PERFORMANCE OF DRYING METHODS ON QUALITY OF MUSHROOMS

BY

SYEDA TASHNIM

DEPARTMENT OF HORTICULTURE
SHER-E-BANGLA AGRICULTURAL UNIVERSITY
DHAKA-1207

JUNE, 2011

PERFORMANCE OF DRYING METHODS ON QUALITY OF MUSHROOMS

BY

SYEDA TASHNIM

REGISTRATION NO.05-01643

A Thesis
Submitted to the Faculty of Agriculture,
Sher-e-Bangla Agricultural University, Dhaka,
in partial fulfillment of the requirements
for the degree
of

MASTER OF SCIENCE (MS)
IN
HORTICULTURE

SEMESTER: JANUARY-JUNE, 2011

Approved by:

Dr. Nirod Chandra Sarkar
Project Director
Strengthening Mushroom Development Project
National Mushroom Development & Extension Centre
Sobhanbag, Savar, Dhaka-1340.
Supervisor

Prof. Dr. Md. Ismail Hossain
Dept. of Horticulture
SAU, Dhaka
Co-Supervisor

Prof. Dr. Md. Ismail Hossain
Chairman
Examination Committee

Strengthening Mushroom Development Project
National Mushroom Development & Extension Centre
Department of Agriculture Extension
Sobhanbag, Savar, Dhaka-1340.

Ref: ***Dated:***

CERTIFICATE

This is to certify that the thesis entitled, "**Performance of drying methods on quality of mushrooms"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka in the partial fulfillment of the requirements for the degree of **Master of Science (MS)** in **HORTICULTURE,** embodies the result of a piece of *bona fide* research work carried out by **Syeda Tashnim,** Registration no. **05-01643** under my supervision and guidance No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has been acknowledged.

Dated: June 2011
Dhaka, Bangladesh

Dr. Nirod Chandra Sarker
Project Director
National Mushroom Development & Extension Centre
Sobhanbag, Savar, Dhaka-1340.
Supervisor

ACKNOWLEDGEMENTS

First of all I express my best gratitude to Almighty Allah for His never-ending blessing to complete this work successfully.

*I would like to express my heartiest respect, my deep sense of gratitude and sincere, profound appreciation to my supervisor, **Dr. Nirod Chandra Sarkar**, Project Director of National Mushroom Development and Extension Centre (NAMDEC), Savar, Dhaka for his sincere guidance, scholastic supervision, constructive criticism and constant inspiration throughout the course and in preparation of the manuscript of the thesis.*

*I would like to express my heartiest respect and profound appreciation to my Co-supervisor, **Professor Dr. Md. Ismail Hossain**, Chairman, Department of Horticulture, Sher-e Bangla Agricultural University, Dhaka for his utmost cooperation and constructive suggestions to conduct the research work as well as preparation of this thesis.*

It is great pleasure for me to express my sense of gratitude to the honourable Minister of Science, Information and Communication Technology of People's Republic of Bangladesh for giving me opportunity of M.S. study under the National Science, Information and Communication Technology Scholarship.

I am highly grateful to all of my honourable teachers of the department of Horticulture, Sher-e Bangla Agricultural University,Dhaka for their proficient teaching and providing me information by which my experiment was successful.

I am pleasure to all stuffs and workers of the department of Horticulture, Sher-e-Bangla Agricultural University, Dhaka and National Mushroom Development and Extension Centre (NAMDEC), Savar, Dhaka for their valuable and sincere help in carrying out the research work.

Mere diction is not enough to express my profound gratitude and deepest appreciation to my father, mother, my sister, brother, my cousins, relatives and friends for their ever ending prayer, encouragement, sacrifice and dedicated efforts to educate me to this level.

The Author

PERFORMANCE OF DRYING METHODS ON QUALITY OF MUSHROOMS

BY

SYEDA TASHNIM

ABSTRACT

The experiment was conducted at National Mushroom Development and Extension Centre, Savar, Dhaka from April 2010 to March 2011. The experiment consists of two factors, factor A- four drying methods; gas burner (D_1), white polypropylene covered tunnel (D_2), open sundry (D_3)and indirect dryer (D_4), factor B- three species of mushroom: oyster (M_1), shiitake(M_2) and white milky (M_3). Results revealed that D_2 showed the best performance in terms of weight and containing minimum moisture. Total drying time of D_2 was comparatively lower than other drying methods. Though D_1 took the shortest time for drying it also reduced the quality of mushroom. Different drying methods also influenced the colour of mushroom. For M_1 the best colour: upper pileus- tan, lower pileus – corn silk and stipe – corn silk /wheat was found in D_2. For M_2 the best colour: upper pileus – saddle brown, lower pileus – moccasin and stipe –tan was obtained from D_3 and D_4. For M_3 the best colour: upper pileus and stipe –wheat colour, lower pileus –corn silk was found under D_2, D_3 and D_4. Considering the total drying time, weight loss efficiency and colour, D_2 appeared to be recommendable for oyster, shiitake and white milky mushroom. However D_4 may also be used for drying of mushroom.

Materials
And
Methods

TABLE OF CONTENTS

Title	Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATED TERMS

ABBREVIATION	FULL NAME
et al.	and others
°C	Degree Celsius
g	Gram
Kg	Kilogram
ft	Feet

hr	Hour
cm	Centimeter
%	Percent
RH	Relative Humidity
LSD	Least Significant Difference
DMRT	Duncan’s Multiple Range Test
CRD	Completely Randomized Design
CV	Coefficient of Variance
pp	Polypropylene
NAMDEC	National Mushroom Development and Extension Centre

CHAPTER I

INTRODUCTION

Mushrooms are reproductive structure of edible and medicinal fungi that belong to classes Ascomycetes and Basidiomycetes (Pathak *et al*., 1998). The part of the organism that is seen and called a mushroom is really just the fruiting body (sporophore). There are about 2000 species of edible mushroom of which only 20 are commercially cultivated (Pathak *et al*., 1998). Among them Oyster, Milky, Straw, Shiitake, Reishi mushrooms are usually cultivated in our country. The shelf life of mushrooms is very short. It is highly perishable as it contains 85-95% water. To store the mushrooms for longer time canning, freezing and drying processes are employed (Kim, 2004). But drying is more suitable for long term storage in our country.

Oyster mushroom is known as *Pleurotus ostreatus*. It is also known as oyster, abalone, or tree mushrooms. The oyster mushroom is an edible mushroom. It is the mushroom of all season. Growers cultivate it on a commercial scale for food. Oyster mushrooms have been used for thousands of years as a culinary and medicinal ingredient. They have a rich history in traditional Chinese medicine as a tonic for the immune system.

Shiitake mushroom (*Lentinula edodes*) is commonly known as Japanese mushroom, Black Forest mushroom, golden oak mushroom, oakwood mushroom. Shiitake is the winter mushroom. It is the second most commonly cultivated edible mushrooms in the world. Shiitake mushrooms also offer a wide variety of conventional nutrients as well as very good source of vitamin B_2. The dried mushrooms are used in herbal remedies.

The White Milky mushroom is scientifically known as *Calocybe indica*. The name is derived from the Ancient Greek terms *kalos* "pretty", and *cubos* "head". Milky is the summer mushroom. It is a good source of fibre. Fibre is a special type of carbohydrate that passes through the human digestive system virtually unchanged, without being broken down into nutrients. Carbohydrates constitute the main source of energy for all body functions.

Though, there are several types of mushrooms are grown in Bangladesh, among of them oyster, shiitake and white milky mushrooms were chosen for the experiment, because of their production availability and wide consumption. .

Many farmers of the world are faced with the problem of reducing moisture content of their harvested crops to prevent spoilage during storage. The situation is worse for farmers in the rural areas of developing countries where there is no access to electricity and harvested crops are often stored in heaps. Most of the harvested crops are susceptible to deterioration due to poor preservation. Moisture contributes greatly to the deterioration of agricultural products specially mushrooms (Deshpande and Tamhane, 1981; Itodo *et al*., 2002 and Bolaji, 2005). When crops are harvested, the amount of moisture they contain is of little consequence if the crops are to be consumed immediately, but if the crops are to be stored for a reasonable length of time, it is essential that its moisture level be reduced to a certain well-defined limit (Singh *et al*., 1995) . Preservation of foods by drying is perhaps the oldest method known. Drying is a thermo-physical action and its dynamic principles are governed by heat and mass transfer laws inside and outside the product (Matrawy, 1998; Hossain and Islam-ud-Din, 2008; Tripathy and Kumar, 2009). The weight of the product is reduced to the extent of 1/4th to 1/9th of its original fresh weight (Sethi, 2007). Drying of mushrooms and biological products is a widely applied process for different purposes such as increasing shelf life, reducing packaging costs, lowering shipping wastes, encapsulating flavours, making food available during off-season, adding value by changing the phase structure of the native material and maintaining nutritional value (Kamal *et al*., 2009).

