PREPARATION AND STORAGE OF DEHYDRATED PADDY STRAW MUSHROOM

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CERTIFICATE-I

This is to certify that the thesis entitled **“Preparation and storage of dehydrated paddy straw mushroom”** submitted in partial fulfillment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Processing and Food Engineering** to the Orissa University of Agriculture and Technology, Bhubaneswar is a faithful record of *bona fid*e and original research work carried out by **Khushboo Gupta** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that the assistance and help received by him from various sources during the course of investigation has been duly acknowledged.

Bhubaneswar
Date:11.06.2018

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CERTIFICATE-II

This is to certify that the thesis entitled **"Studies on drying and storage of dehydrated paddy straw mushroom"** submitted by **Khushboo Gupta** to the Orissa University of Agriculture and Technology, Bhubaneswar in partial fulfillment of the requirements for the degree of **Master of Technology (Agricultural Engineering)** in **Processing and Food Engineering** has been approved by the student's advisory committee and the external examiner.

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ABSTRACT

Mushrooms are consumed as a source of protein throughout the world and the drying of mushroom can be employed for extending the shelf life of this highly perishable commodity. However, a standard method for preparation of dried mushroom and its storage is yet to be made available for small processors. Thus, different drying methods and parameters were studied for preparation of dried mushroom. Mushrooms were dried in a tray dryer (50, 60 and 70°C), microwave convective dryer (0.72, 1.44 and 2.16 W/g power levels and constant air temperature of 50°C) and freeze dryer. Results indicated that the Page model offered the best fit for experimental drying data for hot air drying and Wang and Singh model for microwave convective drying. The value of effective diffusivity in MWCD was more than that of hot air drying. The calculated activation energy (E_a) was 0.336 W/g in MWCD and 44.97 kJ/mol in HAD. The mushroom samples were tested for colour, rehydration ratio, shrinkage ratio, proximate composition (moisture, ash, total crude fibre, protein and carbohydrate content), total phenolics, DPPH , hardness, chewiness and minerals. The results and statistical analysis revealed that freeze dried samples were found to be best. Ash, prorein, fibre, reducing sugar and ascorbic acid reduced with increasing drying temperature. Rehydration ratio and water absorption index were maximum in hot air drying after freeze drying. The retention of total phenolic compounds were maximum in freeze dried sample and minimum in hot air (70°C) dried sample. Scanning electron microscopy (SEM) images revealed that a higher temperature or microwave power caused greater damage to the microstructure of the mushroom samples. The current study revealed that the hot air drying at 50°C is suitable to dry the paddy straw mushroom. The flakes and powder were stored for three months in three different packaging materials like LDPE, MPP and PET pouches and the MPP packages offered least change in all quality parameters as compared to other two packaging materials.

Keywords: Paddy straw mushroom, thin layer drying, microwave convective drying, freeze drying, colour, rehydration ratio, nutritional value, minerals and microscopic structure.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	Percent
@	At the rate
°C	Degree Celsius
cm	Centimeter
w.b	Wet basis
d.b.	Dry basis
g	Gram
h	Hour
min	minute
kJ	Kilo joule
W	Watt
s	second
HAD	Hot air drying
MWCD	Microwave convective drying
mg	Milli gram
GAE	Gallic acid equivelent
mm	Millimeters
ml	Millilitre
Δ	Change
PET	Polyethylene terephthalate
MPP	Metallized polyester polyethylene
LDPE	Low density polyethylene
wt.	Weight
OA	Overall acceptability
SAS	Statistical analysis software
conc.	Concentration
Et al.	Et aliae
Etc	Etcetera

Chapter 1

INTRODUCTION

Mushrooms are found all over the world and have been a time honoured food in many cultures. These are tropical and subtropical saprophytic fungus belonging to the family Pluteaceae of Basidiomycetes. These are liked for their delicious flavour, low calorific value and high protein, vitamins of B-groups and minerals. They contain proteins and have no cholesterol and are almost fat free (Walde *et al*., 2006). They have been used not only as a food but also for medicinal purpose (Bobek *et al*., 1997; Yang *et al*., 2001; Chang and Lee, 2004; Chocksaisawasdee *et al*., 2010). Medicinal mushrooms have become important due to their antitumor, antifungal and reducing hyper cholesterolemia activities (Chang and Buswell, 1996). Studies reveal that *Agaricus bisporus*, *Hericium erinaceus*, *Flammulina velutipes*, *Lentinus edodes* and *Pleurotus ostratus* exhibit potential antioxidative effects in preserving food and also have anti-aging properties (Kim *et al*. 2001; Lee *et al*. 2003). Studies indicate that some of the edible mushrooms possess potential anti-carcinogenic, anti-cholesterolaemic and anti-viral properties (Emilia *et al.*, 2006; Roman *et al.*, 2006). Apart from giving excellent nutritious food and medicine, mushroom growing can be efficient means of waste disposal, especially for agriculture wastes such as paddy straw, hay, etc. (Mandeel, 2005).

Literally, there are less than 25 species of edible mushrooms out of more than 2000 species that exist. At present three varieties of mushrooms, viz. white mushroom (*Agaricus bisporus*), paddy straw mushroom (*Volvariella volvacea*) and oyster mushroom (*Pleurotus sajor-caju*) are widely cultivated in India for commercial purpose (Barros *et al.* 2007). These mushrooms possess good quality of proteins, unsaturated fatty acids, fibres, minerals and vital vitamins that we need in our daily diet (Ouzouni *et al.* 2009; Hung and Nhi, 2012).

The *Volvariella volvacea,* locally known as paddy straw mushroom or straw mushroom, or Chinese mushroom ranks sixth among the cultivated mushrooms of the world. Being started cultivating in 1940 at Coimbatore, this mushroom could not make much headway with time except in some coastal states like Odisha, Andhra

Pradesh, West Bengal, Tamilnadu and Kerela. *Volvariella volvacea* is the fifth most important edible mushroom in the world according to yield (Chang, 1993).

In the state of Odisha straw mushroom is grown commercially for 10 months a year (February-November) involving poor farmers and the production stands at 9550 tonnes/annum (AICRP, 2016). However, the straw mushroom growers often suffer from distress sell because of its short shelf life and unavailability of suitable storage technology. The farmers usually sell fresh mushroom to the market without any post-harvest treatment. However, the mushroom starts to spoil with undesirable smell, texture and odour very quickly even after 6-7 hours. This indirectly creates economic loss to the people who rely on it for livelihood. The commonly used food preservation techniques such as canning, freezing and drying can be employed for preservation of mushrooms. Although canning is widely used on a commercial scale, it is quite expensive. Cold chain is often beyond the reach of common mushroom growers. Drying seems to be more effective approach to extend shelf life than freezing as the process is cheap, convenient and if properly packaged can extend the shelf life for years.

Drying can be used for preparation of dehydrated mushroom flakes and powder, to have good shelf life. A good quality product will also have good marketability and export potential, thus yielding higher income to farmers. Dried mushroom can also be used as a raw material for the instant soup and pizza industries, or as an auxiliary material for various sauce products and baby formulae, or processed to mushroom flour. There are many drying methods, such as solar drying, convection drying, freeze drying, fluidised bed drying and microwave drying. Drying under open sun results in unhygienic and poor quality products (Chua *et al*. 2001). Hot air drying is simple, economical and a more efficient method of drying, but there may be darkening of the product leading to poor acceptance by consumers. Freeze drying is frequently applied to materials that are prone to heat damage and it yields products with excellent structural characteristics. It may also overcome the problem of mushroom darkening. But the process is capital intensive and may not be recommended to small mushroom growers. Fluidized bed drying is also a newer method that is faster and produces better quality product than that obtained by conventional hot air drying; but it is also more expensive than cabinet dryers. Microwave drying is considered as the fourth generation drying technology. Waves can penetrate directly into the material and the heating is volumetric (from inside to outside). It also offers many advantages such as less start up time, faster heating, uniform heating throughout the entire product, better energy efficiency (most of the electromagnetic energy is converted to heat), saving in space, and precise process control. Besides the final product also has a better nutritional quality than conventional methods, but the commercial microwave dryers are yet to take up. For small and marginal farmers, these costly technologies may not be recommended and the use of hot air cabinet drying could be the most practicable solution. Limited study has been carried out on analysing the effects of different drying methods and the operational parameters on the quality of straw mushroom. It is very important to know the nutritional status of the dehydrated straw mushroom as the mushrooms are valued for their nutrition benefits. In view of the above, this study was planned to investigate the effects of different drying methods and the operational parameters on the quality of dehydrated paddy straw mushroom and to suggest some drying solution to the farmers without compromising on the nutritional value. The present study has been undertaken with following objectives:

1. To study the drying kinetics of paddy straw mushroom under different drying conditions.
2. To have the comparative evaluation of drying methods based on physico-chemical properties of dehydrated product.
3. To assess the storability of the dehydrated mushroom in flakes and powder form using different packaging materials.

Chapter 2

REVIEW OF LITERATURE

Mushroom is oldest single cell protein food with protein content in between low grade vegetable and high grade meat protein. Mushroom contains 20-35% protein (dry weight) which is higher than those of vegetables and fruits and is of superior quality. It is also rich in vitamins, minerals. Also, they are low in fat, salt, calories, starch, cholesterol, which make them an ideal nutritional and diet supplement. Mushrooms are perishable in nature, owing to high moisture content. Approximately 20-25 per cent of vegetables are wasted due to the glut in the market during season, inadequate storage conditions, lack of transport and processing facilities at the production point. Preservation can prevent such huge wastage and increase their availability in lean season. Several preservation techniques are available of which drying/ dehydration is a traditional, user friendly method. It is the process of removal moisture by the application of heat under controlled condition of temperature, humidity and air flow. Removal of moisture can be achieved either through exposure to sun, drying in sun or shade, cabinet, microwave or hot air ovens. In addition to reducing bulk, ease of transportation and possibility of storage at ambient conditions are the preferred characteristics of drying.

This chapter deals with review of literature on nutritional qualities of paddy straw mushroom and its different health benefits. It also includes the studies on the effect of drying on the nutritional value of straw mushroom. Further, the literature on the effect of storage on nutritional value of the paddy straw mushroom also reviewed.

2.1 Composition and its health benefits

The chemical composition of mushroom determines their nutritional value, functional and sensory properties. *Volvariella volvacea* contain 90% water, high amount of protein, fibres, fats (0.25g), carbohydrates (56.8), amino acids (all essential amino acid like alanine, arginine, glycine, serine etc.), unsaturated fatty acids, essential minerals (calcium, potassium, sodium, potassium and phosphorus) and low calorific value (Chang and Buswell, 1996; Jiskani, 2001; Buigut, 2002; Ouzouni *et al.*, 2009).

Reguła and Siwulski (2007) presented potential health benefits of shiitake *Lentinula edodes* and oyster mushroom *Pleurotus ostreatu*, chemical composition as well as Fe, Cu and Zn ions sorption (in conditions related to human digestive tract) by dried shiitake and oyster mushrooms. Both dried mushrooms had the high content of dietary fibre, Fe, Cu, Mg, K but low of fat, Na and Ca. The results of the research suggest that dried shiitake and oyster mushrooms can be used as additives in food products.

Ramkumar *et al.* (2012) studied the evaluation of nutrients, trace metals and antioxidant activity in *Volvariella volvacea.* The different organic and inorganic additives were used in mushroom culture. Methanolic extracts were prepared from these mushrooms and their antioxidant properties, 1, 1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity, reducing power, and nutrient analysis were studied. Biomass productions, the additives calcium carbonate and Sawdust were recorded better results. Calcium carbonate recorded maximum levels of enzymatic antioxidants that are catalase, superoxide dismutase, glutathione peroxidase, glutathione-s-transferase and Glutathione reductase, DPPH scavenging activities, reducing power, nutrients and trace metals were also significantly high in calcium carbonate. The ongoing research will lead to a new generation of nutritional food because *V. volvacea* may have potential as natural antioxidants and the calcium carbonate could be used as a suitable additive to improve the production of antioxidative substances, nutritive value and yield in the mushroom food industry.

Two cultivated mushroom species, namely, *Lentinula edodes and Pleurotus florida* and two wild growing species *Lentinus cladopus* and *Pleurotus djamor* were studied by Mallikarjuna *et al.*(2013) for their mineral contents such as Ca, Mg, Na, K, Fe, Zn, Mn, Cu, Ni, Se, Pb, and Cd by Inductive Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) and also Atomic Absorption Spectroscopy(AAS). Phosphorus was estimated by spectrophotometric method. K, Ca, Na, and P were in higher concentrations ranging from 59.3 mg to 3634 mg, 8.27mg–174.9mg, 22.2mg–327.4mg, and 100.5mg–769.9 mg/100 g dry weight respectively in the four mushroom species. Fe, Zn, Mg and Se were ranging from 6.27 mg to 35.3 mg, 1.58 mg–9.44 mg, 21.1 mg–40.7 mg and 0.048 mg–0.182 mg/100g dry weight, respectively, amongst the mushroom species analyzed. However, Ni, Cu, and Mn contents showed relatively lower concentrations, whereas Pb and Cd were below detectable level.

Chemical profile and amino acids composition of edible mushrooms was conducted by Rana *et al.* (2015) to evaluate the functional properties of popularly cultivated mushrooms viz.,white button mushrooms *(Agaricus bisporus)* and oyster mushrooms *(Pleurotus pulmonarius*. Both types of mushroom exhibited high moisture, crude protein and amino acid content. The *Pleurotus* and *Agaricus* mushrooms contained 3.26% and 1.78% soluble protein, respectively. The thin layer chromatography separation of amino acids showed that all the nine essential amino acid were present in *Agaricus bisporus* whereas, only five are present in *Pleurotus pulmonarius*. Hence, the supplementation of these mushrooms with cereal diet can help to overcome essential amino acids deficiency and reduce the post-harvest losses of this high value perishable crop.

2.2 Study of drying kinetics

Arora *et al.* (2003) reported the drying kinetics of two species of mushrooms (*Agaricus bisporus* and *Pleurotus florida*). Mushrooms, blanched in boiling water and treated in solution containing 0.1% citric acid and 0.25% KMS for 15 min at room temperature, were dried in a tray dryer at selected temperatures (45°C, 50°C, 55°C, 60°C, and 65°C). Results indicated that drying took place in the falling–rate period, and the drying kinetics were adequately described by Page’s model. The process activation energy for drying sample were 19.79 and 23.59 kJ/mol, respectively, for *Agaricus bisporus* and *Pleurotus florida.*

Krokida *et al.* (2003) studied the effect of air conditions (air temperature, air humidity and air velocity) and characteristic sample size on drying kinetics of various plant materials (potato, carrot, pepper, garlic, mushroom, onion, leek, pea, corn, celery, pumpkin, tomato) during air drying. A first-order reaction kinetics model was used, in which the drying constant is function of the process variables, while the equilibrium moisture content of dried products within the range of 0.10–0.90 water activity at two temperatures (30°C and 70°C) was fitted to GAB equation. The parameters of the model considered were found to be greatly affected by the air conditions andsample size during drying. In particular the temperature increment increases the drying constant and decreases the equilibrium moisture content of the dehydrated products.

Shivhare *et al.* (2004) determined the moisture adsorption isotherms of *Agaricus bisporus* and *Pleurotus florida* mushrooms at temperatures (30–70°C) typically found in drying and storage. The samples were equilibrated above saturated salt solutions. Equilibrium moisture content of mushroom decreased with an increase in temperature at constant water activity. Comparisons were based on mean relative error, standard deviation and coefficient of determination. The Chung and Pfost model showed the best fit. The Chung and Pfost model described well the adsorption isotherms of mushroom over 30–70°C and for water activity between 0.2 and0.8. The net isosteric heat of sorption was determined using the Clausius–Clapeyron equation. The net isosteric heat of sorption decreased from 13 to about 1 kJ/mol when the moisture content increased from 5 to 50 g /100 g dry matter.

Walde *et al.*(2006) carried out 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 like hot air cabinet dryer, fluidized bed dryer, vacuum dryer and microwave oven. For both oyster and button mushrooms using pre-treatment by dipping in curds or fermented whey the time of drying was less compared to other treatments in all types of dryers. The diffusion coefficient was found maximum (469.7×10^{-6} m^2/s) for the whey treated microwave dried mushroom and minimum (2.609×10^{-6} m^2/s) for the control cabinet tray dried sample. The diffusion coefficient was maximum (331.02×10^{-6} m^2/s) for the blanched button mushroom dried by microwave drying and minimum (0.3225×10^{-6} m^2/s) for the control sample dried by vacuum oven.

