International Food Research Journal 26(6): 1861-1869 (December 2019)

Journal homepage: *http://www.ifrj.upm.edu.my*

Drying effect on the properties of traditionally processed sago starch

[1]Mustafa Kamal, M., [1]Baini, R., [1]Lim, S. F., [1]Rahman, M. R., [2]Mohamaddan, S. and [3]Hussain, H.

[1]Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia
[2]Department of Mechanical Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia
[3]Centre of Sago Research (CoSAR), Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia

Article history

Received: 30 July, 2018
Received in revised form: 14 October, 2019
Accepted: 17 October, 2019

Keywords

Drying
Moisture content
Sago starch
Starch properties

Abstract

Local people in Sarawak, Malaysia produce sago starch, commonly referred as *lemantak*, using traditional method for authentic meals and delicacies. The quality of *lemantak* degrades with time due to its high moisture content limiting the potential for a wider market, and hence affecting the socio-economy of those whose livelihood depends on sago starch production. The objective of the present work was to evaluate the changes in the properties of traditionally processed dried Sarawak sago starch. In order to achieve this, sago starch was extracted using a well-established traditional process and was dried at 40°C to produce sago starch with moisture contents of 40%, 30%, 20% and 10% wet basis. The effect of moisture content on the physical properties was studied through colour analysis, microscopic analysis, and particle size distribution. Analysis on resistant starch content was also performed. Changes on the hydration and functional properties was monitored by measuring the water absorption index (WAI), water solubility index (WSI), swelling capacity (SC), and gelatinisation behaviour. Lastly, Fourier transform-infrared spectroscopy (FT-IR) was applied to observe the changes in amorphous and crystalline areas. The physical properties analysis showed changes in starch colour and granule surface; but the change on granule size varied. Dried starch with lower moisture content exhibited higher resistant starch, absorption index, and peak temperature, but lower solubility index, swelling capacity, peak viscosity, crystalline index, and amorphous index. It is suggested that moisture content affected the changes in traditionally processed sago starch properties which was influenced by few components namely polyphenol, lipid, amylose-lipid complex, and inter-molecular hydrogen bond.

Introduction

Sago starch has various applications from local meals and delicacies, foods, glue, and cosmetic industries, to the production of bio-degradable plastic, alcohol, ethanol, and acid citric. Malaysia is one of the top leading countries producing and exporting sago starch worldwide; with Sarawak being the largest contributor to this market (Ahmad, 2014). In Sarawak, sago starch is processed commercially by modern factories, and traditionally by small-medium enterprises owned by the locals. Traditionally produced sago starch, commonly referred as *lemantak*, has high moisture content (up to 38.8% w.b.), which is higher than commercial standards. Nevertheless, it still has high demand among the locals due to its suitability for preparing various traditional meals and delicacies (Mustafa Kamal *et al*., 2017a). The maximum standard for moisture content for industrial sago starch is 15% w.b. as stated in the Malaysia Standard of 'Requirements for Industrial Sago Starch' (MS468:1976) while maximum moisture content for edible sago starch is 13% w.b. as stated in the 'Requirements for Edible Sago Starch' (MS470:1992). The demand for traditionally processed sago starch despite its high moisture content creates interest to understand the relation between moisture content and other

*Corresponding author.
Email:mkmaswida@gmail.com

properties of the traditionally processed sago starch (Mustafa Kamal *et al*., 2017a).

The interaction of water with starch brings in several important phenomenon such as swelling, melting, pasting, gelatinisation, and retrogradation, which are widely and intensively applied; not only in industrial processing such as extrusion of cereal based products, and thickening and gelling of sauces and pie fillings, but also in domestic applications such as in soups, porridges and bakery products (Karim *et al*., 2008). Several researchers have reported that moisture content is one of the key aspects that influence starch properties, for instances, the flow properties (Ali and Lamb, 1991), the structural changes (Takahashi *et al*., 1982), gelatinisation and melting temperature (Jang and Pyun, 1996), and retrogradation (Liu and Thompson, 1998).

Sim *et al*. (1991) indicated that two batches of sago starch with different processing times showed similar moisture content (11.8% and 11.9%) but exhibited differences in their protein content (0.015% and 0.06%), amylose-lipid content (25.5% and 23.8%), peak viscosity (590 BU and 555 BU), swelling power (45% and 65%) and varying degrees of pitting between both samples. The results suggested that sago samples have different granular networks, even though their moisture content is similar. Rao and Tattiyakul (1999) found that tapioca granule size increased upon longer drying times at specific temperature but in their work, the change in moisture content was not observed. Ahmad *et al*. (1999) analysed the physical properties of various sago starches provided by factories from different places with moisture content in the range of 10.6% to 20.0%. They concluded that the significant difference found in the starch samples was the amylose content and molecular weight, which were affected by sago palm growth at the time it was harvested, and the pH of water during processing stage. Moreover, Maaruf *et al*. (2001) studied the effect of water content on the sago starch gelatinisation, which was analysed as the ratio of starch to water during gelatinisation for samples with moisture content of 10.4%. Uthumporn *et al*. (2014) demonstrated the relation between moisture content with granule size and amylose content as the result of different growing stages.

