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Hydration kinetic of maize grain under varying temperature

Kapil Kumar, Jaivir Singh, Suresh Chandra, BR Singh, Neelash Chauhan and MK Yadav

Kapil Kumar
Department of Agricultural Engineering, College of Post-Harvest Technology and Food Processing, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Jaivir Singh
Department of Agricultural Engineering, College of Post-Harvest Technology and Food Processing, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Suresh Chandra
Department of Agricultural Engineering, College of Post-Harvest Technology and Food Processing, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

BR Singh
Department of Agricultural Engineering, College of Post-Harvest Technology and Food Processing, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Neelash Chauhan
Department of Agricultural Engineering, College of Agriculture, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

MK Yadav
Department of Agricultural Biotechnology, College of Post-Harvest Technology and Food Processing, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Corresponding Author
Kapil Kumar
Department of Agricultural Engineering, College of Post-Harvest Technology and Food Processing, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

Abstract

Corn (*Zea mays* L.) also known as maize, the hydration characteristic of it was studied by soaking of kernels in to water at 30, 40, 50, 60, 70, 80 and 90 ^{0}C. The samples of corn kernels, about 20g each, were weighed using an electronic balance. Each sample was placed in a flask containing 250 ml of water. The flasks were placed in water bath. Individual flasks were removed from the water bath at 1, 3, 5, 10, 20, 35, 60, 120, 300, 700, 1440 and 1800 min. the kernels were dried using blotting paper to eliminate the surface water. The weight gain due to the hydration process was determined in terms of moisture content (% d.b.). Water absorption rate was high at the early stage of hydration and the gradual increase in the absorption up to 300 min and after 300 min the curve becomes liner for water absorption. The agreement between experimental and estimated values of hydration data (R^2 = 0.9086-0.9463) confirmed that Peleg's equation could be used to describe the hydration characteristics of maize under the experimental condition considered.

Keywords: Corn, hydration, kinetics, peleg models

Introduction

Maize is a domesticated grass that originated approximately 7000 years ago in now Mexico. It is also referred to as corn (both yellow and white) are produced in abundance in India but is not being utilized properly and most of the produce is used for cattle feed, especially in Bihar. There is a need of developing a ready to eat (RTE) food from the yellow corn, which would not only help to utilize this available maize but also help in solving the problem of food shortage. Maize is a coarse grain and after initial resistance, it is now being accepted as staple diet and its demand is increasing, consumption of maize in the form of various types of traditional foods such as bread, porridge, steamed products, beverages and snacks. In India, maize grains are roasted and ground to prepare a traditional food *Sattu* (roasted grain flour) which is consumed as a breakfast item by mixing either water or milk with salt or sugar. Maize is also ground whole to make flour and is consumed in the form of chapatti (unleavened Indian bread) at rural level.

Maize, also known as corn is the important cereal crop which is produced all over the world. It has a greatest productivity among the cereals as 3.5 tones/ hectare. It is used as human food and also as feed for animals. It provides nutrition to both humans (33.3%) and animals (66.6%). The principle constituents of whole-maize kernel are protein, lipid and carbohydrate. Small quantities of minerals and miscellaneous organic substances including vitamins are also present. Earle *et al*. (1946) have reported the constituents as protein, oil, sugars, starch, and ash in the range of 8.1 to 13.6%, 3.9 to 5.8%, 1.61 to 2.22%, 66.8 to 74.2% and 1.27 to 1.58% respectively.

Clean raw Corn (*Zea mays* L.) was soaked at different temperatures in constant temperature water bath, under atmospheric condition, to determine the hydration behavior of maize. Fan *et al.* (1963) studied on the diffusion rates of water in three varieties of corn and reported an Arrhenius type relationship between diffusion and the reciprocal of the absolute temperature (temperature ranging from 0 °C to 100 °C). Radha Charan and Prasad (1996) found moisture diffusivity of maize during water soaking to vary from 1.57×10^{-7} to 17.46×10^{-7}. Laria *et al.* (2005) investigated the kinetics of the overall water uptake by three corn varieties (Cacahuazintle corn, Yellow Dent corn and Chalco corn) soaked in water and in alkaline solution with two different concentrations of $Ca(OH)_2$ at room temperature and observed that the water uptake into the corn kernel in alkaline solution takes place by different kinetic stages of reaction and diffusion process.