Giri and Prasad (2007) investigated the effect of drying parameters, namely microwave power, system pressure and product thickness on the drying kinetics and rehydration characteristics of button mushroom. The drying system was operated in the microwave power range of 115–285 W, pressure range of 6.5–23.5 kPa having mushroom slices of 6–14 mm thickness. Convective air drying at different air temperatures (50, 60 and 70°C) was performed to compare the drying rate and rehydration properties of microwave-vacuum drying with conventional method.

Microwave-vacuum drying resulted in 70–90% decrease in the drying time rehydration ratio was significantly affected by the system pressure.

Tripathy and Kumar (2009) described a methodology for the determination of coefficients of moisture diffusion, D_{eff} and convective mass transfer, h_m using variable drying parameters (lag factor, k_o and drying coefficient k). Mixed-mode solar dryer with potato cylinders and slices was used to obtain variable (temperature dependent) k_o and k from drying kinetics. Results of investigation indicate the increasing trend of D_{eff} and h_m with temperature and their values are found to be higher for cylinders compared to slices. Temperature rise from 33 to 48 °C for cylinder during drying results in the increase of 85.6% and 159% of D_{eff} and h_m, respectively, whereas these figures are 72% and 89% for slices.

Tulek (2011) studied the drying kinetics of oyster mushroom, *Pleurotus ostreatus* mushrooms using a cabinet-type convective dryer. Air temperatures of 50, 60 and 70 °C were used for the drying experiments. The experimental drying data were fitted to different theoretical models. Nonlinear regression analysis was performed to relate the parameters of the model with the drying conditions. The performance of these models was evaluated by comparing the correlation coefficient (R^2), root mean square error (RMSE) and the chi-square (χ^2) between the observed and the predicted moisture ratios. Among all the models, the model of Midilli *et al.* (2002) was found to have the best fit in this study. Effective moisture diffusivities (D_{eff}), diffusivity constant (D_0) and activation energy (E_a) were calculated. The D_{eff} varied from $9.6x10^{-10}$ to $1.556x10^{-9}$ m^2s^{-1} over the temperature range studied and E_a was22.228 kJ mol $^{-1}$.

Silva *et al.* (2013) studied the thin-layer drying of whole bananas. To describe the convective drying process, a mathematical model is normally used. In this study, several empirical models were selected to simulate experiments of thin layer drying accomplished with whole bananas at temperatures of 40, 50, 60 and 70 °C. In the selection, it was imposed that mathematical expressions must be obtained from each model to calculate the drying rate and also the process time. The process time ranged from 1200 (70°C) up to 3265(40°C) min. The maximum drying rate occurs at the beginning of the process and varied between1.95 × 10^{-3} (40 °C) and 3.60 × 10^{-3} (70 °C) min^{-1}.According to the statistical indicators, Page and Silva et alii, models well describe the thin layer drying kinetics of whole banana.

Darvishi (2014) investigated the influence of microwave power on the drying kinetics, energy consumption and drying efficiency of green pepper during microwave drying at 180, 240,300, 360, 420, 480 and 540 W. Seven mathematical models for describing the thin-layer drying behaviour of pepper samples were investigated. By increasing the microwave output powers (180–540 W), the drying time decreased from 9 to 2.5 min. The drying process took place in the falling rate period. The results show that the Midilli model is the most appropriate model for drying behaviour of thin layer pepper samples. The effective moisture diffusivity increased with decrease in moisture content of pepper samples. The average effective diffusivity varied from 8.315×10^{-8} to $2.363 \times 10^{-7} m^2 s^{-1}$, over the microwave power range studied, with an energy activation of 14.19 W/g. Energy efficiency increased with increase in microwave power and moisture content. The least specific energy consumption (4.99 MJ/kg water) was at the microwave power of 240 W and the highest (6.80 MJ/kg water) was at 180 W.

Doymaz (2014) investigated the effect of pretreatment (0.5% citric acid solution) and drying air temperature 40, 50, 60, and 70°C on drying characteristics of button mushroom slices in a cabinet dryer. The experimental results show that the drying temperature and pretreatment have significant effects on the moisture removal from mushroom. In addition, rehydration ratio of pretreated samples was higher than that of control ones. Four kinds of classical model were used to obtain moisture data and the logarithmic model was the best for representation of mushroom drying. The values of effective moisture diffusivity were found to range between 1.70×10^{-10} and $7.12 \times 10^{-10} m^2/s$ over the temperature range studied. The activation energy was found to be 35.04 and 37.21 kJ/mol for control and pre-treated samples, respectively.

Drying behaviour of prickly pear cladodes and fruits were studied by Touil *et al.* (2014) with an Infrared dryer. The volume shrinkage for *Opuntia ficusindica* products is calculated and a linear relation was established to describe the experimental variation of shrinkage of the product versus its moisture content. Effective diffusion coefficient of moisture transfer was determined using the Fick's law at three drying temperatures (40, 50, and 60°C). Shrinkage was also included into the diffusion model for the determination of the effective diffusion coefficient. The obtained results of the effective moisture diffusivity, for the cladode and the fruit, were evaluated in the range of 1.77×10^{-10}–5.07×10^{-10} m^2/s and 2.53×10^{-10}–

7.6×10^{-10} m^2/s, respectively. The values of the activation energies for cladode and fruit were estimated to be 45.39 and 47.79 kJ/mol, respectively. However, these values of moisture diffusivity were estimated independently of the evolution of moisture content during drying process.

Tzempelikos *et al.* (2014) examined experimentally the thin-layer drying behaviour of quince slice as a function of drying conditions. In a laboratory thermal convective dryer, experiments were conducted at air temperatures of 40, 50 and 60°C and average air velocities of 1,2 and $3ms^{-1}$. Increasing temperature and velocity resulted in a decrease of the total time of drying. In the ranges measured, the values of the effective moisture diffusivity (D_{eff}) were obtained between 2.67×10^{-10} and 8.17×10^{-10} m^2s^{-1}. The activation energy (E_a) varied between 36.99 and 42.59 $kJmol^{-1}$.

Drying parameters including drying temperatures (20, 30, and 40 °C), chamber pressures (70, 100, and 130 Pa) and material layer thicknesses (single, double, and triple) during FD process, and microwave power densities (20, 40, and 60 W/g) and material layer thicknesses (single, double and triple) during MVD period of FD+MVD process were investigated (Pie *et al.* 2014). The FD and FD+MVD products were then rehydrated at two temperatures (20 and 70°C). Different mathematical models were tested with the drying and rehydration behaviours of button mushroom slices, and the effective diffusivities (D_{eff}) in the FD and FD+MVD processes were also calculated. The results indicated that based on the statistical tests, the Page model and logarithmic model provided the best fit for FD (in both FD and FD+MVD processes) and MVD (in FD+MVD process) curves, respectively. The regression equations obtained from selected models can accurately predict the relationships between moisture ratio (MR) and time (t). Furthermore, the D_{eff} values of the MVD period in FD+MVD process were about ten times greater than those in FD process. In addition, the Peleg model gave a better fit for rehydration conditions applied in both FD and FD+MVD products. The values of equilibrium moisture content of FD+MVD products were almost similar to those of FD products, which indicated that the rehydration capacities of the two dehydrated products were comparable.

Xiao-hui *et al.* (2014) used nine kinds of classical mathematical models to define drying process of mushroom (*Lentinus edodes*) and observed that the Midili-model could describe the drying process with the coefficient R^2 ranging from 0.99790 to 0.99967), chi-square (χ^2) ranging from 0.00003 to 0.00019 and root mean square error (RMSE) ranging from 0.000486 to 0.0012367.

Zarein (2015) studying of thin layer microwave drying of apple in a laboratory scale microwave dryer at 2450 MHz. The drying experiments were carried out at 200, 400 and 600 W. The experimental data were fitted to nine drying models. The Midilli model best described the drying curve of apple slices. The effective moisture diffusivity was determined by using Fick's second law and was observed to lie between 3.93×10^{-7} and 2.27×10^{-6} m^2s^{-1} for the apple samples. The microwave power dependence of the effective diffusivity coefficient followed an Arrhenius-type relationship. The activation energy for the moisture diffusion was determined to be 12.15 W/g. The highest energy efficiency was recorded for the samples dried at 600 W as 54.34% and lowest at 200 W as 17.42%.

Nistor *et al.* (2017) studied the effects of the drying conditions on red beetroot (Beta vulgaris L.) in terms of betalain variance, polyphenol, and microstructure changes (SEM), using the combination of the three drying methods, free convection (at 50, 60, and 70 °C),forced convection at 40 °C and 315W microwave power. A strong thermal shock, provided by convection at 60° followed by microwave wattage 315W, 9 min, leads to a better preservation of bioactive compounds content(0.631 ± 0.0042 mg/g of betacyanin and 0.795 ± 0.0019 mg/g betaxanthin) when compared to convection at 50, 60 and 70 °C. The results showed that combined drying methods led to a significant preservation of the phytochemical content as compared to the traditional methods.

2.3 Effect of dehydration on quality of mushroom

Naik *et al.* (2006) optimized the drying method for drying of oyster mushroom *(Pleurotus florida)* in three different drying methods were followed *viz.*, Solar cabinet, microwave-oven and cabinet tray drying methods. The rehydration ratio and sensory evaluation scores were used as criteria for evaluating the product quality. The results revealed that, cabinet tray dried (at 60°C and 1%KMS pre-treatment) mushroom samples were found to be good. The KMS treated samples had highest rehydration ratio and sensory evaluation scores as compared to the control (untreated) and balanced samples.

Barros *et al.* (2007) studied antioxidant activities of three Portuguese wild edible mushroom species, *Leucopaxillus giganteus*, *Sarcodon imbricatus*, and *Agaricus arvensis*. Methanolic extracts were screened for their reducing power, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging capacity, inhibition of erythrocytes hemolysis and antioxidant activity using the β-carotene linoleate model system. The amounts of ascorbic acid, β-carotene and lycopene found in the mushroom extracts were very low. Otherwise, the high contents of phenolic compounds might account for the good antioxidant properties found in all species. L. giganteus had the highest content of phenols and proved to be the most active, presenting lower EC_{50} values in all the antioxidant activity assays.

Kotwaliwale *et al.* (2007) studied textural and optical properties of paddy straw mushroom during hot air drying of mushrooms in a cabinet tray drier at different air temperatures 50, 55, 60, and 70 °C. Effect of pre-drying treatments, viz. blanching and sulphitation, was also monitored. Texture Analyser TM and Hunter lab TM Colorimeter were used to determine textural and optical properties, respectively. During drying, hardness and chewiness of mushrooms were increased, while cohesiveness and springiness increased initially and decreased at the final stage of drying. Hardness of mushroom dried at higher temperature was higher. Cohesiveness decreased with increased drying temperature. Blanched and dried mushrooms had more hardness compared to other dried samples. Whiteness index of mushrooms decreased while yellowness index increased during drying. Drying temperature had an inverse effect on whiteness of mushrooms. Sulphitation helped while blanching deteriorated whiteness retention during drying.

Argyropoulos *et al.(*2008) evaluated the process parameters for hot-air drying to obtain high quality dried mushrooms in the Mediterranean region. The air temperature and slice thickness were significant factors affecting the hot-air drying characteristics of mushrooms .The most favourable rehydration ability was observed in freeze dried samples. The effect of the observed range of relative humidity was insignificant. Two-phase drying at lower initial temperature resulted in a lighter slice colour, softer in texture with good reconstitution. Freeze drying produced dried mushroom slices of superior quality exhibiting the highest lightness, lowest hardness and maximum rehydration ratio. Samples dried by combination of hot-air and microwave-vacuum indicated improved quality parameters as compared to samples dried only by hot air.

Apati *et al.* (2010) investigated dehydration and rehydration processes of *Pleurotus ostreatus*. Mushroom samples were dehydrated at 40, 50 and 60ºC, using drying air with relative humidity of 75%. The rehydration was investigated at different temperatures of water (25, 55 and 85ºC) and different immersion times (30, 75 and 120 minutes). The best rehydration occurred for the samples dried at 40ºC. The rehydration could be done in water at room temperature, during 30 minutes. Water sorption isotherms of samples were determined at 30, 40 and 50 ºC. Both GAB and BET models satisfactorily represented the data of moisture sorption of dried mushrooms.

Lombrana *et al.* (2010) studied different operational conditions related to temperature control position and pressure and their effects on drying kinetics and quality of mushroom. Thin sliced mushrooms were dried in a guide cavity by applying microwave energy at 2.45 GHz. The influence on the quality of the dehydrated mushrooms was studied by two different techniques: sorption isotherms (Halsey and B.E.T. equations) and scanning electron microscopy (SEM). Drying kinetics were also analyzed through the determination of diffusivity by applying a mathematical model that takes into account changes in moisture on the product surface during the process. Thus, the results of SEM observations and quality can be linked with diffusivity values in each experiment.

Segovia *et al.* (2010) studied the air-drying of Shiitake mushroom (*Lentinus edodes*). The caps were rehydrated using conventional and vacuum techniques, at different temperatures (30, 40, 50 and 80°C) and times (1, 2, 3, 6, 9, 12, 15, 18, 21, 120, 150 and 210 min). Three empirical models were used to model the rehydration process: 1st order kinetics, Peleg’s model and the Weibull distribution function. The texture of the rehydrated material was determined, evaluating peak shear force and microstructure using cold-stage scanning electron microscopy (cryo-SEM). The vacuum rehydration of dried Shiitake mushroom caps was found to be a feasible alternative to the conventional rehydration process, resulting in a lower immersion time and in a desirable texture.

Aishah and Rosli (2013) determined the nutritional values of the dried oyster mushroom with different drying techniques. They used three different drying techniques. These include low heat air blow (LHAB), sun drying (SD) and gas laboratory oven (LO) drying. All three samples were analyzed for beta-glucan content, water activity, colour, proximate analysis and dietary fibre concentration. The result showed that LHAB method confers the lowest water activity compared with the other two drying methods. It also has the lowest colour measurement for brightness. Mushroom samples dried by LHAB techniques contain the highest concentration of both fat and carbohydrate compared with the other two methods. On the other hand, dietary fibres observed in LO dried samples contain the highest fibre content among the three drying treatments.

Bansal *et al.* (2013) carried out the effect of multi layer-cum-microwave drying process parameters viz. loading density, air velocity and power level on the quality characteristics of the dried mushroom. Quality characteristics viz. rehydration ratio, shrinkage ratio, texture, colour, overall acceptability of dried mushroom were analyzed. The process parameters were optimized using response surface methodology for responses with significant model and non significant lack of fit. The optimum operating conditions for air velocity, loading density and power level were 3.80 m/sec 38.80 kg/m^2 and 413 W at 600°C drying air temperature. Corresponding to these values of process variables, the value of rehydration ratio, shrinkage ratio, hardness, chewiness, colour change was 2.15, 0.84, 720 N, 473N and 15.50 respectively. The overall desirability was 0.78.

Izli and Isik (2014) studied the effects of microwave, convective and microwave-convective drying treatments on the drying parameters, colour and microstructure properties of mushroom samples. Based on evaluation by statistical tests, the Midilli model, the Diffusion Approach model, Logarithmic model, and Wang and Singh model were found to be the best-fitting models to describe the drying behaviour of the mushroom samples. The colour values of the samples dried at 50°C were closest to the fresh samples for all drying conditions. Scanning electron microscopy images revealed that a higher temperature or microwave power caused greater damage to the microstructure of the mushroom samples.

Pei *et al.* (2014) used freeze-drying (FD) and three different combinations of drying methods, freeze-drying combined with hot air drying (FD+AD), freeze-drying combined with vacuum drying (FD+VD) and freeze-drying combined with microwave vacuum drying (FD+MVD) to dry the button mushroom slices. The results showed that, under conditions of 38% moisture content changing point, most of the parameters including L* values, a* values, average density and hardness of FD+VD and FD+MVD samples had no remarkable changes ($p>0.05$) compared with FD samples. However, only FD+MVD method can reduce drying time by 35.63% in comparison of FD, although all the combination drying methods can reduce the energy consumption. Moreover, FD+VD and FD+MVD products were better than FD+AD products in nutrient retention except that content of vitamin C was comparatively lower during FD+MVD process. In conclusion, the FD+MVD method has advantages in terms of efficiency and energy saving and could be preferred to produce high-quality products.

