (Table 3).

In the case of WCS/XG complexes, syneresis significantly decreased from the first to the fifth cycle when sucrose was present. However, during (2ndto 5th) freeze thaw cycles significantly higher synerises was observed in 30% concentration WCS/XG-sucrose gel when compared to 10% and 20% WCS/XG-sucrose gels (Table 3). The findings suggested that WCS/XG-sucrose below 30% concentration would be a suitable combination for better frozen stability. Similar results were observed by Ferrero et al., (2000) forcorn starch. The increment in percent exudation of water in WCS/XG and WCS/XG-sucrose was less pronounced than WCS and WCS-sucrose gels upon frozen storage after 5 cycles. Nevertheless, it followed same trend as WCS/XG>WCS/XG-10%sucrose>WCS/XG-20%sucrose>WCS/XG-30%sucrose.

3.5. Effect of sucrose on pasting properties

Sucrose is a dimer of glucose and fructose which exhibited substantial effects on pasting parameters of WCS and WCS/XG complex, summarized in Table 3. The abbreviation (Tg) denotes the temperature at which starch started to gelatinize and starch granules began to increase its volume resulting in the rapid increase in viscosity of the system (Huang et al., 2017; Medrano et al., 2019). The pasting temperature of WCS and WCS/XG was increased significantly after the addition of sucrose at varying concentration (10-30) %. The significantly highest temperature of gelatinization for WCS and WCS/XG was recorded (81.7 °C) and (75.6 °C) in the presence of (30%) concentration of sucrose, respectively. This could be due to the increase complexity of starch granule because of penetration of sucrose molecules followed by the development of sugar bridge (cross linking) between the starch chains, which made the amorphous regions more stabilize (Zhou et al.,2017). It indicated the strong interaction of sucrose with WCS, resulting in the increased gelatinization temperature. Moreover, gelatinization temperature of WCS/XG pastes in the presence of sucrose were found lower than WCS-sucrose gels. Similar results were reported earlier in case of corn starch. The XG did not decrease the Tg of native WCS, it is in agreement with previously published report (Nawab et al., 2017). Rapid increment in gelatinization temperature of native WCS was observed with the increase in levels of sugar addition was also reported in earlier studies (Hester et al., 1956; Slade and Levine, 1989; Slade and Levine, 1993). Therefore, the combined effect has the tendency to initiate the swelling of starch granule at the temperature nearly of native WCS (Sudhakar et al., 1995).

The maximum increase in viscosity during heating, when starch granules are completely gelatinized is termed as peak viscosity (PV) (Zavareze and Dias, 2011). The enlargement of starch granule is mostly depending on the amylopectin content, whereas amylose plays an inhibitory effect towards expansion which ultimately sustain its integrity. As the heating temperature increased, the amylose leached out from the granule and the ratio of amylopectin increased within the granule caused the rapid rise in viscosity of the starch suspension. The linear increase in PV was noticed after the addition of sucrose. This effect is harmonized with the amylography results reported by Gunaratne et al., (2007), who added sucrose to wheat and potato starch. Richardson et al., (2003) explained that the initial increase in gel viscosity in the presence of sugar could be due to the strong effect of sugar on the swollen starch granule as explained by Doublier et al. (1987). This might allow granules to swell for a longer period of time resulting greater peak viscosity before the collapse of granular structure.

The effect of sucrose addition on peak viscosity of WCS/XG complexes was also presented in Table 3. Significant increase in Pv was observed with the increment in sucrose concentration (P<0.05) however, percent increment in Pv is lower than WCS-sucrose pastes. For starch and gum to interact strongly, they must both be well-hydrated. In the absence of sugar, this occurs readily, and the viscosity rises. However, adding sugar reduces hydration, which weakens the interaction between gum and starch. As a result, the percent increase in paste viscosity is lower than for WCS-sucrose pastes.

3.6. Effect of sucrose on thermal properties

The thermal behavior of starch mixtures was studied by Differential scanning calorimetry. The onset, peak, final, range temperatures and enthalpyof all dispersions in the presence and absence of sucrose are shown in Table 4. As the concentration of sucrose was raised, the gelatinization temperatures (To, TP, and Tf) of the WCS-sucrose mixture considerably shifted to the upper side (P<0.05). Same increasing trend was observed in WCS/XG complex with sucrose concentration (Table 4).

Table 4. Thermal properties of WCS and WCS/XG dispersions at different concentration of sucrose[a].

