Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.5758

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **5 (6):** 708-715 (2017)

Research Article

OPEN ACCESS

International Journal of Pure & Applied Bioscience

Analysis of Hydration Behaviour and Physico-Chemical Properties of Wheat for the Development of Cereal Flakes

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Received: 22.09.2017 | Revised: 27.10.2017 | Accepted: 2.11.2017

ABSTRACT

Physico-chemical properties along with hydration behavior of cereals play an important role for the development of cereal flakes. An experiment was conducted to determine the physical properties like length, width, thickness, geometric mean diameter, sphericity of wheat in lab condition at three moisture content level 10, 15 and 20 % (d.b) and all these parameters were found in increasing order. The linear increase in spatial dimension might be due to expansion resulting from moisture uptake by the seeds in their intercellular space. Porosity and true density increased from 44.35 to 48.09 kg/m^3, 1236.91 to 1304.80 kg/m^3 where as bulk density decreased from 646.45 to 696.75 kg/m^3 respectively with increase in moisture content from 10 % to 20 % (d.b). The angle of repose increased from 23.09° to 25.88° and hardness was decreased from 129.57 to 91.07 N in same range of moisture under study. As per chemical composition is concerned the carbohydrate (72%) and protein (12.90%) content of wheat is very quite where as availability of crude fibre, fat and ash content were also very low but together provide a balanced diet in value added products.

Key words: *Hydration, Wheat, Geometric Mean Diameter, Flaking, Sphericity, Hardness.*

INTRODUCTION

Wheat (*Triticum aestivum)* is a cereal grain, originally from the Levant region of the Near East and Ethiopian Highlands, but now cultivated worldwide. This grain is grown on more land area than any other commercial food. World trade in wheat is greater than for all other crops combined. Globally, wheat is the leading source of vegetable protein in human food, having higher protein content than either maize (corn) or rice, the other major cereals. In terms of total production tonnages used for food, it is currently second to rice as the main human food crop and ahead of maize, after allowing for maize's more extensive use in animal feeds. Some physical properties of this grain and comparison with other grains are considered to be necessary for the proper design of equipment for handling, conveying, separation, drying, milling, storage and other processes[8].

Cite this article: Kumar, S., Kumar, A., Kumar, J., Kumar, D. and Kumar, S., Analysis of Hydration Behaviour and Physico-Chemical Properties of Wheat for the Development of Cereal Flakes, *Int. J. Pure App. Biosci.* **5(6):** 708-715 (2017). doi: http://dx.doi.org/10.18782/2320-7051.5758

Despite an extensive search, no published literature was found on the detailed physical properties of wheat grain and their dependency on operational parameters which would be useful for the design and process optimization of wheat flaking systems. Bulk density, true density and porosity can be useful in sizing grain hoppers and flaking machine. They can affect the rate of heat and mass transfer of moisture during aeration and drying processes. Grain bed with low porosity will have greater resistance to water vapour escape during the drying process, which may lead to higher power to drive the aeration fans.

In this study, some physical properties of wheat grain were determined, namely, size and shape, geometrical mean diameter, sphericity, bulk and true densities, porosity, angle of repose and hardness at various moisture contents in the range of 10-20% d.b. Although moisture content has been reported to influence several physical properties, *Gupta and Prakash*[6] reported non-significant variations of sphericity for a wide range of moisture contents in safflower grain. An increase in grain moisture content was found to increase the angle of repose in fababean[7] as well as the coefficient of static friction in safflower grains[6]. Thus, various physical properties of grains and their fractions are dependent on moisture content and appear to be important in the design of handling and processing equipment.

Flaking is a relatively simple process, consisting in its most elemental form of cooking fragments of cereal grains (or sometimes whole grains), flattering the soft particles between rollers, and toasting the resultant flake at high temperatures. Apparently the first commercial production of such a food occurred around the turn of the century when whole wheat flakes in a barn behind the Battle Creek Sanitarium. Many complications have been introduced into the process since that time in attempts to improve the flavor and the efficiency of operations, and to increase the uniformity of flake size and appearance which so desirable to the manufacturer and perhaps to the consumer. Flakes owe their popularity with consumers to their crisp but friable texture, to their sweet but rather bland flavor, and to the ease with which a portion may be readied for consumption.