Xiao-hui *et al.* (2014) determined the characteristics and drying process of mushroom (*Lentinus edodes*) by six different hot-air drying methods namely isothermal drying, uniform raise drying, non-uniform raise drying, uniform intermittent drying, non-uniform intermittent drying and combined drying. The chemical composition (dry matter, ash, crude protein, crude fat, total sugars, dietary fibre, and energy), colour parameters (L, a*, b*, c*, and h_0) and rehydration capacities were determined. Among all the experiments, non-uniform intermittent drying reached a better comprehensive results due to the higher chemical composition, better colour and rehydration ratio.

Yuen *et al.* (2014) conducted the study to investigate the effect of different drying temperature to the nutritional compositions of edible wild mushroom (*Volvariella volvacea*) and to determine the best drying temperature suitable for post-harvest handling without compromising their nutritional value. The mushroom samples (fresh and treated with 40, 50, 60°C) were tested for proximate analysis (moisture, ash, total crude fibre, fat, protein and carbohydrate content). The fresh mushroom contained high protein (12.38%) and carbohydrate (13.51%), but low in fat content (0.77%) as compared to the commercial one (*Lentinus edodes* and *Agaricus bisporus*). Mushroom treated at 60°C has comparable high energy (1468.73kJ) and calorie (346.04kcal) content. The current study revealed that the treatment using 60°C is suitable to dry the edible wild mushroom as it preserves most nutritional values.

Yasmin *et al.* (2015) carried out the air drying behaviour of fresh and osmosed oyster mushroom. Three different temperatures (55, 60 and 65°C) were used to determine the effect of temperature on drying behaviour of oyster mushroom in a mechanical dryer and an Arrhenius type relationship was developed from which activation energy value of 13.48 kcal/g-mole for fresh mushroom16.47 ,15.01and 4.19 kcal/g mole for mushroom osmosed at 12°C ,27°C and 45°C, respectively were found. Combined osmotic dehydration (in 20% salt solution) and air drying results in significantly higher (4 times) drying throughput compared to fresh mushroom. The values of proximate composition of fresh mushroom are 89.56, 3.83, 0.44, 0.91 and 5.26% moisture, protein, fat, ash, and total carbohydrate, respectively, while the corresponding values are 11.70, 31.5, 2.90, 5.92 and 47.98% moisture, protein, fat, ash and total carbohydrate for developed mushroom powder.

Muthu and Shanmugasundaram (2016) studied the proximate and mineral compositions of edible mushrooms species *Agrocybe aegerita.* The results of the analysis indicated that the mushrooms are good sources of moisture (92.36%) fat (0.20 mg/100g), crude fibre (8.05 mg/100g) and ash (1.22 mg/100g). The result also showed that the mushrooms are also good sources of nutritionally important mineral elements including iron, zinc, potassium, phosphorus, calcium and sodium, but low in Selenium, Manganese and Magnesium.

Oluwafemi *et al.* (2016) carried out proximate composition, minerals, functional properties and the protein fractionation on edible oyster mushroom (*Pleutrotus ostreatus*). The mushroom was separated into three parts; Cap, Stalk and the mixture i.e. cap + stalk dried and ground into powder. The results showed that the stalk had the highest moisture content of 6.33%, cap had the least moisture content of 3.48%. There was noticeable difference in their protein content; 34.19% cap, 20.96% stalk, and 30.48% cap + stalk. The ash content was between 5.30 - 8.24%, fat content were 1.48%, 1.5%, and 1.55% for stalk, stalk and cap, and cap respectively. Crude fibre of the cap, stalk and stalk and cap were 3.14%, 7.53% and 8.12% respectively. Carbohydrate content ranged between 51.94- 61.77%. Water absorption capacity of the cap, stalk, and cap + stalk were 487%, 675% and 530% respectively while oil absorption capacity were within the range of 290 – 330% the bulk density varied as; 0.483g/ml cap, 0.297g/ml stalk and 0.501g/ml cap + stalk. Cap had the highest emulsion and foaming capacity of 17.33% and 30.67% respectively. Phosphorus, magnesium and potassium were the major abundant minerals in mushroom with 497.35mg/100g in cap, 340.59mg/100g stalk and 466.24mg/100g cap and stalk. Protein fractionation revealed that Globulin had the highest proportion with 47.31% cap, 23.31% stalk and 44.65% cap and stalk, while Albumin varied between 3.29 – 4.18 % in cap, stalk and cap + stalk.

2.4 Storage quality of dehydrated mushroom

The main purpose of dehydration of vegetables is to preserve for a long duration with the retention of good quality, in terms of nutrients availability and sensory attributes. The related literature is reviewed here.

Jayathunge and Illeperuma (2001) studied dehydration of oyster mushroom in cabinet air drying and its storability. Changes in moisture, total carbohydrate, crude fat, crude protein, total ash, total calcium and total iron contents during dehydration were determined. The acceptability of the product was tested by using a sensory evaluation panel and a five-point Hedonic scale. Immersing the mushroom torn into 3 cm strips in 0.05% sodium bicarbonate for one minute was successful as a pre-treatment to improve the physical properties of the dehydrated product. Drying at 45°Cfor 5 h was sufficient to reduce the water activity from0.84-0.56 and to obtain a shelf stable product with good physico-chemical properties. Dehydrated product packed in pouches made out of aluminium foil laminated with high density polyethylene could be stored at 27±2°C and 82±3% RH for 9 months.

Kortei *et al.* (2014) evaluated the effect of gamma radiation on the total phenolic content, flavonoids, and antioxidant activity of dried *Pleurotus ostreatus* stored in different packaging materials like polythene and polypropylene, exposed to gamma radiation from a cobalt- 60 source at doses of 0, 0.5, 1, 1.5, and 2 kGy at a dose rate of 1.7 kGy/h and stored for a period of 1 month. Total phenolic contents, flavonoids, and free radical scavenging activity DPPH (2,2-diphenyl-1-picrylhydrazyl) were determined using aqueous, ethanol, and methanol extracts by Folin-Ciocaultaeu method as a source of potential natural antioxidants. Total phenol content ranged 0.56 ± 0.01–10.96 ± 1.7mg/GAE, flavonoids ranged 1.64 ± 0.05–8.92 ±0.6 mg/QE, DPPH radical scavenging activity also ranged 7.02 ± 0.10–13.03 ±0.04%, and IC_{50}values also ranged 0.08–0.16mg/ml. Statistical differences (P <0.05) were recorded for the extracts and the treatment doses of mushrooms stored in polythene and polypropylene packs. The high contents of phenolic compounds indicated that these compounds contribute to high antioxidant activity.

Storage studies for extension of shelf-life of fresh oyster mushroom in different containers *viz.*, open vessels, polyethylene bags and paper bags at room temperature studied by Shashi *et al.* (2016). House-hold cold storage system and refrigerator conditions revealed that house-hold cold storage system and refrigerator conditions in paper bags gave better results from storage points of view. From sensory point of view, fresh mushroom could not be stored more than two days at room temperature, four days in cold storage system and six days in refrigerated conditions.

Ramaya and Kumar (2017)conducted to study the influence of packaging material along confined storage condition and duration on quality attributes of osmo-cum-microwave dehydrated *Pleurotus sajor-caju* mushroom flakes during storage. Mushrooms pre-treated with salt-sugar were dried by microwave drying technique to a moisture content of around 6% (w.b.) was stored under different storage conditions. Various quality attributes that contributes for overall consumer acceptability were studied along storage period. The mushroom flakes were found to be highly acceptable up to two months of storage that was packed in high density poly ethylene material with greater overall acceptability.

Chapter 3

MATERIALS AND METHODS

The paddy straw mushroom was dried in hot air dryer (at three different temperatures), microwave assisted convective dryer (at three different microwave power levels) and freeze dryer to study the drying kinetics and end product quality. This chapter deals with the experimental set up and procedures followed for the study to assess the feasibility of different drying conditions on the quality of mushroom. Further, procedures used for the determination of quality parameters of dried flakes and powder, changes in the quality parameters during storage in different packaging materials have also been presented.

3.1 Raw material

Freshly harvested *Volvariella volvacea* mushroom was purchased from a local mushroom grower. The mushroom samples were then cleaned by hand to separate the undesirable portions. The mushrooms were sorted on the basis of size and then the samples were cut longitudinally to four parts with the help of a sharp knife. The caps and stem both were used for drying. The initial moisture content of fresh paddy straw mushroom was estimated by calculating the loss of water in a hot air oven at 85°C for 24 hours.

3.2 Independent and dependent parameters used in the study

3.2.1 Drying kinetics of paddy straw mushroom under different drying conditions.

- **Independent parameters (dryers and drying conditions)**

1. Hot air drying (at 40°, 50° and 60°C with constant air velocity of 1 m/s)
2. Microwave convective drying (at 0.72, 1.44 and 2.16W/g microwave power with constant air temperature of 50°C)
3. Freeze drying (Condenser temperature -40°C)

- **Dependent parameters**

1. Moisture content
2. Total drying time
3. Drying rate
4. Moisture ratio

5. Effective moisture diffusivity and activation energy
6. Mathematical modelling

3.2.2 Physico-chemical properties of the dehydrated product

- **Independent parameters**

1. Hot air drying (40°, 50° and 60°C; constant air flow rate of 1 m/s)
2. Microwave convective drying (0.72, 1.44 and 2.16 W/g microwave power, air temperature: 50°C)
3. Freeze drying (Condenser temperature -40°C)

- **Dependent parameters**

1. Colour
2. Rehydration ratio and shrinkage ratio
3. Nutritional quality (ash, protein, carbohydrate, fibre, ascorbic acid and reducing sugar, DPPH, total phenolics)
4. Functional quality (water solubility index, water absorption index, oil absorption index)
5. Minerals (Ca, Mg, Mn, Na, K, Se, Fe and Zn)
6. Texture (hardness, chewiness)
7. Microscopic structure

These drying temperatures in hot air drying were selected on the basis of preliminary studies. It was observed that drying at 40°C took a very long time and doing that at 80°C gave charred product which was unacceptable.

3.2.3 Storability of the dried product

To study the storability of the dried products, the dried flakes were stored in metalized polyester polyethylene (MPP) pouch and low density polyethylene (LDPE) pouch. The dried powder samples were kept in two types of packages; viz. polyethylene terephthalate (PET) bottle, metalized polyester polyethylene (MPP) pouch and changes in different quality parameters with time were studied. The independent and dependent parameters of the study are thus as follows:

- **Independent parameter**

Packing materials
Flakes (LDPE pouch and MPP pouch)
Powder(PET bottle and MPP pouch)

- **Dependent parameters**

  Flakes

  1. Moisture content
  2. Colour
  3. Total phenolics and DPPH
  4. Rehydration Ratio

  Powder

  1. Moisture
  2. Colour

3.3 Drying Equipment

3.3.1 Hot air dryer

A laboratory hot air dryer (Make:Smita Scientific, Model: STRD-1) was used for this investigation. The dryer has 6 trays of 400mm×800mm×30mm size. The samples were kept in the dryer after the dryer reached the desired air temperature for drying. Six hundred grams of sample was placed on trays and dried until the desired weight corresponding to the final moisture content was achieved. The sample tray was removed from dryer and weighed regularly, initially at intervals of 15 minutes (up to 1 hour) and then onwards at 30 minutes intervals. Three replicates were taken for each experiment. The drying of samples in hot air dryer was continued till a final moisture content of 9% (d.b.) (Kim, 2004). The drying air temperature was maintained at 50, 60 and 70°C. The drying rate were computed from the experimental data and corresponding drying characteristics curves were plotted.

3.3.2 Microwave convective dryer

A laboratory microwave convective dryer (Mohanta *et al.* 2014) was used for the study. The system has a maximum output 900W at 2450 MHz. The dimension of the microwave cavity was 215mm × 350mm × 330mm. The oven has a fan for hot air flow in drying chamber and cooling of magnetron. The blower and heater were connected to the oven. The moisture from drying chamber was removed with blower air by passing it through the openings on the top of the oven wall to the outer atmosphere. The oven was fitted with a glass turntable (30 cm diameter) and had a digital control facility to adjust the microwave output power by the 20% decrements and the time of processing. The fresh cut mushrooms were uniformly spread on paper cardboard plate and kept on turntable inside the microwave cavity, for an even absorption of microwave energy. Three replicates were taken for each experiment. Depending on the drying conditions, moisture loss was recorded at 5 min, 3 min or 2 min intervals by removing the plate from the microwave, and periodically placing the sample on the digital balance (Soysal *et al.*, 2006). The material loaded for each section of drying was 250g and the drying was continued till the samples reached a moisture content of 9% (d.b.).

3.3.3 Freeze dryer

A laboratory freeze dryer (MAC: MSW-137) was used for the study. The fresh sliced mushroom were frozen at -20°C for 24 h and then lyophilized in a freeze dryer for 17h. The condenser temperature was set at -40°C, the vacuum was maintained at 0.8 mbar, and shelf temperature was set at 20°C.

3.4 Drying kinetics and mathematical modelling

3.4.1 Moisture content

Moisture content of fresh and dried samples were measured by using hot air oven method. A digital balance (Mettler Toledo, Switzerland; Model number: ME54E) was used for taking the weight of the samples. The samples were kept in hot air oven (Make: Uni-Tech, Model-UTS1.01C) at 105°C for 24 hours (AOAC, 1990).

3.4.2 Moisture ratio

The moisture ratio (MR) of the samples during drying process was calculated at any time using the following equation**.**

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad \ldots(3.1$$

where, M_t= moisture content (% d.b.) at the particular time, M_e = Equilibrium moisture content (% d.b.) and M_o = Initial moisture content at time, t=0

Various exponential forms of empirical models have been developed and tested by many investigators. In this expression, the moisture ratio has been simplified to

M_t/M_0, instead of equation 3.1, because of the fact that air humidity in the hot air dryer was not constant (Rayaguru and Routray; 2012).

3.4.3 Drying rate

The removal of water with time for each drying condition was observed regularly. The drying rate of each time interval for each drying temperature was calculated by considering the water removed per unit time for the interval.

$$\text{Drying rate} = \frac{\text{Amount of water removed (g/g)}}{\text{Time taken in min.} \times \text{amount of dry matter (g)}} \qquad \text{...(3.2}$$

3.4.4 Effective moisture diffusivity and activation energy

Drying of most food materials occurs in the falling rate period (Wang and Brennan, 1992), and moisture transfer during drying is controlled by internal diffusion (Saravacos and Charm, 1962). For most biological materials, Fick’s second law of diffusion has been widely used to describe the drying process during the falling rate period (Saravacos and Maroulis, 2001; Crank, 1975) as follows:

$$\frac{\partial M}{\partial t} = \nabla\left[D_{eff}(\nabla M)\right] \qquad \text{...(3.3}$$

where, D_{eff} is the effective moisture diffusivity representing the conductive term of all moisture transfer mechanisms. This parameter is usually determined from experimental drying curves (Saravacos and Maroulis, 2001). The solution of Fick’s second law in slab geometry is given by Crank (1975) as shown in Eq. (3.4), assuming moisture migration being only by diffusion, constant temperature and effective moisture diffusivity, and negligible shrinkage:

$$\frac{\partial M}{\partial t} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2 D_{eff} t}{4L^2}\right) \qquad \text{...(3.4}$$

where, L is the half thickness of the slab in the samples (m) and n is a positive integer. In practice, only the first term of Eq. (3.4) is used, yielding

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \qquad \text{...(3.5}$$

The effective moisture diffusivity can be determined from the slope of the normalized plot of the unaccomplished moisture ratio, ln (MR)-vs-time, using the following equation:

$$D_{eff} = \frac{-slope 4L^{2}}{\pi^{2}} \qquad ...(3.6$$

Temperature dependence of the effective diffusivity has been shown to follow an Arrhenius relationship.

$$D_{eff} = D_{0} \exp\left(\frac{-E_{a}}{RT}\right) \qquad ...(3.7$$

where, D_0 is the pre-exponential factor of the Arrhenius equation (m^2s^{-1}), E_a is the activation energy (kJ mol^{-1}), R is the universal gas constant (kJ $mol^{-1}K^{-1}$), and T is the absolute air temperature (K). The activation energy is determined from the slope of the Arrhenius plot, ln (D_{eff}) vs. $1/T$.

