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FULL PAPER

Physicochemical properties of tarap *(Artocarpus adoratisimus)* starch

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Abstract

The objective of the research was to investigate the physicochemical characteristics of Tarap fruit starch. In this study, young Tarap fruit starch was extracted and the percentage of total starch, resistant starch, amylose and amylopectin were determined. Scanning electron microscope was used to evaluate the morphological features of the starch granule. Swelling, pasting, gelatinization, retrogradation and *in vitro* digestibility were also investigated. A total of 17.85% starch was successfully extracted from unripe Tarap fruit, whereas the amount of total starch and resistant starch were 89.14% and 47.82%, respectively. The amounts of rapid digestible starch and slowly digestible starch were 6.58% and 23.25%, respectively. Results found that the amylopectin content was higher than amylose (77.15% and 11.97%). The starch granules were round and polygon in shapes with smooth surfaces. The average of starch granules size was range from 6.50 to 8.30 µm with 7.4 µm of mean granule diameter. Pasting properties showed that peak viscosity was observed at about 6.5 min at 73.5°C. Tarap starch gelatinization temperatures (onset, 71.63°C; peak, 74.56°C; conclusion, 78.24°C) and enthalpy of gelatinization (ΔH_{gel}) (3.74 J/g) were higher while the retrograded starches show lower retrogradation temperature and enthalpy than native starches. Unripe Tarap starch showed good potential to be utilized as adhesives and thickener for industrial applications.

1. Introduction

Tarap fruit is a native fruit in Sabah, Malaysia. Botanically it is known as *Artocarpus odoratissimus* and belongs to the *Moraceae* plant family. From a morphology perspective, the fruit can be regarded as an intermediate shape between the jackfruit and breadfruit. Their flesh and seed are such a potential food source but they are not fully exploited (Noorfarahzilah *et al.,* 2017). It is reported that Tarap fruits are rich in phenolic compounds that may contribute to the health benefit when consumed (Abu Bakar *et al.,* 2009). Due to the high carbohydrate content (76.8%) in the pulp, Tarap fruits can be a valuable source of starch. Past research showed that substantial efforts have been made to obtain starches from non-conventional sources to be used in food application. There is a growing tendency towards finding alternative sources of starch from novel and underutilized starch varieties rather than relying on known starch cultivars (Adebowale *et al.,* 2005; Nwokocha and Williams, 2011; Rengsutthi and Charoenrein, 2011).

Starch is an abundant source of energy stored in plants and it is the second largest biomass after cellulose. Lately, the growing commercial value of starch is due to demand by large industry, small and medium enterprises as a source of raw material in the manufacture of food, cosmetics, paper, textile and pharmaceutical (Vaclavik and Christian, 2008; Othaman *et al.,* 2010). The use of starch in the food industry is expanding, particularly in the production of food products that act as a thickener, stabilizing agent and also provide a good product texture. This prompted more studies focusing on non-conventional starch carried out in an effort to diversify its sources of starch from local agricultural products that can be commercialized. Identification of native starch sources is required for desired functionality and unique properties. The physicochemical properties and functional characteristics that are impacted by the starches to the aqueous systems and their uniqueness in various food applications vary with the biological origin

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(Svegmark and Hermansson, 1993).

It is well known that starch is composed of a mixture of two distinct macromolecules, namely amylose and amylopectin, where both the granules vary in size and molecular structure. The difference in the two macromolecular structures affects the functional features such as starch pasting viscosity, elasticity and strength of the gel, and its gelatinization temperature (Jane *et al.,* 1999; Tattiyakul *et al.,* 2007). Application in the starch industry is dependent on the functional characteristics of starch, which vary according to botanical resources (Yuan *et al.,* 2007; Wickramasinghe *et al.,* 2009) as well as influenced by the shape and structure of starch molecules (Wang and White, 1994).