Each stage was correlated with a specific structural change that mainly occurs in the pericarp, in the aleurone layer and in the outermost structure of the endosperm. Bhattacharya (1994) studied on the Hydration of raw and roasted corn semolina at 30, 50 and 70 °C shows that raw semolina absorbs more water, has higher equilibrium moisture content and hydration rate constant values than roasted semolina. The rate of hydration is linearly related to average moisture content. Hydration rate index (HRI), defined as the change of hydration rate constant per unit change in hydration temperature ($\Delta k / \Delta T$), and is determined for raw and roasted semolina. The activation energies for raw and roasted semolina were 10.6 and 7.7 KJ $mole^{-1}$ respectively. Singh v. *et al.* (1996) reported that to recover the high valued germ from dry milling corn was hydrated around 12 hr. at 59 °C, Results showed that soak time decreased with increasing soak temperature up through 59 °C. A reduction in a germ quality and quantity occurred at soak temperature of 75 °C.
Richard *et al.* (2008) studied on the hydration and drying characteristics of amaranth verities of corn grains at different drying temperature and result was compared with the fresh corn. In general, for corn hydrated grain particles the moisture content was found to be in a looser condition than it was in the fresh grains, and hence, smaller effective diffusion coefficients where found for the latter. Such differences were found to increase with increasing drying temperature. Also a first-order irreversible kinetic model was applied to the drying data for hydrated and fresh corn and a reduction on the drying activation energy was observed by the humidification process.

Materials and Methods

Corn (*Zea mays* L.) of proper maturity procured from the local market was used in the study. The raw maize was subjected to conventional cleaning by screening to remove foreign matter, broken kernels, chaff etc.

Moisture content: Moisture content of raw maize was determined by standard air oven method (AACC, 1983). About 20 g of maize sample was weighed and kept in oven at 103 ± 2°C for 72 hours. The moisture content loss after 72 hours was measured and the moisture content of the material was expressed in percent (w.b.) and (d.b).

Experimental setup: A constant temperature water bath (Fig.1) was used for soaking experimental consist of a water holding chamber with an immersion heating coil for heating the water and a thermostat for control of water temperature. The required temperature can be obtained by adjusting the knob.

Fig 1: Water bath

Experimental procedure: The soaking test was conducted in an aluminum container. The constant temperature water bath was adjusted to a temperature of 2 °C higher than the required temperature of soaking. Water uptake of maize grain was determined by soaking 10 g samples in screw-tap flasks containing 150 ml of distilled water. The soaking temperatures studied were 30, 50, 60 and 70 °C. Before performing hydration experiments the flasks with water were placed in thermostatically controlled oven fixed at the required soaking temperature for several hours to reach thermal equilibrium. Then, the grains were poured into the screw-tap flasks and experimental procedure was started. These were placed in a constant temperature stirred water bath, controlled within ± 0.5 °C of the testing temperature. At regular intervals the flasks were withdrawn from the bath for moisture content determination. The soaked grains were filtered through an 80 mesh sieve to remove the surface water and weighed to an accuracy of ± 0.1 mg. This procedure was established based on the preliminary test results and other previous studies (Abu-Ghannan and McKenna, 1997; Haros, Viollaz and Suarez, 1995; Muthukumarappan and Gunasekaran, 1991). Then, the grains were placed in an oven for moisture content determination (AOAC, 1995).

Hydration techniques: Several hydration techniques were investigated for determining hydration behavior of the corn which increase the hardness of the grains by absorbing maximum amount of water and also caused minimum stress cracks in the kernels. The hydration techniques *viz.* water spray, steam treatment, steaming–water soaking and soaking in water was investigated for determining hydration behavior of maize with minimum stress cracks development and maximum water absorption.

Soaking in water: The techniques which we used for the present research was soaking of kernels in to water. The experimental kernels were visually inspected for relatively uniformed weight. Then samples of corn kernels, about 20 g each, were weighed using an electronic balance. Each sample was placed in a flask containing 250 ml of water. The flasks were placed in water bath. Individual flasks were removed from the water bath at 1, 3, 5, 10, 20, 35, 60, 120, 300, 700, 1440 and 1800 min. the kernels were dried using blotting paper to eliminate the surface water. Then they were weighed and the percentage of the moisture content of the sample M, at each interval was determined by following:

$$M\ (\%) = \frac{(m - m_i) + m_i \times IM}{m} \times 100$$

Where,
m = mass of the sample at a specified time interval (g)
m_i = mass of the sample prior to soaking (g)
IM= initial moisture content of the kernels (%)
The experiments were performed at temperature of 30, 40, 50, 60, 70, 80 and 90 °C.