3.4.5 Mathematical modelling

The moisture loss data obtained from the drying experiments were fitted to different standard drying equations as given in Table 3.1.

Table 3.1 Different drying models used for analysis of drying data

S. No.	Model equation	Name	Reference
1	$MR = ae^{\left(-kt^{n}\right)} + bt$	Midilli	Midilli *et al.* (2002)
2	$MR = e^{\left(-kt^{n}\right)}$	Page	Page (1949)
3	$MR = e^{(-kt)^{n}\,n}$	Modified page	Modified page (1965)
4	$MR = ae^{(-kt)}$	Henderson and Pabis	Henderson and Pabis (1961)
5	$MR = e^{(-kt)}$	Newton	O' Callaghan *et al.*, (1971)
6	$MR = 1+at+bt^{2}$	Wang and Singh	Wang and Singh (1978)
7	$MR = ae^{(-kt)} + c$	Logarithmic	Dawn *et al.* (2015)
8	$MR = a * b^{x}$	Modified power	Tuncay *et al.* (2015)
9	$MR = ae^{(-k_{0}t)} + be^{(-k_{1}t)}$	Two -term	Dadali and ozbek (2008)

Based on the initial moisture content from oven drying, the weight loss during drying was used to calculate the moisture content at different time intervals. The drying characteristic curves were plotted. Mathematical modelling was carried out to describe the drying curve equations and to determine the parameters of the thin layer drying models by fitting experimental data to the model equations. The thin layer drying equation was tested to select the best model. The non-linear regression analysis was performed using the software DATAFIT 9.0 and the graphs were plotted using Microsoft Office 2007 Excel. Although the coefficient of determination (R^2) was one of the primary criterions for the selecting the best model to describe thin layer curves of leaf samples, the statistical test methods such as standard error of estimates (SEE) and residual sum square (RSS) were also used to evaluate the goodness of fit of the models. The lower SEE value and the higher R^2 (Coefficient of determination) values were determined as the basis for goodness of fit.

The drying curve for each experiment was obtained by plotting the dimensionless moisture ratio of the sample vs. the drying time. Modelling the drying behaviour of different agricultural products often requires the statistical method of regression and correlation analysis. Linear and non–linear regression models are important tools to find the relationship between different variables, especially, for which no established empirical relationship exists.

3.5 Quality analysis of dried product

3.5.1 Colour measurement

Colour of the sample was measured by a colour reader CR-20 (Konica Minolta, INC. Japan) as shown in fig. The colorimeter was calibrated using white control sample (L*= 56.56, a* = 1.96, b* = 10.86). Coordinates ‘L’ represented the lightness of colour (0 = black; 100 = white), −a/+a greenness or redness, and –b/+b blueness or yellowness. The mushroom samples were ground in a laboratory grinder and passed through a 60 mesh sieve prior to colour analysis. Samples were kept in petri plates and colour was measured. For each sample, five measurements were taken and averaged. The total colour change (ΔE) was calculated as (Altan *et al.* 2008).

$$\Delta E = \sqrt{\left(L - L^*\right)^2 + \left(a - a^*\right)^2 + \left(b - b^*\right)^2} \qquad \text{...(3.8}$$

where, L, a and b are the average measured values of the sample by colorimeter.

3.5.2 Rehydration ratio and Shrinkage ratio

Rehydration ratio was evaluated by soaking known weight (5-10g) of each sample in sufficient volume of water in a glass beaker (approximately 30 times the weight of sample) at for 20 minutes. After soaking, the excess water was removed with the help of filter paper and samples were weighted. In order to minimize the leaching losses, water bath was used for maintaining the defined temperature (Rangana, 1986). Rehydration ratio of the sample was computed as follows:

$$\text{Rehydration ratio} = \frac{w_r}{w_d} \qquad ..(3.9$$

where , W_r= Drained weight of rehydrated sample, g and W_d = Weight of dried sample used for rehydration, g.

Shrinkage ratio of dried sample was measured by toluene displacement method. Shrinkage ratio was calculated as the percentage change from initial apparent volume (Rangana, 1986).

$$\text{Shrinkage ratio} = \frac{V_r}{V_O} \qquad ...(3.10$$

where, V_r and V_o are volumes displaced by rehydrated sample and fresh sample, respectively.

3.5.3 Nutritional quality

3.5.3.1 Carbohydrate

100 mg of the sample was taken into the boiling tube and hydrolysed by keeping in a boiling water bath for 3 hours with 5 ml of 2.5N HCl and cooled to room temperature. Then it was neutralised with solid sodium carbonate until the effervescence ceased. The volume was made up to 100 ml and centrifuged. Then 0.2, 0.4, 0.6, 0.8 and 1ml of the working standard were pipetted out into a series of test tubes. 0.1 and 0.2 ml of the sample solution were pipetted out in two separate test tubes. The volume was made up to 1ml with water. A blank was set with 1ml of water and 1 ml of phenol solution was added in each tube. Then 5 ml of 96% sulphuric acid was added to each tube and shaken well. After 10 min shaking, the content in the tube was placed in a water bath at 25-30°C for 20 min. The colour was read at 490 nm

using spectrophotometer. The total amount of carbohydrate present in the sample solution was estimated as

$$\text{Total carbohydrate}\,(\%) = \frac{C \times 7}{20 \times W} \qquad ...(3.11$$

where, C=Concentration of sample after absorbance reading and W=Weight of sample taken.

3.5.3.2 Crude protein (CP)

Kjeldahl method is used for determination of crude protein content in raw and dried paddy straw mushroom. This included digestion followed by distillation and then by titration. During the digestion step, all the amino nitrogen is converted to ammonium radical. Distillation involves the separation of the nitrogen from the digestion tube. This isdone by raising the pH with NaOH and by doing this the ammonium radical is converted to ammonia. On heating, the ammonia is distilled out and is collected in 4% boric acid as at rapping medium. In the titration method the determination of the amount of nitrogen in the condensate flask is done by titrating with a standard solution of 0.1N H_2SO_4 in the presence of mixed indicator.

0.3-0.4 g of feed sample was digested on heater after adding 5 ml commercial grade sulphuric acid and 2.5 g digestion mixture (copper sulphate: sodium sulphate in 1: 5 ratio) until it became clear. The flask was allowed to cool and about 50 ml of water was poured slowly along the neck of the flask. The content was shaken and transferred completely into 250 ml volumetric flask by giving repeated washings with tap water and the final volume was made up to 250 ml. 10 ml aliquot of digested feed samples were distilled in a Micro Kjeldahl assembly (as shown in Fig.4) by adding 10 ml of 40% sodium hydroxide solution. Gaseous ammonia thus released was trapped in 10 ml boric acid containing Tashiro’s indicator (boric acid 20 g, 1% solution of methyl red, 12 ml; 1% solution of bromocresol green, 6ml; dehydrated alcohol, 200 ml and distilled water 782 ml). The nitrogen trapped in boric acid was estimated by titrating it against 0.1N sulphuric acid. The normality of acid was checked by titrating against sodium carbonate using methyl orange as indicator. The value of blank was subtracted from sample readings. The crude protein content of samples was determined by the formula.

$$\text{Crude Protein (\%)} = \frac{14.01 \times (\text{ml titrant - ml blank}) \times N \times 6.25}{W \times 1000} \qquad ...(3.12$$

where, N = Normality (0.025) and W = weight (g) of oven dried sample taken for digestion. 6.25 is factor for converting nitrogen into crude protein of sample.

3.5.3.3 Crude fibre

Two grams of fat free dried sample was weighed and transferred to one litre capacity spoutless beaker. 200 ml 1.25% $H_2S0_4$was added to it. The beaker was connected with a round bottom condenser for reflux and heat was applied so that the content of beaker began to boil. The contents were shaken frequently so that the material would not stick to the wall of the flask. The boiling was continued for 30 minutes. Then the beaker was removed and the contents were filtered through the muslin cloth with the help of vacuum or suction pump and the residue was washed with hot water till it was free from acid. The material was transferred to the same beaker and 200ml of 1.25% NaOH solution was added. Again the contents were refluxed for 30 minutes. The contents were filtered again through the sintered glass crucible with the help of vacuum or suction pump and the residue was washed with hot water till it was free from alkali. Then the sintered glass crucible was kept in hot air oven, dried at 100°C to a constant weight and its weight was recorded. The residue was then ignited in muffle furnace at 600°C for 2 hours and then cooled and weighed again. The loss of weight due to ignition is the weight of crude fibre.

$$\text{Crude fibre \% (on d.b.)} = \frac{W_1 - W_2}{W_0} \times 100 \qquad ...(3.13$$

where, W_0 = Weight of dried material taken, W_1 = Weight of crucible and contents before washing and W_2= Weight of the crucible with ash.

3.5.3.4 Ash content

Five gram sample was weighed accurately in to a tared platinum or porcelain crucible (which has previously heated to about 600°C and cooled). The crucible is placed on a clay pipe triangle and heated first over a low flame till all the material was completely charred, followed by heating in a muffle furnace for about 3-5 hours at 600°C. It was then cooled in a desiccator and weighed. This was repeated till two consecutive weights were the same and the ash was almost white or greyish white in colour.

$$\text{Ash content}\,(\frac{g}{100g}) = \frac{\text{weight of ash}}{\text{weight of sample taken}} \times 100 \qquad ...(3.14$$

3.5.3.5 Ascorbic Acid (AA)

Five grams of sample was grand in a mortar and pestle by adding 10ml of 3% metaphosphoric acid (HPO_3). It was then transferred to a beaker and 40ml of metaphosphoric acid was added to it. Then it was centrifuged for 10-15 minutes and the aliquot or the filtrate was collected. 5ml of standard ascorbic acid solution and 5 ml of 3% metaphosphoric acid was taken in a conical flask and mixed together. It was titrated against the prepared dye solution to get the dye factor and a onion pink colour end point. The dye factor was calculated as 0.5/Titre value.

Then, 2-10 ml of the aliquot or filtrate sample was taken and titrated with the dye to a pink end which persist for at least 15 seconds. The aliquot of the sample taken should be such that the titre should not exceed 3 to 5 ml. Ascorbic acid (mg/100g) was calculated using following expression:-

$$AA = \frac{\text{Titre value} \times \text{dye factor} \times \text{volume made up}}{\text{extracted liquid taken for estimation} \times \text{wt.of sample taken for extraction}} \times 100 \; ...(3.15$$

3.5.3.6 Reducing sugar

One hundred mg of the sample was weighed and extracted with hot 80% ethanol twice (5ml each time). The supernatant was collected and evaporated by keeping on a water bath at 80°C. 10 ml water was added to dissolve the sugars. 0.5 to 3 ml of extract was pipette out in test tube and equalised to 3 ml with water in all the tubes. 3ml of DNS reagent was added. The contents were heated in a boiling water bath for 5 min. When the contents of the tubes are still warm, 1ml of 40% Rochelle salt solution was added. It was then cooled and the intensity of dark red colour was read at 510 nm. The total amount of reducing sugar present in the sample solution was estimated as

$$\text{Reducing sugar (\% per100gram)} = \frac{C}{50 \times W} \qquad ...(3.16$$

where, C= concentration of sample after absorbance reading and W= Weight of sample taken.

3.5.3.7 Total phenolics

Total phenolic content was determined by using Folin-Ciocalteu colorimeter method based on method of Harborne (1989) with several modifications. One gram sample was kept in 10 ml of 80% methanol for 15 hours at room temperature. Then it was centrifuged and homogenized to get a clear extract. Now 0.5 ml of extract, 7.5 ml of distilled water and 1 ml of Folin-Ciocalteu reagent were mixed and left for 5 minutes. After that 1 ml of saturated Na_2CO_3 solution was added. Then the spectrophotometer (as shown in plate 3.14) reading was taken at 760 nm after 1 hour.

For standard solution, 10 mg gallic acid in 10 ml pure methanol (1mg/ml) of 1000 ppm was prepared. If the solution was dark in colour then the standard and sample were diluted 10 times (i.e. 1ml sample and 9 ml distilled water).

$$\text{Total phenolic}\,(\text{mg}\,\frac{\text{GAE}}{100\text{g}}) = \frac{\text{Concentration of sample after absorbance reading}}{\text{Weight of sample taken} \times 10} \quad ..(3.17$$

3.5.3.8 Radical scavenging activity DPPH (%)

Determination of antioxidant activity of sample was done by 2,2- diphenyl-2-picryl-hydrazyl (DPPH) inhibition method. Sample (1 g) was taken in 10 ml methanol and was kept overnight for extraction. This eluted extract was taken (0.2 ml) and to it 1 ml of DPPH solution (80 µg/ml methanol) was added. The sample sets were centrifuged at3,000 rpm for 15 min (Sigma laboratory centrifuge 3 K 18, Germany).0.5 ml of centrifuged solution was taken in a cuvetteand to it 1 ml of methanol was added. Absorbance was taken at 515 nm separately for blank and samples with pure methanol as reference using Perkin Elmer UV/VIS spectrometer Lambda 25, Germany.

$$\text{Radical scavenging activity DPPH}\,\% = \frac{A_C - A_S}{A_C} \times 100 \qquad ....(3.18$$

where, A_C = absorbance of control and A_S=absorbance of sample

3.5.3.9 Minerals

One gram ground plant material is placed in 100 ml volumetric flask. To this, 10 ml of acid mixture was added and the content of the flask was mixed by swirling. The flask was placed on low heat hot plate in a digestion chamber. Then, the flask was heated at higher temperature until the production of red NO_2 fumes ceased. The contents were further evaporated until the volume was reduced to about 3 to 5 ml, but not to dryness. The completion of digestion was confirmed when the liquid became colourless. After cooling the flask, 20 ml of deionised or glass-distilled water was added. Volume was made up with deionised water and the solution was filtered through Whatman no. 1 filter paper. Aliquots of this solution were used for the determination of Ca Mg, Mn, Zn, K, Na, Fe and Se by using ICP-OES (Inductive coupled plasma optical emission spectrometer).

$$\%Element = \frac{5P}{W} \qquad ...(3.19$$

where, P = sample concentration reading taken by ICP-OES and W = weight of sample taken.

3.5.4 Functional Quality

3.5.4.1 Water Absorption Index (WAI)

The water absorption index dried mushroom powder sample was determined according to Anderson *et al.* (1969). Powdered sample (2.5 g) was suspended in 30 ml distilled water in a 50 ml pre weighed centrifuge tube by vortexing. They were then placed at 30^{0}C in water bath and intermittently stirred for 30 min. The suspension was centrifuged for 30 min. at 2000 rpm and the supernatant was decanted into a pre-weighed 50 ml breaker. The weight of wet sediment was used to calculate the water absorption index. It is calculated from the following expression.

$$\text{WAI(g starch/ g dry sample)} = \frac{\text{wt.of the wet sediment}}{\text{Initial dry wt.of the powder}} \qquad ...(3.20$$

3.5.4.2 Water solubility index (WSI)

The water solubility index of dried mushroom powder was determined according to Anderson *et al.* (1969). Powdered sample (2.5 g) was suspended in 30 ml distilled water in a 50 ml pre weighed centrifuge tube by vortexing. They were placed in 30^{0}C water bath and intermittently stirred for 30 min. The suspension was centrifuged in the centrifuge for 30 minute at 2000 rpm and the supernatant was decanted into a pre-weighed 50 ml beaker. The weight of wet sediment was used to calculate the water absorption index. The supernatant was dried at 95^{0}C to constant weight and the weight of the dried solids was used to determine the water solubility index. WSI is the ratio of the wt. of the solids recovered by evaporating the supernatant taken from the above study and the initial weight of the powdered sample taken.

$$\text{WSI }\% = \frac{\text{Weight of solid recovered by evaporating of supernatant (g)}}{\text{Initial weight of powder}} \times 100 \quad ...(3.21$$

3.5.4.3. Oil absorption index (OAI)

The oil absorption index of mushroom powdered was determined using the method of Okezie and Bello (2006). One gram of powdered sample was introduced into a centrifuge tube and was thoroughly mixed with 30 ml sunflower oil (sp. gravity 9.2). The sample was then allowed to stand for 30 minutes and then centrifuged at 1500 rpm for 30 minutes. The free oil was decanted into a graduated cylinder and the volume was measured.

$$\text{OAI}\left(\frac{\text{g}}{\text{g}}\right) = \frac{\text{Weight of oil absorbed}}{\text{Dry weight of powder}} \quad ... (3.22$$

3.5.5 Texture Analysis

A texture analyzer (Make: Stable Micro System, Surrey, United Kingdom, Model: TA.XT plus) was used to determine hardness and chewiness of dried mushrooms sample. The cylindrical probe selected for analysis had a diameter of 25 mm. The peak force was recorded as the hardness was measured in terms of number of positive peaks in the curve. For analysis the experimental parameters were taken as per Geetha*et al*. (2014). The curves were recorded and analyzed. The TA.XT2 settings were kept as follows:

Probe : 25mm
Pre-test speed : 1 mm/sec
Test speed : 0.5 mm/sec
Post-test speed : 10mm/sec
Distance : 50% strain

3.5.6 Microscopic Structure

The structure of the dehydrated paddy straw mushroom slices was examined using a scanning electron microscope (HITECH- 53400N) coupled with an energy dispersive X-ray microanalytical system (OXFORD ISIS-300). Thin slice of about1 mm thick was cut from the dried samples and fixed on the SEM stub, which were subsequently coated with gold in order to provide a reflective surface for the electronbeam. Gold coating was carried out in a sputter coater (BIO-RAD E-5200) under a low vacuum with the presence of the inert gas, argon. The gold-coated samples were subsequently viewed under the microscope.