Additionally, in terms of nutrition, starches are classified on the basis of their rate and extent of digestion into three categories; rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS). Resistant starch is defined as the fraction of starch in foods that are resistant to digestive enzymes (Haralampu, 2000), cannot be digested in the small intestine, but may be fermented in the large intestine (Englyst *et al.,* 1992). Englyst *et al.* (1992) defined RDS as the starch fraction that causes a rapid increase in blood glucose level after ingestion, indeed SDS is the starch fraction that is digested slowly but completely in the human small intestine which is good in stable glucose metabolism, diabetes management, mental performance, and satiety (Lehmann and Robin, 2007). However, starch digestibility is largely ascribed to the plant source and is dependent on the physicochemical properties of the starch. Thus, the exploration of the nutritional value of starch in food is very important in order to increase the production of functional food products that have added value especially in terms of health improvement.

Furthermore, there is still no information and/or any research related on the physicochemical properties of Tarap fruit starch in Sabah, Malaysia. Hence, this study was undertaken to identify the characteristics of the physicochemical young Tarap fruit starch content including the total starch, resistant starch, and *in vitro* starch digestibility, amylopectin/amylose content, swelling capacity, starch granule morphology, pasting properties, and thermal properties. It is hoped that the data generated from this study will complement the search for novel starch sources which will be useful for food industrial applications.

2. Materials and methods

2.1 Materials

The unripe fruits of *A. odoratissimus* were collected from different locations (Sipitiang, Kota Marudu and Tenom) in Sabah, Malaysia during September – November 2012 (fruit seasoning).

2.2 Isolation of Tarap fruit starch

Tarap fruit starch was isolated using the method described by Agboola *et al.* (1991) with some modifications. The grated pulp was suspended in 5 L of distilled water for 12 hrs to allow the starch to come out of the pulp. The suspended pulp was sieved using a muslin cloth with retained fibre. The fibre was rewashed to remove adhering starch. The extracted starch was allowed to sediment for 4 hours, the supernatant was decanted off and the starch washed with 5 L of distilled water twice to remove proteins and fibre and finally sediment for another 4 hrs. The supernatant was then decanted. The sediment was washed with water three times. The slurries were centrifuged at 2,000 x *g* for 15 mins at 4°C. The supernatant was drained and the upper brown sediment was scraped and the remaining was washed with distilled water for 3 times and centrifuged at 2,000 × *g* for 15 mins at 4°C. Finally, the extracted starch then dried using hot air at 40°C for 12 hrs. The dried starch was grounded with a mortar and passed through a sieve (0.15 mm mesh size), packaged in an air-tight container until further analysis.

2.3 Morphological characteristics of starch granules

The starch sample was mounted on a scanning electron microscopy (SEM) stub with double-sided adhesive tape and coated with gold. Scanning electron micrographs were taken with a JEOL JSM-5600LV microscope (JEOL, England). The average of granule size was determined by using the width and length of 300 granules from SEM micrograph.

2.4 Total starch

The total starch was determined using the total starch Megazyme assay kit, a total starch assay kit based on the use of thermostable a-amylase and amyloglucosidase (Megazyme International Ireland Limited, Wicklow, Ireland) (McCleary *et al.,* 1997) and this method has been adopted by AOAC (Method 996.11) and AACC (Method 76.13).

2.5 Amylose/Amylopectin content

Amylose and amylopectin content were determined using Megazyme Amylose/Amylopectin Assay kit (Megazyme International Ireland Limited, Wicklow, Ireland).

2.6 Resistant starch

Resistant starch content was determined by a Megazyme Resistant Starch Assay Kit (AOAC Method.

2002.02) (McCleary *et al.,* 2002).

2.7 In vitro digestibility starch

In vitro starch digestibility was analysed following the method described by Englyst *et al.* (1992) as modified by Chung *et al.* (2006). The glucose released was measured using a glucose oxidase-peroxidase (GOPOD) reagent kit (K-GLOX, Megazyme Bray, Co. Wicklow, Ireland) by absorbance at 510 nm against the reagent blank. This was then converted into starch by multiplying the amount of glucose by 0.9. The rate of starch digestion was expressed as a percentage of the total starch hydrolysed at different times (30, 90, 120 mins). The 30 and 120-min hydrolysis represented the rapidly digestible starch (RDS) and slowly digestible starch (SDS) respectively (Rosin *et al*., 2002). The equation by Rashmi and Urooj (2003) was adopted for the calculation of starch digestion Index (SDI) = RDS/ TS X100.