To the best of our knowledge, research on quality of traditionally processed sago starch is still very limited. Therefore, the aim of the present work was to determine the quality changes of traditionally processed sago starch during drying process in order to initiate further study on drying process of traditional sago starch.

Materials and methods

Samples were prepared by extracting the sago starch in the laboratory following the method of Mustafa Kamal *et al*. (2017b). Sago barks for the sample preparation was obtained from Kota Samarahan, Sarawak. The obtained fresh (wet and un-dried) sago starch sample was characterised prior to analyses, and labelled as MC40.

The dried samples were prepared by drying the sago starch in a convection oven. Briefly, 150 g of sago starch, which was divided into three lots of 50 g each (samples A, B, C), were placed in an aluminium foil-container, and oven-dried at 40°C. Each sample was dried at different drying times, and the initial and final mass of the samples were recorded. Sample A was dried for 8 h, while samples B and C were dried at 16 and 24 h of drying, respectively. Samples A, B and C were henceforth labelled as MC30, MC20, and MC10, respectively.

During the sample mass measurement, the container was removed from the oven and placed on a weighing balance, and then it was put back in the oven, quickly. This weighing process took place in less than one minute. The moisture content was then analysed following the method of AOAC (2000) using Eq. 1:

$$MC = \frac{M_i - M_t}{M_i} \times 100 \qquad \text{(Eq. 1)}$$

where M_i = weight (g) of sample before drying, and M_t = weight (g) of sample after drying.

Characterisation of sago starch sample

The sago starch sample was characterised following the standard Officials Methods of Analysis 1995 (AOAC, 1995). The protein content was determined through Kjeldahl method with 6.25 of protein-nitrogen conversion factor. Starch sample was burned at 550°C in a furnace. Crude fibre content was extracted with petroleum ether at 80 to 90°C for 14 h in a vacuum condenser. The solution was then dried to a constant weight.

The physical properties of the sago starch were analysed using the procedures described below.

Sago starch granule morphology analysis

Granule morphology of the sago starch was examined using a Scanning Electron Microscope (SEM) TM3030, HTACHI, Japan. A thin layer of starch granule was mounted on a specimen holder and the specimen holder was loaded in a sputter coater. Once metalised, the sample was viewed under

a 2,000× magnification. All optical measurements were performed at room temperature under ambient conditions.

Sago starch colour analysis

Colour analysis of the sago samples was carried out by taking their images manually, and was analysed by using Mat-lab software R2012b which provided the pixel data of samples image in RGB value. The RGB values were then converted into CIE-*L*a*b** value by using a RGB-to-Lab converter program available online (http://colormine.org/convert/rgb-to-lab). *L** measures the luminosity/lightness of the sample (0 = black, 100 = white). In order to calibrate, a white A4 paper was used to mark 100 reading, while black paper was used to mark 0 reading. *a** (green to red) and *b** (blue to yellow) were measured from -60 to +60. Whiteness index (WI) were calculated using Eq. 2 (Ramesh Yadav *et al*. 2006).

$$WI = 100 - \sqrt{(100 - L)^2 + a^2 + b^2} \qquad \text{(Eq. 2)}$$

Particle size distribution of dried sago starch

The mean size distributions of samples were measured by using CILAS 1090 Laser Particle Size Analyser at room temperature. Deionised water was used as the medium for wet size measurement of flours. Sonic measurements were performed to avoid the aggregation of samples.

Resistant starch

The experiment was performed based on AACC (1995) Method 76-13.0. The total starch assay was performed based on Megazyme Amyloglucosidase/ Alpha-Amylase Method (Megazyme, 2019).

Viscosity analysis of sago starch

The viscosity analysis was performed based on MS470:1992. Briefly, the starch samples were examined in a Brabender Amylograph (Brabender GmbH, Duisburg, Germany), pasted at a heating rate of 1.5°C/min from 35 to 95°C, held 15 min at 95°C and cooled down to 50°C. The initial gelatinisation temperature, peak viscosity, breakdown viscosity, and setback viscosity were determined from the amylograph curve.

