

# Characterizing Physicochemical Properties of Enset Starch

Abdulkader Mohammed Awol\*, Kavita Waghay, Rao P.G. Prabhakara, and Math G. Rudrayya

**Abstract-** Enset (*Ensete ventricosum*, family musaceae) is a plant of Ethiopia. Ethiopians are farmed enset plant for food uses. It is very similar to the banana plant (*Musa acuminata*, Family musaceae) and hence termed “false banana”. However, the starch of enset plant is stored in major quantities in the pseudostem and underground corms. The properties of the enset starch were not studied in detail. The native enset starch (ES) was evaluated for proximate composition and physicochemical properties. The enset starch properties, such as bulk density, tapped density, granule size, color of enset starch powder and gel, pH, swelling capacity, solubility, and gelatinization properties were examined. Sorption isotherm of enset starch was studied. The effect of NaCl and sucrose on swelling capacity, solubility and gelatinization properties has been examined. The kinetics of gelatinization of enset starch (starch:water weight ratio, 1:2) were investigated using differential scanning calorimetry (DSC).

**Keywords:** enset starch, physicochemical properties, native, gelatinization, kinetics, DSC

## I. INTRODUCTION

Enset (*Ensete Ventricosum*, Family Musaceae) is a major Ethiopian crop widely grown for staple food uses. It is mainly distributed in Eastern and Southern Ethiopia and a majority of the population (15 million) are consuming this crop cultivated by a subsistence farming system. Though plant resemblances that of a banana plant structurally, the starch gets accumulated in the pseudostem and underground corms of enset plant. These two parts constitute the reservoirs of starch which find applications in food and industrial applications [1].

The various industrial applications of starch are in

A.M. Awol, P.G. Prabhakara, and R.G. Math  
CSIR-Central Food Technological Research Institute, Resource Centre,  
500 007, Hyderabad, India.

K. Waghay  
Department of Food Technology, University College of Technology (A),  
Osmania University, 500007, Hyderabad, India.

Correspondence should be addressed to A.M. Awol  
e-mail: adulkader1485@gmail.com

regulating texture, consistency by acting as a thickening and gelling agent and as a stabilizer [2]. The demand for new starch sources is ever increasing as its use in food and industrial applications are multifunctional. The bridge the gap, potential sources of starch like enset have to be studied extensively for physicochemical (e.g. gelatinization and retrogradation) and functional (e.g. solubility, swelling, water absorption, syneresis and rheological behavior of pastes and gels) properties [2,3]. Studying enset starch increases the possibility of using this starch as food ingredients instead of other common starches like corn and potato starch. Therefore, in this research the physicochemical properties, gelatinization kinetics and rheological properties of enset starch will study. They determine the potential of the starch to use in food system under a range of processing conditions.

The granular and molecular structures of native starches from vegetable resources have positive effects on the physicochemical and functional properties [2]. Proximate compositions (moisture content, ash content, fat content, protein content etc.), sieve analysis, bulk and tapped densities, whiteness of the enset starch are determined using different methods. These all determine the physicochemical properties of the starch. The swelling properties, solubility and water holding capacity of the enset starch at different time and temperature and at different concentrations of salt and starch were determined. Gelatinization properties and kinetics of the enset starch is studied using differential scanning calorimetry (DSC). Kinetics parameters were determined by fitting the data to Kissinger and Ozawa plots.

## II. EXPERIMENTAL

### A. Materials

Enset starch was purchased from local market in Addis Ababa, Ethiopia. All of the chemicals used were of analytical-reagent grade or the highest purity available.

### B. Methods

#### B.1. Starch Preparation

The sample material, enset starch was sieved using mesh

number 400 in order to remove extraneous materials.

### B.2. Proximate Composition

The proximate composition of enset starch samples was determined in triplicate as follow: moisture content by oven drying according to AOAC (2000) using the official method 925.09 [4], fat content by soxhlet extraction method using hexane as a solvent, ash content was determined by incineration in a furnace at a temperature of 550 °C. The residue left after incineration is the ash content of the enset starch. The protein content was estimated using Kjeldahl method and 6.25 is taken as a conversion factor [4,5].

### B.3. Starch Content

The defatted sample was analyzed for starch content by acid hydrolysis method. The test sample was dispersed in water and heated in acidic solution to hydrolyze the starch and release the sugars. The resulting sugars are then determined by titration with Fehling solution according to the method of Lane-Eynon [4,6]. Apparent amylose content (%) was estimated by colorimetric iodine assay index method from defatted enset starch.

### B.4. Determination of Bulk and Tapped Densities

The starch sample (50 g) was weighed accurately using an analytical balance and carefully transferred to a measuring cylinder (100 mL). The cylinder was tapped gently on a wooden table for three times leaving an interval of 2 s to loosely pack the particles. The volume occupied by the starch was noted as bulk volume. To record the tapped volume, the cylinder was tapped on the wooden platform continuously till the volume occupied is constant. The bulk and tapped densities were computed and presented as the ratio of mass per volume [7].

### B.5. pH Measurement

Solution of 10% enset starch (10 g/100 mL) was prepared using distilled water. Then it was stirred for 30 min using a magnetic stirrer. The pH of the supernatant was measured using a calibrated pH meter [8].

