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Generalized starch Gelatinization kinetics during Hydrothermal treatment of whole wheat grains

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ABSTRACT

Hydrothermal treatment is the first and vital step of the cereal processing, control of this process depends upon the degree of starch gelatinization inside the grains. The quality of the final products also depends upon the extent of starch gelatinization. The purpose of this study was to investigate the starch gelatinization kinetics of the whole wheat flour during hydrothermal treatment and to enumerate the effect of moisture content on starch gelatinization rate constant for both the grains during hydrothermal treatment. Hydrothermal treatments were designed for different combinations of moisture contents (25-50 % w.b) that commonly occur during cooking of cereal foods and an isothermal temperature of 100 °C. The degree of starch gelatinization (DG) was measured from the DSC endotherms. The starch gelatinization during hydrothermal treatment followed first-order reaction kinetics and it depends on the moisture content. A linear fit was observed between starch gelatinization rate constant and moisture content.

Key words: *hydrothermal treatment, kinetics, moisture contents,Starch gelatinization, whole wheat grains.*

Cereals such as wheat, rice, oat, and barley and their products are one of the most important staple foods. About two billion tons of cereals are produced in the world, annually (Pandey *et al.,* 2015). The structural and physical properties of starch correlate highly with the processing and palatability of cereal food (Hu *et al.,* 2010).

Hydrothermal treatment:

In order to consume or convenient for further processing, the grains must undergo a hydrothermal treatment such as parboiling or steaming or boiling or autoclaving etc. in order to gelatinize the starch into a digestible form. The hydrothermal treatment is a first step in the production of instant cereal foods such as breakfast cereals, hot cereals and other whole grain products (Kent, 1994).

Hydrothermal treatment is a physical method in order to induce functional changes in starch without use of chemicals, therefore it is considered as safe for human consumption, it involves the incubation of grains about gelatinization temperature at a limited moisture content for different time periods (Majzoobi *et al.,* 2015). Hydrothermal treatment often used to inactivate the enzymes to prevent the rancidity of lipids during processing of grains such as oats (Hu *et al.,* 2010; Doehlert *et al.,* 2010).

Evaluation of Degree of starch gelatinization:

As the texture of the final product depends up on the degree of intact starch gelatinization it is necessary to control the degree of gelatinization during hydrothermal treatment. The most acceptable definition of starch gelatinization is: The collapse of molecular orders within starch granules manifesting in irreversible changes in properties such as granular swelling, native crystallite melting, loss of birefringence, and starch solubilisation. Many of the researchers have been reported that the starch gelatinization depend mainly on the available water content and associated diffusion of water during the treatment (Bhakshi and Singh, 1980). Most of the studies of starch gelatinization have been based on the application of differential scanning calorimetry (DSC). DSC is a thermo analytical technique for monitoring changes in the physical and/or chemical properties of materials as a function of temperature by detecting the heat changes associated with such processes (Biliaderis, 1983).

Kinetics of starch gelatinization

Bhakshi and Singh, (1980); Lund and Kartaksuma (1984); Kokini *et al.,* (1992); Oke *et al.,* (1996) have proposed that the starch gelatinization follows first order irreversible reaction.

$$\frac{dS}{dt} = -kS \quad (1)$$

Where 'S' is the fraction of the un-gelatinized starch and 'k' is the reaction rate constant (sec^{-1})
('t' is time (s).
The rate constant k is dependent on temperature according to the Arrhenius equation

$$k = k_o \exp\left(-\frac{E_a}{RT}\right) \quad (2)$$

Where, k_o is the pre-exponential factor, E_a is the activation energy (Kj/mol), R is the universal gas constant (8.314 J/mol.K), T is the temperature in K.

Kinetics of starch gelatinization can be investigated using liquid water or steam either in vitro using pure starch or in situ using whole grain flour. Kinetics of in situ starch gelatinization of some legume starches (Kubota, 1979a, and 1979b), rice starch (Bhakshi and Singh, 1980) and corn starch (Carbera *et al.,* 1984) has been reported in the literature. Hydrothermal treatment is not merely the first step of cereal processing but also a vital process, which effectively governs the quality of the final product. Accordingly, kinetic data regarding starch gelatinization is a pre-requisite for the effective processing of the grains. Hence, the goal of this study was to develop a kinetic model during hydro thermal treatment of wheat. The specific objectives were to determine the specific rate constants and effect of moisture content on the rate of degree of gelatinization.

