EVALUATION OF DRYING CHARACTERISTICS AND QUALITY OF MAIZE DRIED BY TWO STAGE DRYING TECHNIQUES

A THESIS

BY

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Student No: 1605216

Admission Session: January-June, 2016

MASTER OF SCIENCE (MS)

IN

FOOD ENGINEERING AND TECHNOLOGY

DEPARTMENT OF FOOD ENGINEERING AND TECHNOLOGY

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

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DEDICATED TO

MY

BELOVED PARENTS AND HONORABLE SUPERVISOR

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The Author

LIST OF ABBREVIATIONS

Symbol	Abbreviation
AOAC	Association of the Official Analytical Chemists
ANOVA	Analysis of Variance
BBS	Bangladesh Bureau of Statistics
db	Dry Basis
wb	Wet Basis
FBD	Fluidized Bed Drying
IBD	Inclined Bed Drying
CRD	Completely Randomized Design
DMRT	Duncan Multiple Range Tests
SD	Standard Deviation
HSTU	Hajee Mohammad Danesh Science and Technology University
MC	Moisture Content
EMC	Equilibrium Moisture Content
MT	Metric Ton
min	Minute
RH	Relative Humidity
T_{db}	Dry Bulb Temperature
T_{wb}	Wet Bulb Temperature
et al.,	and others
^0C	Degree Centigrade
%	Percentage
g	Gravitational Acceleration
cm	Centimeter
m	Meter
Fig.	Figure

ABSTRACT

Drying of freshly harvested maize is a great concern in all maize producing countries. This research was conducted to investigate suitable and efficient two-stage drying options for high moisture maize. First option was employed by fluidized bed drying and tempering followed by sun drying method and second option was carried out in fluidized bed dryer using variable temperature i.e fluidized bed drying at high temperature and tempering followed by further fluidized bed drying at low temperature. First stage drying in fluidized bed dryer was carried out using three temperatures (120, 140 and 160^{0}C) at constant bed thickness of 7.0 cm. After first stage drying, all dried samples were immediately tempered for 45 minutes at grain temperature. Further, all the tempered samples were dried in second stage by sun drying method and in the same fluidized bed dryer using 65 ± 2^{0}C, respectively in first and second option of two stage drying. Drying performances in terms of drying time, effective moisture diffusivity and specific energy consumption of the drying options and quality of dried maize were evaluated. Drying results indicated that total drying time required 4.25 hours in first option and 1.41 hours in second option of two-stage drying technique. On the other hand, total drying time for single stage drying (complete sun drying method) required 10 hours. Effective moisture diffusivity of maize kernel was found to be ranged from1.05×10^{-08} m^2/s to 1.15×10^{-08} m^2/s and 4.4×10^{-08} m^2/s to 6.3×10^{-08} m^2/s in first and second option, respectively. Specific electrical energy consumption in terms of primary energy and specific thermal energy consumption varied from 0.13 MJ/kg to 0.35 MJ/kg and 0.28 MJ/kg to 0.68 MJ/kg water evaporated for the first stage of fluidized bed drying. Physical properties such bulk density and porosity of the dried product varied between two stage drying and sun drying option. Total color difference of the dried maize obtained from both the two stage drying options was higher (6.32±1.11) in contrast to the sun dried sample (3.64±0.49). The values of % crude protein (6.24±0.27) and % starch content (69.20±0.96) increased during two stages drying whereas amylose content (19.05±0.30 mg/100g) and β-carotene content (0.14±0.02) were found to be decreased in compare to control drying. Even though both the options yielded almost same quality dried product yet second option is preferable for quick drying using lower energy. Therefore, the proposed two-stage drying can be introduced as alternating drying techniques for high moisture maize in commercial drying complexes of Bangladesh. However, further study is required for design and development of commercial dryers to be used at farm level.

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CHAPTER I

INTRODUCTION

Maize drying is a major issue in all maize producing countries of the world. Drying can be described as a preservation method in which water content of foods are decreased by heated air to minimize biochemical, chemical and microbiological deterioration. The major objective of drying of food products is the reduction of the moisture content to a level, which allows safe storage over an extended period. Moisture removal from an agricultural product depends on drying temperature, air velocity and relative humidity, variety and maturity. Various isolated and combined parameters are involved in moisture removal from a grain (Couto, 2002).

Using two-stage drying, high moisture grain is rapidly reduced to a more manageable level (around 18-19% wb) using fast rate fluidized bed drying in first stage (Bunyawanichakul *et al.*, 2007). At 18-19% wb moisture content, cereals can be kept for up to three weeks without excessive deterioration in quality (Discroll and Adanezak, 1987). The moisture content of grain should be further reduced to 14% wb using a slow rate dryer. Normally, two-stage drying systems require specific types of dryers for each stage. The first stage requires a dryer that has a high drying rate such as a fluidized bed dryer. Safe storage requires rapid decrease in moisture to preserve quality (Soponronnarit *et al.*, 2000). Dryers that use a low air temperature and low air velocity (such as in-store dryers) are normally selected for the second stage of drying.

Fluidized bed dryer (FBD) is a dryer that has been recommended by a number of researchers for drying high moisture food grain, as it provides rapid drying and high drying efficiency (Jittanit *et al.*, 2010). Fluidized bed drying is the most efficient drying of grain having in the range of moisture contents from 18-31% wb (Taweerattanapanish *et al.*, 1999). Therefore, the most appropriate way of using this type of drying is as part of a two stage drying system.

Maize (*Zea mays* L.) is one of the main food resources in the world which plays a significant role in human and livestock nutrition world-wide. In view of Bangladesh, special attention is given to maize meeting the challenge of food and feed security. Maize production was 2.23 million metric tons in Bangladesh during 2013 - 2014 (BBS, 2014). Maize yield reached to high of 2.75 million tons in 2015 - 2016 and 90 percent of the home-grown maize is feeding a burgeoning poultry and fish feed industry (USDA, 2016). The nutritional value of maize is also important for using as human and animal consumption. Its grain contains 11.2% protein, 66.2% carbohydrate, 3.6% fat, 1.5% minerals and 2.7% fiber (Gopalan *et al.*, 1981). Additionally, it contains carotene, niacin, thiamine and riboflavin. Maize is also good source of pro-vitamin A and β -carotene, which can prevent human blindness. Maize can be consumed directly as a green cob, boiled, roasted or fried form. It is also used for manufacturing of several industrial products such as corn starch, corn flakes, alcohol, corn oil, paints and similar products.

The knowledge of engineering properties of biomaterials is fundamental in order to optimize the design of equipment's for post-harvest handling and processing of agricultural products. In addition, this information is helpful for data collection in the design of machines, structures, processes and controls; and in determining the efficiency of a machine or an operation. (Mohsenin, 1986; Srivastava *et al.*, 1990; Aviara *et al.*, 1999).

One of the important post-harvesting processes in agriculture is drying process. Since the duration of drying has an important effect on economic yields and the amount of required energy, therefore, checking the effect of drying conditions on the energy consumption is very important. In order to optimize energy consumption, it is needed to pay attention on management and drying of the agricultural products including precise control of other factors affecting the drying time (Sharifi *et al.*, 2010).

1.1 Problems statement

In Bangladesh weather condition, drying of agricultural produces especially maize drying is very important issue. Post-harvest operation especially drying becomes difficult due to unavailability of sunlight. A large amount of freshly harvested maize is wasted due to lack of appropriate quick drying technique at farm level. Microbial and fungal infestation of maize is a common problem in rough weather condition and results in producing aflatoxin of grains. This serious problem may easily be eliminated by ensuring suitable dryer for the farmers and maize processors.

Labor intensive maize drying using traditional sun drying method may not be economic and safe in near future where infestation is common. Mechanical dryers are important for commercial drying of grains. Performance evaluation of any drying method facilitates in optimization of dryer parameters, drying conditions and evaluation on quality dried grain. However, the effect of drying on the quality of maize in Bangladesh has not yet been precisely studied. Very limited works related to the present research are found to be reported in the literature. The outcome of the present study is expected to be beneficial for the maize growers and processors of Bangladesh. Hence, the proposed research is undertaken to develop suitable quick drying techniques for achieving quality dried maize.

1.2 Specific objectives of this study:

- To compare drying behavior in terms of drying time and effective moisture diffusivity of two-stage drying options of freshly harvested maize.
- To evaluate physical and nutritional qualities of dried maize.
- To assess the specific energy consumption during fluidized bed drying of maize.
- To determine suitable two stage drying option for quality dried maize.

CHAPTER II

REVIEW OF LITERATURE

2.1 Origin of Maize

Maize is one of the most common human-cultivated crops. The center of its origin is believed to be the Mesoamerica region, at least 7000 years ago when it was grown as a wild grass called *teosinte* in the Mexican highlands (FAO, 2006). Maize spread around the globe after European discovery of The Americas in the 15th century. Maize has tremendous variability in kernel color, texture, composition and appearance.

Fig. 2.1: Maize Grain

2.2 World Maize Production

Maize has the highest production role among all the cereal crops throughout the world. Maize output for 2016-2017 as per the estimate made in June month is 10,11,768 million metric tons, supported by improving yields in the European Union and expanding plantings in the United States. In Brazil maize production for 2016 to 2017 is estimated at 82,000 thousand metric tons compared to 77,500 thousand last year. As well, the global maize producer; United States are projected to produce 3, 66,539 thousand metric tons, up about 21,053 thousand metric tons 2015 to 2016. At the same time, maize production is expected to fall in China for 2016 to 2017 to 21,8,000 thousand metric tons from 22,4,580 thousand metric tons last year, due to drought and other adverse growing conditions. Whereas, maize production in Mexico for 2016 to 2017 is estimated at 24,200 thousand metric tons compared to 23,500 thousand last month.

2.3 Nutritional Value of Maize

The nutritional value of corn is also important for using as human and animal consumption. Its grain contains 11.2 % protein, 66.2 % carbohydrate, 3.6 % fat, 1.5 % minerals and 2.7 % fiber (Gopalan *et al.*, 1981). Additionally it contains carotene, niacin, thiamine and riboflavin. Yellow dent corn is also good source of pro-vitamin A and β-Carotene, which can prevent human blindness. Pigmented corn contains anthocyanins or carotenoids, and phenolic compounds which are phytochemicals synthesized in the plant by secondary metabolism; although these compounds are considered nonnutritive, interest in antioxidant and bioactive properties has increased due to their health benefits (Heinonen *et.al.*, 1998).

2.4 Concept of Grain Drying

Drying is essentially a process of simultaneous heat and mass transfer. Heat necessary for evaporation is supplied to the particles of the material and moisture vapor is removed from the material into the drying medium. Heat is transported by convection from the surroundings to the particle surfaces and from there by conduction, further into the particle. Moisture is transported in the opposite direction as a liquid or vapor on the surface; it evaporates and passes on by convection to the surrounding.

Drying characteristics of grains are complex. The moisture associated with seeds is of many forms viz. a) Chemically bonded b) physico-chemically bonded and c) mechanically bound form, depending on the bond strength of moisture. The nature of drying depends on the formation of its bond with the grain. For instance macro-capillary water enters in by liquid flow; on the other hand swelling moisture is removed or dried by diffusion through the cell wall. Hence the removal of moisture from grain becomes difficult.

Chakraverty (1994) observed that drying involves both heat and mass transfer operations simultaneously. In convective drying, the heat required for evaporating moisture from the drying product is supplied by the external medium, which is usually air.

Trim and Robinson (1994) stated that the drying process involves two basic mechanisms; the migration of moisture from the interior of an individual grain to the surface and the evaporation of moisture from the surface to the surrounding air. They also stated that drying operation must not be considered as merely the removal of moisture since there are many quality factors that can be adversely affected by incorrect selection of drying conditions and equipment. It is therefore important to understand the principles of grain drying whether it is being dried by natural or artificial drying system to ensure that a high quality product is obtained.

2.5 Grain Equilibrium Moisture Content

The concept of equilibrium moisture content (EMC) is important in the study of grain drying because it determines the minimum moisture content to which grain can be dried under a given set of drying conditions (Brooker *et al.*, 1992). As a result, the EMC of a grain as defined by Brooker *et al.* (1992) is the moisture content of a material after it has been exposed to a particular environment for an infinitely long period of time. Alternatively, they defined EMC as the moisture content at which the internal product vapor pressure is in equilibrium with the vapour pressure of the environment. The EMC is useful in determining whether a product will gain or lose moisture under a given set of temperature and relative humidity conditions. Thus, EMC is directly related to drying and storage (Chakraverty, 1994).

2.6 Two Stage Drying

The two-stage or multi-stages in drying is a strategy which some researchers have applied for their high moisture content products or sensitive products due to many benefits such as high product quality and saving energy consumption (Weibye, 1983; Baz *et al.*, 1992; Thakur and Gupta, 2006).

Wiset *et al.* (2001) found that there are obvious advantages in adopting the two-stage drying concept, such as an increase in drying capacity of the first-stage dryer and low energy consumption in the second stage resulting in a substantial overall energy saving. The technique has thus become an increasingly more popular technique for rice drying. High temperature used in their study (during the first stage of drying) led to the development of a moisture gradient inside each grain kernel and resulted in cracking and breakage of the rice kernels.

Morey *et al.* (1981) studied on two-stage drying of rice. They summarized the main advantages of two-stage drying is as follows:

1) Reduced energy requirement due to the increased air efficiency as compared with continuous-flow dryers alone, so that less heat is vented to the atmosphere.

2) Increased drying system capacity: This point is related to the capacity of the first stage dryer, since discharge of the grain at higher moisture content before cooling will free the dryer for next load of high moisture grain, which is where continuous dryers are more efficient.
3) Improved grain quality: This point relates to the relaxation time during the second stage of drying. The moisture gradients within the grain will dissipate during that stage, preventing the outer layer of the grain from being over dried, and hence brittle and susceptible to cracking.

2.7 Tempering between Two Stage Drying

Normally two stages of drying are intermittently interfered by tempering period. Thakur and Gupta (2006) stated that two stage drying with the tempering period in between brought advantages in reducing the breakage of grain. Reducing broken grains leads to a uniform product and increase sensory value of final products. These results are the positive effects of intervening rest periods between the two stages of drying on drying rate, the energy consumption and product quality. During the period of the rest stage, the grain released moisture as an effect of the residual temperature and the grain moisture become uniformly distributed within the kernels (Thakur and Gupta, 2006).

