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Cross-flow thin bed drying characteristics of maize (*Zea mays*) using continuous sample weight measurement

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ABSTRACT

Maize (*Zea mays* L.) is one of the most important nutritious grains which have high moisture content during harvest. Moisture content of 24-25% (db) at the harvest has to be reduced below 14% (db) to prevent its deterioration during storage. Drying process is generally performed by forced convection by heating ambient air and blowing it over grains to be dried. The aim of heating the air at certain temperature is to reduce the relative humidity of the air, which has a positive effect on the drying potential. In this study, drying behaviour of thin layer of maize for different drying air temperatures (40, 50, 60 and 70°C) and different air flow rates (20, 30 and 40) studied. The result shows that drying temperature has significant influence on a drying rate. With the increase in drying temperature drying rate increased. The moisture ratio reduced sharply up to 25 minutes of drying time, after that it decreased with drying time but at slower rate. In the beginning of the drying process, moisture transfer took place at faster rate than later. The effect of air flow rate on moisture content was found to be negligible except at the phase of drying. The analysis also illustrated that the drying of maize grains occurred during the falling rate period and no constant rate period was observed in this study. The drying rate constant was found to increase with increas in air temperature and was maximum for a combination of 70^0C air temperature and 40 air flow rate.

Key words: Air flow rate, Air temperature, Drying, Drying rate, Maize, Moisture content, Moisture ratio

Maize (*Zea mays* L.) or Indian corn is one of the most important crop in the world because of its diversity, high compatibility and vast nutritional values (Coşkun *et al.* 2005). Maize has been important in the human life since 4500 years (Kiniry *et al.* 1992) as it has greatest means to capture and store free energy in the land. Only 20% of maize production is going for food purposes whereas, 64% goes for feed purposes and 14% for processing into various other value added products (FAO 2011). Cereal grains are the major source of food for humans as well as animal throughout the world.

Production of maize has a great economic importance due to its large quantity of starch, corn syrup, ethanol, oil, chemicals. Maize matures in the fall and is usually harvested at high moisture content which is unsafe for storage. Maize with high moisture content stored at moderately high temperature is vulnerable to damage due to deterioration, mold, and insect activities during the period of storage. Whereas weather conditions cannot be controlled to allow harvesting for maximum return after the grain is naturally dried in the field (Clarke 1968). So, the mechanical drying of maize is one of the essential operation in modern processing practices.

Maize seed is a living biological entity which germinate and respire. The respiration process in grain is extremely manifested by reducing moisture content, utilization of oxygen, evolution of carbon dioxide and release of heat. Grain drying, refers to the removal of relative amount of moisture from grain. Maize dry naturally in the field as the crop matures, giving up moisture to the air until the grain moisture is in equilibrium with atmospheric moisture content (Doymaz 2011). Few harvested grains may attain the safe moisture content whereas large numbers of harvested grains are much above the safe moisture content required for storage and processing (Christensen 1974). Drying rate influences by airflow rate, air temperature and air relative humidity. There are many advantages of drying, such as grain quality remains constant for longer period, increase

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in market price, storage for longer period and minimum attack of insects and mold.

Grain drying is classified into thin bed drying and deep bed drying according to the grain bed thickness. In thin bed drying all the grains are subjected to approximately same air conditions (Temperature and Relative humidity). In thin bed drying uniform drying of grains takes place. So that all continuous grain dryers use thin bed drying for grain processing as continuous flow of material is required.

Hot-air drying is usually applied to preserve corn kernels by reducing the moisture content to safe limit. During this process, grains undergo different alterations. An important consideration when dealing with heated air process is the drying temperature, which depends on the particular use of grain and the proposed residence time of grain in dryers (Jayas and White 2003).

To assess the drying time from initial to desired moisture content, it is necessary to determine drying characteristics of the grain. Quite a substantial work has been done to determine drying characteristics of grain. But they have used either hot air oven or sample collection method to determine the drying rate and drying characteristics of grains. Very limited studies are done on direct sample measurement in cross flow thin bed drying. By this method an accurate measurement of moisture removal can be done without disturbing or reducing the sample weight.

