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EFFECT OF DRYING ON GERMINATION INDEX OF SORGHUM

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Abstract

Hot air circulation is one of the most common mechanical methods for drying of grains. The main objective of present work was to measure the effect of hot air circulation drying compared to cost-effective intermittent drying on the germination energy and germination index of sorghum seed. In current study sorghum seeds were dried at 40°C, 60°C and 80°C using both methods, to assess the effective diffusivity during drying and effect of different drying temperatures and drying methods on the seed germination energy and index for malt production. It took around 4 hours, 7 hours and 11 hours to reach moisture level to close to a safe level for storage for 40°C, 60°C and 80°C respectively for continuous hot air circulation drying; while it takes 5 hours, 8 hours and 12 hours in case of intermittent drying. During continuous hot air circulation drying values of germination energy and germination index found between 88% to 94% and 4.52% to 4.70%, 85% to 90% and 4.63% to 4.67%, and 9% to 19% and 4.10% to 4.30% at 40˚C, 60˚C and 80˚C respectively. Similarly, for intermittent drying these values ranged from 87% to 92% and 4.59% to 4.70%, 84% to 92% and 4.63% to 4.80%, and 13% to 19% and 4.10% to 4.48% at 40˚C, 60˚C and 80˚C respectively. The value of effective diffusivity was found varying from 8.35 $\times 10^{-08}$ m^2/s to 9.91 $\times 10^{-08}$ m^2/s for hot air drying and 4.87 $\times 10^{-08}$ m^2/s to 6.16 $\times 10^{-08}$ m^2/s for the intermittent drying process. With regression coefficient more than 0.95, Peleg's model was found effectively applicable for prediction of water uptake under the designed experimental conditions of sorghum hydration process. Both Peleg's constants exhibit inverse relationship with water temperature during the hydration process.

Key words : Germination Energy, Germination Index, Drying, Hydration, Peleg Model.

Introduction

Sorghum is generally considered as one of the most drought-tolerant cereal grain crops, that required very little input during growth. Due to this characteristic, it is the important crop of semiarid tropics of Africa and Asia. The present World total production of sorghum is around 63.9 million tonnes with India producing 4410000 tonnes (FAO 2016). Sorghum along with millet played a dynamic role in Africa and Asia as a major carbohydrate source. It is generally considered as possibly important source of antioxidant phenolics, nutraceutical and cholesterol-lowering waxes. With increase in demand for barley malt, malt production from wheat, sorghum and other cereal grains has been instigated (Saleh *et al.,* 2013). With compared to other millet, sorghum has been studied expansively for malting and production of alcoholic beverage, especially in production of gluten-free beer. Malting is the major pre-processing in brewing process. It basically involves soaking of grain until saturation followed by germination of grain for conversion of starch into fermentable sugar and drying. For malting, a grain should be metabolically active and should have capacity of germination after post-harvest processing.

Post-harvest processing of sorghum involves removal of the foreign particle, sorting, washing and drying before storage of grain. During the drying process moisture content in generally bring down between 10-12% for better storability at ambient conditions. Reducing moisture content below 10% generally result into loss in germination capacity of grain, thus making it unsuitable for malting process. Thus, a suitable drying process is required which dry enough to make grains suitable for storage purpose but also keep them biological active during germination.

There are various methods by which grain could be dried on a large scale. The conventional method involves the continuous flow of hot air throughout the drying process. It is rapid and could be uneven and harsh in few cases if not designed properly. During the process hot air is directly in contact with surface which causes the difference in moisture content at surface and core of the grain. Intermittent drying is another popular method of drying, as the name suggests, process involve repetition cycle of drying of object for a certain period followed by a rest period during which object does not come into direct contact with heat. The intermittent drying process is slower than continuous hot airflow, but its more energy efficient and with better quality product after the drying process. Product has better nutritional value, colour and other physical characteristics.

Drying process could be exemplified by using various mathematical drying rate models, which were found more suitable in cereals and grains. These models are basically based upon the relationship between mass transfer by diffusion or convection, drying time and the temperature.

Present work is designed with two objectives. First to compare conventional hot air drying with intermittent drying process of sorghum kernel with the help of mathematical modelling and effective diffusivity, and the effect of drying temperature variation on germination energy of sorghum seeds. Second objective to study hydration kinetics prior to germination process at different temperature.

Materials and Methods

Sample preparation

Sorghum seeds were obtained from the Indian Council of Agricultural Research, Pusa, New Delhi. Seeds were cleaned physically by removing larger external material and by screening using a sieve to remove of smaller particulate and dust. The cleaned seeds were kept at 4±1°C in the self-sealed polypropylene (PP) bags.