In addition, the rest period between two-stage drying is needed to uniformly spread the moist inside the grain and between grains. During drying time, the rice grains will absorb the heat from the drying agents via various ways such as convection, conduction, or radiation. The moisture content inside grain is hardly uniform especially if the product is thick. During the first period of drying procedure, the moisture can be removed rapidly but the drying rate can decrease at the later drying period due to lower moisture content of sample. On the other hand, if the sample is kept stable during drying process, at same positions, drying agents cannot contact with the sample; as a result, the non-uniformity of dried sample would appear. Therefore, the tempering or agitation step should be considered during drying.

2.8 Basic Principle and Terminology for Grain Drying

Drying is a complex operation involving transient transfer of heat and mass along with several rate processes, such as physical or chemical transformations, which, in turn, may cause changes in product quality as well as the mechanisms of heat and mass transfer. Physical changes that may occur include: shrinkage, puffing, crystallization, glass transitions. In some cases, desirable or undesirable chemical or biochemical reactions may occur leading to changes in color, texture, odor or other properties of the solid product. In the manufacture of catalysts, for example, drying conditions can yield significant differences in the activity of the catalyst by changing the internal surface area.

Drying occurs by effecting vaporization of the liquid by supplying heat to the wet feedstock. As noted earlier, heat may be supplied by convection (direct dryers), by conduction (contact or indirect dryers), radiation or volumetrically by placing the wet material in a microwave or radio frequency electromagnetic field. Over 85 percent of industrial dryers are of the convective type with hot air or direct combustion gases as the drying medium. Over 99 percent of the applications involve removal of water. All modes except the dielectric (microwave and radio frequency) supply heat at the boundaries of the drying object so that the heat must diffuse into the solid primarily by conduction. The liquid must travel to the boundary of the material before it is transported away by the carrier gas or by application of vacuum for non-convective dryers（Mujumdar, 1997）.

2.8.1 Definitions of commonly encountered terms in psychometrics and drying

Term/symbol	Meaning
Unbound moisture	Moisture in solid which exerts vapor pressure equal to that of pure liquid at the same temperature
Adiabatic saturation temperature, T_{as}	Equilibrium gas temperature reached by unsaturated gas and vaporizing liquid under adiabatic conditions. (Note: For air/water system only, it is equal to the wet bulb temperature (T_{wb}).
Bound moisture	Liquid physically and/or chemically bound to solid matrix so as to exert a vapor pressure lower than that of pure liquid at the same temperature.
Constant rate drying period	Under constant drying conditions, drying period when evaporation rate per unit drying area is constant (when surface moisture is removed)
Dew point	Temperature at which a given unsaturated air-vapor mixture becomes saturated
Dry bulb temperature	Temperature measured by a (dry) thermometer immersed in vapor-gas mixture.
Equilibrium moisture content, X^*	At a given temperature and pressure, the moisture content of moist solid in equilibrium with the gas-vapor mixture (zero for non-hygroscopic solids)
Critical moisture content, Xc	Moisture content at which the drying rate first begins to drop (under constant drying conditions).
Falling rate period	Drying period (under constant drying conditions) during which the rate falls continuously in time.
Free moisture, Xf $Xf = X - X^*$	Moisture content in excess of the equilibrium moisture content (hence free to be removed) at given air humidity and temperature.
Humid heat	Heat required to raise the temperature of unit mass of dry air and its associated vapor through one degree (J kg^{-1} K^{-1} or Btu $lb^{-1}$$^oF^{-1}$)
Humidity, absolute	Mass of water vapor per unit mass of dry gas (kg kg^{-1}or lblb^{-1})
Humidity, relative	Ratio of partial pressure of water vapor in gas-vapor mixture to equilibrium vapor pressure at the same temperature
Wetbulb temperature, T_{wb}	Liquid temperature attained when large amounts of air-vapor mixture is contacted with the surface. In purely convective drying, drying surface reaches T_{wb} during the constant rate period
Water activity, aw	Ratio of vapor pressure exerted by water in solid to that of pure water at the same temperature.

Source: (Mujumdar, A.S, 1997)

2.9 Basic Concept of Fluidization

Fluidization is the operation by which fine solids are transformed into a fluid like state through contact with a gas or solid. The process of fluidization with hot air is highly attractive for the drying of different materials. Fluidized bed driers are used extensively for the drying of wet particulate and granular materials that can be fluidized and even slurries, pest and suspensions that can be fluidized in beds of inert solutes. It is operated at superficial gas velocities higher than the minimum fluidization velocity. They are commonly used in processing many products such as chemicals, powder formation, carbohydrates, food stuff, bio materials, beverage products, ceramics, health care products, detergents, surface active agents, fertilizers, waste management process and environmental protection process. Fluidized bed operation gives important advantages such as good solid mixing, high rates of heat and mass transfer, and easy material transport. An induced draught is created by means of blower and fresh air is sucked into the unit. This hot air stream expands the material at certain velocity and creating turbulence in the product.

2.10 Fluidized Bed Drying

Fluidized bed drying is a well-known process that has been widely used in the dairy and pharmaceutical industries for drying, granulating, and coating operations (Sokhansanj and Jayas, 2006). Fluidized bed drying process has been successfully used to dry many agricultural products of different particle sizes (ranging from 10 mm to 20 mm) such as wheat and corn grains; cut green beans; slices of carrot, celery, mango, or kiwifruit; button mushrooms; and green peas. In fluidized bed drying, the drying air is introduced at a velocity at which the material remains fully suspended in the hot air stream and dries with high rates of heat and moisture transfer. The high rate of heat transfer results in instantaneous evaporation of moisture at the entry point.

2.10.1 Advantages of Fluidized Bed Drying

Fluid bed drying offers advantages over other methods of drying of particulate materials. Particle fluidization gives easy material transport, high rates of heat exchange at high thermal efficiency while preventing overheating of individual particle. The advantages are given bellow:

- In fluidized beds, the contact of the solid particles with the fluidizing medium (a gas or a liquid) is greatly enhanced when compared to packed beds. This behavior in fluidized combustion beds enables good thermal transport inside the system.
- Good heat transfer between the bed and its container which can have a significant heat-capacity whilst maintaining a homogeneous temperature field.
- High heat and mass transfer rates, because of good contact between the particles and the drying gas.
- Uniform temperature and bulk moisture content of particles, because of intensive particle mixing in the bed.
- Excellent temperature control and operation up to the highest temperature.
- High drying capacity due to high ratio of mass of air to mass of product.

2.10.2 Disadvantages of Fluidized Bed Drying

The disadvantages of fluidized bed dryer include high pressure drop, attrition of the solids and erosion of the containing surfaces and a possibility of non-uniform moisture content in the product as a result of the distribution of the residence times of individual particles for continuous fluidized bed operations (Kaensup *et al.*, 1998).

On the other hand it is unfavorable to exceed the limits for temperatures in fluidized bed dryers due to the flammability and deterioration risks of particles. This is one of the most important disadvantages of fluidized bed dryers. Therefore, fluidized bed dryer systems which are operated under vacuum pressures can be preferred (Thomas and Varma 1992). Brooker *et al.* (1992) listed some disadvantages of a fluidized bed grain dryer are summarized below:

- Bubbling beds of fine particles are difficult to predict and are less efficient,
- Rapid mixing of solids causes non-uniform residence times for continuous flow reactors,
- Particle comminuting (breakup) is common,
- Pipe and vessel walls erode due to collisions by particles.

2.11 High Temperature Drying of Paddy

Hot air drying is the most common method used for food dehydration. The quality of a food product is sensitive to the drying temperature (Luangmalawat *et al.*, 2007). The temperature may cause the degradation of food qualities, such as colour, shrinkage, nutritional substances, dehydration capability and microstructure (Aguilera 2005; Attanasio *et al.,* 2004; Bello *et al.,* 2006; Silva and Avila, 1999; Thipayarat and Leelayuthsoontorn 2006). All these physical and chemical changes have an influence on consumer acceptability. When heated air is used to dry high moisture paddy, drying of the paddy usually starts from the surface of the kernel and progresses inward. Drying too rapidly causes "case hardening". This happens when the surface of the grain dries out rapidly sealing the moisture within the inner layers. The internal pressure thus developed causes cracks on the grain (Abe *et al.,* 1992). They explained further that the same phenomenon accounts for the development of chalky grains. Grains which are cracked result in the breakage of rice during milling. This leads to a reduction in milling recovery, both quantitatively and qualitatively (Abe, *et al.,* 1992).

A two-stage paddy drying carried out by Messo *et al.* (2004) suggested that high temperature used in the first stage led to the development of a moisture gradient inside each grain kernel and resulted in cracking and breakage of the paddy kernels. This problem, they suggest can be solved by introducing a tempering process between the two stages in order to increase or maintain the two stages so as to increase or maintain the paddy head rice yield and reduce the paddy moisture content in the second stage (Soponronnarit *et al.,* 1999; Steffe *et al.,* 1979).

2.12 Heat Transfer during Drying

The methods of heat transfer during drying generally convection heat transfer, conduction heat transfer and radiation heat transfer. The rate of heat transfer between a solid and fluid may be computed from the following relation proposed by Isaac Newton in 1770.

$Q_c = h_c\, A\, \Delta T$

Where,

h_c= heat transfer coefficient ($w/m^2\,k$)

A= area (m^2)

ΔT= temperature difference (k).

2.13 Emprical Drying Equation

Several emprical equation have been devloped for cereal grains. Page (Hall , 1970 and vanRest and Isaacs 1968) proposed the following equation for shelled corn

$$\frac{M - Me}{Mo - Me} = \exp(-kt^u) \text{.................}(2.1)$$

Overhults *et al.* (1973) studied the thin layer drying of soybeans with initial moisture content ranging from 20 % to 33 % and equation (2.1) was employed to describe the experimental data.

Other investigators (White *et al.*,1973; Wang and Singh,1978) have utilized the modified page equation to predict the drying characteristics other than soyabeans.

2.13.1 Drying Rate

The drying rate for the single exponential equation can be directly computed from the equation

$$\frac{dM}{dt} = -k\,(M\text{-}Me) \text{.................}(2.2)$$

Increase in moisture content and air temperature of grain increase the drying rate whereas the drying rate decreases with the increase in air humidity (Trim and Robinson,1994). Thin- layer drying rates of sunflower seed were determined by Syarief *et al.*(1984) over atemperature range of 27 ^{o}C to 93 ^{o}C, initial moisture contents of 21 % to 26 % and 20 % to 80 % relative humidity.

Where

$\frac{dM}{dt}$ = Drying rate

K= Drying constant (h^{-1})

M= initial moisture content of grain (% dry basis)

Me= Equlibrium moisture content (% dry basis)

2.13.2 Chung and Pfost Equation

Chung and Pfost devloped the following equation based on potential theory and a simplified equation of state

$$\ln(rh) = \frac{-A}{(Ro\ Tab)} \exp(-BM_{sd}) \text{...............}(2.3)$$

Where

rh = Relative humidity %

A,B are the Chung and Pfost constant

R_o= Universal gas constant

T_{ab}= Temperature k

M_{sd}=Static qulibrium moisture conten (% db).

2.14 Different Maize Drying Technology

2.14.1 Solar drying of maize

Foster, Peart, and Baker (1980) dried corn samples using two methods of solar energy. In the first method, the corn was dried to 20–22% moisture content in a high temperature dryer in first stage, and then drying was finished with solar drying. In the second method, the doubled size of solar collector and the bin, which was filled with three layers of corn, were used. Second method can be used successfully to dry corn, which has initial moisture content in the range of 25–30%.

2.14.2 Fluidized bed drying

Palancz *et al.* (1983) proposed a mathematical model for continuous fluidized bed drying based on the two-phase theory of fluidization. According to this theory, the fluidized bed is divided into two phases, a bubble phase and an emulsion phase, which consists of gas and solid particles. Thus, higher inlet temperatures of drying air can be used which lead to shorter drying times. The enthalpy and the entropy of drying air also increase leading to higher energy efficiency.

The effect of temperature was more critical than that of the other parameters and could reduce the drying time substantially.

Soponronnarit *et al.* (1997) investigated the effect of high temperatures (more than 100^0C) on the physical damage to maize and soybean and reported that significant increases in stress cracks and in breakability occurred at reduced moisture contents.

Soponronnarit *et al.* (1994) conducted a feasibility study of paddy drying by fluidization technique. Operating parameters affecting product quality, drying capacity and energy consumption were investigated. Experimental results showed that drying rate of a paddy kernel was controlled by diffusion. However, drying capacity of dryer increased with specific air flow rates and drying air temperatures. Energy consumption was reduced when specific air flow rate decreased or when fraction of recycled air increased. Maximum temperature should be limited to 115^{o}C and final moisture content of paddy at 24-25 % dry basis if product qualities were maintained.

Soponronnarit *et al.* (1997) carried out a batch fluidized bed dryer design for corn drying. Drying characteristics of corn were investigated. The experimental results indicated that moisture transfer inside a corn kernel was controlled by internal diffusion by the following condition: inlet hot air temperatures of 120-200^{0}C, superficial air velocities of 2.2-4 m/s, bed depths of 4-12 cm, fraction of air recycled of 0.5 – 0.9 and initial moisture content of corn of 43% dry-basis.

Gustafson *et al.* (1983) investigated thin layer corn drying at temperature in the range of 70-12O^{0}C, final moisture content of 13-19% wet-basis and at different tempering time. They were concluded that breakage susceptibility depended on final moisture content and tempering time.

Li and Morey (1984) studied thin-layer drying of yellow dent corn and found that it is affected by drying air temperatures, air flow rate, initial moisture content and relative humidity. He also found that drying air temperatures and initial moisture content effect on drying rates, but air flow and relative humidity have negligible effects.

Ulku and Uckan (1987) observed that the modeled batch fluidized dryer as a homogeneous system; the bubbles are ignored and the rate of the internal diffusion inside the solid particles is the controlling step of the overall drying rate.