### B.6. Scanning Electron Microscopy (SEM) and Granule Size Distribution

The enset starch sample granule was analyzed using a scanning electron microscope (S-3700N) and the size distribution was measured using image J software. The accelerating voltage and magnification are displayed on the image (Figs. 1 and 2).

### B.7. Moisture Sorption Isotherm

The equilibrium moisture content of the enset starch was

evaluated by a standard method wherein the samples were exposed to constant relative humidities obtained in airtight chambers by saturated solutions of LiCl, K (CH<sub>3</sub>COO), MgCl<sub>2</sub>, K<sub>2</sub>CO<sub>3</sub>, NaBr, NaNO<sub>2</sub>, NaCl, K<sub>2</sub>CrO<sub>4</sub>, and KNO<sub>3</sub> at room temperature (Bell & Labuza, 2000) [9]. The salts were used to maintain relative humidity in the range of 11% to 92%. Samples weighed in petri dishes in duplicate were exposed to the relative humidity conditions by placing them in respective chambers and were periodically weighed till they reach constant weights. The samples were also examined for lumping or signs of mold growth during the storage. The equilibrium moisture content (EMC) of the product at different RHs was computed based on the initial moisture content and the gain or loss of moisture.

The Brunauer-Emmett-Teller (BET) [10] and Guggenheim-Anderson-de Boer (GAB) [11] (Eqs. (1) and (2), respectively) model equations were applied to predict equilibrium moisture content isotherm characteristics of the enset starch:

$$M_w = \frac{M_o C a_w}{(1 - a_w)[1 + (C - 1)a_w]} \quad (1)$$

$$M_w = \frac{M_o C K a_w}{(1 - K a_w)(1 - K a_w + C K a_w)} \quad (2)$$

Where,  $M_o$  represents the moisture content of the sample,  $C$  energy constant and  $k$  sorption constant. Goodness of fit (the best-fit equation) was determined by the coefficient of determination ( $R^2$ ) the mean square error (MSE) and standard error (SE).

### B.8. Swelling Capacity and Solubility of ES

Solubility and swelling capacity (SC) of starch samples were determined using the method outlined by Bello-Pérez *et al.* with slight modification [12]. The enset starch sample (1 g) was weighed in to pre-weighed centrifuge tubes and 15 mL-distilled water was added. Centrifuge tubes were allowed in a controlled water bath at 40, 60, and 80 °C for 20 min, occasionally mixing at 5 min intervals and then cooled to room temperature. The contents were centrifuged at 3000 rpm for 15 min. The supernatant was carefully decanted and the tubes were allowed to stand at an angle of 45° for 10 min to remove the water drops completely. The weight of the starch sediment was measured to calculate swelling capacity of enset starch. The supernatant solution was transferred to a petri plate and dried on a water bath initially and further in an oven for 2 h at 130 °C for determining the soluble materials. The solubility and swelling capacity were calculated using the following equations, respectively:

$$S (\%) = \frac{w_{ss}(\text{g})}{S_i} \times 100 \quad (3)$$

$$SC \left( \frac{\text{g}}{\text{g}} \right) = \frac{w_p(\text{g})}{S_i(100 - S\%)} \times 100 \quad (4)$$

Where, S% is the percentage solubility, SC is the swelling capacity,  $W_{ss}$  is the weight of soluble material in the supernatant (g),  $W_p$  is the weight of precipitate (g) and  $S_i$  is the initial sample weight (g).

### B.9. Effect of NaCl and Sucrose on Swelling Capacity and Solubility of Enset Starch

Salt (NaCl) and sugar (sucrose) solutions at different concentrations namely, 0.5, 1, 2, 4, 6, 8, and 10% were prepared using distilled water. Enset starch (2 g) suspensions in 15 mL of salt/sucrose were prepared and taken into pre-weighed centrifuge tubes. The tubes containing suspensions were kept in a thermostatically controlled water bath at 60 °C for 10 min, with frequent mixing and allowed to cool to room temperature. The suspensions were centrifuged at 3000 rpm for 15 min and the supernatant containing the soluble was decanted. The tubes were inverted to stand at an angle of 45° to remove the adhering water droplets for 10 min. The tubes containing the supernatant were dried in an oven for 2 h at 130 °C and weighed. The solubility and swelling capacity were calculated using Eqs. (3) and (4).

### B.10. Enset Starch Powder and Gel Whiteness

The colour values of enset starch powder and gel ( $L^*$ ,  $a^*$ , and  $b^*$ ) were measured using a HunterLab UltraScan VIS (Hunter Associates Laboratory, Reston, Va., and U.S.A.). Enset starch suspension (6%) was prepared using distilled water and heated on a hot plate at 90 °C for 5 min. The color of the paste was measured immediately using a hunter Lab color spectrometer. To study the effect of cold storage on the color of the enset starch paste, freshly prepared paste was packed in aluminum foil laminate pouches and stored at 5 °C. The color of the stored paste samples was measured at daily intervals for seven days. The results were recorded and analyzed using Easy Math QC software. Triplicate samples were analyzed for color measurement and means were computed for respective products.