3.6 Storage study

In the storage, three different types of packaging materials were used to study the storability and quality of dried product. The packaging materials used were 280 gauge laminated MPP (Metalised polyester pouch), 240 gauge LDPE (low density polyethene) pouches, PET (Polyethylene terephthalate) bottle. Approximately 50 grams of flakes was stored in each pouch, LDPE and MPP. For storage study of powder, 30 grams of powder was stored in MPP and PET. The packages were stored in dark up to 3 months. Each packet of different packaging material was selected randomly to study the changes in the quality during storage.

3.7 Sensory evaluation

Sensory evaluation of the dried flakes and powder were carried out by panel of skilled members. Mushroom carry of rehydrated flakes and soup were prepared by using home made recipe. Panellist were provided with a glass of water and instructed to rinse and swallow water between samples. They were given between written instructions and asked to evaluate the products for acceptability based on their colour flavour, texture, taste and overall acceptability using nine-point hedonic scale following the procedure of Meilgaard *et al*. (1999), David Peryam *et al.* (2001) developed the scale at the Quartermaster Food and Container Institute of the U.S. Armed Forces, for the purpose of measuring the food preferences of soldiers.

3.6 Statistical Analysis

The experiments were installed using a completely randomized factorial design with three replications. The data obtained were submitted to analysis of variance. For statistical analysis of quality parameters, SAS 9.3 was used.

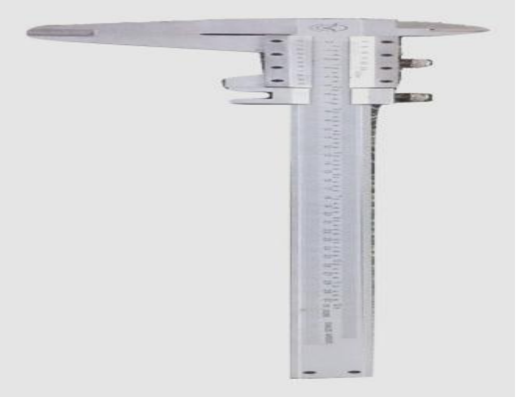
 Fig. 3.1 Hot air oven	 Fig. 3.2 Cabinet dryer
 Fig. 3.3 Raw sample	 Fig. 3.4 Dried sample
 Fig. 3.5 Colourimeter	 Fig. 3.6 Vernier calliper
 Fig. 3.7 kjeldahl assembly	 Fig. 3.8 spectrophotometer

 Fig. 3.9 Fibra plus	 Fig. 3.10 Sealing machine
 Fig. 3.11 ICP-OES	 Fig. 3.12 Centrifuge
 Fig. 3.13 Texture analyzer	 Fig. 3.14 MPP and LDPE
 Fig. 3.15 PET bottle	

Chapter 4

RESULTS AND DISCUSSION

As discussed in the previous chapter, drying characteristics of paddy straw mushroom was studied in convective hot air drying, microwave convective drying and freeze drying. Besides, the effects of different operational parameters during drying on quality characteristics of dried products were studied. Various mathematical models were also tested for representing the drying behaviour of the mushroom under different conditions. The dried mushroom was also stored in different types of packages to know the change in characteristics of dried product during storage. The results obtained from these studies have been presented and discussed in this chapter.

4.1 Drying characteristics

4.1.1 Hot air convective drying

The mushroom samples were dried in a laboratory hot air dryer at temperatures of 50°, 60° and 70°C. As discussed before, the initial moisture content of sample was 837.20 % (d.b.) and the final moisture content of the samples were kept as 9% (d.b.). The air flow was kept as 1 $m.s^{-1}$.

4.1.1.1 Effect of drying air temperature on drying characteristics

Fig. 4.1 represents the variation of moisture content with drying time for hot air convective drying (HAD) of mushrooms at 50, 60 and 70°C. The drying rate, defined as the quantity of water removed per unit mass per unit time-vs.- average moisture content were also calculated and are shown in Fig. 4.2. Fig. 4.3 shows the moisture ratio versus drying time. Fig. 4.4 represents the variation of ln (moisture ratio) with time in HAD. As expected, the drying rates and the moisture ratio decreased with increasing drying time. There was no constant rate drying period and all drying operations were found to occur in the falling rate period. The results agree with the earlier observations of Apati (2010) and Tulek (2011) for oyster mushroom; and Giri and Prasad (2007) for button mushroom, Lee and Lee (2008) for chaga mushroom, Krokida *et al.* (2003) for various vegetables.

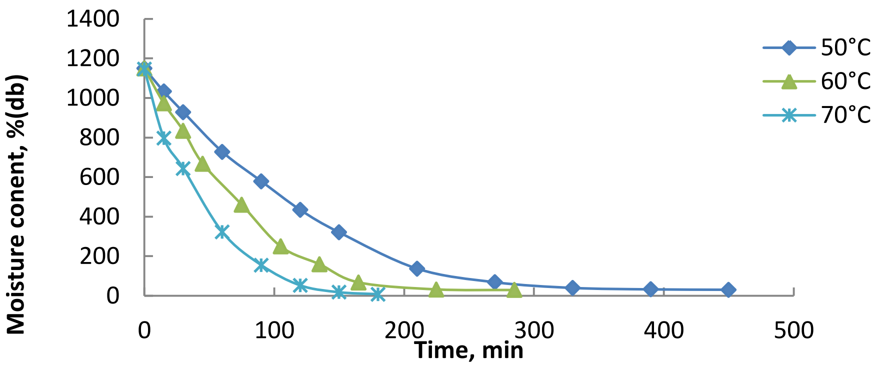


Fig. 4.1 Moisture loss of mushroom in hot air drying (HAD)

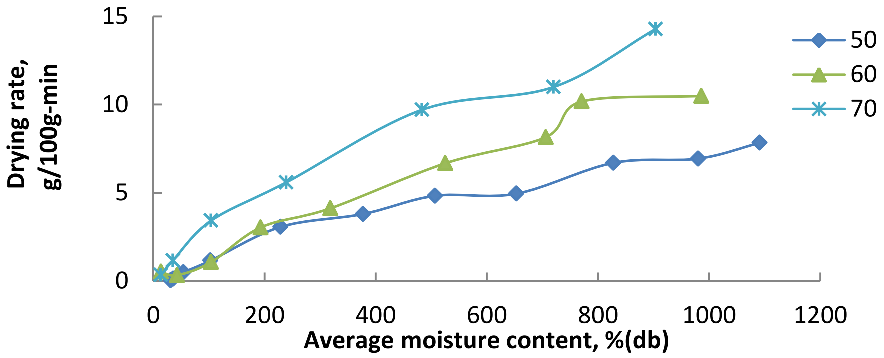


Fig 4.2 Variation of drying rate with average moisture content in HAD

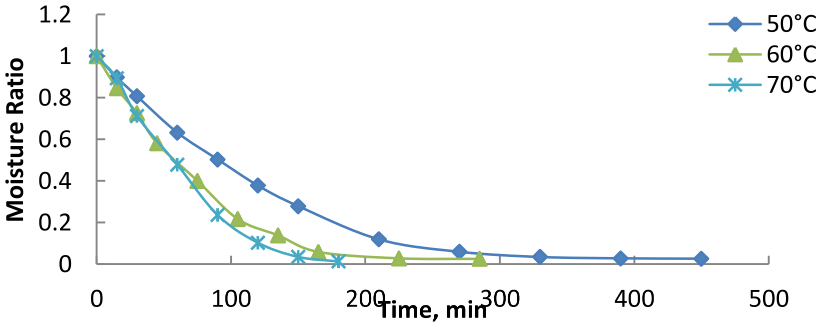


Fig 4.3 Variation of moisture ratio with drying time in HAD

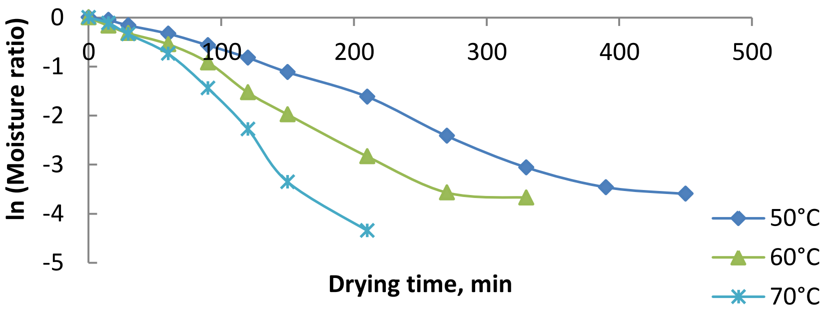


Fig 4.4 Variation of ln (moisture ratio) with time in HAD

4.1.1.2 Effective diffusivities and activation energy

Table 4.2 Effective diffusivity and activation energy in HAD condition

Temperature	Effective diffusivity(m^2/min)	Activation energy
50°C	3.0572×10^{-10}	44.97KJmol^{-1}
60°C	4.0763×10^{-10}	
70°C	8.1526×10^{-10}	

The effective diffusivities obtained by eq. 3.8 at 50°, 60° and 70°C were 3.057×10^{-10}, 4.076×10^{-10} and 8.152×10^{-10} m^2s^{-1}, respectively. These values are within the range reported for different food materials by Madamba *et al.*(1996). This is also consistent with the reports of Chong *et al.* (2008), Doymaz (2007) for pumpkin slices, Doymaz (2009) for spinach leaves, and Bhattacharya *et al.* (2015) for oyster mushroom. The logarithm of effective diffusivity (D_{eff}) as a function of the reciprocal of the absolute temperature (T) is plotted in Fig. 4.5, which is approximated as a linear relationship between ($\ln D_{eff}$) and (1/T). The calculated activation energy (E_a) was 44.97 kJ mol^{-1}.

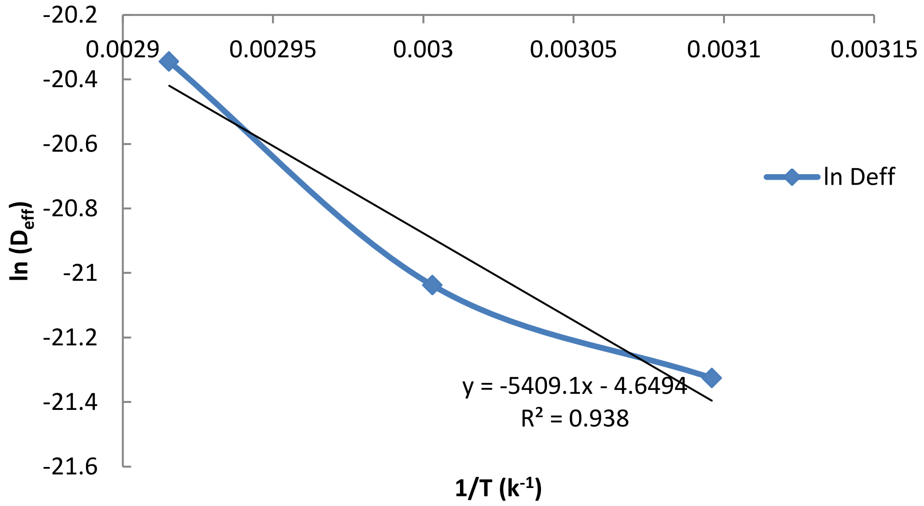


Fig 4.5 Arrhenius relationship between effective moisture diffusivity and reciprocal of the absolute temperature

4.1.1.3 Modelling of drying kinetics

To normalise the drying curves, the data involving dry basis moisture content verses time were transformed to a dimensionless parameter called moisture ratio and plotted against drying time (Fig. 4.4). As discussed in the previous section, the moisture content data for different experimental runs were converted to the most useful moisture ratio expression and the curve fitting computation with the drying time were carried out on four drying models evaluated by previous workers for different products (Table 3.1). The model was evaluated based on R^2, standard error of estimate (SEE), and residual sum of square (RSS) (Arora *et al.* 2003; Giri and Prasad, 2007).

It was observed that the R^2 value was highest with minimum standard error and RSS value for Page Model for all the three drying air temperatures and the Page Model (1949) could satisfactorily describe the drying characteristics of mushroom at all the three selected temperatures. The coefficient obtained for different models fitted at the different temperatures are reported in Table 4.3. The accuracy of the established model for the convective drying process was evaluated by comparing the predicted moisture ratio with observed moisture ratio. The performance of the model for all the drying conditions has been illustrated in Fig. 4.6. The predicted data generally banded around the straight line which showed the suitability of the Page Model in describing the drying behaviour of mushroom in convective drying.

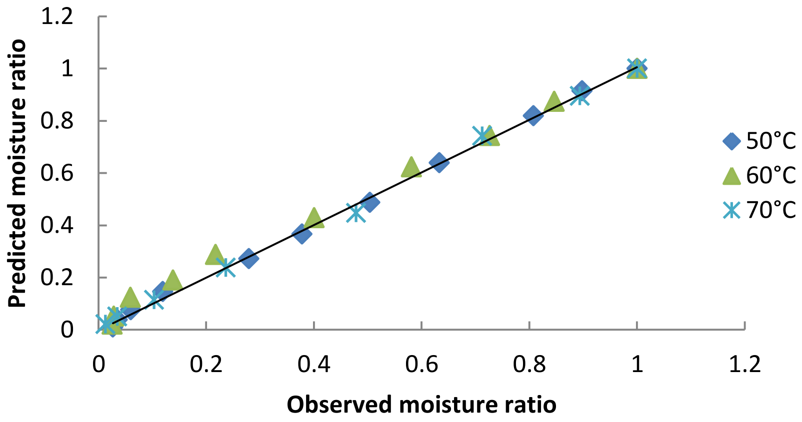


Fig 4.6 Comparison of predicted moisture ratio (Page Model) with observed moisture ratio in HAD

Table 4.3: Results of statistical analysis on the modelling of moisture ratios and drying time for the HAD

Temperature	Model name	Model equation	Coefficient	R^{2}	Std. Error	RSS
50°C	Page	$MR = e\left(-kt^{n}\right)$	k= 0.00383 n =1.16357	0.998468	0.014957	0.002237
	Modified power	$MR = a * b^{x}$	a =1.028299 b = 0.99135	0.995049	0.026884	0.007227
	Modified Page	$MR = e\left(-kt\right)^{n}$	K = -0.091 n = -0.091	0.993906	0.029827	0.008896
	Wang and Singh	MR= 1+at+bt^{2}	a =-0.006 b =0.0000087	0.991287	0.035666	0.012721
60°C	Page	$MR = e\left(-kt^{n}\right)$	K=0.00608 n =1.143655	0.996615	0.022454	0.004033
	Modified power	$MR = a * b^{x}$	a =1.020432 b =0.988178	0.993642	0.030773	0.007576
	Modified Page	$MR = e\left(-kt\right)^{n}$	k = -0.10777 n = -0.10777	0.993022	0.032239	0.008315
	Wang and Singh	MR= 1+at+bt^{2}	a = -0.00820 b =0.0000163	0.987919	0.042421	0.014396
70°C	Page	$MR = e\left(-kt^{n}\right)$	k =0.00231 n = 1.429858	0.997954	0.019339	0.002244
	Modified power	$MR = a * b^{x}$	a = 1.070035 b = 0.984319	0.996043	0.026893	0.004339
	Modified Page	$MR = e\left(-kt\right)^{n}$	k = -0.12135 n =-0.12136	0.978101	0.063265	0.024014
	Wang and Singh	MR= 1+at+bt^{2}	a =-0.0108 b =0.0000294	0.97089	0.072941	0.031922

4.1.2 Microwave convective drying (MWCD)

To investigate the effect of microwave output power on moisture content, moisture ratio and drying time, three microwave power levels 0.72, 1.44, 2.16 W/g were taken at a constant convective air temperature of 50°C. The moisture content was reduced to approximately 9.21% (d.b.) from the initial value of 900% (d.b.) during the drying at different power levels.