MATERIALS AND METHODS

The experimental setup consisted of electric motor blower, air flow pipe, electric heater, plenum chamber, sample container and weighing system (Fig 1).

The air passing through heater was stabilised in a plenum chamber which was kept in line and support frame of weighing system. At the top of chamber, a 20 cm long and 18 cm diameter mild steel sheet cylinder was welded to hold the drying chamber that is the sample container. The sample container which was made of aluminium and had an outside diameter of 17 cm was held in a pipe of 18 cm inner diameter by means of rubber gaskets. The top opening of mild steel sheet cylinder and sample container were inter connected through a polyethylene-lined canvas. The bottom of sample container was made perforated by making 5 mm sized holes. In addition, a wire mesh of 1 mm opening was placed at 2.5 cm above the bottom of sample container to allow uniform air flow through the grain bed (Francis 1995).

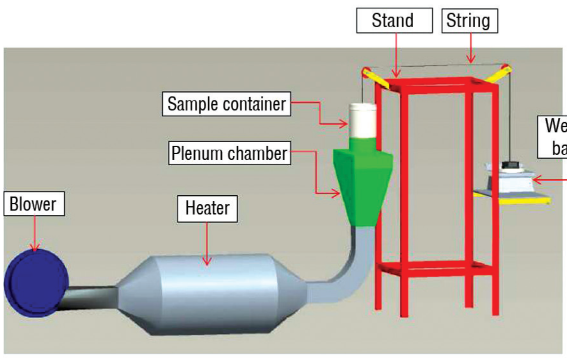

Fig 1 Hot air dryer with continuous sample weighing system.

The maize (PC 3) seed sample was undertaken for study. Average initial moisture content of untreated maize grains was found to be 14% (db). Therefore, maize grain samples were sprinkled with predetermined quantity of water to bring the moisture level approximately 39% (db.). The water sprinkled samples were then thoroughly mixed manually and packed in airtight polythene bags and stored for about 48 h at room temperature for moisture equilibration. The bag was shaken at regular intervals for uniform distribution of moisture inside the sample. The initial moisture content was determined using standard hot air oven method (ASAE S352.2).

The physical characteristics of maize were determined (Tarighi *et al.* 2011). The size of the maize grains was measured with the help of Vernier caliper. Bulk density was measured using a cubical container (10 cm × 10 cm ×10 cm) of 1000 cm^3 volume. The container was filled with the maize grains to the top without any tapping or compression. After filling the container excess grains were removed by passing a flat stick across the top surface using zigzag motions. The container was weighed using a digital balance having accuracy 0.01 g. Bulk density was calculated from the ratio of seed mass in the container to its volume. True density of maize grains was determined by using toluene displacement method (Mohsenin 1986). It was calculated using following equation,

$$\rho_t = \frac{(W_3 - W_1)x\ W_4}{(W_2 - W_1)x\ [W_4 - (W_5 - W_5)]} \quad (1)$$

where, ρ_t = True density of maize grains, kg/m^3; W_1 = Weight of empty measuring cylinder, kg; W_2 = Weight of measuring cylinder filled with 25ml distilled water, kg; W_3 = Weight of measuring cylinder filled with 25ml toluene, kg; W_4 = Weight of maize grains, kg; W_5 = Weight of cylinder + toluene + maize grains, kg.

The completely randomized design of experiment was followed thin layer drying studies. Different combinations of four Inlet air temperature levels (40, 50, 60, and 70°C) and three air flow rates (20, 30, 40 m/min), in total of 12 number of trials, each experiment were performed in triplicate. The experiments were conducted after the system had fully stabilized. For stabilization a dummy sample was kept in container, and blower and heater were operated till difference of weight on weighing scale was very small. Dummy sample was then taken off and actual maize sample was placed in container. The amount of moisture removed from maize sample for different combination of temperature and air flow rate, at an interval of 5 min were measured. Air velocity through the grain bed was measured by means of a digital anemometer having least count of 0.04 m/min. The inlet air temperature to the grain bed was measured by mercury in glass thermometer, range 0-100°C with least count of 1°C.