Artificial dryers have long been in existence. They are used for the preservation of a wide variety of agricultural products; some of these artificial dryers are powered electrically or by natural fuels (Ertekin and Yaldiz, 2004; Giri and Prasad, 2007; Ajao and Adegun, 2009; Yesilata and Aktacir, 2009). However, the ever-rising cost of electricity and natural fuels coupled with growing concern about their availability in both the short and long terms, has resulted in growing interest in the use of renewable resources especially solar energy; in both direct and indirect forms (Adaramola *et al*., 2004; Koua *et al*., 2009).

Several types of dryers and drying methods, each better suited for a particular situation are commercially used to remove moisture from a wide variety of mushrooms (Oei, 2005). Different types of drying processes are as follows: Open sundry, gas burner, electric dryer, indirect sundry, sun drying in polypropylene covered tunnel, drying room etc (Kan and Gupta, 2001; Karim and Hawlader, 2006; Montero *et al*., 2010). Among them gas burner, white polypropylene covered tunnel, open sundry and indirect dryer were chosen for this experiment, because of their low cost and easy mechanism so that rural farmers can use them properly.

The consumer simply dehydrates the material and uses for different purposes. Mushrooms available only during seasons with the help of drying process they can be preserved for all seasons. The biological forces acting upon foods are minimized. Spoilage of foods is easily controlled in drying process.

Therefore, considering the above facts the present investigation was carried out on the following objectives:

i. To evaluate the performance of different drying methods for each of the mushroom species.

ii. To determine the quality of mushrooms dried in different methods.

CHAPTER II

REVIEW OF LITERATURE

Mushrooms are edible fungi of commercial importance and their cultivation and consumption have increased substantially due to their nutritional value, delicacy and flavour. It is rich in vitamins C, D_2, B_2 and Mg, P, Ca, dietary fibers and amino acids. Another important ingredient of mushroom is the polysaccharide compound beta-glucan, which enhances cellular immune function. But mushrooms are extremely perishable and the shelf life of fresh mushrooms is only about 24 hours at ambient conditions and 7-10 days even with refrigerated storage because of its high moisture content and rich nutrients that spoil easily and quickly. Again, various physiological and morphological changes occur after harvest, which make these mushrooms unacceptable for consumption. Therefore, mushrooms are usually dried to extend the shelf-life and drying methods are very important process by which mushrooms are being preserved. However, information available in these aspects of drying mushrooms under open sunlight and some other methods have been reviewed and presented in this chapter.

2.1. LITERATURE ON DRYING OF MUSHROOMS

Bala *et al.* (2009) used solar drying of mushroom to investigate the performance of the solar tunnel dryer for drying mushrooms. The dryer consisted of a transparent UV stabilized plastic covered flat plate collector and drying tunnel unit. The dryer is arranged to supply hot air directly in to the drying tunnel using three dc fans powered by a 40 watt solar module. The products to be dried are placed in a single layer on a wire mesh in the drying tunnel to receive energy from both hot air supplied from the collector and from the incident solar radiation on products. During the experimental period the minimum and maximum solar radiation were $273W/m^2$ and $885W/m^2$

respectively. The generated voltages for the 40W solar modules were 4.5V to 14.8V. The temperature in the drying chamber varied from 37.0°c to 66.5°c. Mushrooms were dried from about 89.41% to 6.14% moisture content (w.b.) in about 8 hours. In the same drying period, the moisture content of mushrooms reduced from 89.41% to 15.0% in the traditional sun drying method.

Kulsheshtha and Singh (2009) used fluidized bed drying of mushroom to study the drying characteristics and quality of the dried mushrooms. Drying was done at drying air temperatures of 50, 70 and 90^{o}C and air velocities of 1.71 and 2.13 m/s. Two batch sizes, namely 0.5 kg and 1.0 kg of sliced milky mushrooms were dried. Drying characteristics and the quality of dried mushrooms were analyzed. The results indicated that the drying time decreased only marginally with increase in air velocity. Drying air temperature of 50^{o}C was better as it resulted in a dried product having better rehydration characteristics, lesser shrinkage and lighter colour. Highest energy efficiency (79.74%) was observed while drying a batch size of 1.0 kg at a drying air temperature of 50^{o}C, using an air velocity of 1.7 m/s. In this experiment, fully matured milky mushrooms were cut in to 5-8mm thick slices. The mushroom slices were dried from an initial moisture content of approximately 90% (w.b.) to the final moisture content of about 10% (d.b.) in a fluidized bed dryer. It was found that the efficiency is best for the batch size of 1.0 kg with air velocity 1.7 m/s at drying air temperature of 50^{o}C. Drying air temperature of 50^{o}C is better as it gives dried product with higher rehydration ratio and higher rehydration fraction, lower shrinkage and better colour.

Jadhav and Chandiwade (2008) conducted the experiment to study the effect of pretreatment, drying temperature and intermittent drying technique on cooking quality of oyster mushroom. The Study revealed that the mushrooms samples dried using treatment control, 50^{o}C, 1:05 h exhibits maximum rehydration ratio (7.32) and also required minimum cooking time (30 min), while maximum water uptake ratio (8.39) was reported for the treatment control, 50°C, 1.5 h. In general, cooking quality of mushroom samples with no pretreatment (control) was found better over other treatments.

Arumuganathan *et al.* (2008) used fluidized bed dryer at air temperatures of 50, 55 and 60°C to dry 10 mm thick slices of milky mushroom. Drying of milky mushroom slices occurred in falling rate period. In order to select a suitable drying curve, eight thin layer-drying models were fitted to the experimental moisture ratio data. The effective moisture diffusivity (*Deff*) of mushroom increased as the drying air temperature increased. The moisture diffusivity in milky mushroom was found to increase from 1.55 to 4.02 x 10^{-9} m^2 s^{-1} during the initial stage of drying and from 8.76 to 16.5 x 10^{-9} m^2 s^{-1} during the later stage of drying. Drying at temperature of 60°C required minimum activation energy to detach and move the water during the drying process.

Combs. (2004) reported that drying mushrooms would extend the shelf life of mushrooms. Dried mushrooms can be used in many different types of products. Furthermore, elevated temperatures during drying enhance enzymatic reaction that can result in improved flavor of dehydrated mushrooms. Over 80% of total production of Agaricus mushrooms, including white and brown strains - Crimini and Portabello are sold on the fresh market as whole or sliced mushrooms. Currently, the pieces of sliced mushrooms that are smaller in size or have irregular shape are considered to be waste and have to be disposed of. The sliced products are still of good quality and could be used in a process such as drying. This would provide mushroom growers with a way to profit from the product that they currently have to dispose of. Dried mushrooms could be used by consumers and by industry in applications such as pizzas, soups and sauces. Consumer benefits include the fact that they can purchase mushrooms to use in products that do not need fresh mushrooms and be able to store the mushrooms for a longer period of time. Producers would reduce expenses required to dispose of organic waste and would gain additional profit from value-added products.

Walde *et al.* (2003) conducted an experiment on the dehydration of button mushrooms (*Agaricus bisporus*) and oyster mushrooms (*Pleurotus flavus*) with various pretreatments like blanching, blanching followed by soaking in potassium metabisulphite (KMS), fermented whey, curds, etc. and dried in different dryers viz, hot air cabinet dryer, fluidized bed dryer, vacuum dryer and microwave oven. The drying times were less in the case of oyster mushrooms (7200-8100 s) compared to button mushroom (8700-10800 s) with cabinet drying. For both oyster and button mushrooms using pretreatment by dipping in curds or fermented whey the time of drying was less compared to other treatments in all types of dryers. The effect of drying methods was expressed by a polynomial equation and the regression coefficients were determined. The time taken for drying from 7.5% (db) moisture to 2.0% (db) was in the order of vacuum dryer > cabinet moisture dryer > fluidized bed dryer > microwave oven. However, fluidized bed drying seems to be a promising method for drying mushrooms, when comparing the lower drying time and good quality products to the faster microwave drying. The diffusion coefficients evaluated were also found in the same order. In case of oyster mushroom, the diffusion coefficient was found maximum (469.70 x 10-6 m^2/s) for the whey treated microwave dried mushroom and minimum (2.60 x 10-6 m^2/s) for the control cabinet tray dried sample. The diffusion coefficient was maximum (331.02 x 10-6 m^2/s) for the blanched button mushroom dried by microwave drying and minimum (0.32 x 10-6 m^2/s) for the control sample dried by vacuum oven.

2.2. LITERATURE ON DRYING METHODS

Wang *et al.* (2007) conducted an experiment for the far-infrared and microwave drying characteristics on peach and far-infrared combined with microwave drying on other food products. Experiments were conducted to study microwave and far-infrared dehydration characteristics and two-stage drying process involving far-infrared following microwave drying on peach. As microwave drying power and infrared drying power increased, dehydration rate of peach increased and whole drying energy consumption decreased. Peach experienced two falling rate periods when dried with microwave drying or far-infrared drying, and the first falling rate period under moisture content of peach more than 1.7 (dry basic, d. b.), the second falling rate period under less than moisture content 1.7 (d. b.). The same water loss will consume more energy and the steeper curve of energy versus moisture content were obtained when the moisture content is less than 1.7 (d. b.). However, differed from microwave drying, an accelerating dehydration rate period existed in the initial period of far-infrared drying. The effects of infrared drying power, microwave drying power and exchanging moisture content at former far-infrared drying converting into latter microwave drying (three factors) on energy consumption rate and sensory quality (two indices) are significant. The interaction effect of infrared drying power and exchanging moisture content on two indices is significant. The effects of second-order of microwave drying power and of interaction between infrared drying power and microwave drying power on energy consumption rate were not significant. The effects of second-order of exchanging moisture content and of interaction between exchanging moisture content and microwave drying power on sensory quality were not significant.

