The influence of temperature in swelling power, solubility, and water binding capacity of pregelatinised sweet potato starch

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Abstract. Sweet potato is a common tuber in Indonesia, however it is less popular than cassava and corn. Sweet potato is also rich for starch that can be used for many industrial applications, although it still have many drawbacks in native form. Pregelatinization can be used to overcome those drawbacks and increase its value. The swelling power (SP), solubility (S), and water binding capacity (WBC) of pregelatinized white sweet potato starch were analyzed. The starch were pregelatinized with different temperature at 35, 40, 45, 50, 55, 60°C. The swelling power and solubility of sweet potato starch ranged from 16.26-30.30 g/g and 1.58-26.39 %, respectively. Moreover, the WBC obtained are 76.07-232.37 %. Pregelatinized sweet potato starch showed a higher SP, S, and WBC as the increasing of temperature until some point. The variation obtained in the starches’ properties was important for some industrial requirements.

1. Introduction
Starch is polysaccharide in the form of granules and can be used in many industrial applications due to its gelatinisation properties [1]. Sweet potato is one of the crop plants commonly found in Indonesia. Indonesian sweet potato production increases from 101,813,946 tonnes in 2012 up to 105,190,501 tonnes in 2016. It makes Indonesia as the one of the largest producers of sweet potato in the world. In Indonesia, sweet potato (Ipomea batatas Lam.) utilisation still low compare to cassava or corn. However, local people use it as a source of energy, vitamins, and minerals for humans and livestock directly. Nevertheless, its usage can be further improved to increase its economic value.

When starch is heated with water and limited shear, starch granule can swell into larger form and amyllose leaching can occurred [2], it happens when the gelatinisation of starch begin. Swelling happen along the amorphous region, while the crystalline region do not expand during swelling and stress increases at the interface [3]. Hence, at a certain point, the crystalline region is irreversibly broken and gelatinisation is initiated. The initial of starch gelatinisation usually occurs between 50-70°C [4].

The starch with high SP and S suitable for instant product manufacture, such as porridge which have high viscosity [5]. Sweet potato starch can be used in many industrial applications, but native starch still have many disadvantages due to its limited properties towards processing conditions and low viscosity [6]. Starch modification can be done to overcome this main drawback.

Pregelatinisation is one of physical modification to produce cold-water swellable forms with improves flowability due to its loss of crystallinity structure [7]. Pregelatinised starch showed higher...
WBC of starch as a consequence of the disruption of internal structure of starch granule [8]. This study was conducted to investigate the functional properties of white sweet potato starch due to the influence of temperature in pregelatinisation.

2. Materials and Method
2.1. Preparation of sweet potato starch
White sweet potato Sembowo variety were purchased from a local market in Kulonprogo, Yogyakarta, Indonesia. Tubers were washed to remove dirt and soil. After that, these tubers were peeled and grated. The water was added into grated tuber and filtered. The filtrate was precipitated, and the water were removed. The sediment was drained, sieved, kept in dark bottle with silica gel.

2.2. Preparation of pregelatinized starch
The starches were fully pregelatinized using the method described by some workers and in The Pharmaceutical Codex [9]. The starch was weighted 100 g and dispersed in 100 mL of distilled water. The mixture was heated in different temperature 35, 40, 45, 50, 55, 60°C with constant stirring for 10 minutes to form a paste which was crisp-dried in an oven. The starch was pulverized, sieved through a 60-mesh screen, and kept for further analysis.

2.3. Swelling power and solubility
SP were determined by using Leach method with some modification [1, 9, 10]. A solution of starch (1%) was made and heated in water bath maintained at 90°C for 30 minutes with constant stirring and cooled. The suspension was centrifuge at 3200 rpm for 10 minutes and the supernatant removed. The precipitated part was weighted and calculated for SP value. After that, the supernatant was drained in petridish, weight, and calculated for S value.

2.4. Water binding capacity
WBC were determined by using Medcalf method with some modification [10]. A suspension of 3 g (dry basis) starch in 60 ml distilled water was agitated for 1 hour and centrifuge at 3200 rpm for 10 minutes. The excess water was removed, and the precipitated part was weighted and calculated for WBC value.

2.5. Fourier transform infrared (FT-IR) spectra
Native and pregelatinised starches samples were characterised by using a FTIR spectrometer (Shimadzu 8400S, Japan). The FTIR spectrum between 400 cm\(^{-1}\) and 4000 cm\(^{-1}\) were measured.

2.6. Morphological properties
Scanning electron micrographs of native and pregelatinized starches were obtained with a scanning electron microscope (Hitachi TM3000, Japan). Starch samples were coated with palladium. Then it was placed in microscope with an accelerating potential of 15 kV during micrography process.

2.7. Rheological measurement
The flow behavior of all samples was determined using a rheometer (TA Instruments DHR-1, USA), with a parallel plate system (25 mm dia.) at a gap of 500 mm. Each sample was submitted to a shear rate from 10 to 1000 s\(^{-1}\). and the data were fitted to the well-known power-law model.