	Sucrose (%)	T_o (°C)	T_p (°C)	T_f (°C)	$(T_f\text{-}T_o)$ (°C)	ΔH (J/g)
without XG	0	72.2 ± 0.61^d	76.3 ± 0.42^d	84.3 ± 0.55^c	12.1±0.11^d	9.34 ± 0.6^d
	10	73.6 ± 0.21^c	77.6 ± 0.75^c	85.3 ± 0.44^b	11.7±0.05^c	10.43 ± 0.20^b
	20	76.1± 0.45^b	80.2± 0.97^b	84.7 ± 0.34^c	8.6±0.14^b	9.60 ± 0.18^c
	30	82.2 ± 0.34^a	82.1 ± 0.21^a	88.3 ± 0.78^a	6.1±0.07^a	12.98 ± 0.31^a
with XG	0	67.3 ± 0.43^b	68.1 ± 0.43^d	72.7 ± 0.19^c	5.4±0.09^a	10.11 ± 0.25^c
	10	63.9 ± 0.11^d	78.4 ± 0.32^c	79.4 ± 0.45^b	15.5±0.06^c	11.01 ± 0.34^b
	20	65.5 ± 0.58^c	79.3 ± 0.67^b	79.1 ± 0.79^b	13.6±0.18^b	9.89 ± 0.41^d
	30	68.3 ± 0.16^a	80.2 ± 0.34^a	88.3 ± 0.11^a	20±0.36^d	12.67 ± 0.19^a

[a]*Values in the same column with different superscript are significantly different (P<0.05). WCS; water chestnut starch and WCS/XG; water chestnut starch-xanthan complexes; To; Onset temperature, Tp; peak temperature, Tf; final temperature, (Tf–To); gelatinization range temperature, ΔH; enthalpy.*

These results are parallel with previously reported literature (Spies and RC, 1982; Kohyama and Nishinari, 1991). The structure of water could be changed in the presence of sucrose which ultimately limits the mobility of water molecules. It has been established earlier that the hydroxyl groups present in the sucrose molecules has a strong stabilizing effect on the structure of water due to the stereospecific nature of sucrose.

Thus, the more energy and high temperature is required for the swelling of starch granules in the presence of sucrose as compared to the WCS alone. With increasing concentration of sucrose, the enthalpy of starch-sugar mixture significantly increased with and without xanthan gum. This is in agreement with the outcomes for sweet potato starch, in which the gelatinization temperature and enthalpy shifted to higher side in the presence of sucrose (Aee et al., 1998; Kohyama and Nishinari, 1991). A significantly ($P \leq 0.05$) decrease in ΔH was observed, at 20% sucrose concentration irrespective of XG added as compared to the control. Sucrose may alter the structure of water as a solvent, causing water molecules to get immobilised. The configuration of glucose is widely known to fit the tridymite structure in water. (Aee et al., 1998). Phase transition temperature range (Tf-To) decreases without XG, while increases when XG added to WCS. The increase could also be due to the stabilization of the crystalline region on the basis of zipper model in which degree of rotational freedom of links decreased with the increasing concentration of sucrose. The newly created hydrogen bonds by the presence of sugar would decrease the mobility of the links. Moreover, according to Kohyama and Nishinari (1991) the increase in Tp after the addition of sucrose was due to the two possible reasons; (1) As the water is involved in hydrating the sucrose molecule resulting in the increase of starch concentration in the system (2) The molecules of sucrose interacted with starch chains stabilizing the crystalline region.

3.7. Correlation analysis of sucrose addition on WCS and WCS/XG gels physicochemical properties

Pearson's correlation analysis of WCS and WCS-sucrose gels with different functional properties of gelsis summarized in Table (5a). It revealed that sucrose concentration is not significantly correlated with swelling factor (SF) however, significant negative correlation was found with water absorption ($P<0.01$), phase transition temperature rang (Tf-To) ($P<0.01$) and freeze thaw cycles ($P<0.05$). Moreover, positive correlation of sucrose concentrations was observed with peak viscosity of gels ($P<0.01$), gelatinization enthalpy ($P<0.05$), onset temperature ($P<0.01$), conclusion temperature ($P<0.05$) and peak temperature ($P<0.01$).

Similar to WCS gels, no significant correlation of sucrose concentration with SF was observed for WCS/XG gels and a strong negative correlation was observed with WA at $P<0.01$ (Table 5b). The correlation of Pv, conclusion temperature, phase transition temperature and peak temperature was found positive with sucrose concentration at ($P<0.01$) for WCS/XG gels.