2.8 Starch swelling power

Starch (0.1%, w/w, dry basis) was dispersed in distilled water by means of a magnetic stirrer. Dispersion aliquots (10 g) containing 1 mg/mLstarch was transferred into pre-weighed tubes, sealed and immersed in a thermostatic water bath equipped with a mechanical shaker for 30 mins from 60°C to 90°C at 10°C intervals. The samples were agitated throughout the heating period to maintain a starch suspension. Then, the samples were centrifuged at 1500 rpm for 10 mins and the supernatant was carefully drawn off. The weight of the paste was determined and used to calculate the swelling power as the weight of paste divided by the original weight of dry starch.

2. 9 Pasting properties

The pasting profiles were analysed using a Newport Scientific Rapid Visco Analyser 4 (RVA-4) (Newport Scientific, Warriewood, Australia) (Hasmadi *et al.,* 2010). A total of 2.5 g of the sample was added with 25.5 g distilled water followed by mixing in the canister and placing in RVA. The suspension was kept at 25^{o}C for 2 mins before heat to 95^{o}C for 6 mins at 13.5^{o}C/min and keep at 95^{o}C for 3 mins. Further, it was cooled to 25^{o}C for 14^{o}C/min for 6 mins and keeps at 25 mins for 2 mins. From the RVA plots, the peak viscosity and final viscosity are determined. The average value is obtained by three repetition measurements.

2.10 Gelatinization properties

The starch gelatinization properties were measured using a Perkin Elmer Pyris 7 DSC (Perkin-Elmer Co., Norwalk, CT) as described by Hasmadi *et al.* (2010). A total of 3.0 mg of the sample with 7.0 mg of distilled water was hermetically sealed in DSC pans and keep at room temperature for 12 hours. Further, the sample was scanned against an empty pan by heating from 5 to 95°C at 10 °C/min. The empty pan was used as a reference. Starch gelatinization parameters, given by DSC thermogram, are the onset temperature, the conclusion temperature, the peak temperature and the enthalphy.

2.11 Retrogradation properties

The starch retrogradation properties were measured using a Perkin Elmer Pyris 7 DSC. The sample pans containing the starches were kept at 4°C for one week to study retrogradation properties. The pans were heated at a rate of 10°C/min from 40-110°C and cooled at the same rate to 40°C. Enthalpy of retrogradation (ΔH_{ret}) was calculated for the endotherms and the exotherms. Percentage of retrogradation (%R) was calculated as (enthalpy for retrogradation/enthalpy for gelatinization) x 100.

2.12 Statistical analysis

All determinations were replicated three times; mean values and standard deviations were reported.

3. Results and discussion

3.1 The percentage recovery of starch extraction

A total of 17.8% of starch was extracted from young Tarap (Table 1). The amount recorded was higher than starch extracted from young breadfruit (14.3%) (Akanbi *et al.,* 2009) but lower than jackfruit seeds (26.1%) as reported by Rengsutthi and Charoenrein, (2011). Starch extraction yield is influenced by the various methods of drying and starch extraction method. In addition, the amount of starch extracted is dependent on the maturity of the fruit, variations and climatic differences and agronomic crops as reported by Rahman *et al.* (1999).

Table 1. The percentage of starch extracted from unripe Tarap starch

Parameter	Percentage (%)
Extracted starch	17.85±0.20
Total starch	89.14±2.20
Resistance starch	47.82±1.50
Digestible starch	41.32±0.00
Amylose	11.97±0.15
Amylopectin	77.15±0.22