### B.11. Gelatinization Properties

Its gelatinization behavior and kinetics were studied using a differential scanning calorimeter (DSC). It is was conducted to determine the thermal properties of enset starch at different heating rates 2.5, 5, and 10 °C/min using Perkin Elmer DSC 8000 (Waltham, MA, USA). Sample (4-6 mg) dry basis was placed in aluminum pans and 8-12  $\mu\text{L}$

distilled water (to prepare 1:2 ratio) was added, while empty reference cell was used.

After sealing, the sample was equilibrated for 1 h and scanned at the above mentioned heating rates between 40 and 100 °C. Then starting, peak and end set temperatures were determined using Pyris DSC 8000 software (PerkinElmer, USA). *Kissinger* (Eq. (5)) [13] and *Ozawa* (Eq. (6)) [14] models were used to calculate the activation energy and to represent the experimental data. In these equations the parameter  $T_m$  is peak temperature (°C),  $\beta$  is heating rate, C is the *Ozawa* constant, E is activation energy, R is gas constant, and z is the pre-exponential factor. The models parameters were determined by non-linear regression, using Microsoft Excel 2016.

From *Kissinger* equation we can obtain the activation energy, E, which is represented by the slope of the line and the pre-exponential factor, z, is the intercept by plotting  $\ln(\beta/T_m^2)$  vs.  $1/T_m$ .

*Ozawa* plot can be achieved by plotting the log of the heating rate,  $\ln(\beta)$ , against  $1/T_m$ , where the slope of the line is the activation energy.

$$\ln\left(\frac{\beta}{T_m^2}\right) = \ln\left[\frac{ZR}{E}\right] - \frac{E}{RT_m} \quad (5)$$

$$\ln(\beta) = C - 1.052 \frac{E}{RT_m} \quad (6)$$

### B.12. Effect of NaCl and Sucrose on Gelatinization Properties of ES

The effect of salt (NaCl) and sucrose on the gelatinization properties of enset starch was determined like the above except here the salt (NaCl) and sucrose solutions (0.5, 1, and 2%), prepared by distilled water and NaCl or sucrose, were used instead of using distilled water.

## III. RESULTS AND DISCUSSION

### A. Proximate Composition

The proximate compositions of enset starch are summarized in Table I. This table presents the data on proximate composition and starch content of enset starch obtained from enset plant (*Ensete ventricosum*, family Musaceae). The starch content is found to be 95.6% and this comply with previously study carried out by Gebre-Mariam and Schmidt (1996) [15]. The analytical data for amylose, moisture, total ash, protein and fat contents of enset starch were 28.3, 14.53, 0.2, 0.4, and 0.33%, respectively. The moisture content is slightly higher than samples analyzed by Gebre-Mariam and Schmidt [15]. The slight variation in moisture content of the enset starch might be attributed to differences in cultivar, part of the enset plant, which the

TABLE I  
PROXIMATE COMPOSITION OF ENSET STARCH

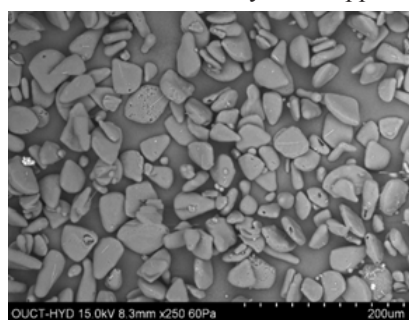
Constituents	Percentage
Moisture content	14.53
Ash content	0.20
Protein content	0.40
Fat content	0.33
Starch content	95.6
pH	4.7

starch extracted, age of the plant, and handling and storage systems [1].

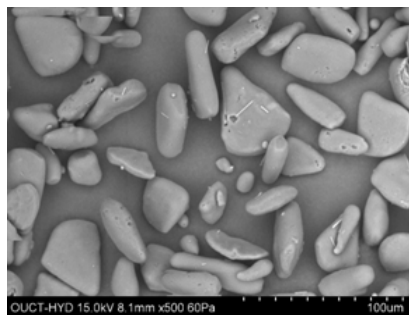
The moisture content is very important in determining the quality of starch. If the moisture content is high, there is always chance of microbiological damage, which not only affects the physical characteristics but also the functional properties. The microbial organisms can breakdown the starch leading to considerable reduction in viscosity and swelling characteristics. The crude ash content of the enset starch resembles the result found by Rieko Hirose *et al.* (2010) [10] and slightly higher than the Gebre-Mariam and Schmidt (1996) [15]. The protein and fat content of the enset starch obtained are higher than founded in other previous work studied by Rieko Hirose *et al.* (2010) [1]. The reasons for the variations might be one or all the points mentioned above.

#### B. Bulk and Tapped Densities

The mean value of bulk density and tapped density of



(a)



(b)

Fig. 1. Scanning electron micrographs of enset starch granules: (a) 250x and (b) 500x.

TABLE II  
EXPERIMENTAL AND PREDICTED EMC DATA

Relative humidity (%)	Exp. EMC	Predicted EMC	
		BET	GAB
0.11	1.113981	2.329062	1.964614
0.22	4.06173	4.67627	4.076757
0.32	6.818246	6.833249	7.018186
0.44	9.338389	9.467888	8.876055
0.56	12.57441	12.19199	11.92467
0.64	14.27476	14.10195	14.18187
0.75	17.45782	17.00285	17.6576
0.86	20.36307	20.90343	21.68716
0.92	25.07476	24.92713	24.18453

enset starch powder was found to be 0.61 and 0.76 g/cm<sup>3</sup>, respectively. The results are slightly higher than found by Efreem Nigussu *et al.* (2013) [15].