Bukola *et al.* (2011) conducted the experiment at the Federal University of Agriculture, Abeokuta, Nigeria, to utilise the benefits of using forced convection solar dryers through the use of a rotary wind ventilator in the remote areas where electricity and other power sources are non-existent. The solar wind-ventilated cabinet dryer was designed, constructed and tested in Nigeria on latitude 7.50 N. The results obtained show that the temperatures inside the dryer and the air were higher than the ambient temperature during most hours of the day-light. The drying of food items in the dryer was compared with open air-drying of similar items. Comparatively, drying with the solar cabinet dryer showed better results than open air-drying. The results also revealed the dependence of the dryer performance on the proper air circulation through the system. The system efficiency increased as the air velocity through the system increased. During the period of test, the average air velocity through the solar dryer was 1.62 m/s and the average daylight efficiency of the system was 46.7%.

Hansson *et al.* (2005) conducted an experiment to investigate the effect of drying method and temperature level on the hardness of wood. The purpose of the work was to investigate whether wood hardness is affected by temperature level during microwave (MW) drying and whether the response is different from that of conventionally dried wood. Matched samples of Norway spruce (Picea abies) were therefore dried from green state to different moisture content (mc) at different temperature levels, both conventionally by air circulation and by MW. The results show that specimens dried by any of the two methods at a temperature level of 100 or 60^{o}C there is a significant difference in wood hardness parallel to the grain between the methods when drying progresses to relatively lower level of moisture content, i.e. wood hardness becomes higher during MW drying. Temperature level in the range 60-110^{o}C during MW drying has no significant influence on wood hardness. Variables such as density and mc have a greater influence on wood hardness than does the drying method or the drying temperature. Since wood is a biological material, its strength varies within the specimens as well as between different samples. For this reason it is important to use matched samples when performing this type of comparative investigation.

Sumnu *et al.* (2005) experimented on drying of carrots in microwave and halogen lamp-microwave combination ovens. Carrot slices were dried by using microwave, halogen lamp-microwave combination and hot-air drying. Microwave and halogen lamp-microwave combination drying were applied after carrots were dried to 0.47 kg moisture/kg dry solid by hot-air drying. Drying time, rehydration capacity and colour of the carrots dried by different methods were compared. The increase in microwave oven power level decreased the drying time. Microwave drying at the highest power and halogen lamp-microwave combination drying reduced the drying time to an extend of 98% in comparison to conventional hot-air drying and a high-quality dried product was obtained. Moreover, in the case of halogen lamp-microwave combination drying, moisture level was reduced to a level, which is lower than the one achieved by other methods. Less colour change occurred when microwave and halogen lamp-microwave combination drying were applied. Carrots dried in microwave and halogen lamp-microwave combination oven had lower L*, higher a* and b* values and had higher rehydration capacity as compared to hot-air drying.

Wang *et al.* (2005) studied on the alternative of using varying microwave power during drying of food products. Experiments were made to study microwave drying characteristics and dried product quality. A two-stage microwave power system using a first and second stage power input for varying times during drying was used. The study focuses on describing microwave drying characteristics of carrot and discussing the effect of sample thickness, power applied during first-stage (first-stage power), power applied during the second-stage (second-stage power) and duration of first-stage on [beta]-carotene content and rehydration ratio. The dehydration rate increased and the drying energy consumption decreased, as the thickness of the sample decreased, power level increased and mass load decreased. There were two falling rate periods when using microwave drying of carrot, the first falling rate period being over moisture contents of 1.0 (d.b.), and the second falling rate period applying at moisture contents less than 1.0 (d.b.). The same water loss will consume more energy and the energy curve was shown to the steeper when the moisture content is less than 1.0 (d.b.). Slice thickness, first-stage power, second-stage power and duration of the first-stage affected [beta]-carotene content and rehydration ratio. The rehydration ratio of the dried products decreased with increase in duration of the first-stage and slice thickness. [beta]-carotene content decreased with increase of power applied during the second-stage and duration of the first-stage. With the exception of the effect of first-stage power on [beta]-carotene content and duration of the first-stage on the two quality indicators slice thickness, first-stage power, and second-stage power significantly affected the two quality indicators.

Soysal. (2004) conducted an experiment where parsley (*Petroslinum crispum Mill.*) leaves were dried in a domestic microwave oven to determine the effects of microwave output power on drying time, drying rate and the dried product quality in terms of colour. Seven different microwave output powers ranging from 360 to 900 W were used in the drying experiments. Drying took place mainly in constant rate and falling rate periods. After a short heating period a relatively long constant rate period was observed. Approximately 40 [middle dot] 5% of the water was removed in this period. The rapidly decreasing falling rate period followed the constant rate period. As the drying progressed, the loss of moisture in the product caused a decrease in the absorption of microwave power and resulted in a fall in the drying rate. Increasing the microwave output power resulted in a considerable decrease in drying time (probability PR_2 of greater than 0 [middle dot] 997 and for the standard error of estimates (SEE) of lower than 0 [middle dot] 0188. The value of the drying constant increased with increased microwave output power. No significant differences were observed between the colour parameters of fresh and microwave-dried leaf materials, except for some decrease in whiteness L value (P>0[middle dot]05). The change in colour values was not dependent on the microwave output power. Although some darkening occurred, microwave drying maintained a good green colour close to that of the original fresh parsley leaves. By working at 900 W instead of 360 W, the drying time could be reduced by 64% with a good quality product.

Sharma *et al.* (2003) investigated on application of microwave for drying garlic cloves. A laboratory microwave-convective dryer was developed which had the provision of regulating microwave power, air temperature and air velocity. Garlic cloves of uniform size were used in the drying experiments which were carried out at air temperatures of 40, 50, 60 and 70^{o}C, air velocities of 1.0 and 2.0 m/s and microwave power levels of 10, 20, 30 and 40 W. Microwave-convective drying was accomplished till the moisture content of the garlic cloves reduced from initial moisture content of 1.85 kg water/kg solids to a safer level of 0.06 kg water/kg solids. The drying time increased as the air velocity was increased from 1.0 to 2.0 m/s at all levels of air temperatures and microwave power. The specific energy consumption involved in all drying conditions was also estimated. The quality attributes of the fresh and dehydrated garlic cloves were evaluated for colour (L, a, b values), flavour strength and vitamin C. The rehydration ratio was also determined for the dehydrated garlic cloves. A convectionally dried commercial sample of garlic cloves from a local manufacturer was obtained. The quality attributes of this sample were compared with products dried by microwave-convective drying technique. The quality of garlic cloves, dehydrated by microwave-convective drying process, was found superior to the commercial sample. The process parameters for microwave-convective drying were optimized for the garlic cloves using Tukey's multi-comparison pair-wise test. The results revealed that the microwave power of 40 W, air temperature of 70^{o}C and air velocity of 1.0 m/s gave a good quality dehydrated garlic cloves and involved low specific energy consumption in the drying process.

Velu *et al.* (2003) Studied on the dry milling characteristics of maize grains, which were dried previously from different IMC in a domestic microwave oven. The IMC ranged from 9.6% to 32.5% db. Drying was also carried out in a convective dryer at temperatures of 65-90^{o}C. The drying rate curve showed a typical case of moisture loss by diffusion from grains. The dried samples were ground in a hammer mill and the Bond's work index was calculated which was found to decrease with increase in duration of microwave drying. The proximate composition of the grains and the ground products showed that there was no change in protein and starch content. Viscosity measurements were made with 10% suspensions prepared out of the flour in water and heated to 80 and 90°C and cooled. Viscosity was found to decrease with increase in microwave drying time of the grains. The colour analysis showed that flour of the microwave-dried samples was brighter than the control and convective dried samples.

Bilbao-Sainz *et al.* (2001) conducted an experiment on the dehydration of apple cylinders applying microwaves (3 and 10 W/g initial incident microwave power) combined with forced air (40°C air temperature) was performed. Drying rate and sample temperature and volume were recorded in order to analyse the coupling of heat and mass transfer mechanisms and deformation-relaxation phenomena in line with the sample dehydration. Experimental results showed the effect of temperature raise on internal evaporation phenomena producing both plasticization of sample matrix and an increase of internal pressure. As a consequence changes in sample temperature and volume, as well as the drying rate and dissipated power showed a common pathway. A general description has been developed to explain the behaviour of apple tissue under microwave drying.

