Comparative Study of Gelatinization Kinetics of Some Edible Tubers

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DOI: 10.29322/IJSRP.11.11.2021.p11906
http://dx.doi.org/10.29322/IJSRP.11.11.2021.p11906

Abstract- The kinetics of water gelatinization reaction in some edible tubers (Manihot esculenta, Colocasia esculenta, Dioscorea alata, Ipomoea batatas, Solanum tuberosum, Dioscorea dumetorum and Dioscorea rotundata) was investigated using a thermostated water bath at various temperatures. At 60 °C, Manihot esculenta (ME) gelatinized in 125 min; Solanum tuberosum (ST), Dioscorea dumetorum (DD) and Dioscorea alata (DA), gelatinized in 140, 165 and 180 mins respectively but there was no gelatinization for Colocasia esculenta (CE) Ipomoea batatas (IB) and Dioscorea rotundata (DR) at this temperature. At 90 °C however, ME gelatinized in 2.00 min while ST, DD, DA, DR, CE and IB showed gelatinization in 3.20, 5.00, 6.50, 7.30, 8.50 and 10.20 mins respectively. The rate of gelatinization of starch was found to be directly proportional to the gelatinization temperature and inversely proportional to the time of gelatinization. A rapid gelatinization rate was observed for ME with the least gelatinization time (Gt). The rate of gelatinization was observed to follow the order: ME > ST > DD > DA > DR > CE > IB.

Index Terms- gelatinization kinetics; retrogradation; starch; edible tubers.

I. INTRODUCTION

Apart from being a principal staple food in Nigeria, tubers constitute a major source of carbohydrate used in the food, drug and textile industries. However, there is a depth of information on the gelatinization of local starches which form the major source of starch for these industries. It is our view that the information reported here will enhance knowledge on the gelatinization of starch.

Califano and Garcia, (2008), worked on the gelatinization of Mung bean (Vigna radiate) starch and concluded that the high activation energy obtained at low temperatures may be as a result of gradual disruption of inter- and intra- molecular hydrogen bonding chains.

Sandhu and Singh, (2007), reported on the gelatinization of starch among other things and concluded that amylase was positively correlated to hardness and gumminess of starch gels. Turhan and Gunasekaran, (2002), using the gelatinization of hard and soft wheat starches concluded that in situ and in vitro processes were first-order kinetic reactions.

Some studies were also carried out on potatoe tubers. Galkowska, (2008) examined the effect of saccharides on gelatinization and retrogradation of modified potatoe starch while Sharpe, (2004) explored their effects on gelatinization of rice and potatoe starches. They concluded that water uptake by rice did not have a linear relationship with time.

The goal of this research work is to investigate the rate/degree of gelatinization of cassava (Manihot esculenta), cocoyam (Colocasia esculenta), water yam (Dioscorea alata), sweet potato (Ipomoea batatas), Irish potato (Solanum tuberosum), trifoliate yam (Dioscorea dumetorum) and white yam (Dioscorea rotundata).

II. MATERIALS AND METHODS

The seven edible tubers listed above were purchased from the farmers market in Marian Road, Calabar Municipality, Calabar, Nigeria. The reagents used were potassium iodide, sodium chloride (Analytical grade) and distilled water (solvent).

2.1. Preparation of Sample

The sample was carefully chosen, peeled, washed with distilled water and sliced into tiny stripes of about 2.5 to 5.0 mm thickness. Each was dried in a Griffin and George thermostated oven (model 1/200) at 60 °C for about twenty-four hours (to constant weight), ground with an electric blender (QLink, model QBL-15L40) and sieved with 0.43 mm mesh sieve to give fine flour.

The prepared samples were individually placed in air tight containers, labeled and stored at 23 – 25 °C.

2.2. Analysis of sample

The method used by Sharpe, (2004) was modified and utilized for gelatinization of the starch sample. The sample (30 g) was mixed with 100 ml distilled water with stirring for homogeneity. This was placed in a thermostated water bath at the required temperature. The stirring continued at an average rate of about 85 rotations per minute. Readings were taken at specific time intervals and recorded. The gelatinization temperatures (GT) as well as the gelatinization time (Gt) were noted for each of the food samples.

The ratio of the concentration of ungelatinized starch to the time of gelatinization gave the apparent rate of gelatinization. The actual gelatinization rate indicated the increment in torque at 1°C
rise in temperature (Perry and Donald, 2002). This was determined by comparing the concentration of the ungelatinized starch with the time of gelatinization.