Water absorption index (WAI), water solubility index (WSI) and swelling capacity (SC) of sago starch samples

WSI, WAI and SC experiments were performed according to Othman *et al*. (2015) with some modifications. Briefly, sago starch samples (2.5 g) and water (30 mL) were vigorously mixed in a 50 mL centrifuge tube, incubated in a water bath at 95°C for 30 min, and then centrifuged (4,000 g, 10 min). The supernatant was collected in a pre-weighed beaker and the residue was weighed after the water was evaporated below 105°C. The percentage of residue with respect to the amount of sago starch used in the experiment was taken as WSI. The weight ratio of centrifuged precipitate to the amount of sago starch used in the test was taken as WAI. The formulas used to calculate WAI, WSI and SC are shown in Eq. 3, 4, and 5:

$$\text{WAI } (g \text{ per } g \text{ dry solis}) = \frac{\text{weight of wet sediment}}{\text{weight of dry sample}} \qquad \text{Eq. 3}$$

$$\text{WSI } (g \text{ per } g \text{ dry solis}),\% = \frac{\text{weight of dry supernatant}}{\text{weight of dry sample}} \times 100 \qquad \text{Eq. 4}$$

$$\text{SC } (g \text{ per } g \text{ dry solis}),\% = \frac{\text{weight of dried sediment}}{\text{weight of sample} \times (1\text{-}WSI)} \times 100 \qquad \text{Eq. 5}$$

FT-IR spectral analysis of sago starch samples

The sago starch samples were recorded on a Shimadzu Fourier transform-infrared spectroscopy (FT-IR) 81001 spectrophotometer. An appropriate amount of starch powder was pressed into a crystal window and the samples were analysed with a resolution of 4 cm^{-1} and average scanning time of 1 min. Furthermore, the spectral resolution range of scan was 4,000 to 400 cm^{-1} (mid-infrared region). The ATR mode was utilised along the measurement. The spectra obtained were transferred into a data analysis package. All optical measurements were performed at room temperature under ambient conditions.

Statistical analysis

All analysis were carried out in triplicate ($n = 3$) and data expressed as means ± standard deviation. One-way analysis of variance (ANOVA) was performed to calculate the significant differences between the means by using the IBM SPSS Statistic 22 software. A significance level of $p \leq 0.05$ was applied. Duncan *post hoc* test was applied to compare the mean of each sample.

Results and discussion

Composition of sago starch samples

The moisture content of fresh/un-dried traditional sago starch was very high (40.21% w.b.), thus giving the starch shorter shelf life as microbial growth becomes greater around moisture content of 10% and above (Abdullah *et al*., 2000). The sago starch sample was mainly composed of carbohydrate (80.45%), but also contained 0.20% ash, 0.15% fat, and protein that were less than 0.10%. The samples showed higher fat content and lower protein content when compared to the result of Ahmad *et al*. (1999). Another work that has similarly higher value for lipid content was from Uthumporn *et al*. (2014) This difference is acceptable as the samples used in the present work were processed traditionally, while Ahmad *et al*. (1999) used sago starch from modern factories around South East Asia. Meanwhile the moisture content for the dried samples were determined to be 30.34%, 20.19%, and 10.25%, which were dried for 8, 16 and 24 h, respectively.

Effect of moisture content on morphology of sago starch granules

Figure 1 shows the SEM micrograph of traditionally processed sago starch sample at 2,000× magnification. Except for MC40, which contained 40.21% of moisture, the rest of samples had been dried to different moisture contents: 30.34% (MC30), 20.19% (MC20) and 10.25% (MC10). As expected, all samples composed of predominantly ovoid granules and some spherical shape with average diameter around 30 µm. Some granules showed truncated end, which is a typical appearances of sago starch granule (Othman *et al*., 2015). In addition, the appearances of each granule in all samples varied as they consisted large, medium, and small broken granules that might have been generated as the result of mechanical injury during extraction.

SEM micrographs show that all granules structure remained intact even at the lowest moisture content since they were dried at temperature lower than neither the pasting temperature, nor the gelatinisation temperature; which is known to disrupt the granular shape. However, granules at lower moisture content (i.e., MC20 and MC10) showed smoother granule surface; while granules at higher moisture content such as MC40 showed some impurities at the surface, presumably bits of proteins and lipids, which are significant properties of native sago starch (Othman *et al*., 2015). It has been suggested that during drying, the water molecules migrate from amylose, but the lipids will penetrate into the granule and bind with the amylose (Rosicka Kaczekmarek *et al*., 2017).

Effect of moisture on sago starch granule size

The starch granule size is an important factor that will affect starch flow properties, apart from its density. In the present work, the mean diameter of sago starch granules for MC40, MC30, MC20, and MC10 were 30.19, 35.08, 34.86, and 35.67 µm, respectively. MC10 showed the highest mean diameter, while MC40 the lowest. Since the changes were not significant, it is suggested that the differences of mean particle size among all samples could be due to the results of inter-batch variability.