The mean value (n = 3) ± standard deviation

3.2 Morphological characteristics of the Tarap starch granules

Image of Tarap starch granules under SEM found

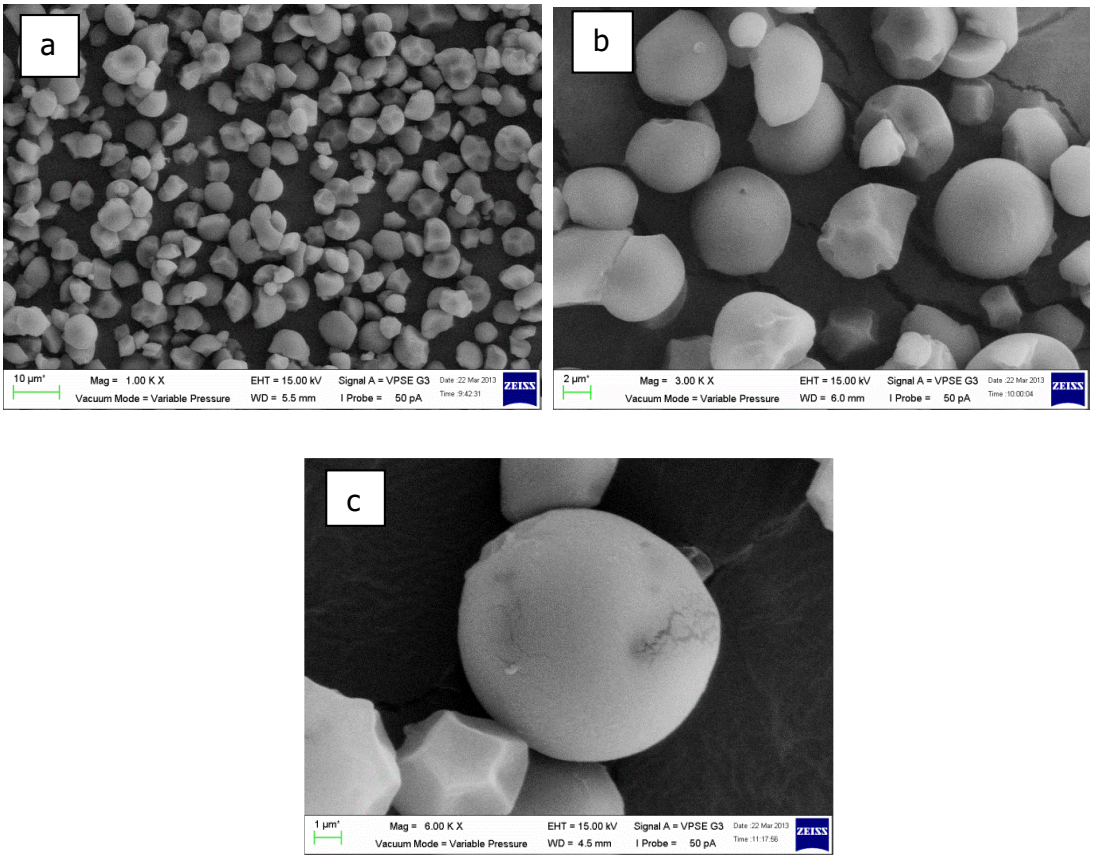

Figure 1. Microfigure SEM of Tarap starch; (a) 1,000 x, bar = 10 µm; (b) 3,000 x bar = 2 µm; (c) 6,000 x bar = 1 µm.

that most of the granules were round and polygonal with a smooth surface as shown in Figure 1. The morphology is similar to corn starch granules as reported by Rengsutthi and Charoenrein (2011). Morphology of starch granules depends on the biochemistry of chloroplasts or amyloplasts refers to physicological of the plant (Badenhuizen, 1969). The observation of Tarap starch granules found that there are broken or damaged starch caused by the impact of the extraction process which similar finding was reported by Oates and Powell (1996).

The size of Tarap starch granules was in the range of 2.0 - 8.5 µm with the mean size of 7.4 µm for 300 starch granules. The size is smaller than corn starch, 13.7- 13.9 µm and potato starch, 30.5 - 42.0 µm (Singh *et al.,* 2003; Rengsutthi and Charoenrein, 2011). According to Hoseney (1998), starch granules can be categorized into two groups, small size of cereal granules (5-10 µm) and large granules size (25-40 µm). The size and shape of starch granules also explain the basic features of plant biology (Delcour and Hoseney, 2010). Previous research has reported that the morphology and size of the starch granules influenced the physicochemical properties such as percentage of light penetration, swelling and water absorption capacity (Singh *et al.,* 2003; Rengsutthi and Charoenrein, 2011). Thus, the average Tarap starches granules categorized as small granules that will improve the efficiency of the starch to absorb water and maximize the ability of starch to swell by the presence of water and heat temperatures that also affect the pasting properties of starch.