Jayaraman and Gupta (1990) studied on different drying methods. Direct and in- direct solar dryers the material to be dried is placed in an enclosure with a transparent cover or side panels. Heat is generated by absorption of solar radiation on the product itself as well as on the internal surfaces of the drying chamber. This heat evaporates the moisture from the drying product. In addition it serves to heat and expand the air, causing the removal of the moisture by the circulation of air. In indirect solar dryers, solar radiation is not directly incident on the material to be dried. Air is heated in a solar collector and then ducted to the drying chamber to dehydrate the product. Generally flat-plate solar collectors are used for heating the air for low and moderate temperature use. Efficiency of these collectors depends on the design and operating conditions. The main factors that affect collector efficiency are heater configuration, airflow rate, spectral properties of the absorber, air barriers, heat transfer coefficient between absorber and air, insulation and insolation. By optimizing these factors, a high efficiency can be obtained.

CHAPTER III

MATERIALS AND METHODS

The investigation was carried out at National Mushroom Development and Extension Centre (NAMDEC), Savar, Dhaka from April 2010 to March 2011 to study the performance of different drying methods. A brief description about the locations of the experimental site, duration, species of mushrooms, description of dryers, description of used materials, data recording procedure and colour analysis which are presented as follows:

3.1. Location and time

The research work was conducted at National Mushroom Development and Extension Centre (NAMDEC), Savar, Dhaka from April 2010 to March 2011. The mushrooms were collected from the centre and different drying equipments were installed at the yard of the centre.

3.2. Species of mushrooms

Three different mushroom species like oyster, shiitake and milky were collected in a fresh condition from the centre. Oyster mushroom (*Pleurotus ostreatus*), is grown round the year. It is widely used as both food and medicine. Shiitake mushroom (*Lentinula edodes)* is mainly a winter mushroom and a good source of vitamins. White milky mushroom (*Calocybe indica*) is a summer mushroom. It is important for its fibre value. So three mushroom species were used-

M_1- Oyster mushroom

M_2- Shiitake mushroom

M_3- White milky mushroom

3.3. Description of different driers

Four different driers were used as treatment in this research work.

D_1- Gas burner

D_2- White polypropylene covered tunnel

D_3- Open sun drier

D_4- Indirect drier

Among them the gas burner was installed in the laboratory and other three driers- white polypropylene covered tunnel, indirect drier and open sun drier were installed at the yard of the centre.

a) **Gas burner:** The gas burner was an iron made frame which is rectangular in shape. At the lower portion of the burner, a round iron pipe having several small holes is adjusted through which gas is blown (Fig. 1). Over the gas pipe there was a steel sheet which becomes heated when the burner starts burning. Three iron net trays were placed over the steel sheet according to the frame one after another by maintaining some distance. The collected fresh mushrooms were cut, spited and spread over the trays **(**Fig. 2**)**. Each of the trays contained the same amount of mushroom. As the gas burner produces the maximum amount of heat so it requires minimum duration of time and it’s about three hours to dried the mushroom.

Fig. 1. Iron made gas burner.

Fig. 2. Fresh mushrooms were dried on gas burner

b) **White polypropylene covered tunnel:** The frame of the tunnel was made of bamboo slices and covered with white polypropylene. The tunnel was about 7 ft long, 5 ft width and 3 ft high. Two opening portion was covered with white mosquito net. Black cloth was used as a base material in the tunnel **(**Fig. 3**)**. Fresh collected mushroom's were cut, spited and spread over the base material in three replications **(**Fig. 4**)**. As it depends on the sun light, it was used for three days to complete the drying process.

Fig. 3. White polypropylene covered tunnel drier

Fig. 4. Fresh mushrooms were dried inside the drier

c) **Open sundry:** It is the most traditional method. Steel trays were used in open sunlight (Oei, 2005). The trays were placed at the yard of NAMDEC. Freshly collected mushroom's were cut, spited and spread over the tray. As the drying process fully depends on the sun light, it required three days to complete the process.

d) **Indirect drier:** The drier was made of iron and tin. The structure was about 6 ft high and 3.5 ft width. Four stands of the drier were made of iron and the drying panel was covered with tin with a ventilation system at the top (Fig. 5). Inside of the panel three steel net trays were placed where freshly collected mushrooms were cut, spited and spread over (Fig. 6). Another iron rod made frame was adjusted at lower part of the panel. Inside of the frame a black cloth was added and the whole frame was covered with transparent polyethylene paper leaving both upper and lower opening end. The opening end of the frame was adjusted at the lower part of the panel (Oei, 2005). The black cloth absorbed the sun light, produced heat and blown it to the panel and thus increase the temperature inside the panel. As this drying process depends on the sun light, mushrooms were dried here for three days to complete the drying.

Fig. 5. Indirect drier

Fig. 6. Fresh mushrooms were dried inside the panel

3.4. Description of used materials

Total 2400 g for each of oyster, shiitake and milky mushrooms were used in four drying methods as well as in four treatments. For every drying process 600 g of each of the mushroom species were used at a time in three replications. Each of the replication contained 200 g of mushrooms. The procedures were closed when the mushrooms become crispy, light in weight and fade in colour. The mushroom was weighted for several times –firstly, at fresh condition, after every two hours of drying and finally at dried condition. Digital balance (low profile weighing scale, Kerndy) was used at the laboratory of NAMDEC for weighing mushrooms. The moisture percentage (%) was taken for two times- at fresh condition and at dried condition. The moisture percentage (%) was collected by using moisture analyzer (A&D company Ltd N92: P1011656, Japan) at the laboratory of NAMDEC.

3.5. Data recording

Data were recorded on the following parameters of mushrooms during the experiment. The details of data recording are given below on individual mushroom species basis.

3.5.1. Oyster mushroom

3.5.1.1. Gas Burner drier

Three trays were used in the burner and each of the trays contained 200 g of oyster mushroom. The drying operation started at 10:30 am and closed at 1:00 pm, 15 March 2011. The total drying time was 2.5 hours. The temperature and relative humidity (RH) inside the dryer were noted down for every half one hour.

3.5.1.2. White polypropylene covered tunnel drier

Three replications were used in the white polypropylene covered tunnel and each of the replication contained 200 g of oyster mushroom. The drying operation started at 10:30 am, 15 March and closed at 1:30 pm, 17 March 2011. At first and second day, drying was done from 10:30 am to 3:00 pm. At last day, it was done from 10:30 am to 1:30 pm. The total drying time was 12 hours. The temperature and relative humidity (RH) inside the dryer were noted down for every one hour.

3.5.1.3. Open sundry

Three trays were used in the open sun light and each of the tray contained 200 g of oyster mushroom. The drying operation started at 10:30 am, 15 March and closed at 2:30 pm, 17 March 2011. At first and second day, drying was done from 10:30 am to 3:30 pm. At last day, it was done from 10:30 am to 2:30 pm. The total drying time was 14 hours. The temperature and relative humidity (RH) inside the dryer were noted down for every one hour.

3.5.1.4. Indirect drier

In the indirect drier panel each of the three replications contained 200 g of oyster mushroom. The drying operation started at 10:30 am, 15 March and closed at 2:30 pm, 17 March 2011. At first and second day, drying was done from 10:30 am to 3:00 pm. At last day, it was done from 10:30 am to 2:30 pm. The total drying time was 13 hours. The temperature and relative humidity (RH) inside the dryer were noted down for every one hour.

3.5.2. Shiitake mushroom

3.5.2.1. Gas Burner drier

Three trays were used in the burner and each of the trays contained 200 g of shiitake mushroom. The drying operation started at 10:30 am and closed at 1:30 pm, 15 January 2011. The total drying time was 3 hours. The temperature and relative humidity (RH) inside the dryer were noted down for every half one hour.

3.5.2.2. White polypropylene covered tunnel drier

Three replications were used in the white pp covered tunnel and each of the replication contained 200 g of shiitake mushroom. The drying operation started at 10:30 am, 15 January and closed at 2:30 pm, 17 January 2011. At first and second day, drying was done from 10:30 am to 3:00 pm. At last day, it was done from 10:30 am to 2:30 pm. The total drying time was 13 hours. The temperature and relative humidity (RH) inside the dryer were noted down for every one hour.

3.5.2.3. Open sundry

Three trays were used in the open sun light and each of the tray contained 200 g of shiitake mushroom. The drying operation started at 10:30 am, 15 January and closed at 2:30 pm, 17 January 2011. At first and second day, drying was done from 10:30 am to 3:30 pm. At last day, it was done from 10:30 am to 2:30 pm. The total drying time was 14 hours. The temperature and relative humidity (RH) inside the dryer were noted down for every one hour.

3.5.2.4. Indirect drier

In the indirect drier panel each of the three replications contained 200 g of shiitake mushroom. The drying operation started at 10:30 am, 15 January and closed at 2:30 pm, 17 January 2011. At first and second day, drying was done from 10:30 am to 3:00 pm. At last day, it was done from 10:30 am to 2:30 pm. The total drying time was 13 hours. The temperature and relative humidity (RH) inside the dryer were noted down for every one hour.

3.5.3. White milky mushroom

3.5.3.1. Gas Burner drier

Three trays were used in the burner and each of the trays contained 200 g of milky mushroom (white). The drying operation started at 10:00 am and closed at 1:00 pm, 15 June 2010. The total drying time was 3 hours. The temperature and relative humidity (RH) inside the dryer were noted down for every half one hour.