Physical properties

A hundred sorghum seeds were arbitrarily selected and measured with the help of a digital calliper (Make: Mitutoyo) (least count 0.01 mm) in all three vertical directions for length (L), width (W) and height (H). Further, the values of geometric mean diameter (D_g), surface area (S), sphericity (ö), and volume (V_g) were computed by means of the below-mentioned equations: (Kaptso *et al.*, 2008):

$$D_g = (LWH)^{\frac{1}{3}} \quad ...(1)$$

$$S = \frac{\pi(WH)^{0.5}L^2}{2L-(WH)^{0.5}} \quad ...(2)$$

$$\emptyset = \frac{D_g}{L} \quad ...(3)$$

$$V_g = \frac{\pi WHL^2}{6[2L-(WH)^{0.5}]} \quad ...(4)$$

Drying procedure

For drying kinetics, pre-weighted samples were kept in two different drying condition, i.e. conventional continuous hot air-drying system and intermittent drying system. Nearly 10±0.05 gm of sorghum grains was dried at three different temperature (40, 60 and 80°C). For intermittent drying cyclic process of drying for 1 hour and rest at room temperature for 1 hour in desiccator is repeated until the completion of the drying process. The test was performed in triplicate, with sample drawn after every 1 hour until the end of drying process.

Determination of germination energy and germination index

Germination energy was calculated as per European Brewery Convention method, in which a hundred grains are placed inside a 90 mm Petri plate, fitted with two layers of filter paper soaked with 4 ml volume of water. The Petri plates were kept in BOD incubator for 3 days at 16°C and sprouted seeds were counted after every 24 hours. The number of germinated seeds within 72 hours represents germination energy (Aparecida *et al.*, 2016).

Germination index is calculated based on the number of germinated seeds after 24 hours, 48 hours and 72 hours, using the following equation:

$$IG = \frac{10*(n_{24}+n_{48}+n_{72})}{(n_{24}+2n_{48}+3n_{72})} \quad ...(5)$$

Germination energy and germination Index, both were calculated for all seed samples dried at 40˚C, 60˚C and 80˚C using both drying procedures.

Effective Diffusivity

Diffusivity is one of the most important properties of the material, especially when talking about drying. It's a complex mechanism here which involves liquid diffusion, vapour diffusion, molecular diffusion and other mass transfer phenomena(Sharanagat, Kansal, and Kumar 2018). Although molecular diffusion is one of the major forces behind water movement inside the grains, still it is not simple, as the material geometry, as well as the composition, are heterogeneous in nature. But for larger drying time, Crank's solution for Fick's second law of diffusion could be utilized, assuming constant moisture diffusivity for a sphere as given by various agricultural products (Crank 1975).

$$MR = \frac{(M_t-M_e)}{(M_o-M_e)} = \frac{6}{\pi^2} e^{-(\frac{D_e \pi^2 t}{r^2})} \quad ...(6)$$

Where, M_t is the moisture content at arbitrary time (t) (g/g), M_0 is the initial moisture content before drying process (g/g), M_e is the saturation moisture content (g/g), r is the geometric mean radius (m) D_e is the effective diffusivity (m^2/s), t is the drying time (h).

A plot between ln (MR) versus time results into a straight line with a negative slope, which can be given by:

$$Slop = -\left(\frac{D_e \pi^2 t}{r^2}\right) \quad ...(7)$$

Diffusivity mainly depends upon temperature, and it changes with it. The relationship between temperature and effective diffusivity could be expressed by following the Arrhenius equation:

$$D_e = D_o\, e^{\left(\frac{-E_a}{RT_a}\right)} \quad ...(8)$$

Where E_a is the activation energy (kJ/mol), R is universal gas constant (8.3143 J/mol K), T_a is absolute air temperature (K). A plot between logarithmic effective diffusivity and the inverse of absolute temperature results into a straight line with a negative slope, which could be used for determination of activation energy.

Hydration kinetics

The Peleg's two-parameter based empirical model for the explanation of water absorption kinetics and desorption kinetics is most commonly used mathematical equation. It is broadly used for both cereal and non-cereal grains. The main equation could be mentioned as(PELEG 1988):

$$M_t = M_0 \pm \frac{t}{K_1 + K_2 t} \quad ...(9)$$

Where t is soaking time (h), M_t is the moisture content at an arbitrary time (t) (g/g), M_0 is the initial moisture content before hydration process (g/g), and K_1 & K_2 are the Peleg's constants. K_1 is associated with sorption rate at the initiation of hydration process known as Peleg's rate constant (1/h%), while K_2 is maximum water retention capacity at the end of the process when samples are in saturated with water, known as Peleg capacity constant.