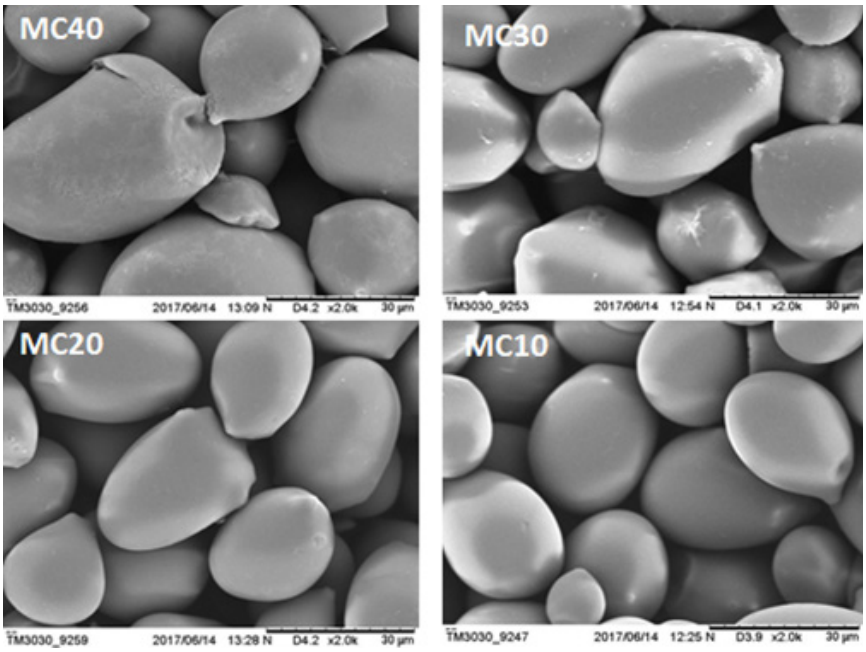

Figure 1. Sago starch granules at different moisture contents (2,000× magnification).

Effect of moisture content on colour of sago starch

Sago starch has the lowest whiteness index among other starches which accounts for its lower price in starch market (Wattanachant *et al*., 2002). The Hunter colour characteristic (*L**, *a**, *b**) of sago starch samples at different moisture contents are shown in Table 1. Hunter *L** values ranged between 75.33 and 85.21, Hunter *a** values ranged between 10.11 and 7.98, while Hunter *b** values ranged between 7.53 and 4.66. The whiteness values varied between 72.29 and 82.56. According to Kaur *et al*. (2013), carbohydrate and protein are the components that may attribute to the *b** value. Statistical analysis showed that the overall colour parameters of samples were affected by different moisture contents. MC40 had the lowest Hunter and whiteness values while MC10 had the highest. Initially, all samples appeared as pale red (pink) colour which indicated either the presence of high level polyphenol oxidase activity or as the effect from the soil condition on which the *Metroxylon sagu* was cultivated (Konuma *et al*., 2012). Changes in the colour of the sago starch are mostly caused by the polyphenol oxidase enzyme activity, which decreases with decreasing water content in sago starch during drying (Alean *et al*., 2016). Thus, this explains the whiter colour observed for MC20 and MC10. Moreover, none of the samples showed browning effect since they were dried at low temperature (40°C).

Table 1. Colour analysis for Hunter *L*, a*, b** and whiteness index of sago starch at different moisture contents.

Sample	*L**	*a**	*b**	Whiteness*
MC40	75.33 ± 0.63^{d}	10.11 ± 0.35^{d}	7.53 ± 0.29^{d}	72.29 ± 0.70^{d}
MC30	78.45 ± 0.46^{c}	9.87 ± 0.18^{c}	6.49 ± 0.10^{c}	75.42 ± 0.41^{c}
MC20	80.33 ± 0.27^{b}	8.43 ± 0.12^{b}	5.42 ± 0.17^{b}	77.93 ± 0.33^{b}
MC10	85.21 ± 0.27^{a}	7.98 ± 0.04^{a}	4.66 ± 0.09^{a}	82.56 ± 0.24^{a}

Data are means of three replications (n = 3) ± standard deviation. Means within a column with different superscripts are significantly different ($p < 0.05$).