A sample of 1 kg maize was taken for each trial. During the drying process, the amount of moisture removed from the sample was determined by continuous sample weighing system. The weight transfer from sample container to pan due to air flow uplift was neutralized by tarring the weighing balance after attaining constant air flow rate. The change in moisture content, relative to drying time, was calculated based on the weight change.

The moisture content data in each of experiment analysed to determine the moisture lost by sample of maize in a known time interval. The drying rate was expressed as g water/g dry matter h. The drying rate was calculated as

$$(dM/dt) = (M_i - M_{i+1}) / (t_i - t_{i+1}) \quad (2)$$

where, dM/dt = drying rate, percent moisture loss per hour, Mi = MC (%) (db) of the sample at time ti, Mi+1 = MC (%) (db) of the sample at time ti+1.

Moisture ratio

The thin drying assumes the complete exposure of product to heated air. The drying action can be represented on the basis of Newton's law:

$$dt/d\theta = -K\,(t - t_e) \quad (3)$$

By replacing moisture content in place of temperature

$$dM/dt = -K\,(M - M_e) \quad (4)$$

By integrating between limits

$$MR = (M - M_e) / (M_0 - M_e) = e^{-k\theta} \quad (5)$$

where, M = Moisture content at any time θ,% db; Me = Equilibrium moisture content,% db; Mo = Initial moisture content,% db; Θ = Time, (hr), K = Drying constant.

RESULTS AND DISCUSSION

Effect of temperature on drying characteristic

The typical drying curves for maize with an initial moisture content of 39% (db) when exposed to different air temperatures and air flow rates are shown in figures 2-4. From the drying curves, it is evident that the rate of drying increased with increase in air temperature and air flow rate. The effect of changes of air flow rate was small as compared to changes in temperature of air.

Relationship between moisture content and drying time The initial moisture content of the maize samples was 39% (db) which was reduced to 15.1, 14.2, and 13.6% (db) in 105 min, for combinations of air temperature of 70^0 C and air flow rates of 20, 30, 40 m/min. Other combinations of air temperature (60, 50, 40°C) and air flow rate (20, 30, 40 m/min) required more time than 105 min to reduce the moisture content from initial 39% (db) to 14% (db). Results are similar to those observed in drying of rice (Yadollahinia *et al.* 2008), wheat (Kassem 1998), soybean (Rafiee 2009), brined onion slices (Sarsavadia 1999), thin layer drying of millet (Ojediran and Raji 2010) and for thin-layer drying of garlic slices (Madamba *et al.* 1996). The relationship between moisture content % (db) and drying time (min) for different temperature in following graphs. Fig 2 to 4 shows that air temperature had an important effect on the drying of maize grains. Drying temperature is an effective factor to influence drying rate. With the increase of the drying temperature, a significant increase at the drying rate took place.

Relationship between moisture ratio and drying time The changes in the moisture ratio of the maize grains with drying time were studied and depicted (Fig 5). The drying of the maize grains exhibited the characteristic moisture desorption behavior. An initial high rate of moisture removal was followed by slower moisture removal in the latter stages. As the drying process progressed the moisture ratio was observed to decrease non linearly with increase in drying time for all the samples. The moisture ratio was reduced sharply up to 25 min of drying time, after that it decreased with drying time but at slower rate. The

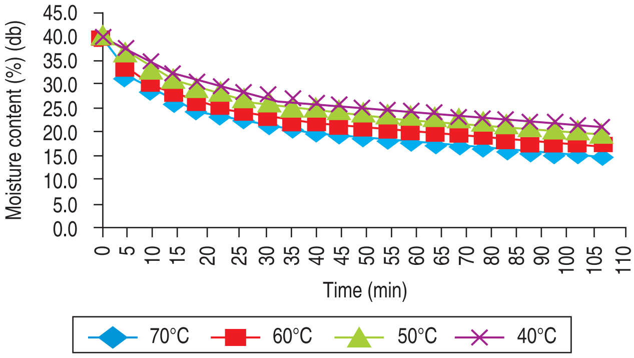

Fig 2 Moisture content vs drying time for air flow rate of 20 m/min.