The above same equation could simplify as below:

$$\frac{t}{M_t - M_o} = K_1 + K_2 t \quad ...(10)$$

The aforesaid equation is comparable to a line equation $y = mx + c$. Hence the intercept and slope of a plot between $t/(M_t-M_o)$ versus soaking time t, will give the values of Peleg's rate constant (K_1) and capacity constant (K_2).

The results were statistically evaluated using the trial version of XLSTAT 2019 and Microsoft office 365 (EXCEL). All the experimentations were performed in triplicate. The assessment of the correlation between predicted data of considered model and actual experimental data was done using the determination coefficient (R^2).

Results and Discussion

Physical Properties

(Table 1) represents the physical dimensional properties of sorghum seed. The major dimension namely length, width, height and geometric mean diameter of the seed were determined to be 4.26± 0.46, 3.78± 0.23, 2.66± 0.18 and 3.57±0.22 mm, respectively. Previous studies reported similar result in the range of 4.77± 0.33, 3.85± 0.43, 2.74± 0.19 and 3.63±0.22 mm respectively for the average length, width, height and geometric mean diameter of sorghum kernels were (M. Kashiri, Kashaninejad, and Aghajani 2010).

Effect of drying on germination energy and germination index

The change in moisture content throughout the drying process for sorghum was calculated at the three different mentioned drying temperatures for both conventional hot air-drying and intermittent drying are shown in Fig. 1. It was found that the rise in drying rate is directly correlated to the rise in drying temperature. As the drying proceeds, this rate goes down, especially for drying at a higher temperature. Also drying rate is higher at high temperature in comparison to a lower temperature. It is mainly because higher water diffusion rate at the higher temperature is responsible for grain to achieve its saturation stat at much faster rate. The driving force, accountable for water transportation inside the seed decreases with time.

During conventional hot air-drying moisture level reaches to 11% after 4 hours of drying at 80˚C, 8 hours of drying at 60˚C and 11 hours of drying at 40˚C, while for same time duration and temperature combination moisture content reduces to 14.5%, 12.8% and 12.6% respectively for Intermittent drying.

Influence of drying temperature, method and time on germination energy (EG%) and germination index (IG%) is shown in table 2. During conventional hot air-drying values of germination energy and germination index found between 88% to 94% and 4.52% to 4.70%, 85% to 90% and 4.63% to 4.67%, and 9% to 19% and 4.10% to 4.30% at 40˚C, 60˚C and 80˚C respectively. Similarly, for intermittent drying these values ranged from 87% to

Table 1: Average values of physical analysis of Sorghum.

Parameter	
Whole seed weight (g)	0.028
Length (mm)	4.259
Width (mm)	3.783
Thickness (mm)	2.657
Geometric diameter (mm)	3.494
Degree of sphericity	0.82
Surface (mm^2)	33.789
Volume (mm^3)	17.854
True density (g/cm^3)	1.562

Table 2: Assessment of the Germination energy (EG%) and Germination index (IG%).

Time (hours)	Temperature	40˚C		60˚C		80˚C	
		EG%	IG%	EG%	IG%	EG%	IG%
2	Hot Air Drying	88	4.52	85	4.67	14	4.30
	Intermittent Drying	87	4.52	84	4.63	19	4.48
4	Hot Air Drying	91	4.59	88	4.66	9	4.10
	Intermittent Drying	90	4.55	90	4.68	13	4.10
6	Hot Air Drying	92	4.62	90	4.64	-	-
	Intermittent Drying	90	4.58	92	4.71	-	-
8	Hot Air Drying	94	4.65	90	4.63	-	-
	Intermittent Drying	91	4.62	92	4.80	-	-
10	Hot Air Drying	94	4.70	-	-	-	-
	Intermittent Drying	92	4.65	-	-	-	-

Table 3: Effective Diffusivity (m^2/s).

	40˚C	60˚C	80˚C
Hot air drying	8.35×10^{-08}	9.02×10^{-08}	9.91×10^{-08}
Intermittent drying	4.87×10^{-08}	5.5×10^{-08}	6.16×10^{-08}

Table 4: Peleg's constant of and goodness of fit for the model.