Chandran *et al.* (1990) developed a kinetic model for the drying of solids in fluidized beds, assuming a falling rate period following a constant rate period. They obtained the experimental data using batch and continuous single and spiral fluidized beds. Their results are satisfactorily matched with the assumed drying kinetics and the residence time distribution of solids appropriate for the type of dryer.

Abid *et al.* (1990) investigated an experimental and theoretical analysis of the mechanisms of heat and mass transfer during the drying of corn grains in a fluidized bed. Their theoretical analysis of the internal mechanisms of heat and mass transfer has been carried out starting from the model of Luikov, which is based on the irreversible thermodynamics. This model takes into account the transfer of water by diffusion under the influence of a gradient of the concentration in moisture and by thermo diffusion under the influence of a temperature gradient.

Thomas and Varma (1992) experimentally investigated fluidized bed drying of granular cellular materials and compared the experimental results for batch and continuous fluidized bed drying investigated at different temperatures such as 60^0C, 70^0C and 80^0C air flow rates of (2-3m^3/s) the heating medium, particle size and mass of solids in a fluidized bed type dryer.

Peplinski *et al.* (1994) varied the temperature of drying air in the range of 25 to 100^oC and finding that high temperature led to a decline in maize kernel test weight and germination rate but increased the percentage of floating kernels.

Somkiat Prachayawarakorn *et al.* (1997a, 1997b) studied the drying characteristics of corn in a batch fluidized bed dryer at 150, 170 and 200^0C air temperatures. They reported that drying corn from initial moisture content 43–16% (dry basis) to final moisture content with air at 170^0C could be done without much loss of quality. Besides, the experimental results indicated that moisture transfer inside a corn kernel was controlled by internal diffusion.

Somkiat Prachayawarakorn *et al.* (2001) investigated the factors affecting on drying rate of high moisture corn at high temperature with fluidization technique and they developed a mathematical model for predicting drying rate. There were three following steps of drying process: (1) rapid drying using fluidized bed dryer at inlet drying air temperature of 130-170°C, (2) corn tempered for period of 40-180 minutes under the same temperature as drying from the step 1 and 3) drying with ambient air. Drying kinetic showed that the inlet air temperature and the specific airflow rate significantly affecting the drying rate. Amongst three semi empirical drying equations (Wang and Singh, Page and Lewis), Page's equation provides the best prediction.

2.14.3 Tray drying

Thuy *et al.* (1999) dried maize seeds in the oven by spreading seeds as a single layer on a wire mesh tray and concluded that maize seeds could be intermittently dried at 60°C for no longer than 10 minutes per drying pass without quality deterioration.

Ibrahim Doymaz and Mehmet Pala (2003) investigated the effect of ethyloleate on the drying rates for corn in a pilot plant air-dryer. Corn was air dried in controlled mention the drying conditions without treatment or after dipping in a cold solution of ethyloleate. Dipping in a solution of 2% (w/w) ethyl oleate and 4% (w/w) potassium carbonate resulted, in most cases, in an increase in the drying rate of corn kernels.

Haros *et al.* (2003) concluded that high drying temperatures increase all the transition temperatures of wet-milled starch. As high-temperatures drying has a negative effect on starch protein separation during the wet-milling. Haros *et al.* (2003) and Altay and Gunasekaran (2006) assumed that the proteins remaining in cornstarch possibly reduce the entrance of water into the granules during gelatinization, limiting interactions between water and starch components and increasing temperatures of gelatinization by the way.

Somkiat Prachayawarakorn *et al.* (2004) developed a theoretical diffusion model for a single maize kernel to describe moisture migration during drying and tempering stages. The effective diffusivity was determined experimentally at a range of temperatures between 90^0C and 170^0C with initial moisture contents of 37% and 43% dry-basis. The functional relationship between the diffusivity and temperature is analogous to a modified Arrhenius equation. They also investigated two-stage drying including tempering between stages provides not only faster removal of moisture, but also a reduced number of stress cracks when compared to single-stage drying.

Bunyawanichakul *et al.* (2007) emphasized on development of an appropriate dryer for grain drying. For the individual farmer, immediate threshing and drying of wet harvested rice to 18-19% wb is a practical method to avoid deterioration and increase selling price. They suggested that, a suitable dryer for this purpose was a compact mobile unit that used high temperature heating and had a very short grain exposure and grain residence time.

Thakur and Gupta (2006) reported that the experimental investigations were carried for the determination of suitable rest duration and the stage; at which resting will provide better redistribution of internal moisture in paddy grains subjected to fluidized bed drying. Incipient velocity was evaluated considering the drying conditions and the characteristics of the high moisture paddy. Intervening rest duration between first and second stage of drying, enhanced drying rate, reduced energy consumption and improved head rice yield. Energy requirement can be significantly saved (9–58 %) by providing rest durations (30–120 min) in comparison to the continuous drying.

Jittanit (2007) studied the effect of drying corn, rice and wheat seed in two stages using germ inability as a measure of quality. For the first stage, fluidized bed dryer (FBD) and spouted bed dryer (SBD) were used to dry seed from 20-25% wb to 18% wb while in-store dryer was used in the second stage for drying from 18%wb to below 14%wb. The drying air temperature range of 40-80°C was studied for the first stage while 18-30°C and relative humidity 60-70% were for the second stage. It was found that dryer type, drying temperature, initial moisture content of seeds and drying time had significant effects on the seed germination. From the result, the drying air temperature of 40°C was safe for corn and rice in FBD while 60°C was acceptable for wheat. In SBD, the 40°C was the maximum drying temperature for rice and wheat without quality deterioration. Meanwhile the second stage drying in an ISD under all specified conditions was safe.

Hideo Inaba *et al.* (2007) investigated the effects of heat and mass transfer parameters on the efficiency of fluidized bed drying in order to optimize the input and output conditions. The analysis was carried out using two different materials, wheat and corn. Energy and exergy models based on the first and second law of thermodynamic are developed. Furthermore, some unified non-dimensional experimental correlations for predicting the efficiency of fluidized bed drying process have been proposed. The effects of hydrodynamics and thermodynamics conditions such as the inlet air temperature, the initial moisture content and well known Fourier and Reynolds numbers on energy efficiency and exergy efficiency were analyzed using the developed model. A good agreement was achieved between the model predictions, non-dimensional correlations and the available experimental results.

Topuz *et al.* (2008) were conducted Fluidized bed drying experiment by applying three different air temperature and two different air velocities. In addition, the Henderson and Pabis model was used to compare experimental and model results. Lastly, activation energy values were determined for the particles. Results revealed that the drying air temperature has the greatest effect on the drying kinetics of particles, whereas air velocity has a small effect.

Burande *et al.* (2008) studied an experiment on fluidized bed drying process of green peas. They optimized the drying process by using the response surface methodology for the process variables: drying air temperature (60-100°C), tempering time (0–60 min), pretreatment, and mass per unit area (6.3–9.5g/cm2). The green peas were pretreated by pricking, hot water blanching, or chemical blanching. Product quality parameters such as rehydration ratio, color, texture, and appearance were determined and analyzed. Optimum conditions of 79.4°C drying air temperature, 35.8 min tempering time, pretreatment of the once pricked peas with chemical blanching in a solution of 2.5 % NaCl and 0.1 % $NaHCO_3$, and mass per unit area of 6.8 g/cm^2 were recommended for the fluidized bed drying of green peas. At these conditions the rehydration ratio was 3.49.

Singh *et al.* (2008) studied the drying characteristics of ginger flakes under fluidized bed conditions in the temperature range of 50 to 80°C and pretreatment of calcium oxide in the range of 1 to 2.5 %. They found drying rate at 60°C air temperature decreased from 0.43 to 0.17 g/s with the change in moisture content from 30 to 10 % db. The volatile oil in dried flakes decreases from 1.2 to 0.99 % with increase in drying temperature from 50 to 80°C.

Malumba *et al.* (2009) showed that high-temperatures drying reduce the swelling capacities of starch granules and their solubility indices during gelatinization. It is likely that structural changes which possibly occur inside of granules during the drying may affect the pasting characteristics of starch–water system during the subsequent gelatinization. Therefore, changes on physicochemical and functional properties of starch extracted from corn dried at high temperature cannot be exclusively attributed to the residual starch of samples.

Madhiyanon *et al.* (2009) employed a fluidized bed technique to evaluate the drying kinetics of thin-layer chopped coconut. The experiments were conducted at drying temperatures of 60 to 120^{0}C and a constant velocity of 2.5 m/s. Chopped coconut was dried from about 105% d.b. to approximately 3% d.b. The moisture transport phenomenon in fluidized bed thin-layer drying is described by immense acceleration in MR diminution in the early stage of drying, followed by considerable deceleration.

Singh *et al.* (2010) reported that kinetics of sliced edible mushrooms was studied during fluidized bed drying at different temperatures (50, 60, 70, 80 & 90°C). Prior to drying, sliced samples were treated: a) blanching, b) soaking in 0.5 % KMS (Potassium Metabisulphite) solution, c) soaking in 1 % KMS, 0.2 % Citric acid, 6 % sugar and 3 % salt. It was found that drying rate was proportional to temperature. The values of energy of activation ranged from12.128 to 40.149 kJ/mol.

Weerachet Jittanit (2011) studied pumpkin seed drying in which seeds were soaked in 25% w/w NaCl solution for 1 h before hot-air drying with a tray dryer or a fluidized bed dryer (FBD) at drying temperatures of 60, 70 and 80°C. The FBD was operated at an air velocity of 1.8 m/s and a bed depth of 3 cm, whereas the seeds were dried as a single layer in the tray dryer with the air velocity over the sample in the range 0.23–0.28 m/s. They fitted the experimental data into four thin-layer drying models namely the Page, Lewis, Wang and Singh, and two-compartment models. Among the various models, both the Page model and two compartment models were the best-fit models for the three drying conditions.

Amiri Chayjan *et al.* (2011) studied the thin layer drying characteristics of high moisture corn under fixed, semi fluidized and fluidized bed conditions with high initial moisture content (66.82% wb) in a laboratory fluidized bed convective dryer at air temperatures of 50, 65, 80 and 95°C.They found a suitable drying curve, seven thin layer-drying models were fitted to the experimental data of moisture ratio.

Nazmiizli and Esreflsik *et al.* (2013) investigated in a batch-type laboratory hot-air dryer for drying of dent corn over a temperature range of 30-60°C. The results showed that increasing the drying air temperature caused shorter drying times and all of the sample drying occurred in the falling-rate period, with the exception of a very small amount that occurred in the heating-up period.

Hosain and Darvishi *et al.* (2015) investigated the effects of air temperature and velocity on the drying qualities (cracking, bulk density, shrinkage and rehydration) of soybean kernels in fluidized bed dryer. Drying was carried out at 80, 100, 120 and 140^0C and air velocity of 1.8, 3.1 and 4.5 m/s. Soybean kernels were dehydrated from the initial moisture content of 25% (w.b) to a final moisture content of 10%. The drying evaluation showed that high drying temperature and air velocity resulted in high cracking and low rehydration ratios ($P < 0.05$).

Vukic (2015) conducted an experiment on laboratory scale fluidized bed for drying of corn. They performed an analysis of the influence of the operational parameters (the drying medium velocity i. e. the fluidization number, the drying medium temperature and the height of a packed bed) on the drying kinetics of corn. The experiment showed that increasing the fluidization number and the velocity of the drying medium, has no significant influence on the drying kinetics of corn, except during the initial period of drying.

2.15 Effective Moisture Diffusivity

The effective moisture diffusivity is an overall mass transport property of water in the drying material involving liquid diffusion, vapor diffusion, hydrodynamic flow and other possible mass transfer mechanisms (Karathonos *et al.*, 1990). Generally there are several methods to determine the effective moisture diffusivity (Ramesh, 2003; Hii *et al.*, 2009), method of slope (Karathonos *et al.*, 1990; Rahman and Lamb, 1991; Ramesh, 2003; Langmalawat *et al.*, 2008); computer optimization method (Bakshi and Singh, 1982; Karathonos *et al.*, 1990) and regular regime method (Karathanos *et al.*, 1990; Jittanit, 2011; Sootjarit *et al.*, 2011). Fick's second law of diffusion is generally adapted to describe the diffusivity. Crank (1975) provided the analytical solutions to estimate the diffusivity of un-steady mass transfer case for most of standard geometries, slab, sphere and cylinder, in terms of finite and infinite. Generally, the solution assumes that the sample prior to drying process has uniform initial moisture distribution, unidirectional moisture movement, constant diffusivity, no volume change and negligible external resistance. With an appropriate initial and boundary conditions, the diffusivity of certain geometry could be estimated.

2.16 Physical Characteristics of Dried Maize

2.16.1 Bulk density

Kikuchi *et al.* (1982) studied the bulk density of dried maize. The test weight was expressed as weight per unit volume and the values were expressed as kg/m^3. Wratten *et al.* (1969) showed that the values of density increased with moisture content for Saturu and Bluebonnet-50 varieties (rough rice) but showed little variation for the Starbonnet variety (brown rice).

2.16.2 Kernel dimensions and sphericity

Sangamithra *et al.* (2016) investigated moisture dependent physical properties of maize kernels. The geometric, gravimetric and frictional properties were measured at different levels of moisture content from 8.7 to 21.7% d.b. The results showed that the changes in moisture content of maize kernel lead to minimum variation in geometric properties. The principle dimensions such as length, width, thickness, geometric mean diameter and surface area increased linearly while volume, 1000 kernel weight and sphericity of maize kernels increased in a non-linear manner with increase in moisture content. An increase in bulk density and true density was observed whereas the porosity decreased nonlinearly in the fixed range of moisture content (8.7, 13, 17.4 and 21.7% d.b).

2.17 Nutritional Quality

2.17.1 Starch content

Maize is the most important source of starch for industrial applications and more than 80 % of starch is produced from maize (Lawton, 2004). Dry and wet-milling is commonly used for extraction of starch from flour (Zheng *et al.*, 2002). Starch is extracted with alkaline agents, such as detergents and sodium hydroxide (Lim *et al.*, 1990; Matsunaga *et al.*, 2003).