3.3 Total starch content

Tarap starch contains 89.14% of total starch and it is estimated the starch may contain ≈ 1.17% as gross amounts of ash, protein, and fat. The moisture content of 9.69% was obtained from the Tarap starch. Previous studies found that the amount of total starch of taro (88.60%), yam (81.72%) and sweet potato (84.15%) reported by Aprianita *et al.* (2009) was lower than Tarap starch. Total starch content for jackfruit seed flour and young breadfruit were 77.8 g/100 g and 98.6% as reported by Steve *et al.* (1995) and Tananuwong *et al.* (2002), respectively. Determination of total Tarap starch is important as the starch in food sources reported giving an impact on some functional properties such as its swelling, gelatinization, pasting properties, starch processing and the formulation of food. In addition, features such as the appearance of starch, size and structure of starch also affect the quality of food products (Tian *et al.,* 1991). Therefore, the total Tarap starch might be affecting the functional properties of starch, which also depends on the structural characteristics and the ratio of macromolecules present in the starch.

3.4 Amylose and amylopectin content

The amylopectin content of Tarap starch is 86.55% which is in agreement with the value reported by Akanbi

et al. (2009) for breadfruit starch. Amylose and amylopectin determination showed a composition of 77.15% and 11.97%, respectively. The result obtained is showing similar trends as reported by Akanbi *et al.* (2009). Amylose content in Tarap starch is lower than unripe banana starch, 20.00 - 25.00%, corn starch, 24.30%, potato starch, 28.08%, and jackfruit seed starch, 32.14% (Rengsutthi and Charoenrein, 2011). This clearly shows that Tarap starch is high in amylopectin where it is should be suitably used as a thickener, adhesive agent and a stabilizing agent to provide a good texture in the food product. In addition, low amylose ratio in Tarap starch will allow the starch absorbs more water and swelling well at high temperatures and might be good in pasting properties. Therefore, Tarap starch tends to be sticky and vicious as compaction in food processing as adhesives and thickeners. In term of health, the high amylopectin content in starch was reported to be able to increase the amount of the hormone insulin in the human body (Behall and Howe, 1998).

3.5 Resistant starch content

Tarap starch contained 47.82% of resistant starch with the ratio of resistant starch to total starch is 1: 2. The previous study found that the amount of resistant starch in taro starch (44.98%) was lower than the starch in Tarap (Aprianita *et al.,* 2009). Resistant starch for corn starch, potato starch and tapioca starch were 7.83%, 79.30%, and 80.80% (Chen *et al.,* 2010). Total resistant starch in Tarap starch is higher than jackfruit seed starch (26.99%) (Phrukwiwattanakul *et al.,* 2014) and other sources such as rice grains (0.60%), and wheat flour (0.60%) (Liu *et al.,* 2006). Many studies in humans show that resistant starch can have positive health benefits such as lower blood sugar levels, reduce insulin secretion and improve digestion (Fuentes-Zaragoza *et al.,* 2010).

3.6 In vitro starch digestibility

Results for Tarap starch in vitro starch digestibility at 30, 90, 120 and 180 mins are based on the amount of glucose produced, mg per 100 g of the sample are shown in Table 1. The total percentage of digestible starch found in Tarap starch was 41.32% where the value is lower than digestible starch present in taro starch (51.22%) and potato starch (98.95%) (Aprianita *et al.,* 2009). In addition, Tarap starch has lower rapid digestible starch at 30th min (6.58%) compared to slow digestible starch at 120th min (33.25%) (Table 2). This shows Tarap starch required a longer time to complete the enzymatic hydrolysis and the digested rate increased for slow digestible starch that is good for digestive purposes. The previous study also found that the resistant starch content of the samples obtained by hydrolysis method (Englyst *et al.,* 1992) showed no significant difference ($p>0.05$) with the values obtained by the AOAC (2000) and AACC (2000) methods. This indicates that both the data collected is accurate and persist. Tarap starch was found to have a relatively high resistant starch, which also contributes to a good digestive system.