MATERIAL AND METHODS

Sample preparation

Whole wheat grains were purchased from the local market of Kakinada, A.P (India).The moisture content of the grains was measured by using an electronic moisture analyser (Sartorius Moisture Analyzer-MA100, Germany). The sample grains were ground into flour in a laboratory grain mill (Pulversetti) passing through 0.1 mm sieve.

Hydrothermal treatment

Sample flours were mixed with distilled water to give different water contents as shown in Table 1. An isothermal method was adapted for the hydrothermal treatment at 100 °C. The sample flours were kept in High Density Poly Ethylene (HDPE) bags which can sustain internal pressure and temperature. The HDPE bags with the sample flours were immersed in an oil bath (Jain Scientific works) which was maintained at 100 °C and kept for different time periods as shown in Table 1. The time taken to reach 100 °C was 28s. After the desired treatment time, the bags were immediately immersed in ice-water mixture to prevent further gelatinization. The samples were dried at 40 °C in a tray drier (Armfield – UOP8-A, UK) and kept in a storage chamber (Thermotech, Make Sanco) at 10 °C for further analysis.

Measurement of Degree of gelatinization (DG)

The degree of gelatinization was measured by using DSC (DSC polyma, NETZCH) the sample flours after the hydrothermal treatment weighing 10-20 mg were placed in 40 micro lit aluminium pans with lid. The sample pans were scanned in the DSC from 20-120 °C at a rate of 5 °C/min to obtain the gelatinization endotherms. The endotherms were analysed to determine the area under the endotherm by numerical integration. The area under the curve gives the value of enthalpy. The % DG was measured by following relation (Miah *et al.,* 2002).

$$S = \frac{\Delta H}{\Delta H_n} \quad (3)$$

$$\%DG = (1 - S) \times 100 \quad (4)$$

Where ΔH is the enthalpy change of the treated sample and ΔH_n is the enthalpy change of untreated (raw) sample. For completely gelatinized standard, 5% of the sample flour solution in 95% of distilled water was autoclaved (Dynamic Scientific works-101) for 1 hr, its enthalpy change was corresponds to 100% degree of starch gelatinization. The enthalpy change of untreated (raw) flour was corresponds to 0% degree of starch gelatinization.

Construction of starch gelatinization kinetics

Many of the researchers have correlated starch gelatinization kinetics with temperature by Arrhenius type of relation (Altey and Gunasekaran, 2006). The correlation of moisture content and treatment time with the starch gelatinization kinetics was described by a very few researchers, Wang et al., (1989) reported the correlation between starch conversion rate constant and a non-dimensional parameter. The effects of moisture content and treatment time were taken into account for kinetics. The starch gelatinization kinetics data was fitted to a first order reaction Eq (1) and the values of rate constants were determined by regression analysis in MATLAB R2015a.

RESULTS AND DISCUSSION

Kinetics of starch gelatinization (DG)

The degree of starch gelatinization was measured from the DSC endotherms according to the equation (4), thus obtained DG values (Table 2) were fitted to the equation (1) to obtain the rate constants at each moisture content (Table.3). The DG values were ranged between 14.15-53.80% for wheat starch Fig. 1 shows the progression of degree of starch gelatinization as a function of moisture content and time. The DG increased with increase in treatment time at particular moisture content and this increase was linear, also the DG increased with increase in moisture content at particular time. The DG value is high for the sample with highest moisture content and treatment time. From this, it can be concluded that the high moisture content during hydrothermal treatment will facilitate in faster rate of starch gelatinization. The kinetic data can be useful for designing the hydrothermal treatment of the cereal grains for the manufacture of breakfast cereals,

Relation between starch gelatinization rate constant and moisture content

To evaluate the relation between DG and moisture content, data was fit by linear regression and the gelatinizaion rate constants were obtained as a function of moisture content as shown below

Conclusions

Starch gelatinization kinetics during hydrothermal treatment of whole wheat followed first-order reaction kinetics. Many of researches have reported the temperature dependence of gelatinization rate constant by employing an Arrhenius type of relation. Starch gelatinization during hydrothermal treatment depends up on both temperature and moisture content of the grains. A linear relation between starch gelatinization rate constant and moisture content was observed. The accuracy of the fit can be improved by considering wide range of moisture contents during the hydrothermal treatment. However, the above relations can be used in the design of hydrothermal treatment of whole wheat grains during manufacture of breakfast cereals.