#### C. pH

The pH of the enset starch suspension was found to be 4.7 (Table I). pH can also affect starch properties. The permitted pH level for starch is between 4 and 7 [16]. Lower levels of pH indicate contamination by low molecular weight organic acids probably formed by microbial actions on starch. Low pH starch can undergo acid catalyzed degradation, especially during heat treatments.

#### D. Scanning Electron Microscopy (SEM) and Granule Size Distribution

Fig. 1 shows the scanning electron microscope image of enset starch granules with small and large grains with a characteristics shape (angular and elliptical). Most of its granules are smooth, however, a few granules showed some fissures (cracks). Similar results were reported by earlier researchers [1,15].

The particle size distribution of enset starch was found to be as shown in Fig. 2. It showed normal particle size distribution with the average granule size of 37.5  $\mu$ m. As shown in the histogram (Fig. 2) of enset starch granule size distribution is in a range of 10  $\mu$ m to 60  $\mu$ m. Another report also showed the same results [1]. However, the result obtained from another researcher showed the average granule size of enset starch is 46  $\mu$ m [15].

#### E. Moisture Sorption Isotherm

The experimental values of equilibrium moisture content at



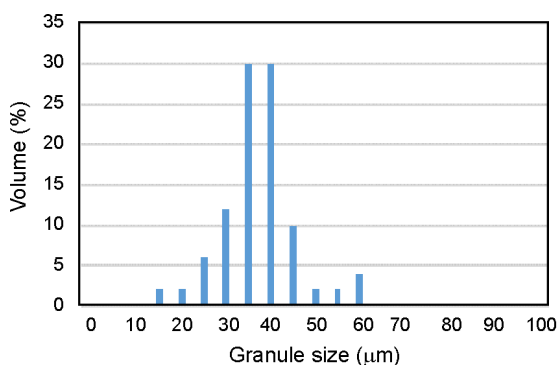


Fig. 2. Granule size distribution of enset starch.

different relative humidities (11% to 92%) and at room temperature (28 °C) are shown in Table II. In the last three samples (at RH of 75, 86, and 92%) mold growth was observed. The predicted EMC values, using model equations BET and GAB are presented in Table II.

The plots of EMC versus water activity (Figs. 3 and 4) also showed the trend that the equilibrium moisture content of enset starch increases with increasing water activity. The regression coefficient ( $R^2$ ), mean square error (MSE) and standard deviation (SD) of the data calculated by empirical model equations (BET and GAB) are 0.93, 0.97, 0.285, and 0.444, and 0.57 and  $4.7 \times 10^{-8}$ , respectively.

*F. Swelling Capacity and Solubility of ES*

When starch is heated in water, the starch granules absorb water and swell with leaching of some soluble starch components [6]. As shown in Figs. 5 and 6, the swelling capacity and solubility of ES at 40, 60, and 80 °C are 1.19 g/g and 14.04%, 2.34 g/g and 16.05%, and 9.74 g/g and 21.23%, respectively. The profile shows a general trend of increase with increase in temperature. Swelling capacity of starch affects the viscosity in starch-water systems. The solubility profile also shows an increase in solubility with

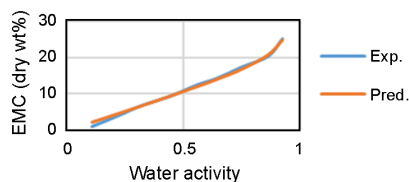


Fig. 3. BET prediction of EMC.

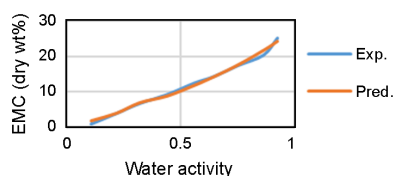


Fig. 4. GAB prediction of EMC.

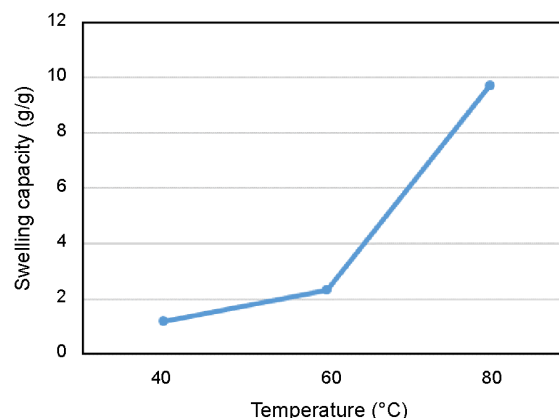


Fig. 5. Swelling profile of enset starch.

temperature rise. Increase in temperature resulted in higher leaching of amylose from the starch, as granules gelatinize at higher temperature resulting in higher swelling power and swelling of starch granules also affects their solubility.