4.1.2.1 Effect of power level on drying characteristics

Fig. 4.7 represents the variation of moisture with drying time for microwave convective drying (MWCD) of mushroom at 0.72, 1.44 and 2.16 W/g. The microwave power level affected the drying rates for all conditions and the drying rates increased with the increase in microwave power levels (Fig. 4.8). Figs. 4.9 and 4.10 show the moisture ratio versus drying time and the variation of ln (moisture ratio) with time, respectively. The moisture content of the material was very high during the initial phase of drying which resulted in higher absorption of microwave power and higher drying rates due to the higher moisture diffusion. 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. These results are similar to those reported by Naik *et al.* (2006), Arumuganathan *et al.* (2009) and Giri and Prasad (2007) for the microwave drying of mushroom.

4.1.2.2 Effective diffusivities and activation energy

The effective diffusivities for drying of mushroom as obtained by Eq 3.8 at 0.72, 1.44 and 2.16 W/g were 4.99×10^{-9}, 6.14×10^{-9} and 6.35×10^{-9} m^2s^{-1}, respectively (Table 4.4).

Table 4.4 Effective diffusivity and activation energy in MWCD

Microwave power level, W/g	**Effective diffusivity (m^2/min)**	**Activation energy**
0.72	4.99346×10^{-9}	0.336 W/g
1.44	6.14841×10^{-9}	
2.16	6.35222×10^{-9}	

The logarithm of effective diffusivity (D_{eff}) as a function of the mass per unit power level is plotted in figures 4.11, which is approximated as a linear relationship between (ln D_{eff}) and (m/P). The calculated activation energy (E_a) was 0.336 W/g. It was observed that the value of effective diffusivity was higher than that of hot air drying. The effective moisture diffusivity increased with decrease in moisture content. Further, the moisture diffusivity was higher at any level of moisture content at a higher microwave power level. The temperature of the product rose rapidly in the initial

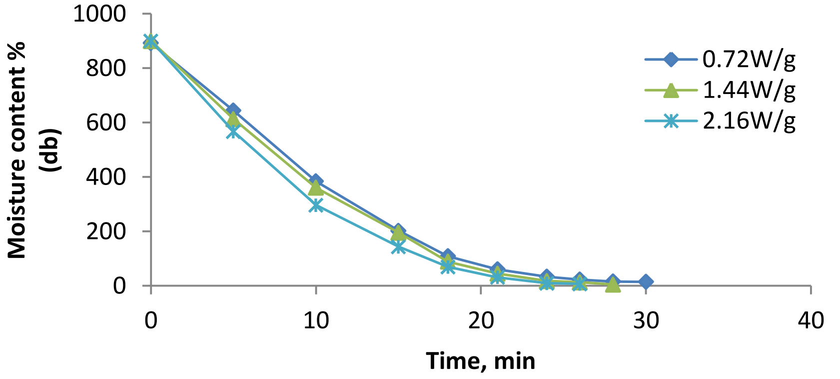


Fig 4.7 Variation of moisture content (d.b) with time in MWCD

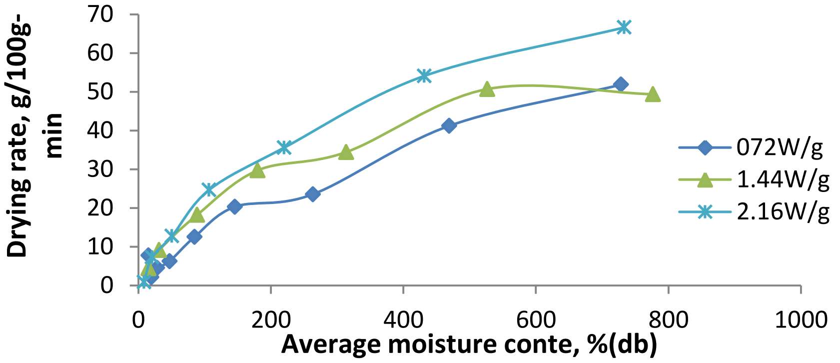


Fig 4.8Variation of drying rate with average moisture content MWCD

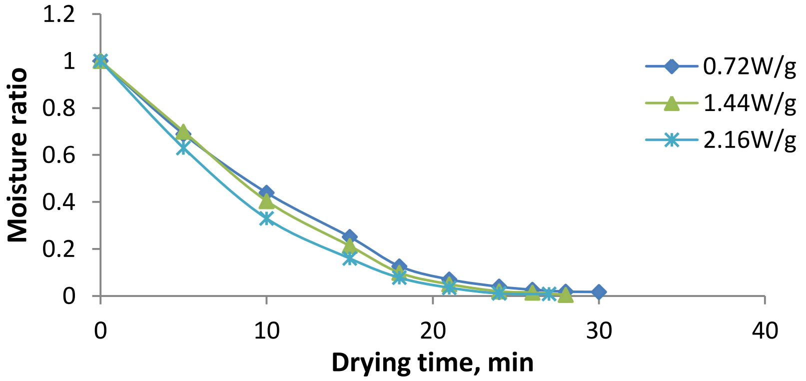


Fig 4.9 Variation of moisture ratio with drying time in MWCD

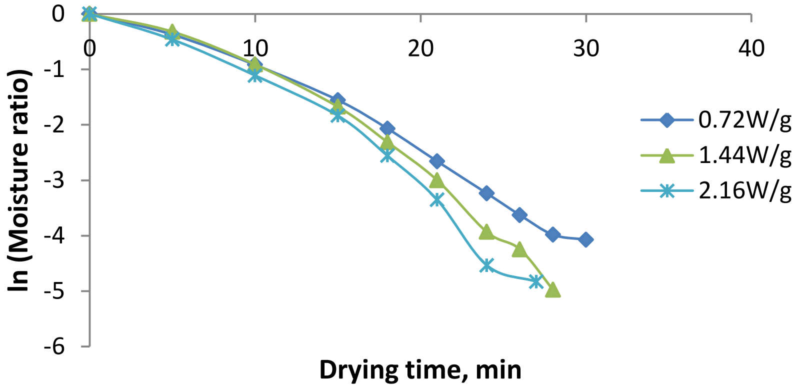


Fig 4.10 Variation of ln(moisture ratio) with time in MWCD

stages of drying, due to more absorption of microwave heat, as the product had a high loss factor at higher moisture content. This increased the water vapour pressure inside the pores and resulted in pressure induced opening of pores. In the first stage of drying, liquid diffusion of moisture could be the main mechanism of moisture transport. As drying progressed further, vapour diffusion could have been the dominant mode of moisture diffusion in the latter part of drying. Sharma and Prasad (2004) and Sharma *et al.* (2005) also reported a similar trend in the variation in the moisture diffusivity with moisture content.

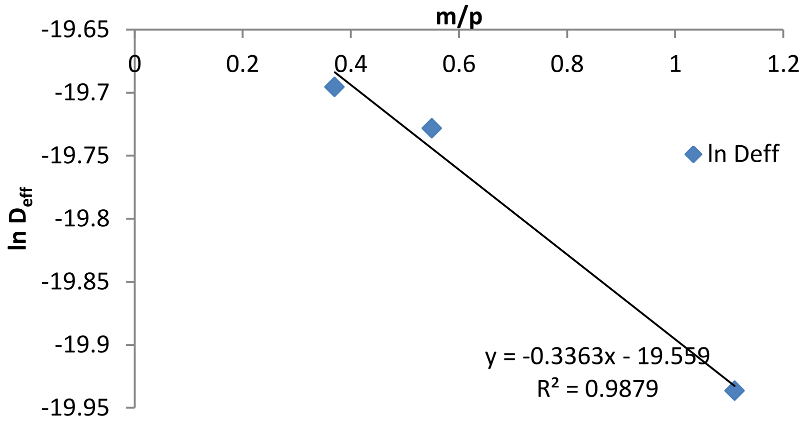


Fig 4.11 Arrhenius type relationship between effective ln (Deff) and reciprocal of microwave power

4.1.2.3 Modelling of drying kinetics

To describe the effect of microwave output power on the drying kinetics of paddy straw mushroom, nine different semi-empirical thin layer drying models, as mentioned in Table 3.1, were used. Among the models examined, the Wang and Singh (1978) was observed to be the most appropriate one for representing the drying behaviour with the higher value for the coefficient of determination (R^2) and lower standard error and RSS compared with those obtained for the other models. It was observed that the value of drying rate constant (k) increased with the increase in microwave output power. This implies that with the increase in microwave output power, drying curve becomes steeper indicating increase in drying rate. The reported results are in agreement with Izki and Iski (2014) for button mushroom. Ghaderi *et al.* (2012) and Artnaseaw *et al.* (2010) reported that drying characteristics of mushroom were best described by model proposed by Midilli *et al.* (2002). On the other hand, Xanthopoulos *et al.* (2007) found that the Logarithmic model (2002) showed the best fit to experimental drying data of mushrooms. Diffusion Approach (2001) and Wang and Singh (1978) models were also suggested by Sacilik *et al.* (2006) and Farhang *et al.* (2010) to describe drying behaviour of different food products. The fitness of the data is illustrated in Fig 4.12.

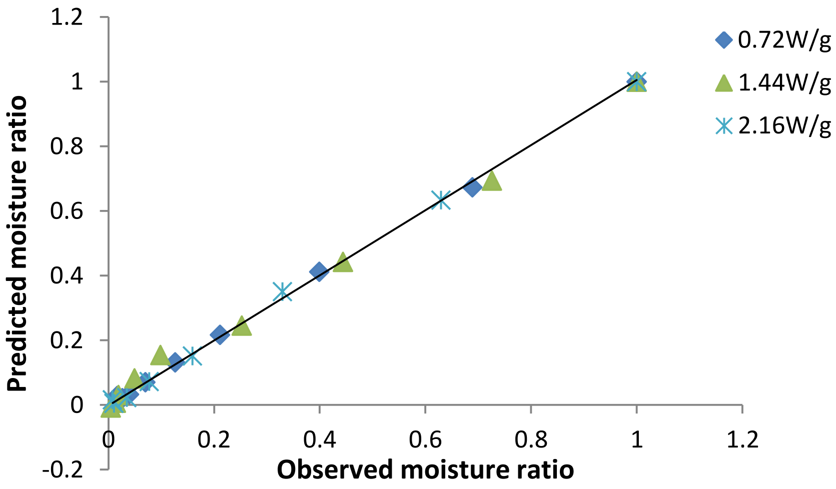


Fig. 4.12 Variation of predicted moisture ratio (Wang and Singh) with observed moisture ratio in MWCD

4.1.2.4 Drying times in different drying systems

Table 4.1 gives the drying times obtained for paddy straw mushroom at different dying conditions. It was observed that freeze drying took maximum time of 17 hours, whereas the hot air drying took a time of 180-450 minutes. The microwave assisted convective drying required only 27-30 minutes for drying of mushroom to the desired moisture level.

Table 4.1 Drying time and moisture content at different drying conditions

Method of drying	Temperature and power level	Final moisture content, %(d.b)	Total drying time, min
Hot air drying	50°C	10.13	450
	60°C	9.81	330
	70°C	9.4	180
Microwave Convective drying	0.72 W/g	10.09	30
	1.44 W/g	9.3	28
	2.16 W/g	9.21	27
Freeze drying	-40°C	9.0	17 hours

4.2 Nutritional quality of fresh paddy straw mushroom

The paddy straw mushroom was tested for selected nutritional quality parameters as per the methods explained in the previous chapter. The moisture content of the fresh paddy straw mushroom was obtained as 89.33±0.47% (wet basis). Total carbohydrate content was estimated as 32.17 ± 0.46% on dry weight basis. The protein content was 40.23±1.14% on dry weight basis. The results are in agreement with Brinda *et al.* (2017) for paddy straw mushroom. Usha and Suguna (2014) have reported the protein content of *Pleurotus ostreatus* and *Agaricus bisporus* mushrooms as 33.3% and 28.1%, respectively. The crude fibre and ash content were 17.48±0.024 g/100g and 7.86±0.015 g/100g (on dry weight basis), respectively. Besides some other important constituents, for which the mushroom is valued, were also studied and the results are presented in table 4.6.

Table 4.6: Nutritional quality of fresh paddy straw mushroom

Quality	Amount
Moisture content	89.33 ± 0.47%
Ash	7.86 ± 0.015 g/100g
Carbohydrates	32.17±0.46%
Protein	40.23±1.4%
Fibre	17.48±0.024 g/100g
Ascorbic acid	60.13±0.26 mg/100g
Reducing sugar	9.74±0.017 g/100g
Total phenolics	13.77±0.02 mg GAE/ g of sample
DPPH Scavenging activity	78.23±0.709%

Table 4.5: Results of statistical analysis on the modelling of moisture ratios and drying time for the MWCD

Microwave power	Model name	Model equation	coefficient	R^2	Std. Error	RSS
0.72 W/g	Wang and Singh	$MR = 1+at+bt^2$	a=-0.0720 b =0.00132	0.999506	0.007909	0.0005
	Page	$MR = e\left(-kt^n\right)$	K=0.040285 n =1.3628	0.999248	0.009756	0.000761
	Modified Power	$MR = a * b^x$	a =1.036168 b =0.899093	0.982661	0.046856	0.017564
	Two term	$MR = ae^{(-k_0t)} + be^{(-k_1t)}$	a =0.51808,k_0 =0.10636 b=0.518084,k_1=0.10636	0.982661	0.054104	0.017564
	Modified Page	$MR = e(-kt)^n$	K= -0.32184 n =-0.32194	0.981115	0.0489	0.01913
1.44 W/g	Wang and Singh	$MR = 1+at+bt^2$	a= -0.0668 b=0.0011	0.997411	0.01936	0.002624
	Page	$MR = e^{\left(-kt^n\right)}$	k=0.0253 n=1.513198	0.996014	0.024021	0.004039
	Modified Power	$MR = a * b^x$	a= 1.050541 b= 0.90326	0.965467	0.0707	0.03499
	Two term	$MR = ae^{(-k_0t)} + be^{(-k_1t)}$	a= 0.525271 b=0.525271 k_0= 0.10174 k_1=0.10174	0.965467	0.083654	0.03499
	Modified Page	$MR = e(-kt)^n$	K=-0.31325 n=-0.31316	0.962384	0.073789	0.038113
2.16 W/g	Wang and Singh	$MR = 1+at+bt^2$	a= -0.0818 b=0.00168	0.999046	0.011905	0.00085
	Page	$MR = e\left(-kt^n\right)$	k=0.0521 n=1.336811	0.998918	0.012678	0.000964
	Modified Power	$MR = a * b^x$	a= 1.02416 b=0.886067	0.985062	0.0471	0.01331
	Two term	$MR = ae^{(-k_0t)} + be^{(-k_1t)}$	a=0.51208,k_0=0.12096 b=0.51208,k_1=0.12096	0.985062	0.057685	0.01331

4.3 Quality of dehydrated mushroom

4.3.1 Colour

The initial colour values of mushroom obtained from the colorimeter were recorded as L=42.7±2.81, a=3.86±0.63, b=9.62±1.35. The mean surface colour (L) values as well as the change in colour (ΔE) of the mushroom dried under different conditions of hot air drying, microwave drying and freeze drying are presented in Table 4.7. The variations of colour change (ΔE) of the dried mushroom samples at different drying conditions are shown in Fig. 4.13.