Yongfu Li *et al.* (2016) studied the structural and functional properties, as well as the in vitro digestibility of corn. After High Temperature Air Fluidization treatment and observed that the degree of gelatinization of corn starch increased from 10.79% to 24.60%, which greatly reduced the relative crystalline of corn starch from 32.17% to 16.15% respectively.

2.17.2 Amylose content

Determination of amylose content is an important aspect of starch characterization from both a fundamental and applied point of view. Spectrophotometric methods for amylose determination in maize starch have been studied for many years.

2.17.3 Crude protein content

Barbour *et al.* (2008) obtained 14.0 % humidity and 8.54 % crude protein on dry basis in corn grain imported by Lebanon, including in Brazilian samples. Average crude protein values ranged from 7.2 % to 9.1 %, with an average 8.1%. Similarly results were reported by Rostagno (2005) and Rostagno (2011) of 8.6 % and 7.9 %, respectively, but higher than those obtained by Agostini *et al*. (2004), who obtained average crude protein 7.3 %.

2.17.4 β-carotene content

Safawo *et al.* (2010) evaluated the total carotenoid and β-carotene content of sixty four maize varieties that grown in India by using UV/Vis spectrophotometer and high-performance liquid chromatography (HPLC) respectively. The finding indicated that averaged total carotenoids were 14 μg/g (5.58 to 63.9 μg/g) and β-carotene 1.69 μg/g (0.122 to 4.74 μg/g). Dixon *et al.* (2000) determined total carotenoid content of 16improved yellow maize varieties and reported the result ranged 143 to 278 μg/g. Drinic *et al*.(2014) reported the β-carotene content of 17 maize genotypes ranged from 8.69 to21.90 mg/kg.

2.17.5 Ash content

Duxton *et al.* (2000) reported the ash content of dried maize and he found the ash content of maize in the range of 1.4 % to 3.3 %. Other researcher Maly *et al.* (2005) reported 5.1 % ash content of maize bran.

2.18 Specific energy consumption

Drying is considered as an energy-consuming act with great economic importance because it is consuming a lot of energy in industrial drying (Sahin & Dincer, 2002). Corzo *et al.* (2008) were analyzed energy and exergy of the thin layer drying of coroba slices at three different air temperatures (71, 82 and 93˚C) and velocities (0.82–1.00 and 1.18 m/s). The effects of inlet air temperature and velocity and drying time on both energy and exergy were studied. Both energy utilization and energy utilization ratio increased with increasing drying time while exergy efficiency decreased. The values of energy utilization and energy utilization ratio were found to be in the range of 0.009–0.65 kJ/s and 0.00007–0.008, respectively.

Akpinar *et al.* (2006) examined the amount of energy and exergy of potato drying process. Samples used in this study are sufficiently dried in the ranges between 60 and 80˚C and 20% and 10% of relative humidity at 1 and 1.5 m/s of drying air velocity during 10-12s. In these experiments, the energy losses were calculated 796/1-0 KJ safely.

Zahra Noorghadami *et al.* (2014) investigated the energy consumption for drying corn in dryer reservoir with flow of warm air and the effect of the temperature and height of product layer on the amount of energy consumption per unit mass. The results showed that the product at temperature of 100˚C with layer height of 60 cm had the minimum amount of energy consumption per unit mass while at temperature of 70˚C with layer height of 20 cm the maximum amount of energy consumption per unit mass occurred.

Sarker *et al*. (2013) and Ibrahim *et al*. (2014) investigated overall energy requisite and rice quality with industrial Inclined Bed Dryer (IBD) in Malaysia; although their observations showed that there was considerable inconsistencies during actual drying operations in terms of drying temperature, air flow rate and drying time, which justify the need for in depth study of this popular dryer. Whilst it is important for rice industries to understand different aspects of these dryers in order to optimize their drying system to achieve higher drying efficiency, however information on important drying aspects of these common dryers such as energy usage and drying capacity are very scarce especially for IBDs.

2.19 Summary of the review of literature

Maize grains are important source of food for human and feed for livestock. As they are produced on a seasonal basis, it is essential to store the grains for late consumption for periods varying from one month up to a year. From the above literature it can be observed that maize is dried by several drying techniques. In developing countries like Bangladesh sun drying methods are commonly followed because sun drying uses limited resources, free hot air to lower the moisture content of maize. It is relatively slow method of drying and microbial attack is common. In Bangladesh, there is no study on two-stage drying of maize. Thus, the present study is a new drying approach for the drying of high moisture maize grains in Bangladesh. After harvesting of maize, a large portion is destroyed due to lack of drying in rural areas of Bangladesh if adverse weather exists. If it is possible to develop such two-stage drying technique that will reduce drying time, maintaining quality of dried grain and a significant post- harvest loss can be minimized that will contribute to the national economy of the country.

CHAPTER III

MATERIALS AND METHODS

3.1 Sample Collection

Freshly harvested high moisture maize (Kavari 60 variety) was purchased from local farmer of Dinajpur district of Bangladesh. This variety is commonly grown and its yield is higher than other varieties.

3.2 Determination of Moisture Content of Sample

Moisture content of the drying samples was calculated on the basis of weight difference by oven method AOAC (2005). Moisture content of dried maize was determined by digital grain moisture meter (GMK-303RS, Korea) during drying operation. The meter was calibrated with oven method before using. Moisture content was determined using the following formula.

$$MC_{wb} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Weight of sample}} \times 100\ \% \qquad 3.1$$

where; MC_{wb} = moisture content in wet basis

Fig. 3.1 Digital Grain Moisture Meter (GMK-303RS, Korea)

3.3 Description of the Fluidized Bed Dryer Used for the Experiments

A laboratory scale batch type Fluidized Bed Dryer was used for both first stage and second stage drying of the samples. The dryer was previously designed and installed in the Department of Food Engineering and Technology, HSTU, Dinajpur. The dryer basically consists of a cylindrical fluidized bed column of 100 cm height, electric heater unit of 18 kw power and blower motor of 3 hp. The schematic diagram the dryer is shown in Fig. 3.2

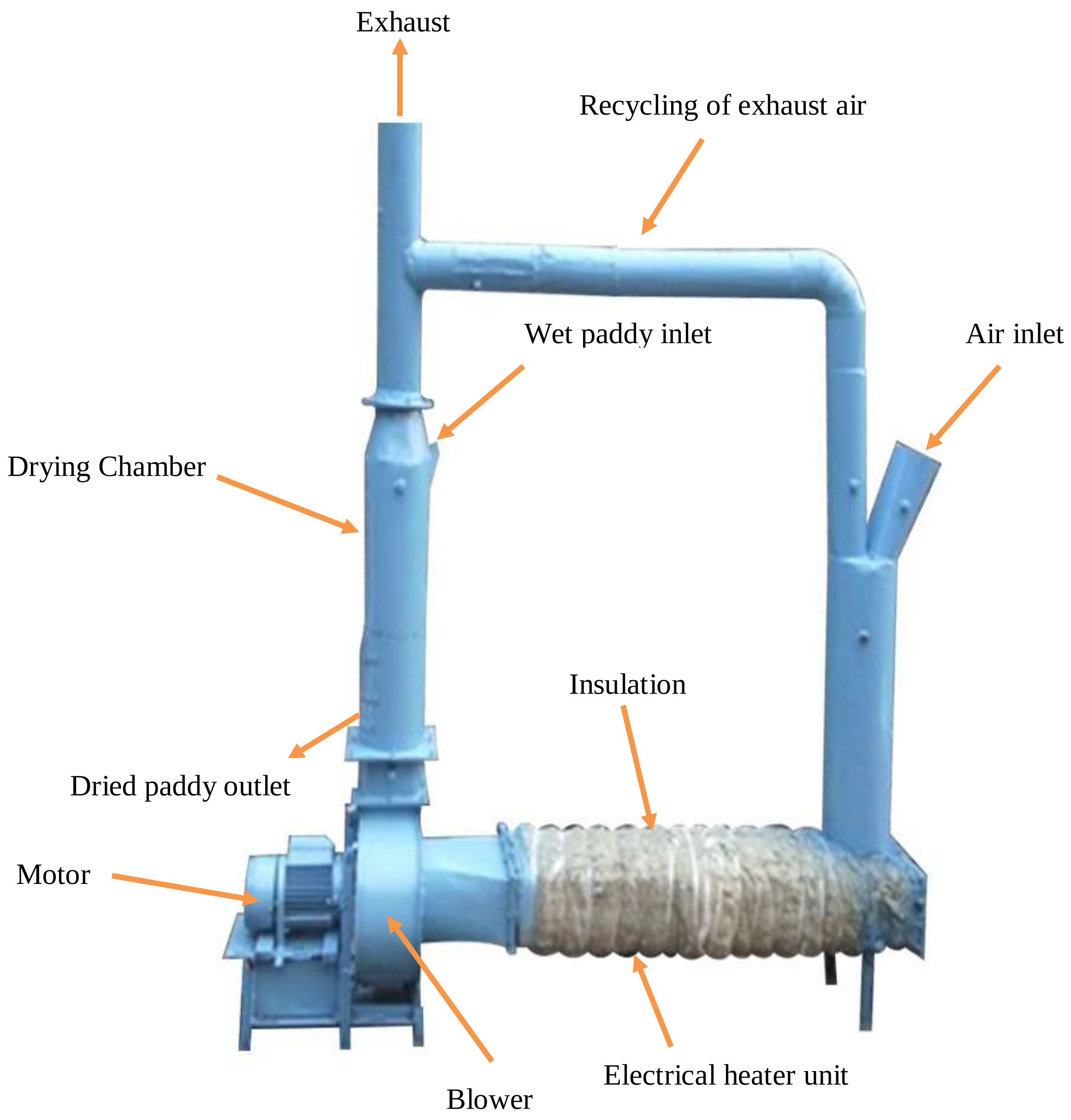

Fig. 3.2 Photographic view of the fluidized bed dryer

3.4 Trial Drying Operation of High Moisture Maize in Fluidized Bed Dryer (FBD)

Before starting of trial drying operations, the blower was switched on 5-10 minutes before switch on the electric heater to heat up ambient air until the desired drying temperature was raised. Then air velocity was measured by the digital Anemometer (Digital Anemometer, TA430). In order to select the suitable bed thickness of FBD for optimum fluidization and to find required drying duration in reducing moisture content of freshly harvested maize from 26.7% to 18-19%, a good number of trial operations were accomplished. During trial operation, bed thicknesses were considered as 6, 7 and 9 cm for observing sufficient fluidization in the drying bed. From the trials, 7 cm bed thickness was found to be appropriate bed thickness for the dryer that exhibited nice fluidization behavior of samples. Therefore, all the experiments were conducted at 7 cm bed thickness. Fluidized drying time was calculated as the time required for reducing grain moisture content from any high initial moisture content to intermediate moisture content (18-19% wb).

Fig. 3.3: Digital anemometer (Model: TA430, UK).

3.5 Experimental Design for Drying of Samples in Fluidized Bed Dryer and for Quality Analysis of Dried Maize

Fluidized bed dryer was used for first stage drying of the samples.

3.5.1 Experimental design for fluidized bed drying operation

Single factor CRD design was employed in this drying experiment in order to know the effect of drying air temperatures on drying time. The factor was drying air temperatures which have three levels such as 120^0C, 140^0C and160^0C and the response was drying time. The drying temperatures were selected based on previous studies (Soponronnarit & Prachayawarakorn, 1994; Soponronnarit *et al.,* 1997; Prachayawarakorn *et al.,* 2011; Ibrahim *et al.,* 2015; Sarker *et al.,* 2015 and Wiset *et al.,* 2001). Based on trial dying operations, the effect of 10^oC was not found so much prominent therefore temperature interval was considered as 20^oC.

3.5.2 Experimental design for quality evaluation

Single factor CRD design was also applied for quality evaluation in order to know the effect of drying options on physical and nutritional quality attributes. The factor was drying options such as fluidized bed drying tempering followed by sun drying, fluidized bed drying tempering followed by fluidized bed drying and existing sun drying.

3.6 Two Stage Drying Experiments

In this study, two options of two stage drying were accomplished. First option of drying operations was carried out by Fluidized Bed drying and tempering followed by sun drying while the second option was conducted using only fluidized bed dryer (i.e. Fluidized Bed drying at high temperature and tempering followed by Fluidized bed drying again at low temperature).

3.6.1 Drying procedure of samples in first option of two stage drying

3.6.1.1 Fluidized bed drying of samples as first stage drying

The motor of blower was switched on 5-10 minutes before switch on the electric heater to heat up ambient air until the desired drying temperature. Air temperature was measured by thermocouple (TM 1296, origin Taiwan). Then 1.82 kg of maize was loaded into the fluidized-bed drying chamber by inlet port for maintaining fixed bed thickness 7cm. Then stopwatch was started for continuing drying until targeted drying time (2-3 min) for reducing sample moisture to the desired final moisture content of 18-19%. Then dried maize was discharged immediately by the outlet port and stored in a well-sealed container for tempering at grain temperature for 45 min. Then the sample was cooled by spreading on concrete plastered pavement floor. During the period of drying, a Hygrometer was used to record ambient air temperature and the relative humidity.

3.6.1.2 Second stage drying of maize samples by sun drying method

Tempered and cooled maize samples that had been previously dried using fluidized bed dryer were further dried in second stage by using sun drying method at 33-36^{o}C temperature by spreading on plastered pavement at 2-3 cm thickness. During the period of drying, moisture content of maize was measured by using digital grain moisture meter at 20 minutes interval. Drying was continued until the desired moisture content (13-14%, wb) of maize sample was achieved.

3.6.2 Second Option of Two Stage Drying

In second option of two stage drying, the first stage drying was similar with the first option of two stage drying which was described in previous section 3.6.1. However, the second stage drying in the fluidized bed dryer is described in section below.

3.6.2.1 Second stage drying of maize in by fluidized bed dryer

The tempered and cooled maize sample of 18-19 % mc was further dried using drying temperature of 65±2^{o}C in second stage by the same fluidized bed dryer to 13-14% mc which is the safe level of moisture content of dried maize to prevent the fungal infestation, insects and mites.