Table 2. Percentage of in vitro starch digestibility of unripe Tarap starch at 30, 90, 120 and 180 minutes

Parameter	Digestibility reference	in vitro digestibility (%)
RDS	30	6.58±1.05
SDS	120	33.25±2.11
RS	180	47.40±1.16
pGI	90	56.20±0.70
DSI	-	6.65±0.45

The mean value (n = 3) ± standard deviation. RDS = fast digestible starch, SDS = slowly digestible starch; RS = resistant starch, DSI = Index of starch digestion, DSI = (RDS / Starch total) x 100

Predict glycemic index (PGI) value measured based on the percentage of digestible starch obtained at the 90th minute. Values obtained (56.20%) was less than 70% of the glycemic index (GI) and categorized as medium glycemic content (Allen *et al.,* 2012). According to Chiu *et al.* (2011), the GI is very important information in any foods that high in carbohydrates and low intake of GI values will give better health. In addition, the digestible starch index (DSI) of Tarap starch is low as the starch fraction that can be rapidly digested and hydrolyzed is lower than the total starch. Therefore, it can be concluded that Tarap starch has good nutritional value with the benefit of resistant starch and high in slowly digestible starch, medium in glycemic index value and low digestibility index.

3.7 Swelling capability

Figure 2 depicts the swelling capacity of Tarap starch at 60^{o}C, 70^{o}C, 80^{o}C and 90^{o}C. The swelling capacity of Tarap starch increases with increase in temperature. This is in agreement with findings of Adebowale *et al.* (2005). Termination of hydrogen bonds between molecules begins at temperatures below 70^{o}C resulted in enhancing the development of starch. This explains the increase of swelling as soon as the water is absorbing (De la Torre-Gutiérrez *et al.,* 2008). Starch molecules bind with water molecules through hydrogen bonding. Thus, when the bond between the hydrogen and the starch molecules disintegrate, the hydrogen replaced by hydrogen bonds and water after gelatinization process.

Generally, amylose dissolves in water at elevated temperatures. As the temperature rises, gelatinization occurred, the starch granules ruptured, and amylose

released out of the granules. This explains that at 90°C, more amylose starch released (Akanbi *et al.,* 2009; Rengsutthi and Charoenrein, 2011). Other factors were also reported the presence of lipids (Galliard and Bowler, 1987) and low protein will enhance the swelling and solubility of starch granules (Singh *et al.,* 2003) however not determined in this study.

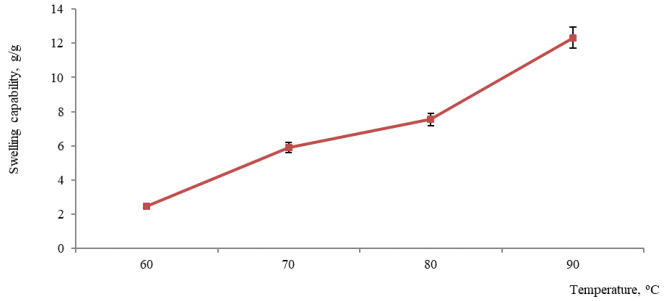

Figure 2. Swelling capability of Tarap starch at different temperatures

3.8 Pasting properties

Studies on the pasting properties of Tarap starch was carried out using RVA and the results are shown in Figure 3. Viscosity parameters determined during the swelling process as the starch is pasting and the soluble material released from starch granules (Sandhu and Singh, 2007). It was found that the pasting peak temperature of Tarap starch is 73.50°C occurred at 6.52 minutes (Table 3). This is influenced by the low amylose content that gives good pasting development as reported by Rengsutthi and Charoenrein (2011). However, the temperature is lower than jackfruit seeds starch (85.83°C) reported by Mukprasit and Sajjaanantakul (2004). This is because the jackfruit seed starch granules contained high amylose which required high temperature for the starch granules to burst out before forming a paste. This also led to a slower peak time (8.74 mins) compared to Tarap starch. Thus, Tarap starch required moderately high energy and can be cooked quickly as compared to jackfruit seeds starch.