*G. Effect of NaCl and Sucrose on Swelling Capacity and Solubility of ES*

To investigate the effect of NaCl on the ES granules during heating, swelling capacity was determined in the presence of different concentrations of NaCl (0.5, 1, 2, 4, 8, and 10%). As shown in Fig. 7, there is a slight decrease in swelling capacity with addition of NaCl. More or less the effect is uniform for all concentrations. The electrostatic interaction between starch and NaCl ions can be attributed to the decrease in swelling capacity [17]. NaCl shows a limited promoting effect on wheat starch at higher temperatures, however salt significantly decreases the swelling capacity of cassava starch or rice starch. To investigate the effect of sucrose on the starch granules during heating, swelling power was determined in the presence of sucrose (Fig. 7). Here also a slight decrease in the swelling capacity was observed except at 4% sucrose concentration, there

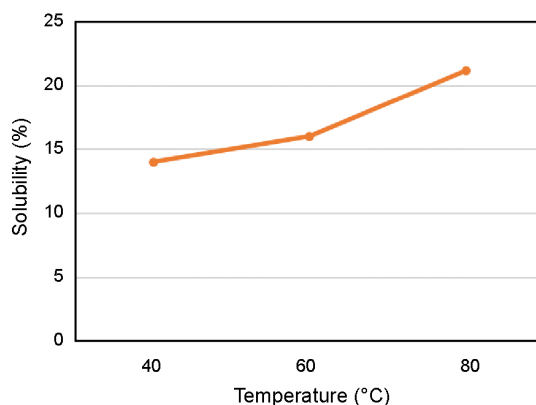


Fig. 6. Solubility profile of enset starch.

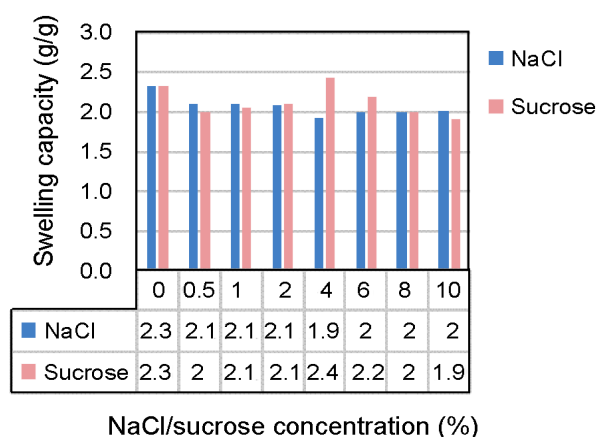


Fig. 7. Swelling capacity of enset starch in the presence of NaCl and sucrose.

was a slight increase. In this study both NaCl and sucrose have a similar influence on enset starch swelling capacity. Solubility of ES decreased with increase in NaCl and sucrose concentrations. As shown in Fig. 8, at a concentration of 4% and onward the solubility was highly reduced. Presence of sucrose inhibits the degradation of the starch molecules leading to lower solubility. Spies and Hosney proposed that stabilization of amorphous region in the starch granules occurs by forming bridges with sugar [18].

#### H. Enset Starch Powder and Gel Whiteness

The whiteness of ES powder was found to be 86.2. It is similar to the result obtained by Rieko Hirose *et al.* (2010) [1]. Changes in Hunter whiteness of starch gel during cold storage are presented in Table III. Initially after preparation, the enset starch gel showed lower whiteness ( $L^*=34.05$ ) which increased, with large variation, after one day storage at 5 °C ( $L^*=60.59$ ). Cold storage of ES enhanced its whiteness. However, on the seventh day, water was separated from the bulk gel. The Hunter whiteness of starch gels has been reported previously [1] by Rieko Hirose *et al.*, 2010 who indicated that whiteness of enset starch gel increased after 15 min storage at room temperature [19]. A large increase in whiteness of the ES gel with time indicated that these starch samples underwent

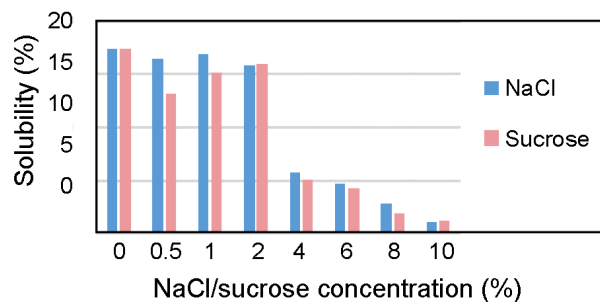


Fig. 8. Solubility of enset starch in the presence of NaCl and sucrose.

TABLE III  
RESULTS OF COLORS FROM HUNTER WHITENESS ANALYZER

S.ID	Days	Colors		
		L*	a*	b*
1	0	34.05	0.13	0.12
2	1	60.59	2.32	6.21
3	2	62.40	2.51	6.17
4	3	66.65	2.53	5.62
5	4	68.41	2.52	5.22
6	5	70.20	2.51	4.92
7	6	72.11	2.50	4.53
8	7	72.36	2.50	4.23

\*Values are mean of three replicates; \*\*L = white; a = greenish (negative value), pinkish (positive value); b = yellowish

serious aging when was stored at a low temperature [20]. The whiteness of starch gel is appropriate for foods that have pure white color.