Mainly puffed and flaked products are famous as ready to eat breakfast cereal and in some literature it has been found that cereal puffs may be tastier than flakes but it has been also found that flakes are healthier than puffs. However, world population increasing & due to fast lifestyle human being, dependence on ready to eat breakfast cereals is more because it provides all nutrition for human health, also wheat provides all nutrition if enriched. There are many research work on the development of rice, oat, sorghum & corn flakes, but there is no work on the development of wheat flakes.

MATERIAL AND METHODS

Selection of the raw material

Wheat (*Triticum aestivum*, local name: Kalyan) wheat of proper maturity procured from the local market was used in the study. The raw wheat was subjected to conventional cleaning by screening to remove foreign matter, broken kernels, chhafs etc.

Physical and Engineering Properties of Wheat Crop

1. Size and shape indices

The wheat crop, in terms of the three principal axial dimensions, that is length, breadth and thickness as the grain shape tester (K200, Japan) with an accuracy of 0.01 mm. The kernel shape was also determined in terms of its geometric mean diameter, sphericity, roundness and aspect ratio. The geometric mean diameter (D_p) of the seed was calculated by using the following relationship[10]:

$$D_p = (LWT)^{1/3} \quad (1)$$

The degree of sphericity (Φ) was calculated using the following formula as described by *Mohsenin*[10]:

$$\Phi = \frac{(LWT)^{1/3}}{L} \times 100 \quad (2)$$

Where L is the length, W is the width and T is the thickness.

2. Bulk density

Bulk density was measured using the AOAC method, in which a cylinder of inner diameter

106 mm and length 228 mm was filled with wheat crops. The excess seeds were removed and the weight recorded. The bulk density was then calculated as the ratio of wheat crop weight to the volume occupied[11]. The bulk density was calculated using formula.

$$\text{Bulk density}, \rho_b = \frac{M}{V} \qquad (3)$$

Where, ρ_b = Bulk density, M = Total mass of seed (g) and V = Total volume of grain (m^3)

3. True density

Seeds of known weight were taken and known volume of Toluene was put into measuring cylinder and reading was recorded. After that the known weight of seed taken was put into the measuring cylinder and the reading of the volume raised in the cylinder was recorded. In order to determine the volume of seed the initial recorded reading of the cylinder was subtracted from the later recorded reading. Finally the true density was calculated in forms of kg/m3 by using the following formula[18].

$$\text{True density}, \rho_t = \frac{Ms}{Vs} \qquad (4)$$

Where, Ms = mass of solid particle (Kg) and Vs = volume of solid particle (m^3)

4. Porosity (ε)

The porosity (ε) of bulk cereal was computed from the values of true density and bulk density using the relationship given by *Mohsenin*[10] as follows:

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \qquad (5)$$

Where, ρ_t = True density (Kg/m^3) ρ_b = Bulk density (Kg/m^3)

5. Coefficient of friction

A tilting top drafting apparatus was used and wheat crops of known weight were filled in the hollow wooden box. The box was kept on the surface in such a way so that seeds were in contact with the surface. The middle of the box was tied with a non stretchable string and connected to a plastic disc having minimum weight. A pulley having minimum friction was fixed at one end of the table in such a way that the disc connected with the end of the string passing over the pulley could hang freely. Different weights from a weight box were kept on the pan till the wooden box in the seeds just starts sliding. This is the condition where frictional force is nullified and motion starts. This process was repeated thrice for each surface[3,16]. As the coefficient of friction varies with characteristics of the surface, three different surfaces namely, wooden, glass and mild steel sheet were used.

$$\mu = \frac{F}{W} \qquad (6)$$

Where,
μ = Coefficient of friction, W = force normal to surface of contact (N) and F = force of friction (N)

6. Hardness

Compressive strength of cereals grain was considered an important mechanical property in relation to seed breakage during extraction. The compressive strength of the cereal grain was measured by using Instron Universal Testing machine. The Instron machine consist of a rectangular plate, flat, clamps and digital display unit. The load cell was attached with the help of a flat and clamps to the vertically moving upper cross-head of the Instron machine. The base of the Instron machine was used as the base for placement of wheat crops.