Temperature (°C)	K_1	K_2	R^2
10°C	0.115	0.033	0.957
20°C	0.081	0.029	0.979
30°C	0.055	0.026	0.990
40°C	0.050	0.023	0.990
50°C	0.030	0.023	0.997

92% and 4.59% to 4.70%, 84% to 92% and 4.63% to 4.80%, and 13% to 19% and 4.10% to 4.48% at 40˚C, 60˚C and 80˚C respectively. As the temperature increases, seed germination energy goes down. Drying at higher temperature results in the destruction of cellular structure and inability of seed to germinate. At higher moisture, level seeds show lower germination capacity as they are unable to activate germination process. With increase in time duration of drying seeds show higher germination energy in both conditions. Germination energy is slightly better in case of intermittent drying at 60°C compared to 40°C. Similar results were reported for barley too (Aparecida *et al.*, 2016).

Effective Diffusivity

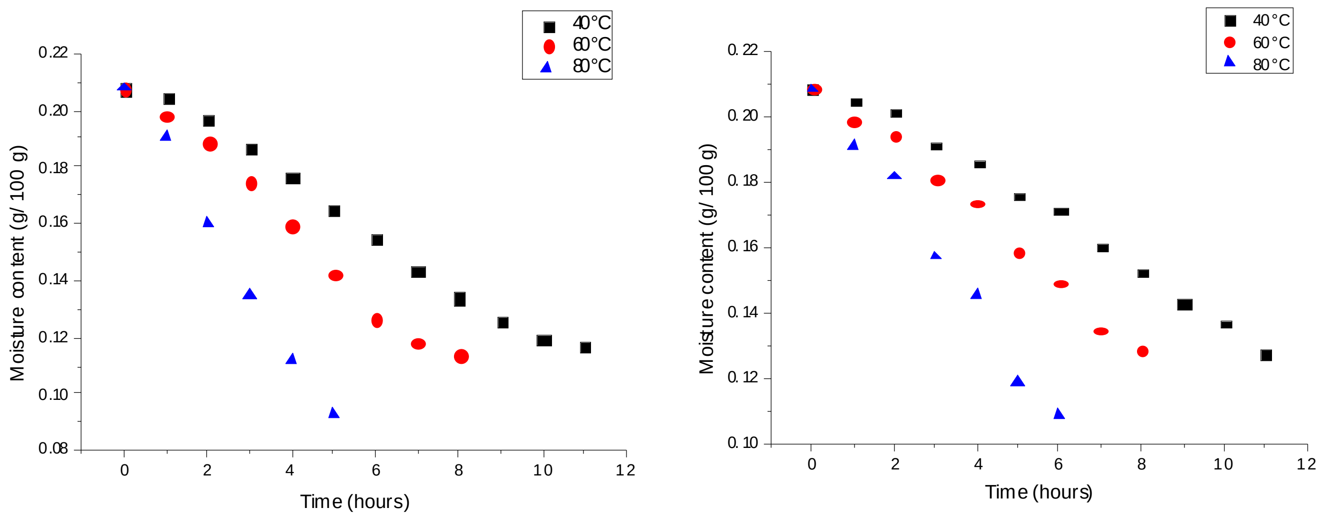
Diffusivity is one of the more important property while designing any drying or hydration process. Effective diffusivity was calculated as per eq (8). The value of effective diffusivity varies from 8.35×10^{-08} m^2/s to 9.91×10^{-08} m^2/s for hot air drying and 4.87×10^{-08} m^2/s to 6.16×10^{-08} m^2/s for intermittent drying process. Value of effective diffusivity increases with increase in temperature(Sandeepa and Rao 2013). Value of effective diffusivity is higher for continuous hot air-drying process compared to the intermittent drying process.

Hydration Kinetics

The variation in moisture content during the grain hydration process was measured for different soaking temperatures. As indicated in results, the water absorption is directly influenced by the rise in process temperature. Because of high water diffusion rate at the higher temperature, the rate of water absorption is higher compare to lower temperature. But after completion of initial hydration, the water absorption rate decreases as system reaches towards equilibrium. The main reason behind this behaviour is reduction in driving force, accountable for water transportation inside the grain. Same phenomena were reported by different studies (Shafaei, Masoumi, and Roshan 2016), (Mahboobeh Kashiri, Daraei Garmakhany, and Dehghani 2012).

Fig. 3 represents the data fitting as per Peleg's model. The intercept of the fitted straight line represents the value of Peleg's rate constant (K_1) while slop represents the value of capacity constant (K_2). The values of Peleg's rate constant (K_1) and capacity constant (K_2) are mentioned in Table 4 for different hydration temperature. The acceptance of the Peleg's model for explaining the hydration kinetics could be established by the value of the coefficient of determination (R^2), which found to be greater than 0.95 for the studied temperature range.