#### I. Gelatinization Properties

The ES samples were thermally scanned in a DSC at different heating rates (2.5, 5, and 10 °C/min) and a moisture level of 1:2 (~67%). Fig. 9 shows the curves of enset starch at different heating rates. As shown in Table IV the onset, peak, end set temperatures and enthalpy ( $\Delta H$ ) of enset starch at heating rates of 2.5, 5, and 10 °C/min are 59.74, 64.13, and 69.1 °C and 12.18 J/g; 62.02, 66.35, and 70.97 °C and 14.86 J/g; and 64.37, 68.77, and 73.37 °C and 19.65 J/g, respectively. The thermal transition temperatures and enthalpies were found to increase with heating rate. The temperature programming of DSC heating is an important parameter as furnace temperature has a greater influence on the data [21]. The results, onset (3.3%), peak (4.4%), and end set (2.3%) temperatures, at the heating rate of 10 °C/min are slightly higher than those obtained by Gebre-Mariam and Schmidt [15]. The sample preparation method, age and variety of the enset plant, part of the enset plant at which the starch obtained, starch composition (amylose to amylopectin ratio), granular architecture (crystalline to

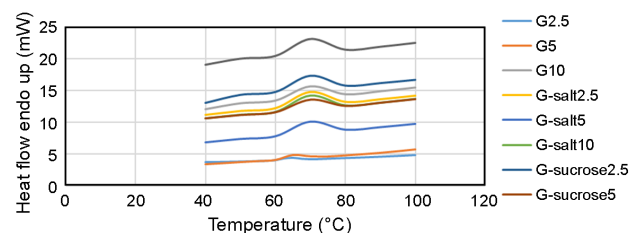


Fig. 9. DSC thermogram of enset starch at starch-to-water ratio of 1:2 where the numbers represent the heating rate at 2.5, 5, and 10 °C/min and salt and sucrose mean in the presence of NaCl and sucrose.

TABLE IV  
GELATINIZATION TEMPERATURES AND ENTHALPIES OF  
ENSET STARCH IN THE PRESENCE OF WATER (STARCH:  
WATER, 1:2 W/W) AS MEASURED BY DSC

Heating rate (°C/min)	T <sub>onset</sub> (°C)	T <sub>peak</sub> (°C)	T <sub>end</sub> (°C)	ΔH (J/g)
2.5	59.74	64.13	69.1	12.18
5	62.02	66.35	70.97	14.86
10	64.37	68.77	73.37	19.65

amorphous ratio), and molecular structure of amylopectin may be attributed to the results obtained [21].

The DSC data shown in Table V represent the parameters required for the determination of activation energy according to *Kissinger* (1956) and *Ozawa* (1970) for enset starch based on Eqs. (5) and (6). The plot indicated that maximum reaction rate occurs at the peak temperature, T<sub>p</sub>, with a heating rate, β, the quantity of ln(β/T<sub>p</sub><sup>2</sup>) against 1/T<sub>p</sub> was plotted. The slope of the *Kissinger* plot, and the Ea was calculated from the Arrhenius relationship by taking the slope of the straight line while the pre-exponential factor will be represented by the intercept of *Kissinger* plot. *Ozawa* model was applied to the data collected from DSC. When *Ozawa* model was applied, a plot of ln(β) was plotted against 1/T<sub>p</sub>. Pre-exponential factor (k<sub>0</sub>) and coefficient of determination (R<sup>2</sup>) were also determined. According to *Kissinger* plot the activation energy (Ea) required for the disordering of internal structure of starch granules is 280.69 kJ/mol. For *Ozawa* plot the activation energy was found to be 272.18 kJ/mol. Table VI shows activation energy (Ea) and pre-exponential factor (k<sub>0</sub>) obtained for enset starch gelatinization by *Kissinger*'s and *Ozawa*'s methods. Both *Kissinger* and *Ozawa* models are suitable to

predict the Ea of enset starch gelatinization along as their coefficients of determination are high.

#### J. Effect of NaCl and Sucrose on Gelatinization Properties of ES

The onset (T<sub>o</sub>), peak (T<sub>p</sub>), and end set (T<sub>e</sub>) gelatinization temperatures, and enthalpy (ΔH) of enset starch in aqueous suspensions with salt and sucrose, determined by DSC, are found to be as shown in Table VII. Addition of NaCl at 0.5% concentration slightly increased the magnitudes of T<sub>o</sub>, T<sub>p</sub>, T<sub>e</sub>, and ΔH as compared with those of the control. However, at salt concentration of 1 and 2% all gelatinization temperatures are slightly increased and their enthalpies are significantly decreased. Similarly by addition of sucrose at the concentrations of 0.5, 1, and 2%, the gelatinization temperatures were increased and their enthalpies were significantly decreased. However, the enthalpy at 2% sucrose concentration, significantly increased, compared to control. Salts have been reported to increase or decrease gelatinization temperature and enthalpy, depending on the type of salts and their concentration [6]. For rice starch, addition of salts at 0.1 M concentration significantly increased the magnitudes of T<sub>o</sub>, T<sub>p</sub>, and T<sub>e</sub> and decreased ΔT values without any significant effect on ΔH as compared with those of the control [22]. Salts affect the gelatinization properties of starch as they have an influence on polymer-solvent interaction, the effects on water structure, and the electrostatic interaction between starch and the ions. Gelatinization temperature of sago starch was found to increase in the presence of sucrose, whereas the gelatinization enthalpy was not affected (Maaruf *et al.*, 1999) [6].