7. Angle of repose

To determine the emptying or dynamic angle of repose, a sunmica box of 300 × 300 × 300 mm, having a removable front panel was used. The box was filled with the sample, and then the front panel was quickly removed, allowing the seeds to flow and assume a natural slope. The angle of repose was calculated from the measurement of the maximum depth of the free surface of the sample and the diameter of the heap formed outside the container. All these experiments were replicated five times, unless stated otherwise, and the average values are reported at the set moisture content.

Proximate/Chemical Analysis of Wheat Crop

The proximate analysis gives useful information about the material, particularly from nutritional and bio-chemical point of view. Following proximate constituents were analyzed.

1. Initial Moisture content

The moisture content of wheat crop was determined by standard oven drying method. About 10 g of representative sample was weighed and kept in oven at 105 ± 2^0 C for 24 hours. The dried samples were cooled in desicator to room temperature and then weighed using electronic balance and the moisture content of the material was expressed in wet and dry basis[12].

2. Ash content

The ash content of a foodstuff or cereal grain represents inorganic residue remaining after destruction of organic matter. It may not necessarily be exactly equivalent to the mineral matter as some losses may occur due to volatilization. Taking tare weight of three silica dishes (7-8 cm dia.). Weigh 2 gm of sample into each. Now ignite the dish and the contents on a Bunsen burner. Ash the material at not more than 525 ^{0}C for 4 to 6 hrs. Now cool the dishes and weigh. The difference in the weights gives the total ash content and is represented as percentage.

3. Fat content

Fat soluble material in a food or cereal is extracted from an oven dried sample using a soxhlet extraction apparatus. The ether is evaporated and the residue weighed. The ether extract or crude fat of a food represents, besides the true fat (triglycerides), other materials such as phospholipids, sterols, essential oils, fat soluble pigments etc. extractable with ether. Water-soluble materials are not extracted since the sample has been thoroughly dried prior to extraction with anhydrous ether.

$$\text{Fat (\%)} = \frac{\text{Weight of the fat soluble material}}{\text{Weight of the sample taken}} \times 100 \qquad (7)$$

4. Protein content

Determination of protein content or Nitrogen content is estimated by Kjeldahl method which is based on the determination of the amount of reduced nitrogen (NH_2 and NH) present in the sample. The various nitrogenous compounds are converted into ammonium sulphate by boiling with conc. H_2SO_4. The ammonium sulphate formed is decomposed with an alkali (NaOH), and the ammonia liberated is absorbed in excess of neutral boric acid solution and titrated with standard acid.

$$N_2\ (\%) = \frac{\text{(sample titre - blank titre)} \times \text{N of HCl} \times 14 \times \text{vol. made up} \times 100}{\text{(Aliqout)} \times \text{Wt. of the sample taken} \times 1000}$$

$$\text{Protein (\%)} = N_2\ (\%) \times 6.25 \qquad (8)$$

5. Crude fibre content

Crude fibre consists largely of cellulose lignin (97 %) plus some mineral matter. It represents only 60-80 % of the cellulose and 4-6 % of lignin. Commonly used in quality & quantity. Extract 2g of ground material with ether to remove fat (Initial Boiling temp. 35.38 ^{0}C and final temp. 52 ^{0}C). After extraction with ether boil 2g of dried material with 200 ml of H_2SO_4 for 30 min. with bumping chips. Then filter through muslin and wash with boiling water until washing are no longer acidic. Then boil with 200 ml of NaOH solution for 30 min. Filter through muslin cloth and wash with 25 ml of boiling 1.25 % H_2SO_4 3.25 ml portion of H_2O and 25 ml OH. Remove the residue and transfer to ashing dish (w_1). Drying the residue for 2 hour at 130 ^{0}C. Cool the dish in desicator and weigh (w_2) and ignite it for 30 min. at 600 ^{0}C then cool in a desicator and weigh (w_3).