3.7 Drying of Control Sample

The maize sample dried completely by sun drying method was regarded as control drying while air temperature ranged from 33-36^{o}C. The samples were spread on concrete plastered pavement at 2-3 cm thickness. Drying was continued to reduce grain moisture to 13-14%. This method is practiced by most of the grain processors of Bangladesh.

3.8 Storage of Dried Maize

All the dried maize samples obtained from different drying options were tightly sealed in polythene bags and stored for about one month at ambient conditions for the selective quality determination.

3.9 Estimation of Effective Moisture Diffusivity

Effective moisture diffusivity is defined by common mathematical model of Fick's second law of diffusion. Therefore, this model was used to evaluate effective moisture diffusivity in maize drying which can be expressed by the equation (3.2).

$$\frac{\partial m}{\partial t} = D_{eff}\left[\frac{\partial^2 m}{\partial r^2} + \frac{2}{r}\frac{\partial m}{\partial r}\right] \tag{3.2}$$

Fick's second law of diffusion is largely studied for the solution of thin layer drying of various foods. The analytical solution for the diffusion equation for spherical food material is given as the following equation (Crank, 1975):

$$MR = \frac{M - M_e}{M_0 - M_e} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-\frac{n^2\pi^2 D_{eff}\,t}{r^2}\right) \tag{3.3}$$

Equation (3.3) assumes that uniform distribution of initial moisture, negligible temperature gradient, negligible volume shrinkage during drying and negligible external resistant (Ochooa-Martinez and Ayala-Aponte, 2009). Reviews on extended drying period (n=1) stated that simplified form of the Eq. (3.3) is a linear logarithmic equation as expressed in equation (3.4) (Pala *et al.*, 1996; Nuh and Brinkworth, 1997; Feng, 2000; Agarry *et al.*, 2013):

$$\ln(MR) = \ln\left(\frac{6}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}}{r^2}t\right) \tag{3.4}$$

The effective moisture diffusivity is finally determined from the plot of the natural logarithm of moisture ratio (ln (MR)) versus time (t) using the following equation:

$$D_{eff} = \frac{\mathrm{Slope}(r^2)}{\pi^2} \tag{3.5}$$

3.10. Calculation of Specific Energy Consumption

Specific energy consumption is one of the most important indexes for evaluating the performance of a dryer. The total energy consumed by fluidized bed dryer can be divided into heat for thermal energy of drying air and electricity for driving the blower fan. The primary electrical energy was calculated using the equation (3.6) after little modification of the equation used by Sarker *et al.* (2014) and Jittanit *et al.* (2010). The thermal energy supplied by the electric heater was obtained from the electric power as a function of time according to equation (3.7) (Fernandez-Seara *et al.,* 2007). Specific electrical energy consumption (SPEEC) and thermal energy consumption (SPTEC) were calculated into mega joule (MJ) per kg water evaporated using eq. (3.8) and (3.9), respectively. Finally, total specific energy consumption was calculated according to equation (3.10).

$$E_{electrical} = \frac{2.6P_{blower} \times t}{\eta} \tag{3.6}$$

$$E_{heat} = P_{heater} \times t \tag{3.7}$$

$$SPEEC = \frac{E_{electrical}}{W} \tag{3.8}$$

$$SPTEC = \frac{E_{heat}}{W} \tag{3.9}$$

$$E_{total} = SPEEC + SPTEC \tag{3.10}$$

Where $E_{electrical}$ is the electrical energy consumption by the blower system (kJ), P_{blower} the blower motor power (kW), t is the total drying time (h), E_{heat} the thermal energy consumption for heating the drying air, P_{heater} the electric heater power.

3.11 Determination of Physical Properties of Dried Maize

3.11.1 Kernel Dimensions

The three dimensions such as length (L), width (W) and thickness (T) of randomly picked 25 maize kernels were measured using vernier calipers with an accuracy of 0.01 mm. The average diameter of the samples was calculated by using the arithmetic mean and geometric mean of three principal dimensions. The geometric mean diameter (Dg) and the arithmetic mean diameter (Da) were calculated for the major dimensions using the following equations (Mohsenin, 1986; Galedar *et al.*, 2008).

$$D_g = (LWT)^{1/3} \quad (3.11)$$

$$D_a = \frac{(L+W+T)}{3} \quad (3.12)$$

3.11.2 Surface Area

The surface area (S) was calculated using the following equations (McCabe *et al.*, 1986; Jain and Bal, 1997).

$$S = \pi D_g^2 \quad (3.13)$$

Where S is the surface Area (mm^2), Dg is the geometric mean diameter (mm);

3.11.3 Sphericity

The sphericity (φ) is defined as the ratio of the surface area of the sphere having the same volume as that of the grain to the surface area of the grain. Sphericity was calculated using the following relationship (Mohsenin, 1986).

$$\Phi = \frac{(LWT)^{1/3}}{L} \quad (3.14)$$

3.11.4 Particle Density Measurements

The particle density (kg/m^3) is the ratio between the mass of the sample and the true volume of the samples, was determined by water displacement method (Mohsenin, 1986). An amount of dried samples were put into the 500 ml volumetric flask prior to filling up a portion of tap water at room temperature until reaching a specified volume of 500 ml. The weight and volume of filled water were known; thus, the particle volume and subsequent particle density could be calculated. To avoid the effects of moisture diffusion into the dried maize kernel and the sample swelling on the particle density measurement, the measurement was conducted and recorded immediately after filling the water into the flask.

$$\text{Particle density, } p_t = \frac{\text{weight}}{\text{volume of particle}} \quad (3.15)$$

3.11.5 Porosity

The porosity is the fraction of the space in the bulk seeds which is not occupied by the seeds (Mohsenin, 1986). The porosity of the samples were computed from the bulk and particle densities using the following equations.

$$\text{Porosity} = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \qquad (3.16)$$

Where

ρ_b = Bulk density;

p_t = Particle density

3.11.6 Determination of Bulk Density of Maize

Bulk density was determined by weighing the amount of grain in 50 cm^3 calibrated beaker based on a modification of the method used by Kikuchi *et al.* (1982). An average of 5 measurements represented one determination. Test weight was expressed as weight per unit volume and values were converted to kg/m^3. The formula used to calculate the bulk density of dried maize as follows:

$$\text{Bulk density, } \rho_b = \frac{M}{V} \qquad (3.17)$$

Where

ρ_b = bulk density;

M = mass; and

V = volume.

3.12 Determination of Color Parameters

The instrumental color property measurement of dried maize samples were carried out with a Colorimeter Minolta CM-2500d (Konica Minolta Optics, Inc. Japan). Color attributes were recorded as L (lightness), a (redness), and b (yellowness). The color changes (ΔE) of the samples were evaluated as described by Wrolstad and Smith (2010) using the following equations:

$$\text{Color change, } \Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + \Delta b)^2}) \qquad (3.18)$$

$$\text{Chroma, } C = \sqrt{(a)^2 + (b)^2} \qquad (3.19)$$

$$\text{Hue angle} = \tan^{-1}(b/a) \qquad (3.20)$$

Where,

$\Delta L = L - L_o$ $\Delta a = a - a_o$, and $\Delta b = b - b_o$, subscript 'o' indicates color at time zero.

3.13 Determination of Nutritional Quality

In this study, protein, starch, ash and beta carotene content of dried maize were evaluated. Because of these are very important nutrients in the food processing and feed industry.

3.13.1 Crude protein determination

AOAC method 7.056 (2000) was used with some modification to determine the protein content of the maize flour. Usually three stages are used to determine protein content. These stages are given below:

A. Digestion:

Maize powder (1g), Selenium powder (1g), $CuSO_4$ (0.1g), K_2SO_4 (10g) were taken into a volumetric flask. Then 25 ml of H_2SO_4 (conc.) was added. After that the volumetric flask was heated at 100ºC for 3 hours and cooled for 20 minute at room temperature.

B. Distillation

After digestion 300 ml of distilled water and 125ml of 40% NaOH were added to the volumetric flask. 25 ml of 4 % boric acid solution and 2-3 drops mixed indicator were taken in a conical flask. The volumetric flask was connected with one end of the condenser and the conical flask was connected with other end. The volumetric flask was heated continuously until the conical flask was filled to 150 ml.

C. Titration

The conical flask was disconnected and was taken for titration. Titrated against 0.2 N of H_2SO_4 solutions. The end point was indicated by reddish brown color.

i) Calculation for N_2 content:

$$\% \text{ of } N_2 = \text{Burette reading} \times \text{Normality of } H_2S0_4 \times \text{ml equivalent of } N_2 \qquad (3.21)$$

Here;

Normality of H_2S0_4 = 0.2

ml equivalent of N_2 = 1.4

ii) Calculation for protein content:

$$\% \text{ Protein} = \% \text{ of } N_2 \times \text{Protein factor} \tag{3.22}$$

Here; Protein factor = 6.25

3.13.2 Starch Determination

One gram of oven dried powdered sample was taken in an Erlenmeyer flask and 50 ml of cold water was added. The content of flask was allowed to stand for one hour with occasional stirring. It was then filtered and the residue was washed with 50ml distilled water. The sample was hydrolyzed with 10 % HCl for 2.5 hours under reflux. The hydrolysis was neutralized with dilute sodium hydroxide solution and filtered. The filtrate was collected in a 100ml volumetric flask and volume was made up to 100 ml.

The reducing sugar in the filtrate was determined by Fehling's titration method and the amount of glucose was calculated.

$$\% \text{ starch} = \% \text{ glucose} \times 0.9 \tag{3.23}$$

3.13.3 Amylose Content Determination

3.13.3.1 Materials and Reagents

95% Ethanol, 1N NaOH, 1N Acetic acid, Iodine –Potassium iodide solution, Standard amylase. Distilled water, 100 ml volumetric flask, Water bath, Spectrophotometer, Quartz cuvette.

3.13.3.2 Experimental Procedure

At first 100 mg well powdered maize sample was taken into 100 ml volumetric flask. Then 1ml 95 % ethanol and 9 ml of 1N NaOH was added to it. The samples were heated for 10 minutes in boiling water bath. After that samples were cooled and made the volume to 100 ml. 5 ml samples was pipetted from the 100 ml into another 100 ml volumetric flask. After that 1ml 1 N acetic acid and 2 ml iodide solutions were added. The flask was allowed to stand for 20 minutes. Finally absorbance was taken by Spectrophotometer at 620nm according to the method of (Williams *et al.,* 1958). The amylase percentage was calculated from the following equation

$$\text{Amylose percentage \%} = X\ (\text{mg/ml}) \times \frac{\text{Volume made (ml)}}{\text{Sampleweight (mg)}} \times 100 \qquad (3.24)$$

Where X is the amylose content calculated from the standard curve in mg.

On the other hand, Amylopectin was calculated according to the following equation.

Amylopectin (%) = % Starch- % Amylose (3.25)

3.13.4 β-Carotene Content Determination

3.13.4.1 Chemicals:

1. Acetone.
2. n-Hexane

3.13.4.2 Experimental Procedure:

One gram sample was taken in a test tube with stopper about 15 ml solvent was added to it. Then it was heated for 15 minutes, then it was filtered and measured absorbance at 663 nm, 505 nm and 453 nm by Spectrophotometer. Beta carotene content was estimated in mg/100g by using the following equation (Barros *et al.,* 2007).

$$\beta\text{-Carotene} = 0.216 \times A_{663} - 0.304 \times A_{505} + 0.452 \times A_{453} \qquad (3.26)$$

3.13.5 Total Mineral Content

Total Mineral content of maize sample was analyzed by AOAC official method (2000). 5g powdered sample was taken in a crucible. Then it was placed in muffle furnace at 550^0C to 600^0C temperature for 5-6hrs. After ashing, the crucible was cooled and kept for some time in desiccators and weighed. From the weighs recorded the present ash content was calculated.

Calculation:

$$\%\ \text{Ash} = \frac{W_1 - W_2}{w} \times 100 \qquad (3.27)$$

Here,

w_1 = weight of ash with crucible, w_2 = weight of empty crucible, w = weight of sample.

3.14 Statistical Analysis

The statistical analysis was carried out using a single-factor experiment in completely randomized design (CRD). The only factor was the drying method. Each drying method was replicated thrice. Statistical software (SPSS windows version 22) was used to calculate the mean values, standard error means (SEM), standard deviation and analysis of variance of obtained values of drying time, physical and nutritional attributes. Duncan's Multiple Range Test analysis was employed to determine the effect of fluidized bed drying air temperatures on drying time ($P \leq 0.05$).

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Results Obtained from Trail Operation

The results of trial operation indicated that proper fluidization was achieved when high moisture maize was dried at 7 cm bed thickness in the drying chamber of 20 cm diameter. The bed air velocity was 4.5 m/s and corresponding total air flow rate was 0.14 m^3/s. The specific air flow rate was 0.08 m^3/s. This value is approximately 1.5 times higher than the minimum fluidization velocity (1.8 m/s) for corn (Soponronnarit *et al.,* 1997). Such a value beyond the minimum velocity was certainly sure that high moisture maize could vigorously mix with the drying air. If the air velocity is set too high, then the maize is increasingly agitated due to the formation of large bubble size, detrimental effect on the interchange of heat and mass transfers between gas and solid phases. All the drying experiments were performed at this condition to avoid any problem regarding over or under fluidization process.

4.2 Comparison on Drying Performance of Two Stage Drying Options and Single Stage Drying (Sun Drying).

The drying behavior of two stage drying by fluidized bed drying and sun drying are presented in the following sections.

4.2.1 First Option of Two Stage Drying of Maize Employing Fluidized Bed Drying and Sun Drying Method.

4.2.1.1 Drying Behavior of Fluidized Bed Drying of Maize in First Stage Drying.

Moisture reduction and drying time obtained for drying of maize samples of 25.6±0.1 % (wb) moisture content to18.7±0.15% (wb) during first stage drying in fluidized bed dryer using temperature of 120^{o}C, 140^{o}C and 160^{o}C at constant bed thickness are presented in Table 4.1. Moisture content of the samples was determined after tempering for 45 min of each dried sample. The analysis indicated that drying air temperature has significant ($p \leq 0.05$) effect on drying time. The results showed that shorter drying time was achieved when higher drying air temperature was applied. This occurred because of applying more thermal energy to the bed material which led to increase drying rate. Soponronnarit *et al.* (1997) found similar results during fluidized bed drying of maize.