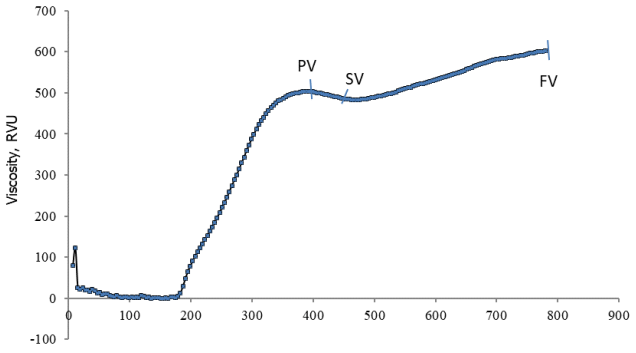

Figure 3. Pasting properties of Tarap starch. PV = Peak viscosity, SV= Setback viscosity, FV = Final viscosity.

The maximum viscosity (PV) of Tarap starch found is higher than jackfruit seed starch, 432.43 RVU (Mukprasit and Sajjaanantakul, 2004) and cassava starch (223.88 RVU) (Rengsutthi and Charoenrein, 2011), which shows the suitability of the starch acts as a thickener. The factors that affect the peak viscosity of Tarap starch are its swelling capability and the possible existence of hydrophobic interaction effects. This was agreed by Singh *et al.* (2006) that there is a positive correlation between peak viscosity and its swelling capability. Hydrophobic interactions occur when the presence of the hydrophilic component is low in starch, such as lack of interaction between the protein and water molecules.

In addition, the final viscosity (FV) (602 RVU) of the Tarap starch found to be lower than potato starch (695.30 RVU) but higher than jackfruit seed starch (39.67 RVU) and cassava starch (66.25 RVU) (Rengsutthi and Charoenrein, 2011). Final viscosity measured the ability of the starch to form viscous paste after cooking and cooling.

The setback viscosity (SV) of Tarap starch was 482.70 RVU, higher than the value recorded for commercial starches, i.e wheat and corn but lower than potato, sweet potato and cassava, as reported by Li *et al.* (2014). According to Charles, (2004), the setback is referred to as the degree of re-association between the starch molecules involving amylose. The set back value is reflecting the degree of retrogradation of a starch paste. High amylose will accelerate retrogradation than low amylose starch (Sriroth and Piyachomkwan, 2003). As Tarap starch low in amylose, the tendency to retrograde is slower compared to other native starch such as corn starch, rice starch and wheat starch (Jane *et al.,* 1999).

The final viscosity of Tarap starch was determined to find out the ability of starch to form a viscous paste. It is indicated by the alignment of the amylose molecules during the cooling period after gelatinization and a formation of a gel network. The value obtained 602.20 RVU was higher than jackfruit seed starch (489.21 RVU) (Mukprasit and Sajjaanantakul, 2004). Tarap starch molecules tend to clump together especially during retrogradation. According to Sandhu and Singh (2007), the final viscosity, peak viscosity, viscosity and setback viscosity of starch has a positive correlation with the swelling power as similar to the Tarap starch properties.

3.9 Gelatinization characteristics

Results on the gelatinization characteristics of Tarap starch using DSC with ratio water to starch, 3:1 as shown in Table 3. Tarap starch was found to have lower onset

Table 3. Thermal properties of unripe Tarap starch

Parameter	Gelatinization	Retrogradation
Onset temperature, °C	71.63±0.08	59.81±0.11
Peak temperature, °C	74.56±0.04	62.15±0.15
Conclusion temperature, °C	78.24±0.10	66.35±0.08
Transition temperature, °C	6.69±0.04	6.53±0.03
Enthalpy energy, J/g	11.50±0.05	3.74±0.12
% Retrogradation		32.52±0.02

Mean (n=3) ± standard deviation, % Retrogradation = Ratio of retrogradation enthalpy to gelatinization enthalpy.

temperature (71.63°C) than yam starch (75.00°C), taro starch (76.80°C) and jackfruit seed starch (82.92°C) but higher than potato starch (61.55°C) and tapioca starch (63.00°C) (Gunaratne and Hoover, 2002; Peroni *et al.,* 2006; Kittipongpatana and Kittipongpatana, 2011). The gelatinization temperature is dependent on the short-chain branches of amylopectin (Jane *et al.,* 1999).