$$\text{Crude Fibre (\%)} = \frac{\{(W_2 - W_1) - (W_3 - W_1)\}}{\text{Weight of the sample}} \times 100 \qquad (9)$$

Hydration characteristics of wheat

Clean raw wheat was soaked at different temperatures in constant temperature water bath, under atmospheric condition, to determine the hydration behaviour of wheat. The different variables influencing the hydration characteristics of wheat are out lined below:

Table 1: Different variables influencing the hydration characteristics of wheat

Independent Variables	Dependent variables
Time (0, 30, 60, 90, 120, 150, 180, 210, 240 min.) Temperature (30, 50, 60, 70 ^{0}C) Moisture Content (%, d.b)	Hardness Gelatinization

Experimental setup

A constant temperature water bath 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.

Experimental procedure

The soaking test was conducted in an aluminium container. The constant temperature water bath was adjusted to a temperature of 2^{0}C higher than the required temperature of soaking. A few gram wheat samples were taken in the container maintaining a grain to water ratio of 1:2 (v/v). For the experiments the water was heated separately to a temperature that when wheat at room temperature was mixed with water, the desired soaking temperature achieved. The temperature of the mixture was measured by mercury in glass thermometer. The sample was frequently stirred manually for maintaining uniform temperature throughout the soaking medium. Small sample were taken out with the help of an aluminium ladle at different time interval and it were gently blotted to remove to adhering moisture. The samples were then quickly weighed by an electronic balance. The moisture content of the sample were determined using standard drying air oven method and moisture contents were expressed both in per cent wet and dry basis.

Hydration Techniques

Several hydration techniques were investigated for determining hydration behavior of the wheat 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 wheat 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 wheat, 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:

$$M\ (\%) = \frac{(m - m_i) + m_i \times IM}{m} \times 100 \qquad (10)$$

Where, M=moisture content, %, 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 ^{o}C.

RESULTS AND DISCUSSIONS

Physical properties of wheat crop

Physical properties of wheat were carried out in lab and major observation has been found at 10%, 15% and 20% (d.b) moisture content and tabulated in table 2. The linear increase in spatial dimension might be due to expansion resulting from moisture uptake by the seeds in their intercellular space. It indicated that high moistures in wheat would result in shrinkage due to decrease in seed dimensions. Table 1 shows that Bulk density of wheat seeds decreases from 695.75 to 646.45 Kg/m^3 as moisture increase from 10 to 20 % (db). This decrease might be due to the higher rate of increase in volume relative to the increase in mass. True density of wheat seed increased from 1236.91 to 1304.80 kg/m^3 with increase in moisture content. The increase in true density was mainly due to the significant increase in volume, which was higher than the corresponding increase in the mass of the material. Porosity of wheat seed increased from 44.35 to 48.09 % with increase in moisture content (Shown table.1). Angle of repose of wheat seed increased linearly from 23.09° to 25.28° with increase in moisture content, at higher moisture content, seeds tend to stick together, resulting in less flowability and angle of repose is increased. The data may be useful for design of hoppers and flaking mill for wheat seed.