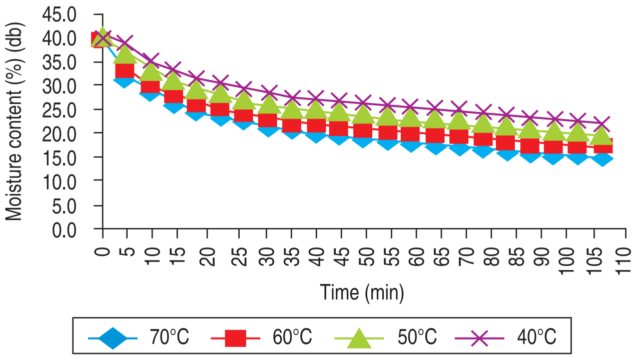

Fig 3 Moisture content vs Drying time for air flow rate of 30 m/min.

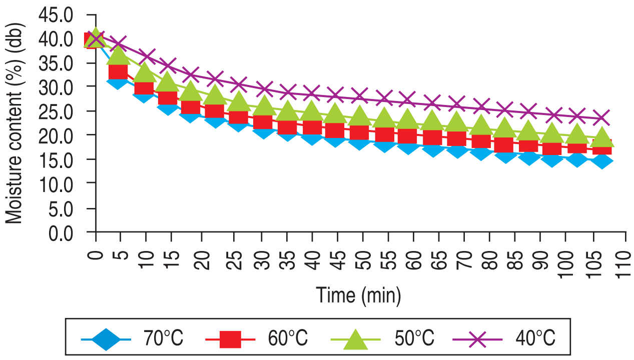

Fig 4 Moisture content vs Drying time for air flow rate of 40 m/min.

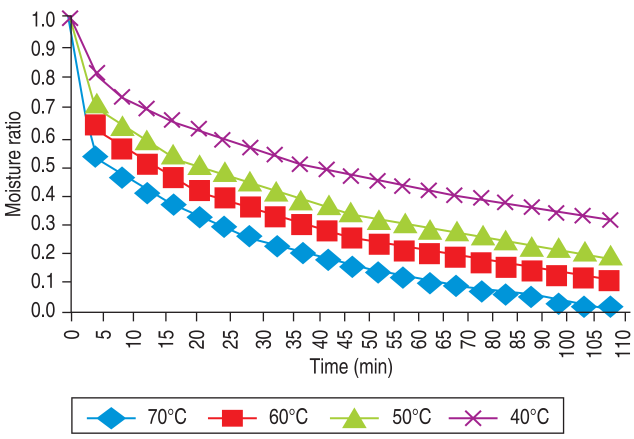

Fig 5 Moisture ratio vs Drying time for air flow rate of 40 m/min.

similar trend has been reported for other food products, e.g. mulberry, eggplant, tomatoes, sweet pepper and peach slices (Doymaz 2011), thin layer drying characteristics of corn (Chen *et al.* 2009, Doymaz and Pala 2003) and wheat (Berbert and Stenning 1996). It was evident from Fig 5 that, moisture content and moisture ratio vs drying time for all constant air flow rate. There was no constant rate-drying period in the entire drying process, all drying processes occurred in falling rate-drying period. During the falling drying rate period, the drying process of maize grains was mainly controlled by diffusion mechanisms. This is in the agreement with earlier research workers (Lopez *et al.* 2000, Hatamipour and Mowla 2006).

The variance analysis was done for finding the effect of temperature and the air flow rate on drying rate of cross flow thin layer bed dryer. The significant difference ($P < 0.000$) was found by drying temperatures and air flow rates as well as their interaction on the efficiency of cross flow thin layer bed dryer (Table 1) while the replication effect was not significant.