Table 4.1 Effect of Temperature on Drying Time during First Stage Drying of Maize in Fluidized Bed Dryer (FBD)

Bed Thickness (cm)	Temperature (^{0}C)	Initial Moisture Content (%)	Final Moisture Content (%)	Drying Time (min)
	120	*25.59±0.08	18.6±0.1	4.07±0.06^a
7	140	25.56±0.05	18.7±0.15	3.03±0.06^b
	160	25.6±0.1	18.6±0.05	1.50±0.10^c

*Mean values ± Standard deviation

4.2.1.2 Drying Behavior of Sun Drying of Maize during Second Stage Drying.

Moisture reduction and corresponding drying time in second stage drying by sun drying method of the fluidized bed dried and tempered samples are shown Fig. 4.1. It appears that drying time for reducing grain moisture from18.7±0.15 % to 13.5 % (wb) was only 250 min (4.2hr). At any applied temperature, the drying rate decreased with time due to decrease in moisture content of the maize samples. Temperature applied in comparatively lower moisture content grain resulted in lesser movement of water from grain center to its surface and, therefore, less evaporation from the grain surface took place with time. It is also observed that the sharp drying rate was observed initially from 0 to 50 min of drying. This is because of using higher drying temperature while faster moisture removal occurred. The drying curve also revealed that drying rate decreased after this period. Subsequently, drying rate further decreased as viewing the falling rate period.

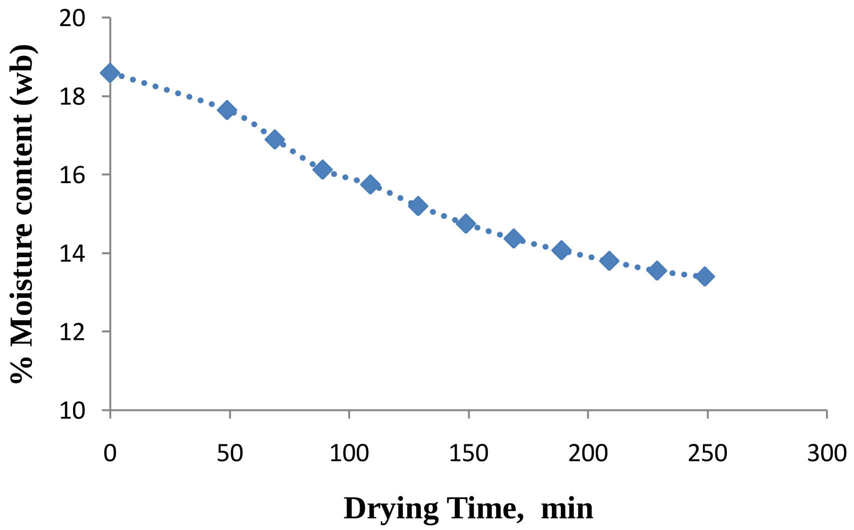

Fig: 4.1. Drying curve during second stage drying by sun drying method

[Sun drying conditions: temp: 33-36°C, relative humidity: 52-65%, air velocity: 0.5-0.6 m/s]

4.2.2 Second Option of Two Stage Drying of Maize Employing Fluidized Bed Tempering and Fluidized Bed Drying.

Second option of two stag drying was carried out in same fluidized bed dryer that means in one type of dryer using variable temperature. The first stage drying was the same as described in section4.2.1.1 above. The drying temperature was considered as 65± 2^{o}C in second stage fluidized bed drying which is discussed in the following section.

4.2.2.1 Fluidized Bed Drying Behavior of Maize during Second Option of Two Stage Drying

Fig. 4.2 display the drying curve obtained during second stage drying of fluidized bed dried and tempered maize sample obtained from first stage while moisture was reduced from 18.7±0.15% to 13.5% (wb) by only 85 min (1.4hr) only. Even though drying process was quicker yet both constant rate and falling rate period were observed during the drying process as depicted in Fig. 4.2. It indicates a usual and gentle moisture removal of such intermediate moisture grains reported by Vega et al. (2007). Similar trend was observed during drying of food materials in fluidized bed (Tasirin *et al.*, 2014). The results indicated that the drying time was shorter because better heat and mass transfer occurred during fluidized bed drying (Soponronnarit *et al.*, 1997). Drying rate generally increases with increasing moisture content of grain and air temperature or decreases with increase in air humidity (Trim and Robinson, 1994).

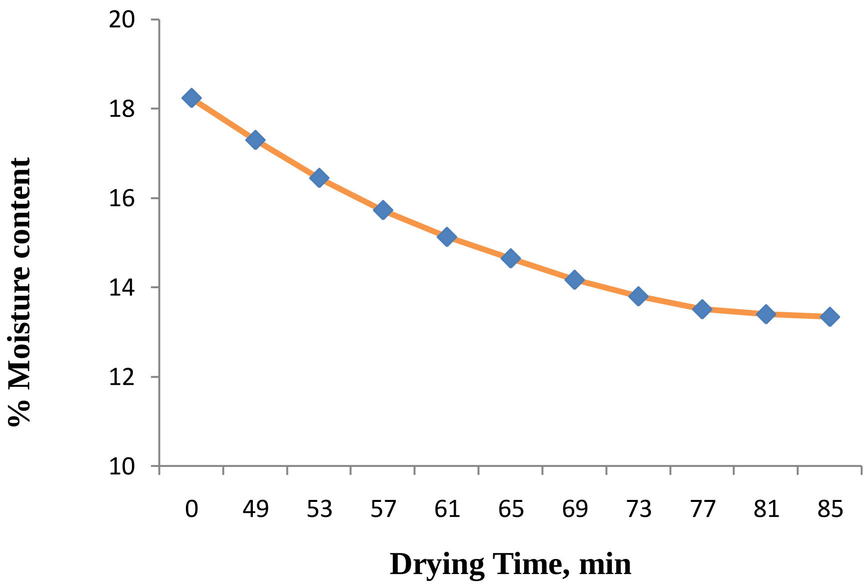

Fig 4.2: Graphical representation of moisture reduction in fluidized bed dryer during second stage drying.
[Drying conditions: Temp: 65± 2^{o}C; air velocity: 4.5 m/s]

4.2.2.2 Comparison on Drying Time between Two Options of Two-Stage Drying of Maize

In case of first option of two stage drying technique, total drying time required 4.25 hours while second option took only 1.41 hours as shown in Fig 4.1 and Fig. 4.2. From Table 4.1 and Fig: 4.1, it is clear that first option of two-stage drying technique took 2.5 times higher drying time than the second option. This is really an interesting matter that high moisture maize is possible to dry at safe level by less than two hrs even. However, the quality of dried maize must be evaluated which has been discussed in the subsequent sections.

4.2.2.3 Comparison on drying time of Single Stage drying (Existing Sun Drying) and Two Stage Drying Method for Maize Drying

Drying time for drying of the same maize sample was almost 10 hrs in reducing moisture from 25.6±0.1 % (wb) to 13-14% (wb) as shown in Fig. 4.3. The result indicates that this method took 5 times higher drying time than first option and 8.5 times lower than second option of two stage drying method. On the other hand, drying time sometimes was found to be varied from two to three days even at farm level depending on weather condition. But in case of two stage drying options, drying time was almost 60-70% shorter than the single stage drying. Again quality of such dried maize should be evaluated which has been stated in section 4.4, 4.5 and 4.6.

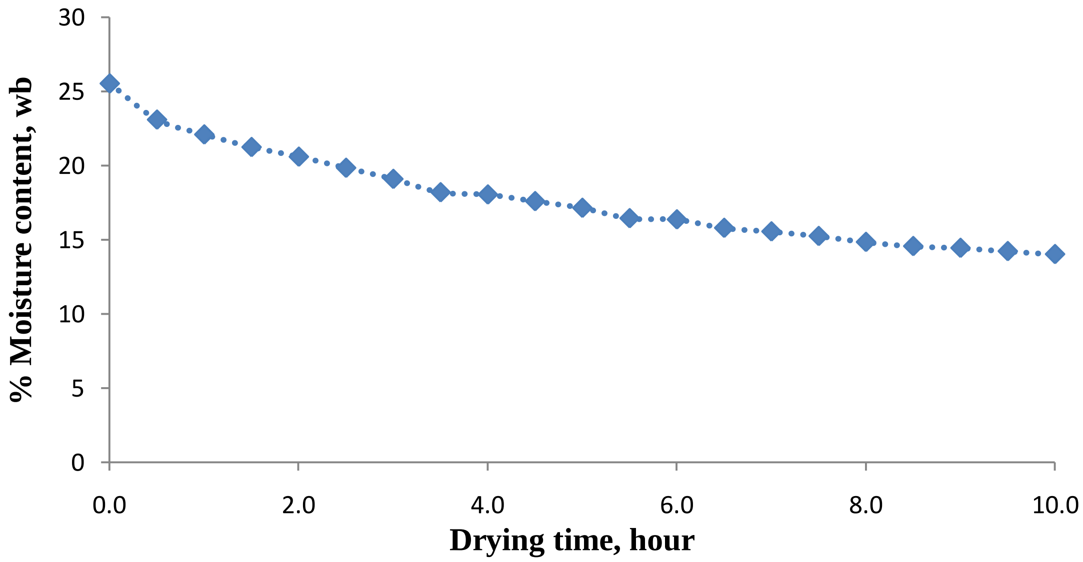

Fig 4.3**:** Effect of control drying of maize on drying time.
[Sun drying conditions: temp: 33-36°C, relative humidity: 52-65%, air velocity: 0.6 m/s]

4.2.2.4 Effective Moisture Diffusivity between Two Options of Two Stage Drying.

The effective moisture diffusivity calculated from the obtained data presented in Table 4.

Table.4.2. Comparison on Effective Moisture Diffusivity Obtained during Two Stage Drying of Freshly Harvested Maize.

Two stage drying options	Drying Temperatures	Effective Moisture Diffusivity(m^2s^{-1})$\times10^{-08}$
First Option	120^0C	1.05
	140^0C	1.08
	160^0C	1.15
Second option	120^0C	4.47
	140^0C	4.98
	160^0C	6.34

First option =Fluidized bed drying + Sun Drying; Second option=First stage FBD at higher temperature then second stage FBD at lower temperature.

The effective moisture diffusivity of samples varied from1.05×10^{-08} m^2/s to 1.15×10^{-08} m^2/s and 4.4×10^{-08} m^2/s to 6.3×10^{-08} m^2/s for first and second option of two stage drying, respectively. Moisture diffusivity increased by applying more thermal energy to the drying bed. Effective moisture diffusivity for different foods and vegetables including Apple, Carrot, Potato etc have been compiled by Mendles *et al.* (2002) which shows that moisture diffusivity varies from 2.2×10^{-10} to 9.4×10^{-10} m^2/s. Doymaz (2004) reported that diffusivity values for carrot varied in the range of 0.776×10^{-9} to 1.371×10^{-9} m^2/s when temperature varied from 50°C to70°C. The results indicate that second option of two stage drying diffuses more moisture than first option. This is because of using thermal energy during fluidized bed drying of samples in second option. Effective moisture diffusivity depends on temperature and the type of material being dried (Rizvi, 1986).

4.3 Specific Energy Consumption during First Stage Drying of Maize by Fluidized Bed Dryer

Figure 4.4 shows the energy consumed by the fluidized bed dryer during drying of maize samples in first stage drying. Specific electrical energy consumption was found lowest (0.14 MJ kg^{-1} water evaporated) at 160^oC and largest (0.35 MJ kg^{-1} water evaporated) at

120°C temperatures respectively. It is also observed that at higher drying temperature the SPEEC in terms of primary energy was found larger. The results revealed that specific electrical energy consumption was less at 160°Cin first-stage drying with a fluidized bed dryer. On the other hand, the specific thermal energy was higher at 120^{0}C which was 0.68MJ kg^{-1} and also lower at 160^{0}C (0.28.MJ kg^{-1}). This variation in specific electrical and thermal energy consumption happened due to differences of longer drying time and drying temperatures taken by fluidized bed dryer. The results revealed that the application of higher temperature (>140 ^{0}C) for drying of high moisture maize by the fluidization technique has great advantages. The specific energy consumption was found to be decreased, because, reducing high moisture by fluidized bed drying technique using higher temperature from grains prompted moisture removal at minimum energy. Ahiduzzaman and Islam (2009) reported that in industrial LSU dryer with drying capacity of 1.5 ton h^{-1} required specific thermal energy consumption of 6.25 MJ kg^{-1} water evaporated for drying of paddy from 25-28% MC to 13-14% MC. Sarker *et al.* (2014) noted that the SPEEC in terms of primary energy consumption was varied between 1.44 to 1.95 MJ kg^{-1} water evaporated for complete drying of paddy at 38-42°C in inclined bed dryer. It is clearly noticed that the higher temperature of 160°C in FBD shortened the drying time, consequently reducing the total energy consumption and quality was also maintained, as discussed in the next section.

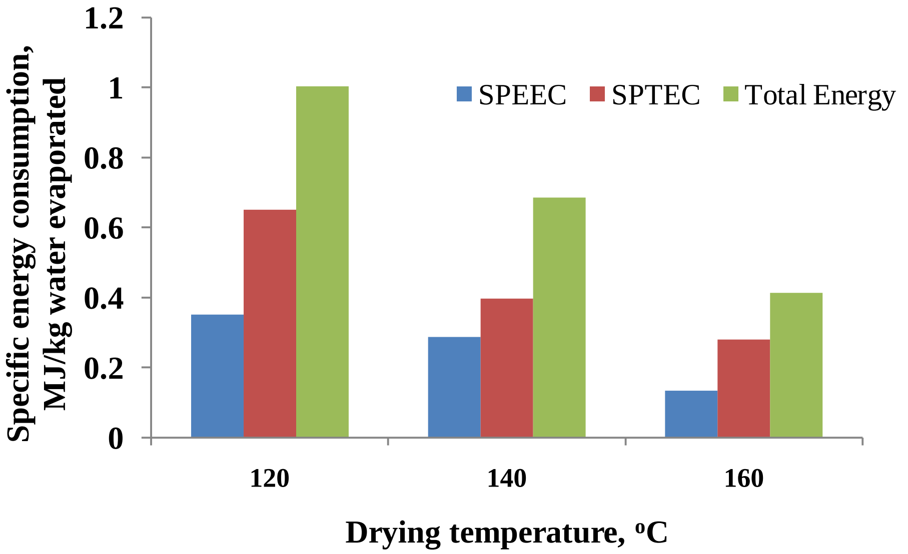

Fig 4.4: Specific energy consumption during drying of freshly harvested maize with fluidized bed dryer. [SPEEC: Specific electrical energy consumption; SPTEC: Specific thermal energy consumption].