3.5.3.2. White polypropylene covered tunnel drier

Three replications were used in the white pp covered tunnel and each of the replication contained 200 g of milky mushroom (white). The drying operation started at 10:00 am, 15 June and closed at 12:30 pm, 17 June 2010. At first and second day, drying was done from 10:00 am to 3:00 pm. At last day, it was done from 10:30 am to 12:30 pm. The total drying time was 12 hours. The temperature and relative humidity (RH) inside the dryer were noted down for every one hour.

3.5.3.3. Open sundry

Three trays were used in the open sun light and each of the tray contained 200 g of milky mushroom (white). The drying operation started at 10:00 am, 15 June and closed at 2:30 pm, 17 June 2010. At first and second day, drying was done from 10:00 am to 3:00 pm. At last day, it was done from 10:30 am to 2:30 pm. The total drying time was 14 hours. The temperature and relative humidity (RH) inside the dryer were noted down for every one hour.

3.5.3.4. Indirect drier

In the indirect drier panel each of the three replications contained 200 g of milky mushroom (white). The drying operation started at 10:00 am, 15 June and closed at 1:30 pm, 17 June 2010. At first and second day, drying was done from 10:00 am to 3:00 pm. At last day, it was done from 10:30 am to 1:30 pm. The total drying time was 13 hours. The temperature and relative humidity (RH) inside the dryer were noted down for every one hour.

3.6. Colour analysis

3.6.1. Oyster mushroom

After the completion of drying process for every treatment, five samples from each of the replication were taken randomly. The colour of upper part of pileus, lower part of pileus and stipe of the selected samples were visibly checked with the colour chart **(**Fig. 9**)**. Several colours were found like peru (brown), moccasin (light brown), wheat colour, tan (dark gray), corn silk (light yellow) etc.

3.6.2. Shiitake mushroom

The dried shiitake mushroom samples were taken randomly from the replications. The colour of upper part of pileus, lower part of pileus and stipe of the selected samples were visibly checked with the colour chart **(**Fig. 9**)**. Several colours were found like peru (brown), moccasin (light brown), wheat colour, tan (dark gray), corn silk (light yellow), saddle brown (deep brown).

3.6.3. White Milky mushroom

The colour of upper part of pileus, lower part of pileus and stipe of the randomly selected sample of white milky mushroom were visibly checked with the colour chart **(**Fig. 9**)** and the following colours were found: moccasin (light brown), wheat colour, corn silk (light yellow).

Statistical Analysis

Data were statistically analyzed following the CRD with MSTAT-C computer programme. Means were computed following Duncun’s Multiple Range Test (DMRT) using the same computer programme.

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was carried out to investigate the performance of different drier and their effect on the quality including colour and hygienist of oyster mushroom (*Pleurotus ostreatus*), shiitake mushroom (*Lentinula edodes*) and white milky mushroom (*Calocybe indica*).The results obtained from the study have been described and discussed in this section.

4.1. Total drying time

4.1.1. Oyster mushroom

Drying time of oyster mushroom for different drying methods ranged from 2.5 to 14 hours. Total drying time for oyster mushroom was significant under 4 treatments (Table 1). The gas burner required the least of time (2.5 hrs) and the maximum time (14 hrs) was required for open sundry method.

4.1.2. Shiitake mushroom

Drying time of shiitake mushroom for different drying methods ranged from 3 to 14 hours. Total drying time for shiitake mushroom was significant under 4 treatments (Table 1). The gas burner required the shortest period of time (3 hrs) and the maximum drying time (14 hrs) was required under open sundry method.

4.1.3. White milky mushroom

Drying time of white milky mushroom for different drying methods ranged from 3 to 14 hours. Total drying time for milky mushroom was significant under 4 treatments (Table 1). The gas burner required the least of time (3 hrs) and the maximum time of drying (14 hrs) was required for open sundry method which was similar (13 hrs) to indirect drier.

Table 1. Influence by drying methods on drying time (hr) of oyster, shiitake and white milky mushroom

Treatment	Drying time (hr)		
	Oyster	Shiitake	Milky
Gas burner	2.50b	3.00b	3.00c
White pp covered tunnel	12.00a	13.00a	12.00b
Open sundry	14.00a	14.00a	14.00a
Indirect drier	13.00a	13.00a	13.00ab
LSD (5%)	2.318	1.648	1.698
CV (%)	11.87	8.14	8.58

Means with in the column and rows, under a parameter, having a common letter do not differ significantly **(P=0.05).**

Increasing the moisture absorption resulted in a considerable decrease in drying time (Soysal, 2004). The treatment of gas burner took the minimum time to dry as it produces higher amount of heat. Heat that produced within a short time may not absorb the moisture from the mushrooms uniformly and might be responsible for darkening. Oei (2005) suggested that the mushrooms could become toasted at high temperatures, longer drying at low temperature is safer than faster drying at high temperature. It was found that the heat inside the white pp covered tunnel and inside the panel were higher than the ambient temperature during the day light (Bukola *et al.*, 20011). The tunnel and the panel retained the heat for a long constant which may absorb moisture uniformly. Heat is generated by absorption of solar radiation on the product itself as well as on the internal surface of the drying chamber (Jayaraman and Dasgupta, 1990).

4.2. Weight (g) per two hours of drying

4.2.1. Weight at 1st two hours of drying

4.2.1.1. Oyster mushroom

The weight of mushroom under different drying methods was taken at every two hours of drying. At 1st two hours of drying the weight of oyster mushroom ranged from 61.07 to 175.53 g. The weight was significant under 4 treatments (Table 2). The treatment of gas burner reduced the moisture and got the weight of 61.07 g. Under the treatment of open sundry, the weight of mushroom became 175.53 g which was statistically similar (173.13g) to indirect drier.

4.2.1.2. Shiitake mushroom

Weight of shiitake mushroom under different drying methods was taken at every two hours of drying. At 1st two hours of drying the weight of shiitake mushroom ranged from 85.12 to 175.57 g. The weight was significant under 4 treatments (Table 2). The treatment of gas burner reduced the moisture and gets the weight of 85.12 g. Under the treatment of open sundry, the weight of mushroom became 175.57 g which was statistically similar to white pp covered tunnel (173.28g) and indirect drier (173.33g).

4.2.1.3. White milky mushroom

The weight of milky white mushroom under different drying methods was taken at every two hours of drying. At 1st two hours of drying the weight of milky mushroom ranged from 85.55 to 175.48 g. The weight was significant under 4 treatments (Table 2). The treatment of gas burner reduced the moisture and gets the weight of 85.55 g. Under the treatment of open sundry, the weight of mushroom became 175.48 g which was statistically similar to white pp covered tunnel (171.11g) and indirect drier (173.64g).

Table 2. Influence by drying methods on weight (g) at 1st two hours of drying

Treatment	Wt. of mushroom species (g)		
	Oyster	Shiitake	Milky
Gas burner	61.07c	85.12b	85.55b
White pp covered tunnel	170.89b	173.28a	171.11a
Open sundry	175.53a	175.57a	175.48a
Indirect drier	173.13ab	173.33a	173.64a
LSD (5%)	3.631	5.162	4.448
CV (%)	1.33	1.81	1.56

Means with in the column and rows, under a parameter, having a common letter do not differ significantly **(P=0.05).**

This study showed the efficiency of different drying methods. At 1st two hours of drying, weight of mushroom differed under different treatments that might be due to the presence of different amount of heat. The situation may accelerate the dehydration of the product (Wang *et al.,* 2007). Higher amount of heat of gas burner might be responsible for excess burning, ununiform drying and low colour quality. Open sundry treatment produced lower amount of heat which might be responsible for improper drying of mushroom. Comparatively uniform dried mushrooms were obtained from the treatments of white pp covered tunnel and indirect panel dryer might be due to the presence of comparatively higher amount of continuous heat. Bukola (2011) supported the results that drying with white pp covered tunnel and indirect dryer shows the better result than open sun drying.

4.2.2. Weight at 2nd two hours of drying

4.2.2.1. Oyster mushroom

At 2nd two hours of drying the weight of oyster mushroom ranged from 141.78 to 151.06 g. The weight was significant under 4 treatments (Table

3). Under the treatment of white pp covered tunnel mushroom got the minimum weight of 141.78 g. In open sundry treatment the maximum weight of mushroom 151.06 g.

4.2.2.2. Shiitake mushroom

At 2nd two hours of drying the weight of shiitake mushroom ranged from 146.56 to 151.14 g. The weight was significant under 4 treatments (Table 3). The treatment of white pp covered tunnel reduced the moisture and got the minimum weight of 146.56 g which was statistically similar to indirect drier (146.66g). Under the treatment of open sundry, the weight of mushroom became maximum 151.14 g.

4.2.2.3. White milky mushroom

At 2nd two hours of drying the weight of milky mushroom ranged from 142.22 to 150.96 g. The weight was significant under 4 treatments (Table 3). Under the treatment of white pp covered tunnel, mushroom weight was 142.22 g. In open sundry treatment the weight of milky mushroom became 150.96 g.