Effect of moisture content to the resistant starch value of traditional sago starch

Resistant starch promotes healthy colon through bacterial fermentation. In the present work, sago starch samples from same origin exhibited different resistant levels with respect to their moisture contents obtained at different durations of low temperature drying. The resistant starch of MC40, MC30, MC20, and MC10 was 73.2%, 73.9%, 74.1%, and 75.3%, respectively. Resistant starch is classified into five types based on its digestive rate, which can be related with its formation mechanism. Since the samples had high amount of lipid (14.75%), it is suggested that during the drying experiments, Type V resistant starch was formed as starch interacted with lipid to form single-helical complexes with fatty acids and fatty alcohol, which prevented starch binding or cleavage by amylase (Birt *et al*., 2013). In addition, high level of polyphenol also will increase the amount of Type I resistant starch (Lemlioglu-Austin *et al*., 2012). As drier starch has fewer polyphenols, the resistant starch in dried starch also becomes less than that in wet sago starch.

Effect of moisture content on the hydration behaviour of traditional sago starch

The functional properties analysis including water absorption index (WAI), water solubility index (WSI), and swelling capacity (SC) were conducted on sago starch samples of different moisture contents and the results are shown in Table 2. In this experiment, 8.3% starch-water system was used, and 70°C was selected since it is the best gelatinisation temperature (Adawiyah *et al*., 2013).

Water absorption index (WAI)

The value of WAI is associated with the volume occupied by the starch after swelling in excess water and also can be related with the extent of starch degradation or gelatinisation (Jamal *et al*., 2016). Table 2 shows the WAI value index which ranged between 0.74% and 0.92%. These were considerably low when compared with literatures, which in turn indicated the low level of starch damage and/or gelatinisation (Aboubakar *et al*., 2008; Ndangui *et al*., 2014). The results obtained may suggest that the change in the moisture content tested in the present work affected the value of WAI, insignificantly. More study for a larger range of moisture content is necessary to evaluate the relationship between the water content and the value of WAI in depth. Starch sample with lower moisture content exhibited higher WAI value which suggested that some changes in the degree of engagement between hydroxyl and hydrophilic groups either in between starch chains or in between non-starch molecules that had increased the starch absorption capacity as the result of drying treatment (Aboubakar *et al*., 2008). Apart from that, protein hydration in MC20 and MC10 led to higher charges of polar constituent which may cause the forming of stronger hydrogen bonding with water, as suggested by Jamal *et al*. (2016).

Table 2. Water absorption index (WAI), water solubility index (WSI), and swelling capacity (SC) of sago starch at different moisture contents.

Sample	WAI* (g/g d.b.)	WSI* (%)	SC* (%)
MC40	0.74 ± 0.25^{a}	35.53 ± 0.14^{d}	85.7 ± 0.16^{a}
MC30	0.79 ± 0.23^{ab}	31.26 ± 0.19^{c}	73.7 ± 0.50^{b}
MC20	0.85 ± 0.29^{a}	18.53 ± 0.14^{b}	65.5 ± 0.29^{c}
MC10	0.92 ± 0.31^{ab}	17.15 ± 0.08^{a}	61.4 ± 0.08^{d}

Data are means of three replications (n = 3) ± standard deviation. Means within a column with different superscripts are significantly different ($p < 0.05$).

Water solubility index (WSI)

When the sago starch samples were mixed with water, they exhibited very low solubility with temporary suspension which only occurred when stirred; however, the solubility would increase when the temperature increased, and became highest at 95°C (Ahmad and Williams, 1998). In the present work, the WSI refers to the starch that has successfully dispersed or soluble in water after complete gelatinisation. Table 2 shows the level of starch solubility with regards to their moisture contents, which clearly became less soluble at lower moisture content (17.15%) in MC10, as compared to 35.53% in MC40. Since amylose plays a major role in starch solubility, the formation of amylose-lipid complex in dried starch (Figure 1) would then inhibit amylose leaching and subsequently reduce the amount of soluble amylose, which in turn explains the low WSI value (Copeland *et al*., 2009). Moreover, Ndangui *et al*. (2014) had suggested that starch with larger granule size (in this case is MC10) exhibits lower solubility than starch with smaller granule size (MC40) due to limitation of water penetration into the granule.

Swelling capacity (SC)

When starch-water system is heated, the starch structure becomes weak thus allowing water to penetrate and causes the granule to swell. Swelling capacity of starch refers to the level of water diffusion into starch granule. The SC of sago starch samples are given in Table 2 which shows that MC40 had the highest SC (85.7%) while MC10 had the lowest (61.4%). Previously, Dehnad *et al*. (2016) had suggested that high drying temperature along with long drying time would decrease the swelling in starch, due to thermal degradation. However, the present work found that long drying time in low temperature also led to the decreasing of starch swelling. Meanwhile, according to Ahmad and Williams (1998), starch with lower moisture content exhibited more inter and intra molecular bond than the starch with higher moisture content or native starch due to limited amount of water molecule. Furthermore, according to Birt *et al*. (2013), the entanglement between amylose-lipid complex with amylopectin molecules will also restrict the swelling of starch granule.