### 2.3. Rate of gelatinization

For the determination of the rate of gelatinization, 30 g of the sample was mixed with 100 ml of distilled water with stirring. The mixture was immersed in a thermostated water bath at a specific temperature. An aliquot of 10 ml of the reaction mixture was taken at specific time intervals. This was then immersed in an ice bath to quench the reaction and titrated against a 0.01 M solution of potassium iodide. A blue-black colouration indicated the end point. Eight readings were taken for each run at each temperature; The readings were used to determine the concentration of ungelatinized starch using the formulae:

\[ \frac{C_A}{V_A} = \frac{n_a}{n_b} \]

Where: 
- \( C_A \): Concentration of potassium iodide (in moles per dm³)
- \( V_A \): Volume of potassium iodide (in ml)
- \( C_B \): Concentration of ungelatinized starch (in moles per dm³)
- \( V_B \): Volume of ungelatinized starch (in ml)
- \( n_a \): Mole ratio of potassium iodide
- \( n_b \): Mole ratio of ungelatinized starch.

The rate of gelatinization was determined by comparing the concentration of ungelatinized starch with the time of gelatinization.

The apparent rate of gelatinization (\( R_A \)) was determined from the concentration of ungelatinized starch using the equation:

\[ R_A = \frac{c}{t} \]

Where: 
- \( R_A \): Apparent rate of gelatinization
- \( c \): Concentration of ungelatinized starch
- \( t \): Time in minutes.

### III. RESULTS AND DISCUSSION

Gelatinization properties of the samples

The gelatinization time for the samples at various temperatures is presented in Table 1. There was no significant gelatinization for CE, IB and DR at 60 °C but they showed a relatively high gelatinization at elevated temperatures at nearly equal time intervals (see figure 1), but at 1min ST, IB and CE demonstrate ungelatination at 0.02mol/L, 0.025mol/L and 0.035 mol/L respectively (see figure 2). This shows that some edible tubers require high temperature for bond breakage and agrees with work done by Salomon and Buchholz, (2000) in their kinetic studies. As earlier mentioned, Turhan and Gunasekaran, (2002), observed that the degree of gelatinization increased with time for all the food samples they studied. The starch of the root tuber, ME, easily dispersed in water, was more soluble and had the highest gelatinization value compared with the stem tubers. This is probably the reason it is used more in the industries especially in the textile industry as cloth starch. On the other hand, the stem tubers such as CE, DA, IB, ST, DD and DR contain mucilage that binds them together, thus, they were not easily dispersed in water and, required more energy to break the inter-molecular hydrogen bonding that exists within them. This agrees with the observations of Agbanyin, et al., (2014). This might be why they showed significant gelatinization at higher temperatures.

**Table 1**

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>ME</th>
<th>CE</th>
<th>DA</th>
<th>IB</th>
<th>ST</th>
<th>DD</th>
<th>DR</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>125</td>
<td>No</td>
<td>180</td>
<td>No</td>
<td>140</td>
<td>165</td>
<td>No</td>
</tr>
<tr>
<td>70</td>
<td>00</td>
<td>gel.</td>
<td>00</td>
<td>gel.</td>
<td>00</td>
<td>00</td>
<td>gel.</td>
</tr>
<tr>
<td>80</td>
<td>30.0</td>
<td>65.</td>
<td>56.3</td>
<td>75.</td>
<td>40.8</td>
<td>48.5</td>
<td>60.</td>
</tr>
<tr>
<td>90</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>4.50</td>
<td>23.</td>
<td>12.5</td>
<td>28.</td>
<td>6.80</td>
<td>8.00</td>
<td>20.</td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>30</td>
<td>0</td>
<td>3.00</td>
<td>5.00</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.5</td>
<td>6.50</td>
<td>10.</td>
<td>7.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From the foregoing, it can be deduced that the gelatinization time is dependent on the type of starch being gelatinized. This was also observed by Sopade, et al., (2004). It follows a first-order reaction kinetics and obeys the Clausius-Clapeyron type equation.

This observation supports the predictions made by Turhan and Gunasekaran, (2002), on *in situ* and *in vitro* gelatinization of hard and soft wheat starches and whole durum wheat during cooking.

The starch of ME gelatinized faster than the others, thus it had the shortest gelatinization time. The longest gelatinization time was observed for IB.
The gelatinization rate expresses the increment in torque during one minute of 1 °C temperature rise. The kinetic studies for the samples at the temperature of 60 °C and 30 mins time interval is shown in Table 2.