Table 4.7: Comparison between drying temperatures for colour parameters during hot air drying, microwave convective drying and freeze drying

Parameter	Lightness, L	ΔE
HAD-50	33.92 ± 3.63^{ab}	8.73 ± 0.17^{e}
HAD-60	31.16 ± 4.63^{a}	8.65 ± 0.66^{cde}
HAD-70	24.46 ± 3.86^{b}	7.85 ± 0.31^{abc}
MWCD-0.72W/g	33.54 ± 4.13^{ab}	10.98 ± 1.45^{de}
MWCD-1.44W/g	30.96 ± 7.07^{ab}	9.84 ± 1.76^{ab}
MWCD-2.16W/g	25.64 ± 5.51^{ab}	8.23 ± 1.22^{bcd}
FD	$\mathbf{37.32 \pm 4.72^{ab}}$	$\mathbf{11.86 \pm 0.15^{a}}$

The statistical analysis of the change in colour (ΔE values) has been presented in Annexure 1A. It is observed that the different drying conditions affected the final colour of the dehydrated mushroom. However, considering that paddy straw mushroom initially had a higher moisture content, which also exhibited higher L values, the change in colour through instrumental analysis could not give any conclusive result. It was observed that the freeze dried samples exhibited the maximum change in colour, though there was no significant difference between the freeze dried samples and the samples dried with microwave (1.44W/g) and hot air (70ºC).

Soto *et al.* (2001) and Nour *et al.* (2011) reported that colour values of dried mushroom samples were critical quality parameters for the acceptance of final product, products with high *L** values being preferred by consumers. Furthermore, a decrease in *L** value as the microwave power or temperature increased was reported by Funebo and Ohlsson (1998), for apple, and Orsat *et al.* (2007) for various products. Kotwaliwale *et al.* (2007) noted that the increased darkening of mushroom samples dried at high temperatures could be attributed to the negative influence of high temperature on mushroom pigments. Kurozawa *et al.* (2012) observed that L^* value decreased with increasing temperature.

4.3.2 Rehydration ratio and Shrinkage ratio

Figs. 4.14 and 4.15 represent the rehydration ratio and shrinkage of the dried mushrooms obtained after different drying conditions. Table 4.8 presents the mean values with standard deviations.

Table 4.8 Rehydration ratio (RR) and shrinkage ratio (SR) of dried mushroom

Parameter	RR	SR
HAD-50°C	2.86 ± 0.11^{a}	0.21 ± 0.025^{a}
HAD-60°C	2.60 ± 0.14^{bc}	0.18 ± 0.009^{a}
HAD-70°C	2.65 ± 0.094^{b}	0.19 ± 0.018^{a}
MWCD-0.72 W/g	2.51 ± 0.017^{bc}	0.19 ± 0.004^{a}
MWCD-1.44W/g	2.48 ± 0.087^{c}	0.19 ± 0.004^{a}
MWCD-2.16W/g	2.51 ± 0.030^{bc}	0.19 ± 0.001^{a}
FD	$\mathbf{2.94\pm0.059^{a}}$	$\mathbf{0.11\pm0.005^{b}}$

The rehydration ratio of dried paddy straw mushroom varied in the range of 2.48±0.087 to 2.94 ± 0.059. The freeze dried sample had the maximum rehydration ratio of 2.94 ± 0.059 and microwave drying @1.44 W/g had minimum. The most favourable rehydration ability was observed in freeze dried samples. This is because of the porous structure and non-shrunken cells that the solid state of water creates when it sublimes during freeze drying, protecting the primary structure and the shape of the products with minimal reduction of volume (Ratti, 2001). However, there was no significant difference in rehydration ratios of freeze dried samples and those dried with hot air at 50°C. It was observed that rehydration ratio did not change appreciably with change in microwave power level, but Mohanta *et al.* (2011), Sahoo and Mohanty (2012) reported that rehydration ratio increased with increase in the power level in microwave drying.

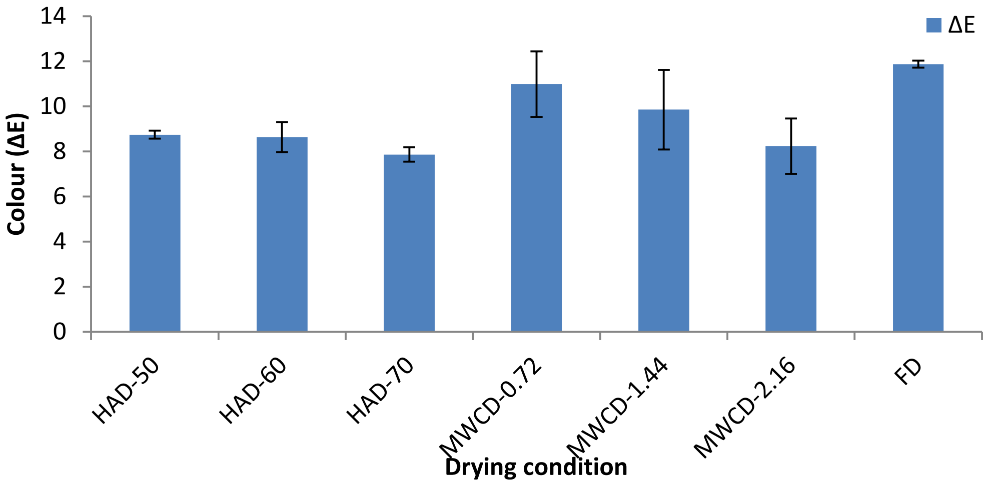


Fig 4.13 Colour change of mushroom at different drying conditions

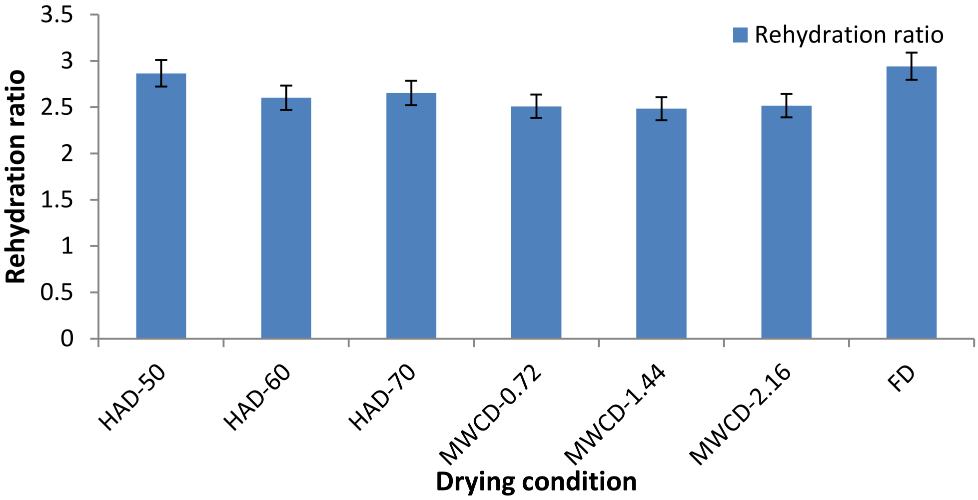


Fig 4.14 Rehydration ratio of mushroom at different drying condition

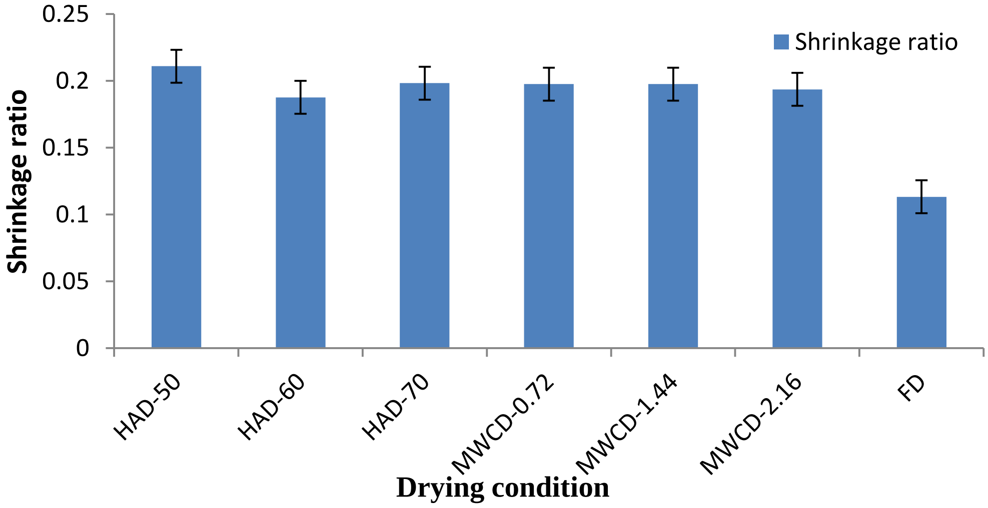


Fig.4.15 Shrinkage ratio of mushroom at different drying condition

The drying temperature increase had a negative influence on the rehydration capacity. The rehydration capacity decreased with increasing drying temperature, which could be associated to the stronger mushroom structure deformation at higher temperatures. This is similar to the results reported by Apati *et al*. (2010). According to Foust *et al.* (1982), increase in drying temperature leads to the increase of water liberation rate, then promoting important structure deformations in the biological material. Thus, considering the rehydration performance, the lower drying temperature (50°C) could be suggested for paddy straw mushroom dehydration.

The shrinkage ratio of paddy straw mushroom varied in the range of 0.11 to 0.21. The freeze dried sample had the minimum shrinkage ratio of 0.11±0.005 and hot air drying at 50°C had maximum 0.21±0.25. However, there was no significant difference in shrinkage ratios of microwave dried samples and those dried with hot air dryer. It was observed that shrinkage ratio did not change significantly by increasing power level, but according to Abasi *et al*. (2009) shrinkage ratio decreased with increase in power level in microwave drying. This was due to outward flux of vapour and generated vapour pressure (Khraisheh *et al*., 1997).

4.3.3 Nutritional Quality

Figs. 4.16 to 4.21 represent the nutritional quality of mushroom obtained after different drying treatments. Table 4.9 also presents the mean values with standard deviations. The dehydrated mushroom flakes were analysed for moisture, protein, carbohydrate, crude fibre, ash, ascorbic acid and reducing sugar. *Volvariella volvaceae* has the least fat content among the mushrooms, therefore here we assumed fat free sample.

4.3.3.1 Crude protein content

The protein content of the samples obtained after drying is shown in Fig 4.16. The maximum protein content was found in freeze drying and minimum in microwave convective drying (2.16W/g). However, there was no significant difference between the freeze dried samples and the samples dried with microwave (0.72W/g) and that dried with hot air at 50°C. The results are in agreement with Yuen *et al.* (2014). Protein content of all samples decreased during drying, which are in agreement with Yasmin *et al.*(2015) for oyster mushroom and Sangwan *et al.*(2010) for onion. The loss of protein could be due to denaturation or changes in solubility during drying. Moreover, another possible cause in this reduction is the release of amino acids from the proteins after denaturation, which could react with other chemical compounds such as sugars to produce melanoidines via the Maillard reaction (Lee and Shibamoto, 2002; Perera, 2005; Miranda *et al*., 2009; Borompichaichartkul *et al*., 2009). Maray *et al*. (2017) also have similar observations for oyster mushroom. However, our results disagree with that of Audrey *et al.* (2004), who reported that protein content increased when heat was applied.

4.3.3.2 Carbohydrate

It was observed that maximum carbohydrate was found in microwave convective (0.72 W/g) dried sample (30.82±1.15%) and minimum (28.51 ± 2.23%) in microwave convective 2.16 W/g dried sample (Figure 4.17 and Table 4.9). There was no significant effect of the drying methods on the final carbohydrate content of the samples. These results are in agreement with those reported by Ouzouni *et al.* (2009), Manjunathan and Kaviyarasan (2011) and Maray (2017).

4.3.3.3 Ash

The ash content of fresh mushroom was obtained as 7.86 g/100g (dry basis). The ash content of dried paddy straw mushroom varied in the range of 7.78±0.54 to 9.18±0.23 g/100g (Table 4.9). Referring to the Fig. 4.18, it was observed that maximum ash content was retained in freeze dried sample; there was no significant difference in the ash content of samples dried under freeze drying and that dried under hot air at 50°C.

In a study by Yuen *et al*. (2014) on drying of paddy straw mushroom, the ash content increased with different drying temperature. However, in the present study, no such systematic trend on the ash content was observed. Literally, the cultivated mushroom may have higher ash content because of the use of organic fertilizer, chemicals or even growth hormone which is applied intentionally. Ash content indicates the availability of mineral content of food substances (Onwuka *et al*. 2002, Tolert and Abera, 2017). The statistical analysis also indicated that there was no significant difference in the ash content of samples in all drying methods except freeze drying.

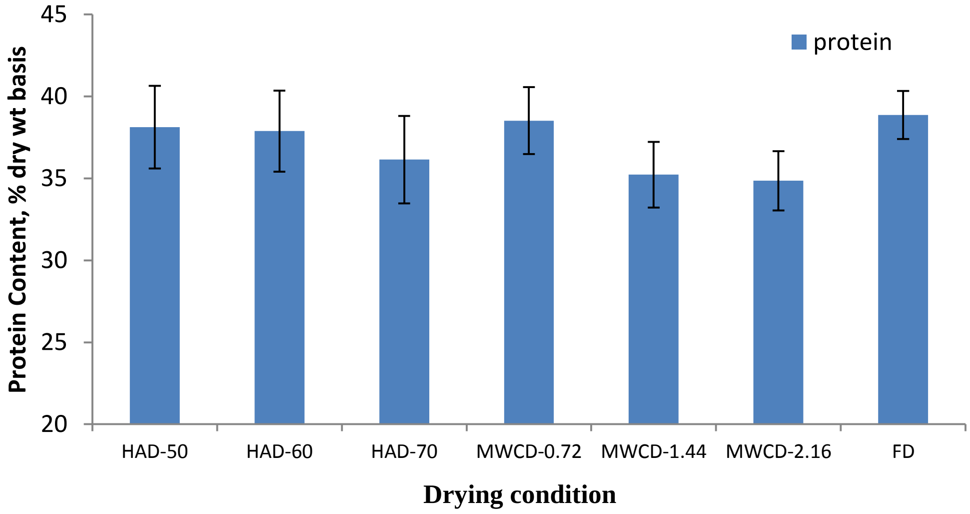


Fig.4.16 Protein content of mushroom dried under different methods

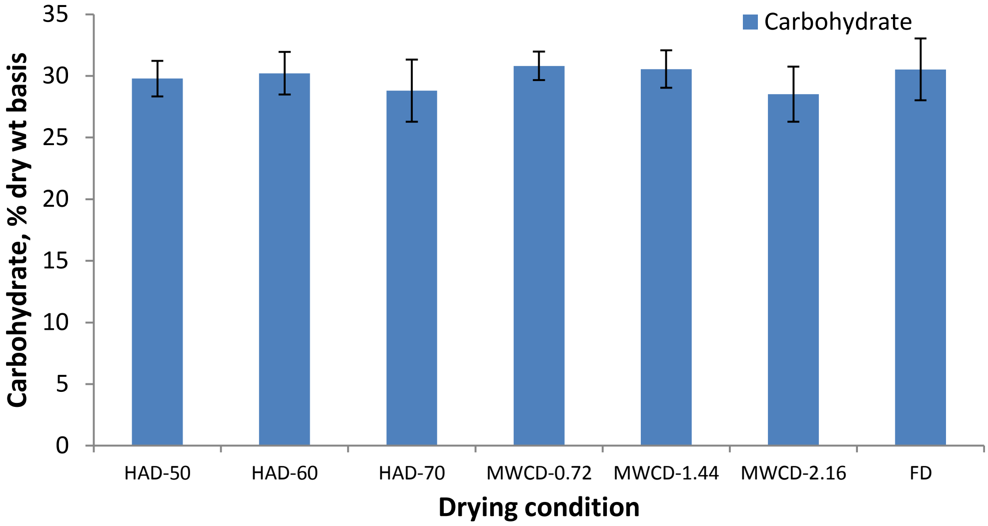


Fig.4.17 Carbohydrate content of mushroom dried under different methods

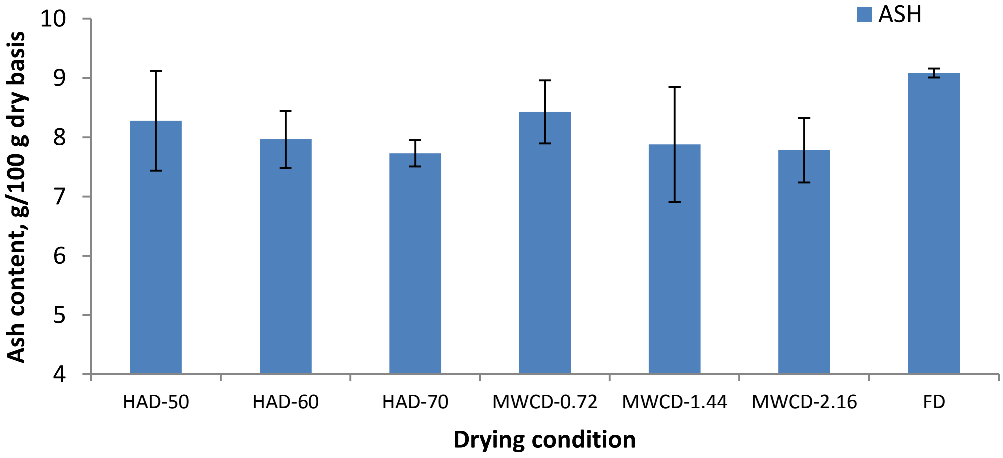


Fig.4.18 Ash content of mushroom dried under different methods

Table 4.9 Comparison between drying temperatures for nutritional quality during hot air drying, microwave convective drying and freeze drying