Effect of moisture content on pasting properties

Brabender Amylograph was used to observe the pasting characteristic of sago starch at different moisture contents. Table 3 shows the pasting temperature, gelatinisation temperature and peak viscosity (PV). Native sago starch is known as good quality high-viscous starch and high thickening power (Wattanachant *et al*., 2002). In the present work, MC40 indicated the highest PV value of 659 AU, followed by MC30, MC20, and MC10 at 621 AU, 607 AU, and 575 AU, respectively. Since viscosity measured the level of swelling and granule dispersion (Correia and Beirão-da-Costa, 2012), the value always has positive correlation with SC and solubility such as the results found in the present work. Starch with lower moisture content showed lower viscosity due to the presence of more inter and intra molecular bonds that had been formed as the result of water dehydration during drying; which subsequently reduced the number of exposed hydroxyl group (Uthumporn *et al*., 2014). Meanwhile, the peak viscosity temperature varied in small range between 79.5°C to 80.9°C; which also indicated small changes of molecular structure in small granule area, either crystalline or amorphous (Correia and Beirão-da-Costa, 2012). The results of gelatinisation temperature and peak temperature showed that gelatinisation occurred at higher temperature as in starch with lower moisture content. This had given insight of higher level of molecular structure stability, probably due to increased number in inter-molecular bond that had increased difficulty in starch gelatinisation.

Table 3. Pasting temperature, peak viscosity, breakdown viscosity, and setback viscosity of sago starch at different moisture contents.

Sample	Gelatinize Temperature (°C)	Peak Temperature (°C)	Peak Viscosity, PV (AU)
MC40	64.3	79.5	659
MC30	64.1	79.0	621
MC20	64.9	80.6	607
MC10	64.5	80.9	575

Effect of moisture content on crystallinity of sago starch

Presently, Fourier transform-infrared spectroscopy (FT-IR) is being applied as part of starch property analyses as it allows for rapid characterisation (Aboubakar *et al*., 2008; Zeng *et al*., 2011) and the identification of biochemical changes in treated samples (Kizil *et al*., 2002; Huang *et al*., 2006; Yu *et al*., 2015). In addition to that, FT-IR also can provide indirect information on the level of crystallinity, amorphousness, and starch order. In the present work, FT-IR was used to estimate the value of crystallinity, amorphousness, and degree of starch order by analysing the bands at 1,022 and 1,047 cm^{-1} (Braşoveanu *et al*., 2013). Table 4 shows that the crystalline index, amorphous index, and starch order index ranged from 0.288 to 0.152, 0.681 to 0.307, and 0.422 to 0.495, respectively. In general, the results from crystalline and amorphous indices showed that all sago starch were more amorphous than crystalline at the granule surface. Table 4 clearly shows that starch with lower moisture content exhibited lower level of both crystallinity and amorphousness. Crystalline index was found to be lower at low moisture content probably due to the hydration in amorphous region that had pulled apart the crystallites before transforming them to amorphous region (Liu *et al*., 1999). Despite the transformation, the decreasing of amorphous index in lower moisture content was more pronounced than crystalline index. The presence of amylose-lipid complex in amorphous region is suspected to be responsible for this reduction. However, the degree of order varied among the samples which suggested random way of molecular associations or rearrangements during drying (Braşoveanu and Nemţanu, 2014).

Table 4. Intramolecular hydrogen bond index, crystallinity, amorphousness, and starch granule order of sago starch at different moisture contents (Aboubakar *et al.*, 2008).

FT-IR characteristic	Sample			
	MC40	MC30	MC20	MC10
Crystalline index (I_{1047})	0.288	0.281	0.206	0.152
Amorphous index (I_{1022})	0.681	0.660	0.404	0.307
Starch granule order (I_{1047}/I_{1022})	0.422	0.426	0.501	0.495

Conclusion

Low temperature drying to manipulate moisture content had shown some effect on the physical and functional properties of traditionally processed sago starch. Dried starch with lower moisture content showed more whiteness index as polyphenol was reduced, and smoother granule surface as amylose-lipid complex was formed, which was supported by FTIR result. The formation of amylose-lipid complex had influenced the resistant starch content of dried starch. Besides, dried starch of lower moisture content is healthier than starch with higher moisture content as drying influence its mechanism of formation. Large granule size affected the water absorption index, while the presence of amylose-lipid complex affected the starch solubility. The formation of more inter- and intra-molecular hydrogen bonds in starch with lower moisture content had reduced the swelling capacity as well as pasting behaviour. The findings in the present work can be compared with other findings on the effect of drying conditions to provide the database, to optimise the drying process, and to promote the commercialisation of traditionally processed sago starch.