Table 3. Influence by drying methods on weight (g) at 2nd two hours of drying

Treatment	Wt. of mushroom species (g)		
	Oyster	Shiitake	Milky
Gas burner	-	-	-
White pp covered tunnel	141.78c	146.56b	142.22b
Open sundry	151.06a	151.14a	150.96a
Indirect drier	146.26b	146.66b	147.28ab
LSD (5%)	4.322	3.250	5.081
CV (%)	1.48	1.10	1.73

Means with in the column and rows, under a parameter, having a common letter do not differ significantly **(P=0.05).**

Weight of mushroom differed under different treatments at 2nd two hours of drying. The study showed that the weight of mushroom become comparatively lower under white pp covered tunnel drier than indirect drier and open sundry treatment. The high amount of relative humidity under open sundry might be responsible for producing low amount of heat. At 2nd two hours of drying, white pp covered tunnel drier got the minimum weight of mushroom might be due to the presence of continuous heat as suggested by Bala (2009).

4.2.3. Weight at 3rd two hours of drying

4.2.3.1. Oyster mushroom

At 3rd two hours of drying the weight of oyster mushroom ranged from 112.67 to 126.59 g. The reduced weight was significant under 4 treatments (Table 4). Under the treatment of white pp covered tunnel, mushroom weight was 112.67 g. In open sundry treatment, the weight of mushroom became 126.59 g

4.2.3.2. Shiitake mushroom

At 3rd two hours of drying the weight of shiitake mushroom ranged from 119.84 to 126.71 g. The weight was significant under 4 treatments (Table 4). Under the treatment of white pp covered tunnel, mushroom weight was 119.84 g. In open sundry treatment, the weight of mushroom became 126.71 g.

4.2.3.3. White milky mushroom

At 3rd two hours of drying the weight of milky mushroom ranged from 113.35 to 126.44 g. The weight was significant under 4 treatments (Table 4). Under the treatment of white pp covered tunnel, mushroom weight was 113.35 g. In open sundry treatment, the weight of mushroom became 126.44 g.

Table 4. Influence by drying methods on weight (g) at 3rd two hours of drying

Treatment	Wt. of mushroom species (g)		
	Oyster	Shiitake	Milky
Gas burner	-	-	-
White pp covered tunnel	112.67c	119.84b	113.35c
Open sundry	126.59a	126.71a	126.44a
Indirect dryer	119.39b	119.99b	120.92b
LSD (5%)	2.934	3.903	2.892
CV (%)	1.23	1.60	1.20

Means with in the column and rows, under a parameter, having a common letter do not differ significantly **(P=0.05).**

At 3rd two hours of drying the weight of mushroom was significantly reduced under white pp covered tunnel drier than indirect and open sundry treatment. The significance might be due to the increasing heat produced inside the tunnel. The indirect drier also gave significant reduction in weight of mushroom than open sundry treatment. According to Oei (2005) the enclosed panel of indirect drier might be responsible for increasing heat and reducing relative humidity inside the panel. It was found that the white pp covered tunnel and indirect drier may show statistically similar result in shiitake mushroom at 3rd two hours of drying.

4.2.4. Weight at 4th two hours of drying

4.2.4.1. Oyster mushroom

At 4th two hours of drying the weight of oyster mushroom ranged from 83.56 to 102.12 g. The weight was significant under 4 treatments (Table 5). Under the treatment of white pp covered tunnel, weight of mushroom was 83.56 g. In open sundry treatment the weight of mushroom became 102.12 g.

4.2.4.2. Shiitake mushroom

At 4th two hours of drying the weight of shiitake mushroom ranged from 93.12 to 102.28 g. The weight was significant under 4 treatments (Table 5). Under the treatment of white pp covered tunnel, the weight of mushroom was 93.12 g. In open sundry treatment the weight of mushroom became 102.28 g.

4.2.4.3. White milky mushroom

The weight of milky mushroom was taken at 4th two hours of drying. The weight of milky mushroom ranged from 84.44 to 101.92 g. The weight was significant under 4 treatments (Table 5). Under the treatment of white pp covered tunnel, the weight of mushroom was 84.44 g. In open sundry treatment the weight of mushroom became 101.92 g.

Table 5. Influence by drying methods on weight (g) at 4th two hours of drying

Treatment	Wt. of mushroom species (g)		
	Oyster	Shiitake	Milky
Gas burner	-	-	-
hite pp covered tunnel	83.56c	93.12b	84.44c
Open sundry	102.12a	102.28a	101.92a
Indirect dryer	92.52b	93.32b	94.56b
LSD (5%)	2.619	2.765	2.883
CV (%)	1.41	1.44	1.54

Means with in the column and rows, under a parameter, having a common letter do not differ significantly **(P=0.05).**

The oyster and milky mushroom showed significant reduction in weight under white pp covered tunnel and indirect drier. For shiitake mushroom the weight might be statistically similar under white pp covered tunnel and indirect drier. The low heat under open sun dry treatment might be responsible for improper drying of mushroom at 4th two hours of drying.

4.2.5. Weight at 5th two hours of drying

4.2.5.1. Oyster mushroom

At 5th two hours of drying the weight of oyster mushroom ranged from 54.45 to 77.65 g. The weight was significant under 4 treatments (Table 6). Under the treatment of white pp covered tunnel, the weight of mushroom was 54.45 g. In open sundry treatment the weight became 77.65 g.

4.2.5.2. Shiitake mushroom

At 5th two hours the weight of shiitake mushroom ranged from 66.40 to 77.85 g. The weight was significant under 4 treatments (Table 6). Under the treatment of white pp covered tunnel, the weight of mushroom was 66.40 g. In open sundry treatment retain the weight became 77.85 g.

4.2.5.3. White milky mushroom

The weight of milky mushroom was taken at 5th two hours of drying. At 5th two hours of drying the weight of milky mushroom ranged from 55.55 to 77.40 g. The weight was significant under 4 treatments (Table 6). Under the treatment of white pp covered tunnel, the weight of mushroom was 55.55 g. In open sundry treatment the weight became 77.40 g.

Table 6. Influence by drying methods on weight (g) at 5th two hours of drying

Treatment	Wt. of mushroom species (g)		
	Oyster	Shiitake	Milky
Gas burner	-	-	-
White pp covered tunnel	54.45c	66.40b	55.55c
Open sundry	77.65a	77.85a	77.40a
Indirect dryer	65.65b	66.65b	68.20b
LSD (5%)	2.452	3.011	1.550
CV (%)	1.86	2.14	1.16

Means with in the column and rows, under a parameter, having a common letter do not differ significantly **(P=0.05).**

Weight of mushroom differed under different treatments at 5th two hours of drying. The study showed that the weight of mushroom become comparatively lower under white pp covered tunnel drier than indirect drier and open sundry treatment. The high amount of relative humidity under open sundry might be responsible for producing low amount of heat. Bala (2009) suggested that white pp covered tunnel drier got the minimum weight of mushroom might be due to the presence of continuous heat.

4.2.6. Weight at 6th two hours of drying

4.2.6.1. Oyster mushroom

At 6th two hours of drying the weight of oyster mushroom ranged from 25.33 to 53.18 g. The weight was not significant under 4 treatments (Table 7). Under the treatment of white pp covered tunnel, the weight of mushroom was 25.33 g. In open sundry the weight of mushroom became 53.18 g.

4.2.6.2. Shiitake mushroom

At 6th two hours of drying the weight of shiitake mushroom ranged from 39.68 to 53.42 g. The weight was significant under different treatments (Table 7). Under the treatment of white pp covered tunnel, the weight of mushroom was 39.68 g. In open sundry the weight of mushroom became 53.42 g.

4.2.6.3. White milky mushroom

The weight of milky mushroom was taken at 6th two hours of drying. At 6th two hours, the weight of milky mushroom ranged from 26.66 to 52.88 g. The weight was significant under 4 treatments (Table 7). Under the treatment of white pp covered tunnel, the weight of mushroom was 26.66 g. In open sundry treatment the weight of mushroom became 52.88g.

Table 7. Influence by drying methods on weight (g) at 6th two hours of drying

Treatment	Wt. of mushroom species (g)		
	Oyster	Shiitake	Milky
Gas burner	-	-	-
White pp covered tunnel	25.33a	39.68b	26.66c
Open sundry	53.18a	53.42a	52.88a
Indirect dryer	38.78a	39.98b	41.84b
LSD (5%)	31.90	1.050	0.4934
CV (%)	1.29	1.19	0.61

Means with in the column and rows, under a parameter, having a common letter do not differ significantly **(P=0.05).**

At 6th two hours of drying, the minimum weight of oyster mushroom was found under the treatment of white pp covered tunnel. It might be required more time to dry under indirect drier and open sundry method. The weight of milky mushroom differed significantly under different driers and the minimum weight might be obtained from white pp covered tunnel. For shiitake mushroom the weight was statistically similar under white pp covered tunnel and indirect drier.

4.3. Dry weight (g) of mushroom

4.3.1. Oyster mushroom

Dry weight of oyster mushroom under different driers ranged from 25.33 g to 28.67 g. Dry weight of oyster mushroom was significant under 4 treatments (Table 8). The minimum dry weight (25.33 g) was found in the treatments of white polypropylene covered tunnel and indirect drier. The maximum dry weight (28.67 g) was found under the treatment of open sun light.