Table 2: Physical/Engineering Properties of wheat

Physical Property	Number of Observations	Mean Value (10%, d.b)	Mean Value (15%, d.b)	Mean Value (20%, d.b)
Length, mm	100	6.083	6.159	6.205
Width, mm	100	3.328	3.485	3.597
Thickness, mm	100	2.697	2.737	2.886
Geometrical mean diameter, mm	100	3.817	3.884	4.027
Sphericity	100	0.620	0.631	0.645
True density, Kg/m^3	100	1236.918	1245.000	1304.800
Bulk density, Kg/m^3	100	695.750	651.800	646.451
Porosity, %	100	44.350	47.340	48.096
Angle of Repose (^{0})	100	23.092	24.885	25.287
Hardness (N)	100	129.574	97.180	91.070

Proximate/Chemical composition of wheat

Proximate analysis of wheat crop was studied at 10 % (d.b) moisture content for the fabrication /development of wheat flaking machine. It was found that carbohydrate (72%) and protein (12.90%) content of wheat is very quite. And availability of crude fibre, fat and ash content were also very low but together provide a balanced diet. This result was in line with observations obtained by *Sayar et al.,*[13] for corn.

Soaking Characteristics of Wheat

The variation in moisture content of kalyan variety of wheat with soaking time at different soaking temperature is shown in Fig 1. There was rapid rate of moisture uptake during initial phase of soaking. This continued up to 1h of soaking. The moisture uptake rate increased with increase in soaking temperature. During hot soaking energy provided in the form of heat weakness the granular structure by disrupting the hydrogen bonds; therefore more surface area is available by starch granular for water absorption. This permits further hydration and irreversible swelling. This result was in line with observations obtained by *Sayar et al*.,[13] for corn.

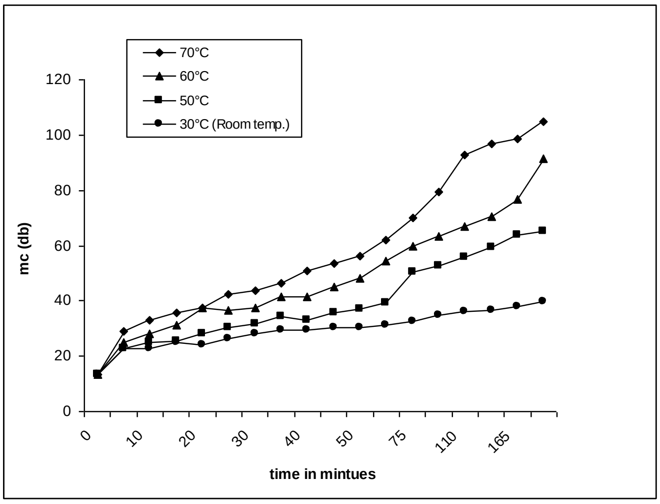

Fig. 1: Hydration characteristics of wheat at different temperature

Hydration Equation

The following hydration equation have been developed to correlate hydration time with moisture content at the temperature of 70^0, 60^0, 50^0 and 30^0C (Room Temp) high correlation coefficients clearly show that the equation developed are good fit to the observed data. This result was in line with observations obtained by *Sayar et al*.,[13] for corn.

Table 4: Hydration equation for wheat at different soaking temperature

Soaking temp.^{0}C	Hydration equations	R^2
70	M = 0.4491x + 30.445	0.92
60	M = 0.3387x + 27.37	0.93
50	M = 0.2531x + 23.476	0.91
30 Room Temp.	M = 0.0996x + 23.417	0.77

CONCLUSION

The length, width, thickness, geometric mean diameter, volume and surface area of wheat increased linearly with moisture content, whereas sphericity was not affected by increase in moisture content. The thousand seed mass increased linearly from 2.67 to 3.59 g with increase in moisture content. Porosity and true density increased from 44.35 to 48.09 kg/m^3, 1236.91 to 1304.80 kg/m^3 where as bulk density decreased from 646.45 to 696.75 kg/m^3 respectively with increase in moisture content from 10 % to 20 % (d.b.). The angle of repose increased from 23.09 to 25.88 ° and hardness was decreased from 129.57 to 91.07 N in same range of moisture under study. As per chemical composition is concerned the carbohydrate (72%) and protein (12.90 %) content of wheat is very quite where as availability of crude fibre, fat and ash content were also very low but together provide a balanced diet. 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. And also found that the gradual increase in the rate of water absorption up to 300 min after 300 min the curve becomes linear for water absorption.

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