The peak temperature obtained is an indicator of the content of amylopectin crystallization where the quality can be measured in terms of the length of the double helix (Singh *et al.,* 2003). The gelatinization peak temperature of the Tarap starch is lower than the jackfruit seed starch (86.01°C) (Kittipongpatana and Kittipongpatana, 2011), and yam starch (83.00°C) but higher than cassava starch (71.50°C) and potatoes starch (66.3°C) (Gunaratne and Hoover, 2002). Normally, the high gelatinization peak temperature was influenced by the architecture and long double helix which requires high temperatures to break the bond completely (Karim *et al.,* 2000).

The gelatinization temperature range of Tarap starch (71.63 – 78.24°C) was higher than the gelatinization temperature range reported by Peroni *et al.* (2006) for cassava starch (61.55 - 72.94°C) and potato starch (62.85 - 77.91°C) as well as potato starch (59.60 - 76.00°C) (Gunaratne and Hoover, 2002), but was lower than jackfruit seed starch (82.92 - 91.23°C), yam starch (75.0 - 91.2°C) and taro starch (76.8 - 95.2°C) (Gunaratne and Hoover, 2002; Kittipongpatana and Kittipongpatana, 2011).

The difference in gelatinization temperature of starch reported influenced by several factors, i) the molecular structure of amylopectin in terms of amylopectin branch chain length and, ii) the composition of starch in terms of the ratio of amylose to amylopectin content of complex lipids, chain amylose and phosphorus content, and iii) crystallization of amorphous granules (Gunaratne and Hoover, 2002). Gelatinization temperature of Tarap starch is high compared to cassava starch and sweet potato starch reported by Peroni *et al.* (2006) shows that there's a strong bond in Tarap starch granules. Tarap starch found to have high amylopectin that leads to high molecular crystallization.

The study also found that gelatinization enthalpy of Tarap starch (11.50 J/g) was in the range of normal enthalpy of starch that is 10-20% (Eliasson and Gudmundsson, 1996). The enthalpy for tapioca starch, sweet potato and jackfruit seeds starch were reported to be 10.4 J/g, 12.9 J/g and 15:19 J/g, respectively (Peroni *et al.,* 2006; Kittipongpatana and Kittipongpatana, 2011). In addition to measuring the quality and quantity of crystallization, enthalpy is an indicator of the loss of molecular order in starch granules (Singh *et al.,* 2003). According to Gunaratne and Hoover (2002), the molecular structure of amylopectin and the layout of the granules is a key factor in a difference starch gelatinization characteristics. The higher the amylopectin content, the increasing the crystallization of starch granules and hence more energy is required to break the bond amylopectin.

3.10 Retrogradation properties

The molecular interactions (hydrogen bonding between starch chains) that occur after cooling of the gelatinized starch paste are known as retrogradation. The study on the retrogradation properties of Tarap starch was conducted by DSC as shown in Table 2. Degree of retrogradation of Tarap starch obtained is 32.52%. The value is lower than a few starches such as potato starch (43.40%), corn starch (47.00 - 47.60%) and wheat starch (33.70%) reported by Jane *et al.* (1999). The retrogradation percentage of starch is typically lower than the gelatinization enthalpy (Karim *et al.,* 2000). The retrogradation temperature range for Tarap starch is higher than sweet potato starch (42.04 - 66.28°C) and retrograded cassava starch (42.73 - 61.98°C) with the enthalpy of 6.4 J/g and 2.7 J/g, respectively as reported by Peroni *et al.* (2006). However, the retrogradation enthalpy of Tarap starch (3.74J/g) is higher than cassava starch reported by Peroni *et al.* (2006). The transition temperatures of retrogradation were found to be lower than the gelatinization temperatures. This might be due to the fact that recrystallization of amylopectin branched chains occurred in a less ordered manner in stored gels, as it is present in native form.

4. Conclusion

Results from the study showed that Tarap starch has a lot of potential in the food industry, especially its uses as a thickener and binding agent in the food systems. This study suggested that young Tarap fruit starch has a good potential for food formulation because of its low in amylose and high in amylopectin. The high amylopectin presents in young Tarap fruit starch promotes very useful in many food and industrial applications especially where high thickening power is desired. Tarap starch also has high in SDS and less than 70% of glycemic index value that is beneficial in health, especially in the digestive system.

Conflict of Interest

The authors declare no conflicts of interest.

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