4.4 Physical Properties of Dried Maize

Selected physical properties as obtained by measurement of dried maize are shown in Table 4.3. The arithmetic and geometric mean diameter ranged from 8.14±1.3 mm to 8.38 ±0.77 mm and 7.80 mm± 0.77 mm to 8.41±0.39 mm respectively. Sangamithra *et al. (*2016) reported almost similar result of arithmetic mean and geometric mean values of dried maize to the present study. Analysis of results showed that there is no statistical difference between Arithmetic mean, Geometric mean values of samples. Arithmetic and Geometric mean diameter of the maize kernel was found to be increased linearly with increase in the moisture content. Similar results were observed for various products such as cucurbit seeds (Milani *et al.*, 2007), soybean (Kibar and Ozturk, 2008).

Table 4.3: Physical Properties of Maize Dried by Two Options of Two Stages Drying Technique and Control Sample Drying of Maize.

Drying Options	Arithmetic Mean (mm)	Geometric Mean (mm)	Bulk Density (kg m^{-3})	Particle Density (kg/m^3)	Sphericiy	Porosity %
First option	8.38±0.77	7.80±0.77	789.3±42.5	1014.92±131.10	0.69±0.4	21.73±5.7
Second option	8.19±0.98	7.85±1.10	733±7.0	957.49±86.88	0.71±0.5	23.0±6.04
Sun Drying	8.14±1.3	8.41±0.39	809.5±10.7	1121.40±20.12	0.66±0.1	27.83±2.3

Mean values ±Standard deviation D; First option =Fluidized bed drying + Sun Drying; Second option = First stage FBD at higher temperature then second stage FBD at lower temperature.

The particle density and bulk density plays a significant role in drying, design of silos and storage bins, separation of undesirable materials, seed purity determination and grading (Mohsenin, 1970). The bulk density and particle density of maize dried by two options of two stage drying varied from 733±7.0 kg m^{-3} to 789.3±42.52 kg m^{-3} and 957.49±86.88 kg m^{-3} to 1014.92±131.10 kg m^{-3} respectively. During the drying process, water escapes the cell causing a decrease in tension that the liquid exerts against the cell wall (Hashemi *et al.,* 2009; Janjai *et al.,* 2010). This decrease in tension causes shrinkage of the material. Mayor and Sereno (2004) reported that heating and loss of water cause stresses in the cellular structure of the food and this leads to changes in shape and a decrease in dimensions. Tarighi *et al.* (2011) reported that the particle density of maize was 990 kg/m^{-3}. The highest porosity of dried maize was 27.83±2.3 % for control drying option but the lowest porosity was observed for first option of dried maize and it was 21.73±5.7 %. Tarighi *et al.* (2011) found the porosity of dried maize was 31.410. This value was higher than the present study. Porosity of dried maize was slightly varied between two stage drying and existing sun drying method.

Table 4.4 Comparisons on First Option of Two Stage Drying and Control Drying Method on Color Properties of Dried Maize.

Drying Options	Temperatures	L value	a value	b value	Color Change (ΔE)	Chroma	Hue Angle
First Option	120^0C	*64.40±2.57	10.50±1.61	26.37±1.87	5.33±0.27	28.40±2.06	68.32±2.69
	140^0C	57.3±1.31	5.46±1.62	25.03±1.91	4.40±0.27	25.65±1.95	77.69±3.43
	160^0C	46.81±1.60	15.84±2.16	26.59±1.98	4.87±0.31	31.00±1.83	59.18±4.17
Sun Drying (Control)	33-36°C	66.88±1.81	8.39±0.53	38.45±2.02	3.72±0.43	39.35±1.91	77.65±1.19

*Mean values ± Standard deviation; First option: Fluidized bed drying and sun drying.

Table 4.5 Comparisons on Second Option of Two Stage Drying and Control Drying on Color Properties of Dried Maize

Drying Options	Temperatures	L value	a value	b value	Color Change (ΔE)	Chroma	Hue Angle
Second option	120^0C	*52.08±1.08	9.25±0.92	24.87±4.62	6.32±1.11	25.23±2.48	68.39±2.11
	140^0C	56.11±1.05	7.73±0.50	25.00±2.87	4.84±0.75	26.17±2.49	72.75±0.83
	160^0C	55.21±1.52	10.24±1.88	25.75±3.32	5.32±0.78	27.65±2.39	68.89±6.49
Control drying	33-36°C	66.88±1.81	8.39±0.53	38.45±2.02	3.72±0.43	39.35±1.91	77.65±1.19

*Mean values ± SD; Second option: First stage FBD at higher temperature then second stage FBD at lower temperature.

4.5 Color Properties of Dried Maize

4.5.1 Comparison of Color Property between First Option and Control Drying Method (Sun Drying).

The color properties of dried grain between first option of two stage drying and control drying are shown in Table 4.4. The table indicates that the highest L value (lightness) was obtained in maize sample dried by sun drying method in contrast to first option of two stage drying. The results indicate that a value and b values were found to be higher in first option of two stage drying technique compare to control drying technique. The color change was higher at 120^{o}C and which was 5.33±0.27, but the lowest color change was achieved in control drying (sun drying) which was 3.72±0.43. The overall result shows that due to application of high air temperature and drying time color properties changed slightly. Ozdemir and Devres (2000) reported that the rate of color changes was affected by temperature and time. However, with the increase of the temperature, the effect of time becomes less and less significant. A similar result was found by Bhattacharya (1996) who shows that an increase in the processing time during rice parboiling markedly decreased its lightness, and increase its redness, yellowness, color intensity chroma and hue angle. However, due to application of high heat treatment during fluidized bed drying the color properties did not affect quality seriously even though a little variation was observed between first options of two stage drying and control drying option.

4.5.2 Comparison on Color Properties between Second Options of Two Stage Drying and Control Drying of Maize

The color attributes of dried grain between second option of two stage drying and control drying are shown in Table 4.5. The results indicate that the highest L value (66.88±1.81) was achieved in sun dried samples compared to samples dried by second option of two stage drying. From table 4.5, it is also cleared that at higher drying temperature (160^{o}C) the reduction of L value was much steeper in contrast to sample dried at low drying temperature (sun drying). The ‘a’ value of the sample increases with drying temperature as shown in Table 4.5. The increase of ‘a’ value was much sharper than the lower drying temperature (Control drying). This indicates that turning of redness of the product during drying process. Therefore, it is concluded that at higher drying temperature (160^{o}C) the affinity of redness of the maize kernel is greater while compare to the lower drying temperature. It may be due to the decomposition of chlorophyll and carotenoid pigments of maize kernel (Lee and Coates, 1999; Maskan, 2000**).** Following previous research work by Soponronnarit *et al.* (1997) showed that 'a' and 'b' values changed with drying times and temperatures. The lowest color change was observed at 120^{o}C during second options of maize drying and it was 68.39±2.11. This result is similar to the work reported by Chotijukdikul (1997). However, results indicate that a little bit difference was observed among color attributes of samples dried by second option of two stage drying and control drying (sun drying) method.

4.6 Nutritional Assessment of Dried Maize

Quality of dried maize was affected by drying options in two stage drying. The results of different nutritional parameters are described below:

4.6.1 Comparison on Nutritional Quality between First Option and Control Drying (Sun drying) of Maize

The results of nutritional quality of dried maize are presented in Table 4.6. The results indicate that all the drying temperatures were suitable for fluidized bed drying of maize employing the first option. In addition, results showed that the drying temperatures have effect on % starch content and β-Carotene content of dried maize. From Table 4.7 it is noticed that the highest crude protein content of dried maize was found to be 5.82% in control drying (sun drying). Almost similar protein content (5.77%) was found in first option of two stage drying. Cortez and Wild (1972) reported that the protein content of dried maize was 8-11% which is higher than the present values. However, Sule *et al.* (2014) reported the protein content of dried maize which was varied from 4.50–9.87 %. This variation could be occurred due to fertilizer application on maize field and environmental conditions (Lima, 2000). From Table 4.7 it is clear that the highest mineral content of dried maize was found to be 1.99% in control sample compared to samples dried by first option of two stage drying. Approximately similar ash content (1.99%) was found in control sample and reported by Watt and Merrill (1950). In addition, Sule *et al.* (2014) stated that the total mineral content of dried maize varied from 1.10–2.95 %. The variation in mineral content in dried maize might be due to the locality (Ocloo *et al.,* 2010).

The total starch content varied from 70.00±0.52 % to 63.93±0.06 % between first option of two stage drying and sun drying method. Amylose content was also increased with an increase in heating temperature, being highest in samples dried at 160°C (23.77±1.53) than the control sample. Yongfu.*et al.* (2016) reported that after high temperature air fluidization the degree of gelatinization of corn starch increases 10.79 % to 24.60 %. Compared to the sun-dried samples, the value of starch, and amylose were increased for the grains dried by two stage drying technique. Conversely, the content of amylopectin was reduced compared with the sun-dried samples. However one of the reasons of this variation in the starch content could be due to the reduction in the moisture content at the increased temperatures. The results indicate that the highest β-Carotene content of dried maize was found 0.38±0.04 mg/100g in control drying method but lowest at 160^{o}C sample for first stage drying which was 0.15±0.002 mg/100g. From the Table 4.6, it is noticed that β-Carotene content of dried maize samples were reduced due to application of high drying temperature. Pro-vitamin A, carotenoids are easily destroyed by exposure to light, oxygen and during processing, heating and storage (Rodriguez-Amaya 1997).

Table 4.6 Effects of First Options in Two Stage Drying and Control Drying Method on Nutritional Quality of Dried Maize.

Drying Options	Temperatures	% Crude Protein	% Starch	Amylose (mg/100g)	Amylopectin (mg/100g)	β-Carotene (mg/100g)	% Total Mineral
FBD + Sun	120^0C	*5.77±0.18	67.50±0.90	21.25±0.10	46.25±0.80	0.31±0.02	1.78±0.12
	140^0C	5.74±0.03	65.40±0.52	22.50±0.40	43.47±0.15	0.26±0.02	1.26±0.05
	160^0C	5.24±0.18	70.00±0.52	23.77±1.53	47.57±0.40	0.15±0.02	1.40±0.05
Sun Drying (Control)	33-36°C	5.82±0.16	63.93±0.06	24.05±0.70	41.82±0.62	0.38±0.04	1.99±0.11

*Mean values ± Standard deviation

4.6.2 Comparison on Nutritional Quality between Second Option and Control Drying (Sun drying) of Maize

Comparison between second option of two stage drying and control drying method on nutritional quality of dried maize is presented in Table 4.7 where it is observed that the highest crude protein and starch content was found in second options of dried maize compared to the control option. The highest crude protein 6.24% was found at 140^{o}C and starch at 160^{o}C sample which was 69.20%. The results indicate the highest mineral content of dried maize was found to be 1.99±0.11in control dried samples compared to sample dried by second option of two stage drying. Approximately similar mineral content (1.99%) was found in control sample and reported by Watt and Merrill (1950). In addition, Sule *et al.* (2014) stated that the total mineral content of dried maize which was varied from 1.10–2.95%. However, the variation in the range of protein and mineral content could be due to the varietal difference or depending on the soil nutrition condition.

The highest β-carotene content was achieved in control drying method compared to second option of two stage drying. Due to application of high heat treatment, β carotene content was found to be reduced (Rodriguez-Amaya 1997).

The result indicated that all the drying temperatures were suitable for fluidized bed drying of maize in first option. In addition, results showed that the drying temperatures have less effect on physical and selective nutritional qualities of dried maize. Overall results showed that the both options of two-stage drying technique yielded almost similar quality dried product. Therefore, both drying options are suitable for maize drying.

Table 4.7 Effects of Second Option of Two Stage Drying and Sun Drying Method on Nutritional Quality of Dried Maize

Drying Options	Temperatures	%Crude Protein	% Starch	Amylose (mg/100g)	Amylopectin (mg/100g)	β-Carotene (mg/100g)	%Total Mineral
FBD + FBD	120^0C	*6.06±0.10	68.23±1.89	19.05±0.30	44.98±0.16	0.22±0.02	1.88±0.03
	140^0C	6.24±0.27	66.70±1.05	18.11±0.08	48.53±1.06	0.14±0.02	1.38±0.03
	160^0C	6.12±0.18	69.20±0.96	22.80±0.44	46.13±1.45	0.03±0.003	1.45±0.05
Sun Drying (Control)	33-36°C	5.82±0.16	63.93±0.06	24.05±0.70	41.82±0.62	0.38±0.04	1.99±0.11

*Mean values ± Standard deviation

CHAPTER V

SUMMARY AND CONCLUSION

An attempt was made to know the effect of two options of two stage drying technique and existing sun drying method on drying time, effective moisture diffusivity, specific energy consumption and quality of dried product. The first option was employed by fluidized bed drying and tempering followed by sun drying method and second option was high temperature fluidized bed drying and tempering followed by fluidized bed drying at low temperature. Shorter drying time required in case of both first option and second option in reducing moisture content from 25.6±0.15% (wb) to 13-14% (wb) in contrast to single stage sun drying for drying of same maize. The lowest drying time (1.41 hours) was achieved in second option however; first option also took shorter drying time (4.25 hours) than sun drying method while drying time was 10 hours.