Acknowledgement

The present work was financially supported by a research grant (FRGS/TK02(04)/1304/2015(210)) awarded by the Ministry of Higher Education.

References

Abdullah, N., Nawawi, A. and Othman, I. 2000. Fungal spoilage of starch-based foods in relation to its water activity (aw). Journal of Stored Products Research 36(1): 47–54.

Aboubakar, Njintang, Y. N., Scher, J. and Mbofung, C. M. F. 2008. Physicochemical, thermal properties and microstructure of six varieties of taro (*Colocasia esculenta* L. Schott) flours and starches. Journal of Food Engineering 86(2): 294–305.

Adawiyah, D. R., Sasaki, T. and Kohyama, K. 2013. Characterization of arenga starch in comparison with sago starch. Carbohydrate Polymers 92(2): 2306–2313.

Ahmad, F. B. and Williams, P. A. 1998. Rheological properties of sago starch. Journal of Agricultural and Food Chemistry 46(10): 4060–4065.

Ahmad, F. B., Williams, P. A., Doublier, J.-L., Durand, S. and Buleon, A. 1999. Physico-chemical characterisation of sago starch. Carbohydrate Polymers 38(4): 361–370.

Ahmad, M. 2014. Farmer empowerment to increase productivity of sago (Metroxylon sago spp.) farming. International Journal on Advanced Science Engineering Information Technology 4(3): 5–9.

Alean, J., Chejne, F. and Rojano, B. 2016. Degradation of polyphenols during the cocoa drying process. Journal of Food Engineering 189: 99–105.

Ali, A. B. and Lamb, J. 1991. Changes in moisture content of corn starch during pneumatic conveying. Pertanika 14(3): 237–241.

American Association of Cereal Chemists (AACC). 1995. Approved method of the AACC. 9th ed. United States: AACC.

Association of Official Analytical Chemists (AOAC). 1995. Official methods of analysis of AOAC International. 16th ed. United States: AOAC.

Association of Official Analytical Chemists (AOAC). 2000. Official methods of analysis of AOAC International. 17th ed. United States: AOAC.

Birt, D. F., Boylston, T., Hendrich, S., Jane, J. L., Hollis, J., Li, L., … and Whitley, E. M. 2013. Resistant starch: promise for improving human health. Advances in Nutrition 4(6): 587–601.

Braşoveanu, M. and Nemţanu, M. R. 2014. Behaviour of starch exposed to microwave radiation treatment. Starch 66(1–2): 3–14.

Braşoveanu, M., Nemţanu, M. R. and Duţă, D. 2013. Electron-beam processed corn starch: evaluation of physicochemical and structural properties and technical-economic aspects of the processing. Brazilian Journal of Chemical Engineering 30(4): 847–856.

Copeland, L., Blazek, J., Salman, H. and Tang, M. C. 2009. Form and functionality of starch. Food Hydrocolloids 23(6): 1527–1534.

Correia, P. and Beirão-da-Costa, M. L. 2012. Effect of drying temperatures on starch-related functional and thermal properties of chestnut flours. Food and Bioproducts Processing 90(2): 284–294.

Dehnad, D., Jafari, S. M. and Afrasiabi, M. 2016. Influence of drying on functional properties of food biopolymers: from traditional to novel dehydration techniques. Trends in Food Science and Technology 57(Part A): 116–131.

Huang, C. B., Jeng, R., Sain, M., Saville, B. A. and Hubbes, M. 2006. Production, characterization, and mechanical properties of starch modified by *Ophiostoma* spp. Bioresources 1(2): 257–269.

Jamal, S., Qazi, I. M. and Ahmed, I. 2016. Comparative studies on flour proximate compositions and functional properties of selected Pakistani rice varieties. Proceeding of the Pakistan Academy of Sciences: B. Life and Environmental Sciences 53(1): 47–56.

Jang, J. K. and Pyun, Y. R. 1996. Effect of moisture content on the melting of wheat starch. Starch 48(2): 48–51.

Karim, A. A., Tie, A. P. L., Manan, D. M. A. and Zaidul, I. S. M. 2008. Starch from the sago (*Metroxylon sagu*) palm tree - properties, prospects, and challenges as a new industrial source for food and other uses. Comprehensive Reviews in Food Science and Food Safety 7(3): 215–228.

Kaur, M., Kaushal, P. and Sandhu, K. S. 2013. Studies on physicochemical and pasting properties of Taro (*Colocasia esculenta* L.) flour in comparison with a cereal, tuber and legume flour. Journal of Food Science and Technology 50(1): 94–100.