The gelatinization temperatures increased with NaCl

TABLE V  
HEATING RATES AND AVERAGE PEAK TEMPERATURES FOR ENSET STARCH

Heating rate (°C/min)	T <sub>onset</sub> (°C)	T <sub>peak</sub> (K)	1/T <sub>p</sub> (×10 <sup>-3</sup> )	T <sub>p</sub> <sup>2</sup>	β/T <sub>p</sub> <sup>2</sup> (×10 <sup>-3</sup> )	ln(β/T <sub>p</sub> <sup>2</sup> ) (×10 <sup>-5</sup> )	ln(β)
2.5	64.13	337.28	2.965	113757.8	2.197	10.72	0.91
5	66.35	339.5	2.946	115260.3	4.338	10.04	1.61
10	68.77	341.92	2.925	116909.3	8.554	9.37	2.30

TABLE VI  
THE ACTIVATION ENERGY (EA) OF GELATINIZATION COMPUTED FROM THE RESULTS, PRE-EXPONENTIAL

Methods	Ea (kJ/mol)	k	R <sup>2</sup>
Kissinger	280.69	2.216*10 <sup>40</sup>	0.9995
Ozawa	272.18	103.04	0.9996

TABLE VII  
EFFECTS OF NaCl AND SUCROSE ON GELATINIZATION TEMPERATURES, AND ENTHALPY ( $\Delta H$ ) OF ENSET STARCH (STARCH:WATER, 1:2 W/W) AS MEASURED BY DSC AT A HEATING RATE OF 10 °C/MIN

Additives	Conc. (%)	T <sub>onset</sub> (°C)	T <sub>peak</sub> (°C)	T <sub>end</sub> (°C)	$\Delta H$ (J/g)
NaCl	0	64.37	68.77	73.37	19.65
	0.5	65.22	69.08	74.43	20.67
	1	65.5	69.32	74.77	13.93
	2	65.91	69.71	75.16	15.65
Sucrose	0.5	65.5	70.05	74.95	16.85
	1	64.91	68.29	74.06	17.19
	2	65.28	69.55	74.66	22.47

concentration initially and later decreased with further rise in NaCl concentration [21].

#### IV. CONCLUSION

The mean moisture, ash, protein, fat, and starch content of enset starch were found to be 14.53, 0.2, 0.4, 0.33, and 95.6%, respectively. The moisture content is higher than the limit that is permitted for many starches, so it should be reduced to allowable limit. If the moisture content is high, there is always chance of microbiological damage which not only affects the physical characteristics but also the functional properties. The microbial organisms can breakdown the starch leading to considerable reduction in viscosity and swelling characteristics. The variation might be attributed to differences in cultivar, part of the enset plant which the starch extracted, age of the plant, handling and storage systems and methodologies used.

The pH of the ES is within the permitted level (4-7). Lower levels of pH indicate contamination by low molecular weight organic acids probably formed by microbial actions. Low pH starch can undergo acid catalyzed degradation, especially during heat treatments. The SEM of ES granules revealed that the surfaces were smooth though cracks were also seen. Its granules consisted of small and large grains, which are angular and elliptical. The particle size distribution is similar to potato starch. The EMC of ES was increased with the increased relative humidity. There was an evidence of mold growth in the sample, which as equilibrated at RH of 75, 86, and 92%. According to the best fit indices both BET and GAB models are suitable for predicting EMC isotherm of ES. Swelling capacity and solubility of ES increase with increasing temperature, making it suitable in products of higher temperature processing. Addition of NaCl and sucrose has a slight decreasing effect on swelling capacity and solubility of ES. However, both NaCl and sucrose cannot be classified

as swelling or solubility inhibitors since they are the function of temperature at which the swelling or solubility is observed and depend on the concentration of the added NaCl and sucrose.

Low temperature storage of ES gel enhances its whiteness like other common starches gel. The thermal gelatinization temperatures and enthalpies were found to increase with increasing heating rate. The gelatinization characteristics of ES were influenced by the presence of NaCl and sucrose. Addition of NaCl and sucrose increases gelatinization temperatures and decreases enthalpies as compared to the control. However, at 0.5% NaCl and 2% sucrose concentrations enthalpies were increased. The effects of NaCl and sucrose on the gelatinization characteristics of ES may have a benefit in processing and properties of starch based foods. Both *Kissinger* and *Ozawa* plots are suitable to estimate kinetic parameters because the linear regression of the straight line generated from the data representing starch gelatinization from beginning to end showed a high R<sup>2</sup> value indicating good fit.

#### ACKNOWLEDGEMENT

We would like to acknowledge CFTRI-Hyderabad, CFTRI-Mysore and Central Analytical Facilities, UCT, OU for allowing us to use their Laboratory.