Theoretical Model: During the water absorption the water transfer in to the kernels and reacts with the starch granules as the water reaches the outer layer of starch granules, it hydrolysis the granules and fill the intergranular spaces. The water is retained by the starch molecules while the moisture diffused processed towards the center of the kernels. A mechanism used for diffusion is Fick's second law of liquid/vapor diffusion (Muthukurappan and Gunappakaran, 1994) described by:

$$\frac{\delta M}{\delta t} = D\left(\frac{\partial^2 M}{\partial x^2} + \frac{\partial^2 M}{\partial y^2} + \frac{\partial^2 M}{\partial z^2}\right)$$

Where

M (g) = moisture, at x, y and z location within the object at time t (s) and

D = the diffusion coefficients (m^2/sec).

For moisture absorption process, with a suitable set of assumptions for initial and boundary conditions (Muthukumarappan and Gunappakaran, 1994) a solution give for the above equation.

$$MR = \left[1 - \exp\left(-kt\right)\right]$$

Where,

k = coefficients of moisture absorption and

MR = the instantaneous ratio defined by:

$$MR = \frac{M - M_o}{M_s - M_o}$$

Where,

M = the instantaneous moisture (%),

Ms = the moisture at saturation (%), and

Mo = the initial moisture content (%) of the objects.

Results and Discussion

Hydration Characteristics of corn: The hydration technique which was used in this experiment was soaking in the water. The amounts of moisture gained by the corn kernels at different time and temperature are presented in the table. The moisture absorption by the corn kernels verses time are presented in the Fig. 2. According to the Fig. 2 with increase steeping water temperature, the amounts of water absorbed is increased. An increase in the rate of water absorption with the increase in the water temperature was also reported by (Sayar *et al.*, 2001). The high rate of water absorption during the initial stages of soaking is generally attributed to the natural capillaries present in the surface of the kernels which can be explained by the diffusion phenomenon.

Fig. 2 showed that the gradual increase in the rate of water absorption up to 300 min and after 300 min the curve becomes linear for water absorption. However, for the treatments above 60 ^{0}C the slope is slightly steeper indicating that in addition to simple water diffusion, some water is also utilized for the gelatinization of starch. Stress crack kernel were observed at a soaking temperature of 80 ^{0}C and 90 ^{0}C this indicate that during hot soaking heat weakens the starch granules by disrupting the hydrogen bond; therefore more surface area is available by the starch granules for the water absorption.