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$$k = -0.0722M + 0.0561\left(for\ moisture\ content, M \leq 45\%\ (w.b)\right), R^2 = 0.9956$$

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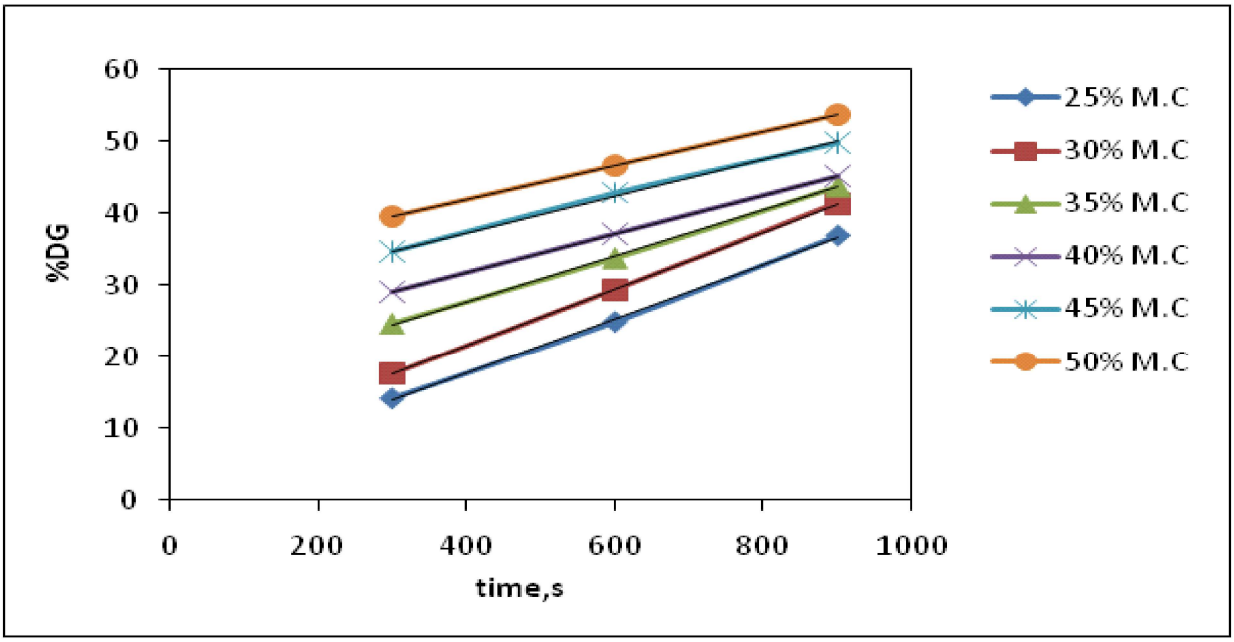

Fig.1. Progression of Degree of starch gelatinization at different moisture contents

Table1: Experimental plan for the hydrothermal treatment

Sample code	Treatment time (min)	Moisture content (% w.b)
W11	5	25
W12		30
W13		35
W14		40
W15		45
W16		50
W21	10	25
W22		30
W23		35
W24		40
W25		45
W26		50
W31	15	25
W32		30
W33		35
W34		40
W35		45
W36		50

Table 2. Degree of starch gelatinization during hydrothermal treatments at different moisture contents

Sample code	%DG
W11	14.15
W12	17.72
W13	24.63
W14	29.06
W15	34.63
W16	39.63
W21	24.87
W22	29.44
W23	33.79
W24	37.22
W25	42.79
W26	46.79
W31	36.88
W32	41.45
W33	43.80
W34	45.23
W35	49.80
W36	53.80

Table 3. Summary of starch gelatinization kinetics during hydrothermal treatment of whole wheat grains

M.C (% W.b)	k (s^{-1})	R^2	SSE
25%	0.03788	0.9989	0.27440
30%	0.03455	0.9999	0.01402
35%	0.03125	0.9993	0.12040
40%	0.02695	0.9999	0.00375
45%	0.02510	0.9981	0.22040
50%	0.02362	0.9999	0.00375

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