Kizil, R., Irudayaraj, J. and Seetharaman, K. 2002. Characterization of irradiated starches by using FT-Raman and FTIR spectroscopy. Journal of Agricultural and Food Chemistry 50(14): 3912–3918.

Konuma, H., Rolle R.S. and Boromthanarat, S. 2012. Color characteristics of sago starch as they relate to the growth environment of the sago palm (*Metroxylon sagu* Robb). Journal of Agricultural Technology 8: 273-287.

Lemlioglu-Austin, D., Turner, N. D., McDonough, C. M. and Rooney, L. W. 2012. Effects of sorghum [*Sorghum bicolor* (L.) Moench] crude extracts on starch digestibility, estimated glycemic index (EGI), and resistant starch (RS) contents of porridges. Molecules 17(9): 11124–11138.

Liu, Q. and Thompson, D. B. 1998. Effects of moisture content and different gelatinization heating temperatures on retrogradation of waxy-type maize starches. Carbohydrate Research 314(3–4): 221–235.

Liu, Z., Yi, X.-S. and Feng, Y. 1999. Effect of bound water on thermal behaviors of native starch, amylose and amylopectin. Starch 51(11–12): 406–410.

Maaruf, A. G., Che Man, Y. B., Asbi, B. A., Junainah, A. H. and Kennedy, J. F. 2001. Effect of water content on the gelatinisation temperature of sago starch. Carbohydrate Polymers 46(4): 331–337.

Megazyme. 2019. Resistant starch assay procedure. Retrieved from Megazyme website: https://www.megazyme.com/documents/Booklet/K-RSTAR_DATA.pdf

Mustafa Kamal, M., Baini, R., Mohamaddan, S., Henry Ragai, A. R., Soh Fong, L., Abdul Rahman, N., … and Abdullah, M. O. 2017a. Comparisons of the physicochemical and functional properties of commercially and traditionally processed sago starch. MATEC Web of Conferences 87: article ID 03007.

Mustafa Kamal, M., Baini, R., Mohamaddan, S., Selaman, O. S., Ahmad Zauzi, N., Rahman, M. R., … and Othman, A. K. 2017b. Effect of temperature to the properties of sago starch. IOP Conference Series: Materials Science and Engineering 206: article ID 012039.

Ndangui, C. B., Petit, J., Gaiani, C., Nzikou, J.-M. and Scher, J. 2014. Impact of thermal and chemical pretreatments on physicochemical, rheological, and functional properties of sweet potato (Ipomea batatas Lam) flour. Food and Bioprocess Technology 7: 3618–3628.

Othman, Z., Hassan, O. and Hashim, K. 2015. Physicochemical and thermal properties of gamma-irradiated sago (*Metroxylon sagu*) starch. Radiation Physics and Chemistry 109: 48–53.

Ramesh Yadav, A., Manisha Guha, Tharanathan, R. N. and Ramteke, R. S. 2006. Influence of drying conditions on functional properties of potato flour. European Food Research and Technology 223(4): 553–560.

Rao, M. A. and Tattiyakul, J. 1999. Granule size and rheological behavior of heated tapioca starch dispersions. Carbohydrate Polymers 38(2): 123–132.

Rosicka-Kaczmarek, J., Tkaczyk, M., Makowski, B., Komisarczyk, A. and Nebesny, E. 2017. The influence of non-starch polysaccharide on thermodynamic properties of starches from facultative wheat varieties. European Food Research and Technology 243(12): 2243–2253.

Sim, S. L., Oates, C. G. and Wong, H. A. 1991. Studies on sago starch. Part I: characterization and comparison of sago starches obtained from *Metroxylon sagu* processed at different times. Starch 43(12): 459–466.

Takahashi, K., Shirai, K. and Wada, K. 1982. Structural changes in starch granules of low moisture content during heating. Agricultural and Biological Chemistry 46(10): 2505–2511.

Uthumporn, U., Wahidah, N. and Karim, A. A. 2014. Physicochemical properties of starch from sago (*Metroxylon sagu*) palm grown in mineral soil at different growth stages. IOP Conference Series: Materials Science and Engineering 62: article ID 012026.

Wattanachant, S., Muhammad, S. K. S., Hashim, D. M. and Rahman, R. A. 2002. Suitability of sago starch as a base for dual-modification. Songklanakarin Journal of Science and Technology 24(3): 432–438.

Yu, H., Cao, Y., Fang, Q. and Liu, Z. 2015. Effects of treatment temperature on properties of starch-based adhesives. BioResources 10(2): 3520–3530.

Zeng, J., Li, G., Gao, H. and Ru, Z. 2011. Comparison of A and B starch granules from three wheat varieties. Molecules 16(12): 10570–10591.