4.3.2. Shiitake mushroom

Dry weight of shiitake mushroom that found under different driers ranged from 26.33 g to 29.00 g. Dry weight of shiitake mushroom was not significant under 4 treatments (Table 8). The minimum dry weight (26.33 g) was found under the treatment of white polypropylene covered tunnel. The maximum dry weight (29.00 g) was found in the treatment of open sun light.

4.3.3. White Milky mushroom

Dry weight of milky mushroom under different driers ranged from 26.67 g to 28.67 g. Dry weight of white milky mushroom was not significant under 4 treatments (Table 8). The minimum dry weight (26.67 g) was found in the treatment of white polypropylene covered tunnel and the maximum dry weight (28.67 g) was found under the treatment of indirect drier.

Table 8. Influence by drying methods on the dry weight (g) of oyster, shiitake and milky white mushroom

Treatment	Dry weight (g)		
	Oyster	Shiitake	Milky
Gas burner	26.33ab	27.67a	28.33a
White pp covered tunnel	25.33b	26.33a	26.67a
Open sundry	28.67a	29.00a	28.33a
Indirect dryer	25.33b	26.66a	28.67a
LSD (5%)	2.876	3.122	3.306
CV (%)	5.78	6.07	6.27

Means with in the column and rows, under a parameter, having a common letter do not differ significantly **(P=0.05).**

In this study, treatment of white polypropylene covered tunnel and indirect dryer was the best because by these treatments dry weight of oyster, shiitake and white milky mushroom became lower. In white polypropylene covered tunnel and indirect dryer, the sun light was absorbed, fixed and increased the heat inside. The increasing heat vaporized the moisture as well as dry weight of mushroom (Oei, 2005). Study also showed that the comparatively poor result was come from the treatment of open sundry might be due to the low heat at open place.

4.4. Final moisture (%) of mushroom

4.4.1.Oyster mushroom

Final moisture (%) of oyster mushroom under different driers ranged from 7.01% to 8.26%. Final moisture (%) of oyster mushroom was not significant under 4 treatments (Table9). The minimum moisture (7.01%) was found in treatments of white polypropylene covered tunnel and the maximum moisture (8.26%) was found under the treatment of open sun light.

4.4.2. Shiitake mushroom

The moisture (%) of shiitake mushroom under 4 driers ranged from 7.01% to 7.88%. Final moisture (%) of shiitake mushroom was not significant under 4 treatments (Table 9). The minimum moisture (7.01%) was found under the treatment of indirect dryer and the maximum moisture (7.88%) was found under treatments of open sun light.

4.4.3. White Milky mushroom

The moisture (%) of milky mushroom under 4 driers ranged from 7.14% to 7.55%. Final moisture (%) of milky mushroom was not significant under 4 treatments (Table 9). The minimum moisture (7.14%) was found the treatment of white polypropylene covered tunnel and the maximum moisture (7.55%) was found under the treatment of open sun light and treatment of indirect dryer.

Table 9. Influence by drying methods on the final moisture (%) of oyster, shiitake and white milky mushroom

Treatment	Final moisture (%)		
	Oyster	Shiitake	Milky
Gas burner	7.77a	7.68a	7.21a
White pp covered tunnel	7.01a	7.79a	7.14a
Open sundry	8.26a	7.88a	7.55a
Indirect dryer	7.68a	7.01a	7.55a
LSD (5%)	2.636	2.612	2.139
CV (%)	18.22	18.28	15.43

Means with in the column and rows, under a parameter, having a common letter do not differ significantly **(P=0.05).**

The study showed that the treatment of white polypropylene covered tunnel and indirect dryer was the best because under these treatment maximum amount of moisture was reduced. Temperature and relative humidity (RH) are inversely related (Bala, *et al.* 2009) When temperature increases, relative humidity (%) decreases. Under the treatment of white pp covered tunnel and indirect dryer the decreasing RH may causes absorption of moisture from the mushrooms. Mushroom losses lower amount of moisture under open sundry may be due to the presence of higher relative humidity. The moisture content of sun dried mushroom is higher and therefore they can be kept for a shorter period of time than the artificially dried ones (Oei, 2005).

4.5. Colour of dried mushroom

The colour of dried mushroom was checked with the colour chart to define the quality colour of upper part and lower part of pileus and stipe (stalk) of the mushroom.

4.5.1. Oyster mushroom

Different types of colour were found under 4 dryers like peru (deep brown), tan (gray), moccasin (light brown), wheat colour, corn silk (light yellow) etc. Among 4 treatments 3 showed the same colour. For three treatments the upper part of pileus colour was tan, lower part of pileus colour was moccasin and stipe colour was wheat (Table 10).

Table 10. Influence by drying methods on the colour of oyster mushroom

Treatment	Upper part of pileus	Lower part of pileus	Stipe
Gas burner	Peru	Moccasin	Wheat
White pp covered tunnel	Tan	Corn silk	Corn silk/ Wheat
Open sundry	Tan	Moccasin	Wheat
Indirect drier	Tan	Moccasin	Wheat

Peru is visibly like deep brown
Tan is visibly like gray
Moccasin is visibly like light brown.
Corn silk is visibly like light yellow
Wheat is visibly like wheat colour

This study showed that the treatment of white pp covered tunnel drier was the best (upper part of pileus - gray, lower part of pileus - light brown and stipe –wheat) for oyster mushroom. According to Oei (2005) mushroom do not need to be crisp to the touch after drying; they should still be slightly flexible. Generally fresh oyster mushroom is grayish white in colour and dried mushroom shows lighter colour (Kulsheshtha *et al.,* 2009). The quality of sun dried mushrooms is generally less than that of artificially dried ones (Oei, 2005) contain higher nutrition than dark coloured dried mushroom. The dark colour indicates excess burning which reduces the food value. So the lower result (deep brown) came from the treatment of gas burner.

4.5.2. Shiitake mushroom

For shiitake mushroom different types of colour were found under 4 driers like saddle brown (dark brown), peru (deep brown), tan (gray), moccasin (light brown), wheat (wheat colour), corn silk (light yellow) etc. 2 treatments showed the same colour. For the treatment of open sundry and indirect dryer the upper part of pileus colour was saddle brown, lower part of pileus was moccasin and stipe colour was tan (Table 11).

Table 11. Influence by drying methods on the colour of shiitake mushroom

Treatment	Upper part of pileus	Lower part of pileus	Stipe
Gas burner	Tan	Moccasin	Peru
White pp covered tunnel	Saddle brown	Corn silk	Wheat
Open sundry	Saddle brown	Moccasin	Tan
Indirect drier	Saddle brown	Moccasin	Tan

Peru is visibly like deep brown	Corn silk is visibly like light yellow
Tan is visibly like gray	Wheat is visibly like wheat colour
Moccasin is visibly like light brown	Saddle brown is visibly like dark brown.

This study showed that the method of open sundry and indirect dryer were the best (upper part of pileus - dark brown, lower part of pileus - light brown and stipe –gray) for shiitake mushroom. Generally fresh shiitake mushroom is brown in colour (Kulsheshtha *et al*., 2009), so it might be deep or dark brown after drying.

4.5.3. White Milky mushroom

For milky mushroom different types of colour were found under 4 driers like moccasin (light brown), wheat (wheat colour), corn silk (light yellow) etc. 3 treatments showed the same colour. For the treatment of white pp covered tunnel, open sundry and indirect dryer the upper part of pileus, lower part of pileus and stipe were wheat, corn silk and wheat in colour respectively (Table 12).

Table 12. Influence by drying methods on the colour of white milky mushroom

Treatment	Upper part of pileus	Lower part of pileus	Stipe
Gas burner	Moccasin	Wheat	Burly wood
White pp covered tunnel	Wheat	Corn silk	Wheat
Open sundry	Wheat	Corn silk	Wheat
Indirect drier	Wheat	Corn silk	Wheat

Corn silk is visibly like light yellow
Wheat is visibly like wheat colour
Moccasin is visibly like light brown.
Burly wood is visibly like burly colour

This study showed that the treatment of white pp covered tunnel, open sundry and indirect dryer were showing the same result (upper part of pileus and stipe –wheat colour, lower part of pileus - light yellow) for milky white mushroom . Generally fresh milky mushroom is milky white in colour and dried mushroom become lighter (Kulsheshtha *et al*., 2009) after drying.

CHAPTER V

SAMMARY AND CONCLUSION

The experiment was carried out at National Mushroom Development and Extension Centre (NAMDEC), Savar, Dhaka during the period of April 2010 to March 2011 with different mushroom to standardize the best performance of different dryers and obtaining the quality product.

The experiment consists of three mushroom species, viz. Oyster (*Pleurotus ostreatus*), Shiitake (*Lentinula edodes***)** and White Milky (*Calocybe indica*) mushroom and four different dryers, viz. Gas burner, White polypropylene covered tunnel, Open sundry and Indirect dryer. The experiment was laid out in Completely Randomized Design (CRD) with three replications. Data were collected on total drying time, moisture evaporation rate, dry weight with final moisture (%) and the colour of dried mushroom for every dryer. Data were collected from randomly selected five samples for colour evaluation from each of the replications. The collected data were analyzed by computer following MSTATC programme and the means were separated by DMRT.