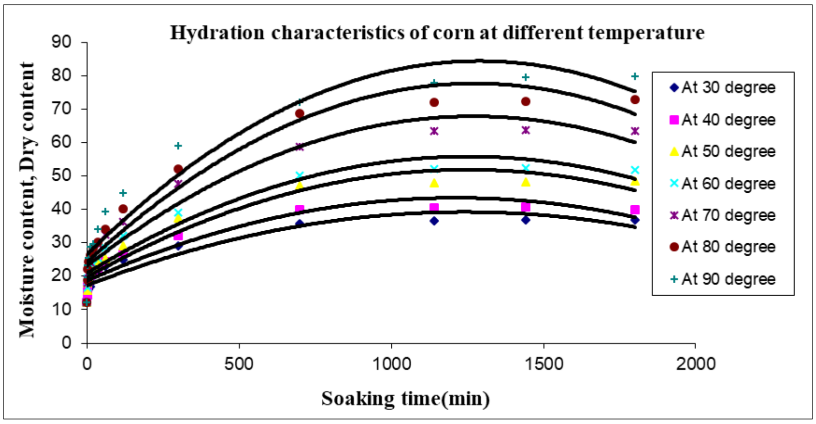

Fig 2: Hydration characteristics of corn at different temperatures

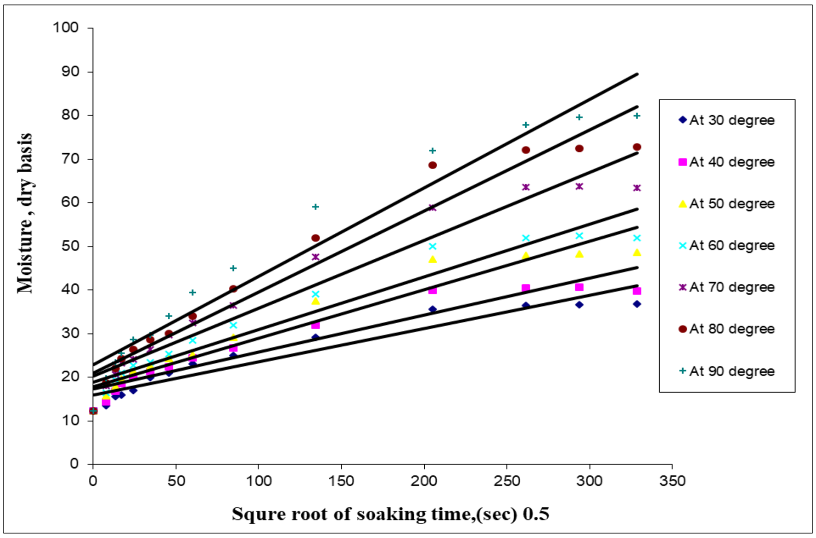

Fig 3: Relationship between square root of soaking time and moisture uptake

Table 1: Hydration behavior of corn at different temperature and time combinations

Time (min)	Moisture content (%) at different temperature						
	30 ^{0}C	40 ^{0}C	50 ^{0}C	60 ^{0}C	70 ^{0}C	80 ^{0}C	90 ^{0}C
0	12.2	12.2	12.2	12.2	12.2	12.2	12.2
1	13.5	14.4	15.7	16.5	18.0	18.7	19.8
3	15.6	16.8	17.9	19.4	20.7	22.1	23.4
5	16.0	18.6	19.6	21.0	23.2	24.3	25.5
10	17.0	20.2	21.4	22.7	24.1	26.3	28.7
20	20.0	21.3	22.6	23.5	26.4	28.6	29.7
35	21.0	22.3	24.3	25.4	29.6	30.1	34.0
60	23.0	24.5	25.16	28.4	32.4	34.0	39.4
120	25.0	26.8	29.12	32.0	36.4	40.1	45.0
300	29.2	32.0	37.5	39.0	47.6	52.0	59.0
700	35.6	40.0	47.0	50.1	58.8	68.6	72.0
1140	36.5	40.4	48.0	52.0	63.5	72.1	77.8
1440	36.7	40.6	48.2	52.4	63.8	72.4	79.5
1800	36.8	39.8	48.6	51.9	63.4	72.8	79.9

Hydration equation

The hydration equations have been developed to correlate hydration time with moisture content at the temperature of 90, 80, 70, 60, 50, 40 and 30 ^{0}C. The correlation coefficients show in Table 1, that the equations developed are good fit to the observed data.

Table 2: Hydration equation for maize grains at different soaking temperature

S. No.	Temperature (^{0}C)	Hydration equations	R^2
1	90	$y= -3E-05x^2+0.0897x+26.539$	0.9435
2	80	$y= -3E-05x^2+0.0838x+24.251$	0.9463
3	70	$y= -3E-05x^2+0.0070x+23.10$	0.9415
4	60	$y= -2E-05x^2+0.0556x+20.955$	0.9337
5	50	$y= -2E-05x^2+0.0513x+19.724$	0.9335
6	40	$y= -2E-05x^2+0.0408x+18.665$	0.9086
7	30	$y = -2E-05x^2+0.0408x+18.665$	0.9177

Table 3: Linear relationships between moisture uptake and square root of time

S. No.	Temperature (^{0}C)	Hydration equations	R^2
1	90	y=0.2027x+22.817	0.9435
2	80	y=0.1854x+22.016	0.9463
3	70	y=0.1555x+20.359	0.9415
4	60	y=0.1204x+18.891	0.9337
5	50	y=0.111x+17.829	0.9335
6	40	y=0.0846x+17.288	0.9086
7	30	y=0.0761x+15.937	0.9177

Conclusions

The following conclusions were drawn within limitation of the present study.

1. The moisture absorption rate and moisture content the increased with increase in soaking temperature at under steady state condition.
2. The hydration kinetics of corn showed linear relationship between soaking time and moisture content with correlation coefficient value more than 0.90.
3. Peleg's equation adequately described the hydration characteristics of maize under the experimental condition.

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