2.8. Statistical analysis
The whole study was repeated, and each value represents the mean of three replicates. The effect of temperature on tested parameters were determined by analysis of variance, using Minitab 17.0 version with p≤0.05.
3. Results and Discussion

3.1. The influence of temperature on SP and S properties

The SP and S properties of white sweet potato starch are shown in Table 1. The SP and S of sweet potato starch ranged from 15.71-30.47 g/g and 5.25-27.55 %, respectively. Native sweet potato starch has the SP and S range from 7.8-31.1 g/g and 1.5-9.5%, respectively [11]. SP represent an evidence of interaction between amorphous and crystalline region. During the gelatinisation temperature, the starch granule has a limited swelling properties which only a small amount of starch is solubilised, but at higher temperature, there is an increase in SP value and a large amount of starch leaks [12]. The solubility of starch increased with the increasing of temperature. At high temperatures, the increasing of S value indicated an increase of solubilised amylopectin and this increase was enormous after granule disruption [13].

The SP and S of sweet potato starch are reduced after 55°C (Figure 1 and 2), which happen due to the initial gelatinisation of the starch. The lowering of SP value in these starches happen due to the loss of granule integrity after successively swelling. The decrease of S value and amylose leaching were positively correlated with SP value, suggesting solubilisation along with granular swelling [13].

Table 1. The effect of temperature on swelling power (SP) and solubility (S) of sweet potato starch (n=3)

| Temperature (°C) | SP (g/g)  | S (%)    |
|------------------|-----------|----------|
| Native           | 16.26±0.52| 1.58±0.07|
| 35               | 17.09±0.61| 8.66±0.35|
| 40               | 19.30±0.46| 8.75±0.15|
| 45               | 20.44±0.93| 11.90±0.21|
| 50               | 27.23±0.77| 16.55±0.57|
| 55               | 30.30±0.61| 26.39±1.14|
| 60               | 29.40±0.24| 16.72±0.31|

(a) (b)

Figure 1. The influence of temperature on a) SP (g/g); b) S (%)
3.2. The influence of temperature on WBC properties

The WBC of white sweet potato starch are shown in Table 2. The WBC of sweet potato starch ranged from 75.44-232.65%. Native sweet potato starch has water binding capacity 78.1±2.66% [1]. Pregelatinisation increased the cold-water swellability of the starches. This effect is probably due to the disruption of the starch granule during pregelatinisation, which would release amylopectin which is partially responsible for the swelling of starch [14]. The WBC is observed higher in treated starch due to the difference in the degree of availability of the water binding sites. The increase of WBC value might be due to the result of gelatinisation which causes the disruption of the weak associative bonds in the amorphous region of granules and enabling the increase of starch hydration [8].

| Temperature (°C) | WBC (%) |
|-----------------|---------|
| Native          | 76.07±0.42 |
| 35              | 84.71±0.75 |
| 40              | 90.52±0.94 |
| 45              | 97.37±0.86 |
| 50              | 126.62±0.84 |
| 55              | 232.37±1.83 |
| 60              | 143.48±1.39 |

The WBC value of sweet potato starch are reduced after 55°C (Figure 2). This value decrease maybe due to an engagement of hydroxyl groups to form hydrogen and covalent bonds between starch chain, so that there is an increasing in crystalline region and decrease in amorphous region in starch granules that reduced the number of available binding sites thus lowering the WBC value [15].

3.3. Fourier transform infrared (FT-IR) analysis

Figure 3 shows FTIR spectra of the native and pregelatinised starch. Native sweet potato starch presented strong peaks in 3900-3300 cm⁻¹ and 2930 cm⁻¹ regions which correspond to OH and CH stretching [16]. For the polysaccharide like starch, a series of overlapping peaks located in the region of 800–1300 cm⁻¹, which are often referred to as the saccharide bands and result from vibration modes.
such as the stretching of COC and COO and the bending mode of COH bonds, were the most intense bands in the mid-IR spectrum [17].

Figure 3. FTIR spectrum of native and pregelatinized starch

There is a decreasing of peak 2000-2930 cm\(^{-1}\) and 400-850 in cm\(^{-1}\) in pregelatinised starch. This is due to the weaken of hydrogen bond of the starch due to the treatment. The decreasing of the peak also found in the result of pregelatinised rice starches [17]. At the molecular level, pregelatinisation causes the rearrangement of intra and intermolecular hydrogen bond between water and starch molecules resulting in the collapse or disruption of molecular orders within granule [18]. It has been reported that pregelatinised starch granules retained their shell, but loose their content [19].

3.4. Morphological characteristics

The scanning electron micrograph (SEM) of native and pregelatinised starches is shown in Figure 4 (a-b). Pregelatinised starch has relatively larger granules than native starch that indicates the swelling process happened due to the presence of heat and water. The sweet potato starch consisted of a mixed population of small to large granules and observed in various shapes [20].

Figure 4. SEM of starches a) Native and b) Pregelatinised
3.5. Flow behaviour

The flow behavior of starch can be concluded from Figure 5. The viscosity decreased with the increasing of shear rate. The viscosity of native starch was lower than pregelatinised starch indicating that the granule of starch was strongly disrupted and exhibit higher swelling and developed higher viscosity. All starch followed the power law equation (R² = 0.99, p<0.05) and exhibiting shear-thinning behavior.

![Figure 5](image)

**Figure 5.** Viscosity of starches a) Native and b) Pregelatinised starch, with the increasing of shear rate 10 to 1000 s⁻¹

4. Conclusions

Pregelatinization can overcome the drawbacks of native starch. The results shown the increasing of SP, S, and WBC of sweet potato starch along with the increase of temperature until some point. Pregelatinised starch also shows larger granule size and larger viscosity than native starch. Pregelatinisation can enhance the starch versatility to meet industrial demand. It is suggested that pregelatinised starch is suitable for instant product manufacturer.

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