It was observed from the results that white polypropylene covered tunnel and indirect dryer showed the best performance in terms of reducing maximum moisture and getting the minimum dry weight with quality, whereas gas burner was responsible for excess burning and open sundry for improper drying and unhygienic condition. The standard drying time for oyster mushroom is 12 hrs, for shiitake mushroom is 13 hrs and for white milky mushroom is 12 hrs was found under white polypropylene covered tunnel. For oyster mushroom the minimum dry weight 25.33 g, for shiitake mushroom, the minimum dry weight 26.33 g, for white milky mushroom, the minimum dry weight 26.67 g was found under white polypropylene covered tunnel. The minimum final moisture for oyster 7.01%, shiitake 7.01% and white milky mushroom 7.14% was found under white polypropylene covered tunnel, indirect dryer and white polypropylene covered tunnel, respectively.

The colour evaluation also showed that for oyster mushroom the best colour (upper part of pileus gray, lower part of pileus light yellow and stipe light yellow /wheat) was found under white polypropylene covered tunnel. For shiitake mushroom, the best colour (upper part of pileus dark brown, lower part of pileus light brown and stipe gray) was found under open sundry and indirect dryer. For white milky mushroom, the best colour (upper part of pileus and stipe wheat colour, lower part of pileus light yellow) was found under white polypropylene covered tunnel, open sundry and indirect dryer.

Conclusion

i) The colour evaluation showed that the white polypropylene covered tunnel dryer to be recommendable for Oyster, Shiitake and Milky mushroom drying.

ii) The Indirect dryer may also be used for drying of mushrooms.

iii) As gas burner produces excess heat and causes burning of mushroom and open sundry is unhygienic and cannot produce optimum heat for drying, so these are not to be recommended.

iv) Further studies are needed to find out other easy and cheap drying methods and their efficiency of drying, nutritional value of dried mushrooms and quality control techniques to reduce the post harvest losses and preserving mushroom for a long way.

REFERENCES

Adaramola, M. S., Amaduobogha, J., Allen, K. O. and Siyanbola, W. O. 2004. Design, construction and testing of box type solar oven. *Nigeria J. Eng. Management*, **5**(1): 38-46.

Ajao, K. R. and Adegun, I. K. 2009. Performance evaluation of a locally fabricated flash dryer. *J. Agri. Tech*, **5**(3): 281-289.

Arumuganathan, T., Manikantan, M. R., Rai, R.D., Anandakumar, S. and Khare, V. 2008. Mathematical modeling of drying kinetics of milky mushroom in a fluidized bed dryer. *J. Int. Agrophysics,* **23**(1): 1-7.

Bala B. K., Morshed, M. A. and Rahman, M. F. 2009. Solar drying of mushroom using Solar tunnel dryer. *Int. J. Sustainable Energy,* **3**(2):143-158.

Bilbao-Sainz, C., Andres, A., Chiralt, A. and Fito, P. 2001. Microwaves phenomena during drying of apple cylinders. *J. Food Eng*, **1**(7): 25-35.

Bolaji, B. O. 2005. Performance evaluation of a box-type absorber solar air collector for crop drying. *J. Food Tech*, **3** (1): 595-600.

Bukola, O., Bolaji, B. O., Tajudeen, M. A. and Taiwo, O. 2011. Performance evaluation of a solar wind ventilated cabinet dryer. *The West Indian J. Eng*, **33**(1): 12- 18.

Combs, B. 2004. Mushroom Drying and the Benefit to Industry. *J. Materials Processing Tech*, **1** (1): 16-22.

Deshpande, A. G. and Tamhane, D. V. 1981. Studies on dehydration of mushroom. *J. Food Sci. and Tech*, **18** (3): 96-106.

Ertekin, C and Yaldiz, O. 2004. Drying of eggplant and selection of a suitable thin layer drying model. *J. Food Eng*, **63** (1): 349-359.

Giri, S. K. and Prasad, S. 2007. Drying kinetics and rehydration characteristics of microwave vaccum and convective hot air dried mushrooms. *J. Food Eng*, **78**(5): 512-521.

Hansson, L. and Antti, A. L. 2005. The effect of drying method and temperature level on the hardness of wood. *J. Materials Processing*

Tech, **1**(1): 13-18.

Hossain, M. Y. and Islam-ud-Din, A. M. 2008, Dehydration of agricultural Products by mixed mode solar dehydrator. *Int.J. Agri. & Biology*, **10**(2): 333-336.

Itodo, I. N., Obetta, S. E. and Satimehin, A. A. 2002. Evaluation of a solar crop dryer for rural application in Nigeria. *Botswana J. Tech*, **11**(3): 58-62.

Jadhav, H. T. and Chandiwade, U. N. 2008. Effect of pretreatment, drying temperature and intermittent drying technique on cooking quality of oyster mushroom. *J. Food Sci. and Tech*, **3**(1&2): 23-26.

Jayaraman, K. S. and Das Gupta, D. K. 1990. Drying of fruits and vegetables. *Int. J. Food Sci. Tech*, **3**(1): 25-47.

Kamal, A. S., Abul, K., Syed, F. U., Nur zaman, A. and Fauzia, B. 2009. Mechanical Detection of Minerals, Heavy Metals and Trace Elements in Processed Mushroom in Relation to Toxicological Aspects. *Bangladesh J. Mushroom.* **3**(1): 53-65.

Kan, A. and Gupta, D. K. 2001. Osmotic dehydration characteristics of buttlon Mushroom. *J. Food Sci. and Tech*, **38** (4): 352-357.

Karim, M. A. and Hawlader, M. N. A. 2006. Performance evaluation of a v-groove solar air collector for drying applications. *Applied Thermal Engineering*.J, **26**(4): 121-130.

Kim, B. S. 2004. Mushroom storage and processing; Mushroom Growers Handbook. Part 2, pp.192-196.

Koua, K. B., Fassinou, W. F., Gbaha, P. and Toure, S. 2009. Mathematical modelling of the thin layer solar drying of banana, mango and cassava. *Sol. Energy. J*, **34**(8): 1594-1602.

Kulsheshtha, M. and Singh, A. 2009. Effect of drying conditions on mushroom quality. *J. Eng. Sci. and Tech*, **4**(2): 90-98.

Matrawy, K. K. 1998. New derivation and analysis for a combined solar storage system coupled with a finned absorber air collector. *J. Energy*

Conversion and Management, **38**(7): 861-869.

Montero, I., Blanco, J., Miranda, T. Rojas, S. and Celma, A. R. 2010. Design, construction and performance testing of a solar dryer for agro-industrial by products. *Energy Conversion and Management J*, **51**(3): 1510-1521.

Oei, P. 2005. Small scale mushroom cultivation of oyster, shiitake and wood ear mushrooms. Agromisa Foundation and CTA. Wageningen, Netherlands. pp. 22-30.

Pathak, V. N., Yadav, N. and Gour, M. 1998. Mushroom production and processing Technology. Agrobios (India), Chopasani Road, Jodhpur 342 002, New Delhi. pp. 138-141.

Sethi, S. 2007. Post Harvest Technology; Principles of Food Processing. Indus Pub-Lications. Co. Pvt.Ltd. New Delhi, India.

Sharma, G. P. and Prasad, S. 2003. Optimization of process parameters for microwave drying of garlic cloves. *J. Food Eng*, **1** (5): 35-43.

Singh, S., Usha, M., Sreenarayanan, V. V., Raghupathy, R. and Gothandapani, L.1995. Dehydration of mushroom by fluidized bed drying. *J. Food Sci. and Tech*, **32**(1&2): 284-288.

Soysal, Y. 2004. Microwave Drying Characteristics of Parsley. *J. Biosystems Eng*, **89** (2): 167-173.

Sumnu, G., Turabi, E. and Oztop, M. 2005. Drying of carrots in microwave and halogen lamp-microwave combination ovens. *J. Food Sci. and Tech*, **38**(3): 549-553.

Tripathy, P. P. and Kumar, S. 2009. Modelling of heat transfer and energy analysis of potato slices and cylinders during solar drying. *J. Applied Thermal Engineering*, **29**(2): 884-891.

Velu, V., Nagender, A., Prabhakara Rao, P.G. and Rao, D.G. 2003. Dry milling characteristics of microwave dried maize grains (Zea mays L.). *J. Food Eng*, **1**(8): 18-21.

Walde, S. G., Velu, V., Jyothirmayi, T. and Math, R. G. 2003 Effects of pretreatments and drying methods on dehydration of mushroom. *J. Food Eng*, **2**(1): 22-25.

Wang, J. and Xi, Y.S. 2005. Drying characteristics and drying quality of carrot using a two-stage microwave process. *J. Food Eng*, **68** (4): 505-511.

Wang, J. and Sheng, K. 2007. Far-infrared and microwave drying of peach. *J. Food Sci. and Tech*, **1**(9): 40-45.

Yesilata, B. and Aktacir, M. A. 2009. A simple moisture transfer model for drying of sliced foods. *J. Applied Thermal Engineering*, **29**(5): 748-752.