#### REFERENCES

- [1] H. Rieko, T. Yoriko, K. Tomoko, H. Kazuko, H. Tamao, N. Seiko et al., "Characteristics physico-chemical properties and potential uses of Enset (*Ensete ventricosum*) starch: comparative studies with starches of potato, sago and corn", *J. Appl. Glycosci.*, vol. 57, no. 3, pp. 185-192, 2010.
- [2] A. Gani, S. Sul Haq, F.A. Masoodi, A.A. Broadway, and A. Gani, "Physico-chemical, morphological and



- pasting properties of starches extracted from water chestnuts (*Trapa natans*) from three lakes of Kashmir, India”, *Int. J. Brazil. Arch. Boil. Technol.*, vol. 53, no. 3, pp. 731-740, 2010.
- [3] L.Z. Wang and P.J. White, “Structure and physicochemical properties of starches from oats with different lipid content”, *Cereal Chem.*, vol. 71, 443–450, 1994.
- [4] AOAC., Official Methods of Analysis, 925.09., Association of Official Analytical Chemists Washington, DC, 2000.
- [5] S. Ranganna, *Handbook of Analysis and Quality Control for Fruit and Vegetable Products*, Tata McGraw-Hill Publishing Company, New Delhi, India, 1986, pp. 1-30.60
- [6] A.G. Maaruf, Y.B. Che Man, B.A. Asbi, and Z.M. Hashim, “Differential scanning calorimetry: gelatinization of sago starch in the presence of sucrose and sodium chloride”, *J. Sci. Food Agr.*, vol. 79, no. 14, pp. 2001-2009, 1999.
- [7] Y.E. Apeji, A.R. Oyi, and H. Musa, “Studies on the physicochemical properties of microcrystalline starch obtained by enzymatic hydrolysis using  $\alpha$ -amylase enzyme”, *Pharmacophore*, vol. 2, no. 1, pp. 9-15, 2001.
- [8] I. Khatijah and H. Patimah, “Physico-chemical properties of local native starches”, *J. Trop. Agr. Food Sci.*, vol. 26, no. 1, pp. 99–104, 1998.
- [9] L.N. Bell and T.P. Labuza, “Aspartame degradation kinetics as affected by pH in intermediate and low moisture food systems”, *J. Food Sci.*, vol. 56, no. 1, pp. 17–20, 1991.
- [10] S. Brunauer, P.H. Emmett, and E. Teller, “Adsorption of gases in multimolecular layers”, *J. Am. Chem. Soc.*, vol. 60, no. 2, pp. 309-319, 1938.
- [11] G.V. Barbosa-Canovas and H. Vega-Mercado, “Physical, Chemical and Microbiological Characteristics of Dehydrated Foods”, in G.V. Barbosa-Canovas and H. Vega-Mercado (Eds.), *Dehydration of Foods*, New York: Chapman and Hall, 1996, pp. 29–99.
- [12] L.A. Bello-Perez, E.A. Acevedo, P.B. Zamudio-Flores, G. Mendez-Montecalvo, and S. Rodriguez-Ambriz, “Effect of high acetylation degree in the morphological, physicochemical and structural characteristics of barley starch”, *LWT– Food Sci. Technol.*, vol. 43, no. 9, pp. 1434-1440, 2010.
- [13] H.E. Kissinger, “Reaction kinetics in differential thermal analysis”, *Anal. Chem.*, vol. 29, pp. 1702–1706, 1957.
- [14] T. Ozawa, “Kinetic analysis of derivative curves in thermal analysis”, *J. Therm. Anal.*, vol. 2, no. 3, pp. 301–324, 1970.
- [15] E. Nigussu, A. Belete, and T. Gebre-Mariam, “Acetylation and characterization of enset starch and evaluation of its direct compression and drug release sustaining properties”, *Int. J. Pharmaceut. Sci. Res.*, vol. 4, no. 11, pp. 4397-4409, 2013.
- [15] T. Gebre-Mariam and P.C. Schimdt, “Isolation and physico-chemical properties of enset starch”, *Starch/Stärke*, vol. 48, no. 6, 208-214, 1996.
- [16] Anon, “pH values of food products”, *Food Eng.*, vol. 34, no. 3, pp. 98-99, 1962.
- [17] H.-H. Chen, Y.-S. Wang, Y. Leng, Y. Zhao, and X. Zhao, “Effect of NaCl and sugar on physicochemical properties of flaxseed polysaccharide-potato starch complexes”, *Sci. Asia*, vol. 40, no. 1, 60–68, 2014.
- [18] R. Puri, B. Singh Gil, and Y. Khetra, “Effect of acacia gum, NaCl, and sucrose on physical properties of lotus stem starch”, *Food Sci. Technol. Dept.*, vol. 2014, 8 pages, 2014.
- [19] Wittaya, licensee InTech, 2012. (<http://creativecommons.org/licenses/by/3.0/>), <http://dx.doi.org/10.5772/47751>
- [20] S. Takahashi, M. Ebihara, and K. Kainuma, “Properties and gel Characteristics of flour and starch obtained from newly developed rice cultivars”, *J. Home Econ. Jpn.*, vol. 49, no. 3, pp. 235-241, 1998.
- [21] Y.B.C. Man, M.B.A. Ghani, D.B.M. hashim, and R.A. Rahman, “Study of sago starch (metroxylyon sagu) gelatinization by differential scanning calorimetry”, *J. Food Process. Pres.*, vol. 25, no. 2, pp. 101-121, 2001.
- [22] S.S. Wang, W. Chiang, Samutsri, and M. Suphantharika, “Effect of salts on pasting, thermal, and rheological properties of rice starch”, *Carbohydr. Polym.*, vol. 87, no. 2, 1559-1568, 2012.