The value of Peleg's rate constant exhibits an inverse relation with the hydration temperature. Due to this relationship, water absorption rate is higher at higher temperature, which progressively decreases with time. Similar behaviour has been reported for other millet in previous work (M. Kashiri, Kashaninejad, and Aghajani 2010) (Swami, Thakor, and Gurav 2013). Peleg's capacity constant was also found expressing an inverse relationship



(a) Continuous Hot Air Drying

(b) Intermittent Drying

Fig. 1: Effect of time and temperature on the moisture content of Sorghum during the drying process.

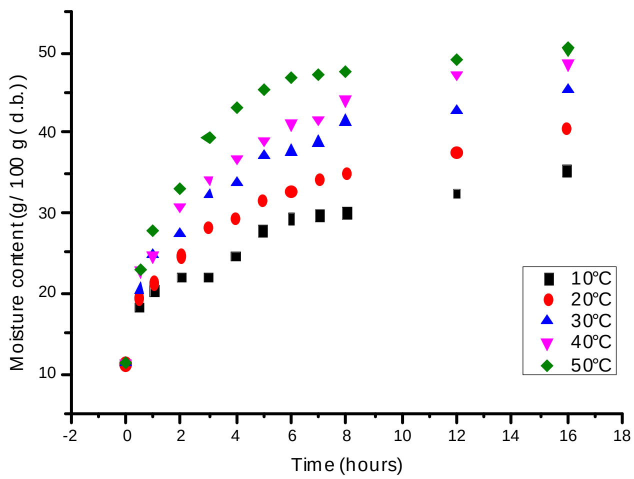


Fig. 2: Effect of time and temperature on moisture gain of Sorghum during the hydration process.

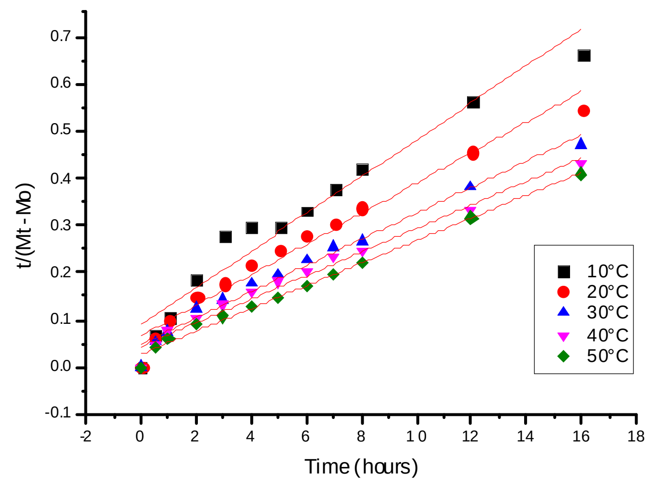


Fig. 3: Curve fitting for Peleg's equation to the experimental data on Sorghum.

temperature. The same behaviour has been stated for amaranth grain, chickpea, sorghum and millet (M. Kashiri, Kashaninejad, and Aghajani 2010) (Shafaei, Masoumi, and Roshan 2016) (Swami, Thakor, and Gurav 2013) (Resio, Aguerre, and Suarez 2006). As the hydration temperature (*T*) rises from 10 to 50°C, the value of rate constant and capacity constant declined from 0.115 to 0.03 and 0.033 to 0.023 respectively (Table 4). It is mainly because of higher water absorption rate and higher water absorption capacity due to rise in hydration temperature during process (Paliwal and Sharma 2019).

Conclusion

Continuous circulation hot air-drying and intermittent drying were evaluated for the drying process of sorghum grain, with their impact on germination energy and germination index of seed. Drying rate and effective diffusivity are higher in case of continuous hot air circulation drying, but germination energy and germination index are higher for intermittent drying when drying temperature are higher. Although low temperature drying at 40°C exhibit the highest germination energy, intermittent drying at 60°C is better in term of process effectiveness and germination index. Dried seeds produced by intermittent drying shows high level of germination capacity. Seed hydration kinetics can easily be described by Peleg's empirical model. Coefficient of determination more than 0.95 confirmed the capability of the Peleg's model for explaining the water absorption kinetics. The values of Peleg's rate constant and capacity constant shows an inverse relation with hydration process temperature. Value of rate constant decreases from 0.115 to 0.03 while value of capacity constant decreases from 0.033 to 0.023 as hydration process temperature rises from 10°C to 50°C.

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