4. CONCLUSION

In the present study the physicochemical, pasting and thermal properties of water chestnut starch/ xanthan/sucrose combinations were evaluated. It has been concluded that the addition of sucrose at varying concentration has pronounced effect on WCS and WCS/XG complexes. The swelling capacity of starch was enhanced in the presence of sucrose whereas water absorption was found to be negatively correlated. The freeze thaw stability of WCS was significantly improved in presence of sucrose suggesting sugar concentration studied could be helpful for frozen dessert formulation.

Table 5(a). Correlation coefficients of WCS among sucrose concentration and physicochemical properties[a].

	SF	WRC	Tg	Pv	ΔH	To	T_f	(T_f-T_o)	T_p	1 Cycle	2 Cycle	3 Cycle	4 Cycle	5 Cycle
Sucrose Concentration	.267	-.892**	.994**	.972**	.760*	.944**	.764*	-.965**	.953**	-.916**	-.736*	-.585	-.732*	-.168
SF		-.614	.289	.425	-.160	-.010	-.126	-.080	.271	-.552	-.787*	-.844**	-.793*	-.891**
WRC			-.894**	-.969**	-.574	-.720*	-.563	.750*	-.808*	.997**	.889**	.885**	.949**	.540
Tg				.972**	.784*	.945**	.789*	-.951**	.956**	-.916**	-.732*	-.589	-.731*	-.148
Pv					.727*	.869**	.721*	-.877**	.905**	-.983**	-.802*	-.743*	-.847**	-.328
ΔH						.893**	.985**	-.732*	.751*	-.625	-.190	-.198	-.295	.353
To							.901**	-.958**	.937**	-.763*	-.481	-.316	-.480	.161
T_f								-.750*	.784*	-.613	-.204	-.173	-.287	.352
(T_f-T_o)									-.938**	.783*	.624	.377	.565	-.007
T_p										-.828*	-.673	-.477	-.629	-.078
1 Cycle											.859**	.853**	.925**	.483
2 Cycle												.884**	.953**	.747*
3 Cycle													.972**	.837**
4 Cycle														.771*

[a]** and * means Pearson correlation is significant at P <0.01 and P < 0.05 level, respectively.

Table 5(b). Correlation coefficients of WCS/XG complexes among sucrose concentration and physicochemical properties[a].

	SF	WA	Tg	Pv	ΔH	To	T_f	$(T_f\text{-}T_o)$	T_p	1 Cycle	2 Cycle	3 Cycle	4 Cycle	5 Cycle
Sucrose Concentration	-.316	-.950**	-.744*	.936**	.644	.295	.933**	.885**	.847**	-.776*	-.575	-.582	-.733*	-.390
SF		.163	-.070	-.043	-.514	-.501	-.435	-.293	.022	-.051	-.278	-.214	-.100	-.289
WA			.821*	-.983**	-.395	-.069	-.804*	-.821*	-.881**	.847**	.759*	.746*	.897**	.611
Tg				-.888**	-.382	.396	-.714*	-.880**	-.979**	.999**	.926**	.954**	.873**	.770*
Pv					.420	-.014	.811*	.857**	.942**	-.909**	-.816*	-.806*	-.906**	-.633
ΔH						.469	.862**	.757*	.498	-.400	-.010	-.098	-.073	.146
To							.311	.005	-.212	.355	.581	.593	.322	.658
T_f								.951**	.814*	-.738*	-.438	-.492	-.549	-.262
$(T_f\text{-}T_o)$									.927**	-.892**	-.650	-.707*	-.673	-.472
T_p										-.987**	-.865**	-.888**	-.856**	-.677
1 Cycle											.920**	.946**	.882**	.761*
2 Cycle												.988**	.931**	.885**
3 Cycle													.917**	.893**
4 Cycle														.839**

[a]** and * means Pearson correlation is significant at $P < 0.01$ and $P < 0.05$ level, respectively.

The delay in gelatinization of WCS was noticed after the sugar addition with higher gelatinization energy requirements. The study proposed that sucrose along with water chestnut and xanthan was more appropriate to be used as stabilizing agent in starch-based food products such as custards, puddings and traditional local desserts like kheer and firni.

Ethical Approval

Ethical approval was not required for this research.

Declaration of interest

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Author Contribution

Concept: ZL
Design: ZL, AM
Data collecting: ZL, QK
Statistical analysis: QK
Literature review: ZL
Writing: ZL, KQ, AM
Critical review: ZL, AM

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