Relationship between ln (MR) and drying time. For diffusion of moisture in solids of any shape the following expression is known to hold true for large value of time.

$$MR = B_o \exp^{(-K\,t)} \quad (6)$$

where, B_o and K = Constant, MR = Moisture ratio, t = Drying time (min).

Fig 6 shows a sample plot of data in terms of ln (MR) and time. It is seen that except for the initial portion ($t \leq 10$ min) corresponding to small values of time, data follow the eq.(6). All three cases (i.e. constant air flow rate of 20, 30, 40 m/min) data exhibited the same behaviour. Thus computed value of drying constant (K) from equation-1 for different temperature which are tabulated in following Table 2. Linear regression of logarithm of moisture ratio on drying time resulted in coefficient of determination (R^2) which was also tabulated in Table1 (Henderson and Pabis 1961, Huckill 1947). From table it was found

Table 1 F value for the result of the performance tests

Source	DF	Type I & III SS	Mean square	F value	Pr > F
Rep	2	0.0490056	0.0245028	0.25	0.7797
Temp	3	169.7454750	56.5818250	581.18	<.0001
Airflow	2	10.9501556	5.4750778	56.24	<.0001
Temp* airflow	6	2.3351333	0.3891889	4.00	0.0074

*Significance at 5% level

Table 2 Values of K and R^2 for different temperature at constant air flow rate

Air flow rate (m/min)	Temperature (˚C)	Drying constant (K)(min^{-1})	Coefficient of determination (R^2)
20	40	0.0097	0.9528
	50	0.0114	0.9589
	60	0.0154	0.9698
	70	0.0212	0.9826
30	40	0.0097	0.9630
	50	0.0124	0.9644
	60	0.0164	0.9752
	70	0.0255	0.9847
40	40	0.0095	0.9676
	50	0.013	0.9656
	60	0.018	0.9781
	70	0.03	0.9793

that the combination of 70^0 C air temperature and 40 m/min air flow rate have maximum value of drying constant. The constant computed in this study appears to lower than those presented for corn with 67^0C air temperature and 4 m/s air flow rate (Krokida *et al.* 2003).

Increase of the drying temperature increased the drying rate, which decreased drying times. The effect of temperature was strong. Air flow rate had negligible effect on drying. Air flow rate had little effect on drying up to the 25 min of drying time, beyond that it had no effect on

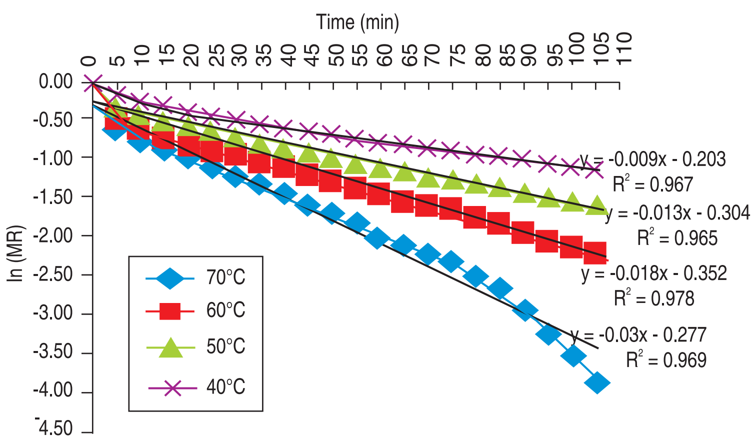

Fig 6 ln (MR) Vs Drying time for flow rate of 40 m/min.

drying (Mulet *et al.* 1987). The moisture ratio was reduced sharply up to 25 min of drying time, after that it decreased with drying time but at slower rate. At the beginning of the drying process, moisture transfer took place at faster rate than later stage. Air flow rate had negligible effect on drying rate constant. The analysis also illustrated that the drying of maize grains occurred during the falling rate period and that no constant rate period was observed in this study. The drying rate constant were found to increase with increasing air temperature and was maximum (0.03/min) for a combination of 70°C air temperature and 40 m/min air flow rate. The effect of air flow rate on moisture content was found to be negligible except at the beginning of drying.

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