Effective moisture diffusivity of second option of two stage drying technique was higher than the first option. Therefore, based on the effective moisture diffusivity it is concluded that two stage drying of grain with fluidized bed dryer is quicker than the other drying method. Specific electrical energy in terms of primary energy and specific thermal energy were found to be lower at higher drying temperature (160^{o}C) and higher energy consumption was found at lower drying temperature (120^{o}C) in fluidized bed drying of maize.

In comparison on physical properties of dried maize, there was very little difference in various physical properties of maize dried by two options of two stage of drying whereas remarkable differences were observed while compare to sun dried sample. Color parameters L, a and b values were slightly decreased in both options of two stage drying without affecting the visual appearance in contrast to the sun dried sample. β-Carotene (mg/100g) and amylose content (mg/100g) were found to be higher than the sample dried by two stage drying options. It was noticed that % crude protein and % starch content increased in the products dried by two stage drying technique. Overall quality analysis results revealed that fluidized bed drying did not affect the quality of dried products.

Thus it can be concluded that the proposed two stage drying technique not only facilitated faster removal of moisture content but also yielded higher quality of dried maize compared to single-stage conventional sun drying method. Therefore, both options of two stage drying can be applied for maize drying in Bangladesh. The outcomes of this work indicated that the two-stage drying methods are suitable options to save drying time and to increase drying capacity.

Further research may be undertaken for producing quality dried maize product for using in the food and feed processing industries. In addition, research will be encouraged for using this proposed drying technique for other crops and vegetables.

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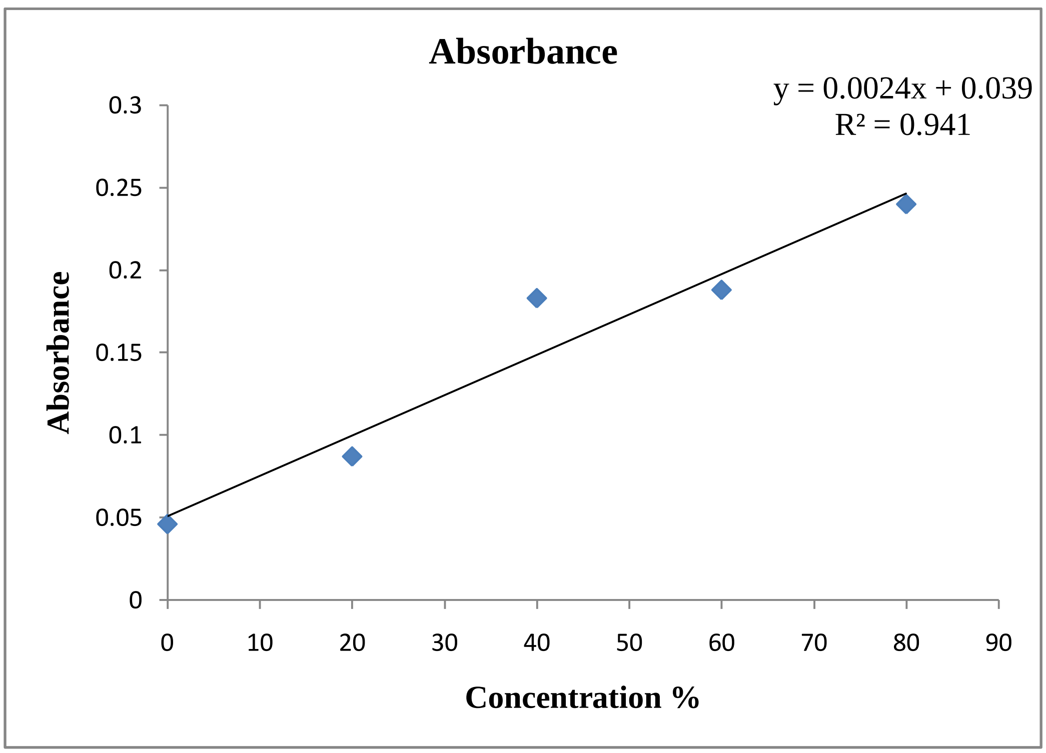
APPENDICES

Appendix 1.1 Analysis of variance (ANOVA) for drying time during first stage fluidized bed drying.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	10.007	2	5.003	900.600	.000
Within Groups	.033	6	.006		
Total	10.040	8			

Appendix 1.2 Standard curve for amylose determination



Appendix 1.3 Statistical analysis results for physical properties of dried grain in different drying options

Physical properties		N	Mean	Std. Deviation	Std. Error
Arithmetic mean	1.00	3	8.3867	.77526	.44760
	2.00	3	8.1900	.98808	.57047
	3.00	3	8.1433	1.32160	.76303
	Total	9	8.2400	.91842	.30614
Geometric mean	1.00	3	7.8033	.77106	.44517
	2.00	3	7.8533	1.10564	.63834
	3.00	3	8.4167	.39425	.22762
	Total	9	8.0244	.76164	.25388
Bulk density	1.00	3	789.3333	42.52450	24.55153
	2.00	3	733.0000	7.00000	4.04145
	3.00	3	809.5000	10.75872	6.21155
	Total	9	777.2778	40.89400	13.63133
Particle density	1.00	3	1014.9233	131.10431	75.69311
	2.00	3	957.4933	86.88279	50.16180
	3.00	3	1121.4033	20.12156	11.61719
	Total	9	1031.2733	107.11347	35.70449
Surface area	1.00	3	192.6333	38.75469	22.37503
	2.00	3	196.3133	56.77418	32.77859
	3.00	3	222.8600	20.99231	12.11992
	Total	9	203.9356	38.67128	12.89043
Sphericity	1.00	3	.6967	.04933	.02848
	2.00	3	.7100	.05568	.03215
	3.00	3	.6667	.01528	.00882
	Total	9	.6911	.04256	.01419
Porosity	1.00	3	21.7333	5.79770	3.34730
	2.00	3	23.0333	6.04511	3.49014
	3.00	3	27.8.5633	2.36984	1.36823
	Total	9	27.7767	9.20370	3.06790

Appendix 1.4 (a) Statistical analysis results for color attributes of dried maize between first option of two stage drying and control drying method.

Color attributes		N	Mean	Std. Deviation	Std. Error	Maximum
L	1.00	3	64.4033	2.57172	1.48478	66.59
	2.00	3	57.3300	1.31898	.76151	58.41
	3.00	3	46.8100	1.60636	.92743	48.63
	4.00	3	66.8867	1.81263	1.04652	68.89
	Total	12	58.8575	8.29313	2.39402	68.89
a	1.00	3	10.4967	1.61420	.93196	12.22
	2.00	3	5.4600	1.61583	.93290	7.29
	3.00	3	15.8467	2.16181	1.24812	18.19
	4.00	3	8.3933	.53594	.30943	8.91
	Total	12	10.0492	4.19084	1.20979	18.19
b	1.00	3	26.3700	1.86743	1.07816	28.18
	2.00	3	25.0300	1.91698	1.10677	26.59
	3.00	3	26.5867	1.98417	1.14556	28.42
	4.00	3	38.4500	2.02030	1.16642	40.45
	Total	12	29.1092	5.90556	1.70479	40.45
Colour change	1.00	3	5.3367	.27429	.15836	5.65
	2.00	3	4.4033	.27301	.15762	4.59
	3.00	3	4.8733	.31021	.17910	5.19
	4.00	3	3.7233	.43317	.25009	4.21
	Total	12	4.5842	.68345	.19729	5.65
Chroma	1.00	3	28.4000	2.06756	1.19371	29.98
	2.00	3	25.6500	1.95471	1.12855	26.93
	3.00	3	31.0033	1.83743	1.06084	32.43
	4.00	3	39.3567	1.91902	1.10795	41.20
	Total	12	31.1025	5.60707	1.61862	41.20
Hue angle	1.00	3	68.3267	2.69359	1.55515	70.01
	2.00	3	77.6933	3.43596	1.98375	80.96
	3.00	3	59.1867	4.17409	2.40991	63.88
	4.00	3	77.6500	1.19512	.69000	79.03
	Total	12	70.7142	8.43165	2.43401	80.96

Appendix 1.4 (b) Statistical analysis results for color attributes of dried maize in second option of two stage drying and control drying.

Color properties		N	Mean	Std. Deviation	Std. Error	Maximum
L value	1.00	3	52.0867	1.08103	.62413	53.31
	2.00	3	56.1100	1.05314	.60803	56.82
	3.00	3	55.2167	1.52487	.88039	56.58
	4.00	3	66.8867	1.81263	1.04652	68.89
	Total	12	57.5750	5.94970	1.71753	68.89
a value	1.00	3	9.2567	.92436	.53368	10.30
	2.00	3	7.7300	.50685	.29263	8.21
	3.00	3	10.2433	1.88123	1.08613	12.03
	4.00	3	8.3933	.53594	.30943	8.91
	Total	12	8.9058	1.36671	.39454	12.03
b value	1.00	3	24.8733	4.62305	2.66912	29.86
	2.00	3	25.0067	2.87865	1.66199	28.13
	3.00	3	25.7567	3.32687	1.92077	28.51
	4.00	3	38.4500	2.02030	1.16642	40.45
	Total	12	28.5217	6.64192	1.91736	40.45
Colour change	1.00	3	6.3233	1.11195	.64198	7.50
	2.00	3	4.8433	.75002	.43303	5.59
	3.00	3	5.3200	.78250	.45177	5.90
	4.00	3	3.6433	.49116	.28357	4.21
	Total	12	5.0325	1.22283	.35300	7.50
Chroma	1.00	3	25.2333	2.48719	1.43598	27.14
	2.00	3	26.1700	2.89798	1.67315	29.30
	3.00	3	27.6533	2.39880	1.38495	29.89
	4.00	3	39.3567	1.91902	1.10795	41.20
	Total	12	29.6033	6.30647	1.82052	41.20
Hue angle	1.00	3	68.3967	2.11285	1.21985	70.79
	2.00	3	72.7567	.83608	.48271	73.72
	3.00	3	68.8900	6.49649	3.75075	72.77
	4.00	3	77.6500	1.19512	.69000	79.03
	Total	12	71.9233	4.88946	1.41146	79.03

Appendix 1.5 (a) Statistical analysis results for nutritional parameters of samples dried by first option of two stage drying and control drying (sun drying) method.

Nutritional qualities		N	Mean	Std. Deviation	Std. Error	Maximum
Crude protein	1.00	3	5.7733	.17502	.10105	5.95
	2.00	3	5.7400	.03464	.02000	5.76
	3.00	3	5.2467	.17502	.10105	5.42
	4.00	3	5.8200	.15716	.09074	5.96
	Total	12	5.6450	.27281	.07875	5.96
Starch	1.00	3	67.5000	.90000	.51962	68.40
	2.00	3	65.4000	.51962	.30000	65.70
	3.00	3	70.0000	.51962	.30000	70.30
	4.00	3	63.9333	.05774	.03333	64.00
	Total	12	66.7083	2.43701	.70350	70.30
Amylose	1.00	3	21.2500	.10000	.05774	21.35
	2.00	3	22.5000	.40000	.23094	22.90
	3.00	3	23.7667	1.53080	.88380	25.50
	4.00	3	24.0533	.69644	.40209	24.85
	Total	12	22.8925	1.37799	.39779	25.50
Amylopectine	1.00	3	46.2500	.80000	.46188	47.05
	2.00	3	43.4667	.15275	.08819	43.60
	3.00	3	47.5667	.40415	.23333	47.80
	4.00	3	41.8167	.62115	.35862	42.20
	Total	12	44.7750	2.40686	.69480	47.80
Betacarotine	1.00	3	.3100	.02000	.01155	.33
	2.00	3	.2600	.02000	.01155	.28
	3.00	3	.1467	.02082	.01202	.17
	4.00	3	.3800	.03606	.02082	.41
	Total	12	.2742	.09140	.02638	.41
Total Mineral	1.00	3	1.7833	.11547	.06667	1.85
	2.00	3	1.2600	.05292	.03055	1.30
	3.00	3	1.3967	.00577	.00333	1.40
	4.00	3	1.9967	.10504	.06064	2.10
	Total	12	1.6092	.31581	.09117	2.10

Appendix 1.5 (b) Statistical analysis results for nutritional parameters of samples dried by second option of two stage drying and control drying (sun drying) method.

		N	Mean	Std. Deviation	Std. Error	Maximum
Crude protein	1.00	3	6.0633	.09815	.05667	6.12
	2.00	3	6.2400	.26514	.15308	6.47
	3.00	3	6.1233	.17502	.10105	6.30
	4.00	3	5.8200	.15716	.09074	5.96
	Total	12	6.0617	.22413	.06470	6.47
Starch	1.00	3	68.2333	1.88768	1.08985	70.30
	2.00	3	66.7000	1.05357	.60828	67.70
	3.00	3	69.2000	.96437	.55678	70.30
	4.00	3	63.9333	.05774	.03333	64.00
	Total	12	67.0167	2.31157	.66729	70.30
Amylose	1.00	3	19.0500	.30414	.17559	19.40
	2.00	3	18.1167	.07638	.04410	18.20
	3.00	3	22.8000	.43589	.25166	23.30
	4.00	3	24.0533	.69644	.40209	24.85
	Total	12	21.0050	2.62130	.75670	24.85
Amylopactine	1.00	3	44.9833	.16073	.09280	45.10
	2.00	3	48.5333	1.05987	.61192	49.50
	3.00	3	46.1333	1.44684	.83533	47.80
	4.00	3	41.8167	.62115	.35862	42.20
	Total	12	45.3667	2.65179	.76550	49.50
Betacarotine	1.00	3	.2233	.02082	.01202	.24
	2.00	3	.1433	.01528	.00882	.16
	3.00	3	.0257	.00252	.00145	.03
	4.00	3	.3800	.03606	.02082	.41
	Total	12	.1931	.13585	.03922	.41
Total Mineral	1.00	3	1.8833	.02887	.01667	1.90
	2.00	3	1.3767	.02517	.01453	1.40
	3.00	3	1.4500	.05000	.02887	1.50
	4.00	3	1.9967	.10504	.06064	2.10
	Total	12	1.6767	.28436	.08209	2.10

Appendix 1.6: Some photographic view during conducting drying experiment.