**TABLE 2**

Kinetic studies on *Manihot esculenta*, *Colocasia esculenta*, *Dioscorea alata*, *Ipomoea batatas*, *Solanum tuberosum*, *Dioscorea dumetorum* and *Dioscorea rotundata* at 60 °C

| Gt (mins) | ME    | CE    | DA    | IB    | ST    | DD    | DR    | ME    | CE    | DA    | IB    | ST    | DD    | DR    |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 0        | 18.0  | 37.0  | 26.0  | 28.0  | 24.0  | 24.3  | 23.8  | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    |
| 30       | 16.1  | 25.2  | 24.6  | 25.9  | 21.8  | 22.5  | 24.9  | 5.37  | 8.40  | 8.20  | 8.63  | 7.27  | 7.50  | 7.80  | 7.30  | 7.60  | 7.90  | 8.30  |
| 60       | 11.2  | 25.0  | 24.5  | 25.8  | 21.5  | 21.7  | 24.8  | 1.87  | 4.17  | 4.08  | 4.30  | 3.58  | 3.62  | 4.10  | 3.80  | 3.90  | 3.60  | 4.00  | 4.20  |
| 90       | 11.0  | 24.9  | 24.1  | 25.7  | 21.1  | 21.5  | 24.5  | 1.22  | 2.77  | 2.68  | 2.86  | 2.34  | 2.39  | 2.70  | 2.20  | 2.30  | 2.40  | 2.50  | 2.70  |
| 120      | 10.5  | 24.8  | 23.8  | 25.0  | 20.9  | 21.3  | 24.3  | 0.88  | 2.07  | 1.98  | 2.08  | 1.74  | 1.77  | 2.03  | 1.60  | 1.65  | 1.68  | 1.60  |
| 150      | 9.30  | 24.3  | 25.5  | 24.8  | 20.5  | 20.7  | 24.0  | 0.62  | 1.62  | 1.70  | 1.65  | 1.37  | 1.38  | 1.60  | 1.30  | 1.35  | 1.36  | 1.33  |
| 180      | 8.40  | 24.1  | 22.7  | 24.5  | 19.0  | 18.0  | 23.9  | 0.47  | 1.34  | 1.26  | 1.36  | 1.06  | 1.00  | 1.33  | 1.05  | 1.08  | 1.09  | 1.00  |
| 210      | 6.30  | 24.0  | 22.0  | 24.3  | 12.5  | 14.5  | 23.8  | 0.30  | 1.14  | 1.05  | 1.16  | 0.60  | 0.69  | 1.13  | 0.70  | 0.71  | 0.80  | 0.75  |
| 240      | 5.90  | 23.8  | 21.5  | 23.9  | 9.20  | 9.51  | 22.6  | 2.46  | 1.00  | 0.80  | 1.00  | 0.38  | 0.40  | 0.94  | 0.50  | 0.55  | 0.65  | 0.50  |
| A        | 4.20  | 20.2  | 19.4  | 22.0  | 7.00  | 7.90  | 19.2  | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    | NA    |

\[\beta_0 \times 10^3 \text{ (mol dm}^{-3}\text{)}\]
\[G_r \times 10^4 \text{ (mol dm}^{-3}\text{min}^{-1})\]

From the results, it was observed that the gelatinization rate decreased with increase in time but increased with increasing concentration (see table 2). This justifies the claims of Turhan and Gunasekaran, in 2002, that the rate constant increased with cooking temperature. The rate was known to be kinetically pseudo first-order and, obeys the Arrhenius model.

The results for gelatinization rate were also obtained for temperature range of 70, 80, and 90°C at various time intervals and is expressed in figure 3.

The gradient of the curves gave the actual (true) rate of gelatinization of the food samples. A higher gelatinization rate was observed for ME, whereas, 1B showed a much lower gelatinization rate compared to the former. The rate of gelatinization was known to follow the trend: 1B < CE < DR <
IV. CONCLUSION

The observed kinetics of gelatinization of some edible tubers used in this research confirms that certain factors such as gelatinization time, concentration of ungelatinized starch and gelatinization temperature influence the rate of gelatinization. Apparent starch gelatinization and gelatinization rate are both irreversible processes but the former is a first-order reaction while the later is kinetically pseudo first-order. The reaction rate constant was also known to vary directly with the gelatinization temperature.

REFERENCES


AUTHORS

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