Parameter	Ash (g/100g)	Protein (%)	Carbohydrate (%)	Fibre (g/ 100g)	AA (mg/100g)	RS (g/100g)
HAD-50	8.27 ± 0.84^{ab}	38.12 ± 2.51^{a}	29.79 ± 1.44^{a}	16.56 ± 1.65^{a}	10.57 ± 2.06^{d}	1.98 ± 0.20^{c}
HAD-60	7.96 ± 0.48^{b}	37.88 ± 2.47^{a}	30.21 ± 1.77^{a}	15.61 ± 0.22^{ba}	8.16 ± 0.035^{e}	1.56 ± 0.17^{d}
HAD-70	7.72 ± 0.22^{b}	36.14 ± 2.66^{ab}	28.81 ± 2.52^{a}	14.36 ± 0.93^{bc}	6.92 ± 1.60^{e}	1.39 ± 0.15^{d}
MWCD 0.72W/g	8.42 ± 0.53^{ab}	38.52 ± 2.04^{a}	30.82 ± 1.15^{a}	14.34 ± 0.69^{bc}	13.44 ± 0.22^{c}	3.68 ± 0.17^{a}
MWCD-1.44W/g	7.87 ± 0.96^{b}	35.22 ± 2.00^{ab}	30.55 ± 1.52^{a}	14.00 ± 0.97^{c}	15.70 ± 0.13^{b}	3.00 ± 0.20^{b}
MWCD-2.16W/g	7.78 ± 0.54^{b}	34.85 ± 1.80^{b}	28.51 ± 2.23^{a}	15.04 ± 0.25^{bc}	14.90 ± 0.31^{bc}	2.90 ± 0.31^{b}
FD	$\mathbf{9.18\pm0.23^{a}}$	$\mathbf{38.86\pm1.46^{a}}$	$\mathbf{30.53\pm2.51^{a}}$	$\mathbf{12.40\pm0.13^{d}}$	$\mathbf{18.86\pm1.05^{a}}$	$\mathbf{3.07\pm0.37^{b}}$

4.3.3.4 Fibre content

Referring to the figure 4.19, it was observed that maximum fibre content of 16.56 ± 1.65 g/100g was in 50°C hot air drying and minimum (12.40 ± 0.05 g/100g) in freeze drying. However, there was no significant difference between hot air dried sample at 50°C and that at 60°C. Generally, crude fibre content observed in this study decreased with drying. The freeze drying induced the highest degree of loss, corresponding to a disintegration of the polymeric fibres. The convective air drying induced intermediate changes in the fibre contents, varying with temperature and operating conditions compared to microwave convective drying, which are in conformity with the observations of Femenia *et al.(*2009) and Borchani *et al*. (2011).

According to Yuen *et al*. (2014), the crude fibre content of mushroom reduced with increasing the drying temperature. The reduction in the crude fibre content can be associated with the nature of the mushroom that dissociate when they are heated at certain temperature. Besides, the breakdown and solubilization of hemicellulose components, especially the arabinogalactan, water soluble pectins and hydrocolloids also facilitate the reduction in crude fibre content (Hassan *et al*. 2007).

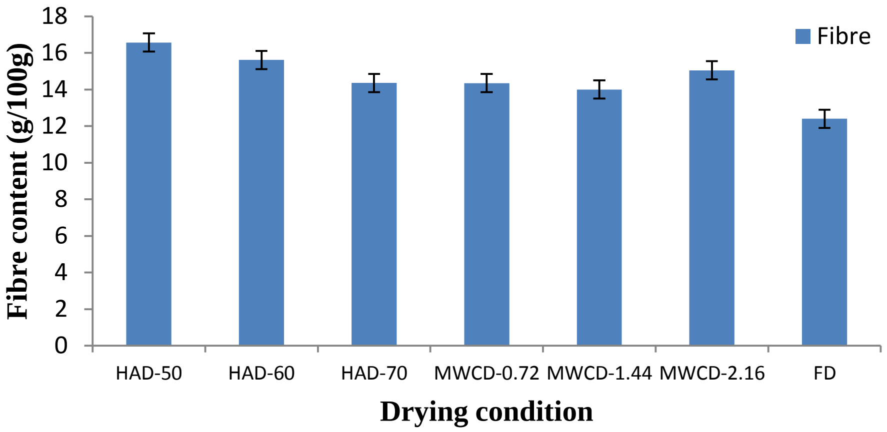


Fig.4.19 Fibre content at different drying conditions

4.3.3.5 Ascorbic acid

The ascorbic acid content of mushroom reduced after drying (Fig. 4.20). It decreased from an initial value of 60.13±0.26 mg/100g (dry basis) to 6.92±1.60 mg/100g, when dried in hot air (50°C). The freeze dried sample had the maximum ascorbic acid retention and the hot air dried samples had the minimum. The microwave assisted dried samples showed higher ascorbic acid retention as compared to the hot air dried samples. It was also observed that ascorbic acid decreased with increasing drying temperature and time during convective drying (Table 4.9), though there was no significant difference between hot air dried sample at 60ºC and 70ºC. During the freeze-drying process, the temperature of the product is pretty low, which reduces degradation reactions and does not make the drying time crucial.

Variations of vitamin C content were determined in microwave-dried fruits and vegetables by Ozkan *et al*, (2007) for spinach leaves, Karatas and Kamisli (2007) for apricot and Khraisheh *et al*. (2004) for potato. Ozkan *et al.* (2007) indicated that the reduction in the ascorbic acid levels of the sample was dependent on time. As the drying time is related with the microwave power level, the reduction can also be dependent on it. The same result was obtained by Karatas and Kamisli (2007). Khraisheh *et al*. (2004) showed that the total ascorbic acid content decreased with increasing processing time at a constant temperature or absorbed microwave power level. At a specific drying time, the loss of vitamin C increased with increasing air temperature. It occurred due to the heat liable nature of the mentioned vitamin. According to results reported by Chang *et al*. (2006), the retention of ascorbic acid in freeze-dried tomato cubes was higher than 90% without any sample pre-treatments, while in hot air–dried samples they were lower than 50%. The drying time required in the first process was about 24 h, whereas it was 8 h in hot air drying. As discussed earlier, drying time is one of the variables that influence the ascorbic acid retention.

4.3.3.6 Reducing Sugar

The maximum reducing sugar (3.68±0.17 g/100g) was in microwave convective dried sample (0.72W/g) and minimum (1.39±0.15 g/100g) in hot air drying (70°C) (Fig. 4.21). There was no significant difference in reducing sugar of freeze dried sample and microwave convective dried sample at power levels of 1.44 and 2.16 W/g, but there values were much lower than the MWCD 0.72 W/g.

It was observed that the reducing sugars were much lower in hot air dried sample compared to freeze dried and microwave convective drying method, which is similar to results reported by Henriques *et al.* (2012), Barba *et al.* (2014) and Guine *et al*. (2011) for dried pumpkin.

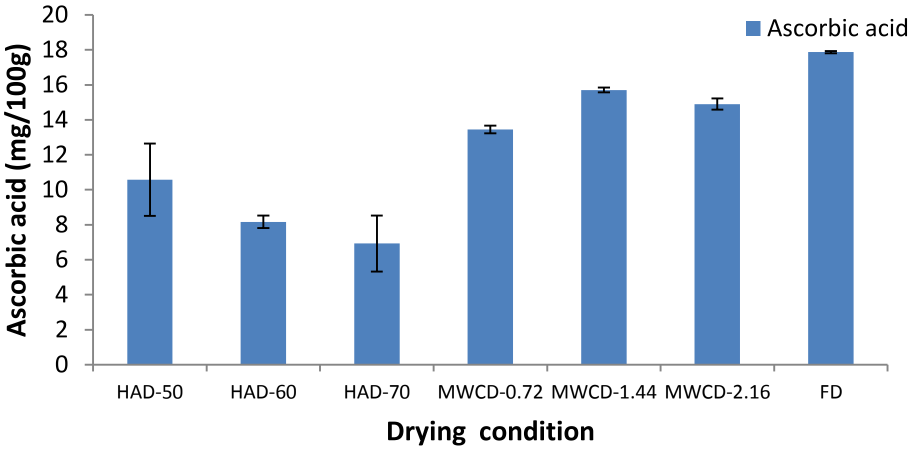


Fig.4.20 Ascorbic acid at different drying condition

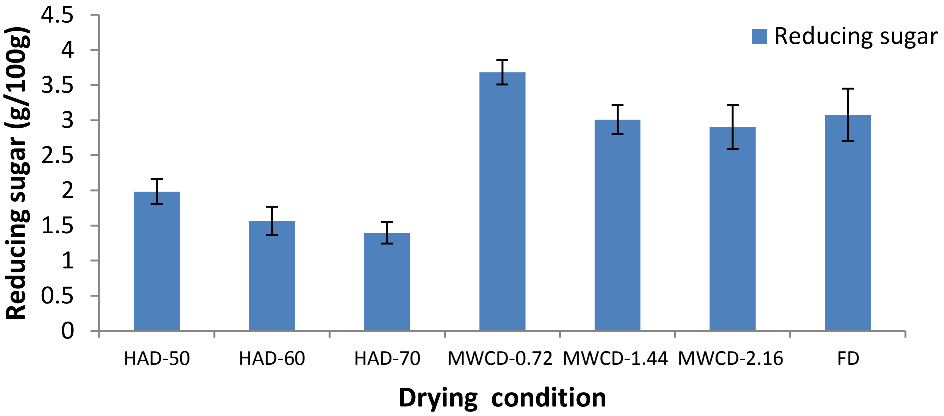


Fig.4.21 Reducing sugar at different drying condition

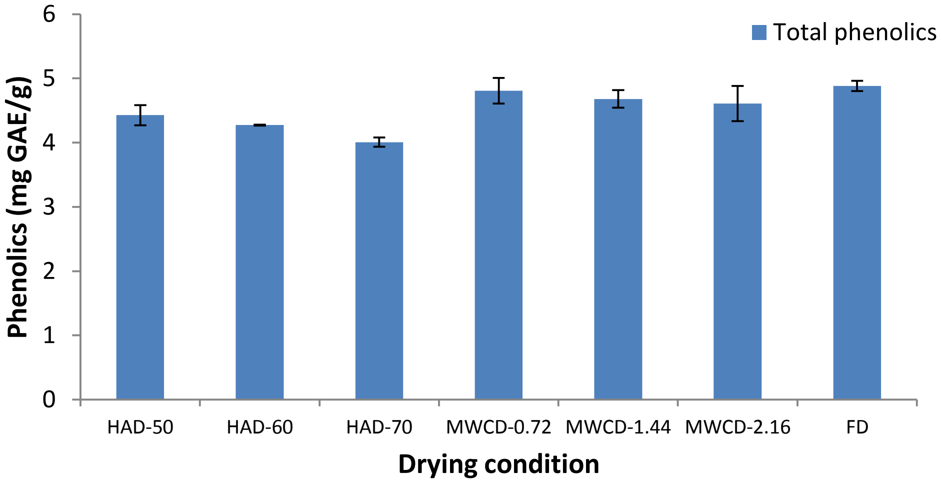


Fig.4.22 Total phenolic content of mushroom dried at different conditions

4.3.3.7 Total Phenolics

The total phenolic compounds in fresh paddy straw mushroom was 13.77±0.02 mg GAE/ g on dry basis as shown in table 4.10. Total phenolic contents of dehydrated mushroom samples have been shown in Fig. 4.22. It was observed that total phenolic compounds were maximum in freeze dried sample (4.88±0.08 mg GAE/g) and minimum (4.0±0.15 mg GAE/g) in hot air (70°C) dried sample. However, there was no significant difference between hot air (50°C) and microwave convective (1.44 W/g and 2.16 W/g) dried samples. It was observed that during the drying processes, activation of oxidative enzymes, such as polyphenol oxidase and peroxidase, may lead to the loss of phenolic compounds. This is similar to results found by Cheung *et al.* (2003). In addition, binding of phenolic compounds to proteins, changes in chemical structures or low extraction efficiencies are other factors related to the loss in total phenolic content (Gumusay *et al.*, 2015). Vashisth *et al.* (2011) and Mohamad Shofian *et al.* (2011) have reported that freeze drying induced a high retention rate of the phenolic compounds relatively to the fresh state, when compared to hot air drying, for muscadine pomace. Some researchers suggested that polyphenols are heat labile and that prolonged heat treatment and high temperatures cause irreversible chemical changes to such compounds. Harbourne *et al.* (2009) studied the effect of drying methods on the phenolic constituents of herbs and freeze drying and oven or tray drying at 30°C did not affect the phenolic compounds, while if the temperature was raised to 70°C, some reduction was observed.

Table 4.10 Total phenolics and DPPH activity in dried mushroom

Parameter	Total Phenolics (mg GAE/ g)	DPPH, activity %
HAD-50	4.42±0.07^{bc}	57.65±3.04^{b}
HAD-60	4.27±0.008^{dc}	41.74±3.34^{c}
HAD-70	4.00±0.15^{d}	23.28±1.58^{d}
MWCD-0.72 W/g	4.80±0.19^{a}	38.45±0.79^{c}
MWCD-1.44 W/g	4.68±0.13^{ab}	54.22±3.14^{b}
MWCD-2.16 W/g	4.60±0.27^{ab}	47.20±7.27^{c}
FD	**4.88±0.08^{a}**	**81.58±0.89^{a}**

4.3.3.8 DPPH activity

It was observed that the minimum value (23.28 ± 1.58 %) of DPPH was in hot air (70°C) dried mushrooms and maximum value (81.58 ± 0.89 %) was in freeze dried sample (figure 4.23). If the freeze drying is ignored, the maximum DPPH activity was observed in samples dried in hot air at 50°C. However, there is no significant difference between hot air dried sample at 50°C and microwave convective dried sample at 1.44 W/g. It was observed that DPPH activity decreased with increasing temperature in hot air drying. The decrease in antioxidant activity as a result of drying is related to the degradation of biologically active compounds at high temperatures, due to chemical, enzymatic or thermal decomposition (Nicoli *et al*. 1999; Kamiloglu *et al*. 2014). However, certain drying treatments, especially freeze-drying, increases the total antioxidant capacity of dried fruits and vegetables. Recent research suggested that the high antioxidant activity in fruits and vegetables after drying might be related to the fact that partially oxidized polyphenols have greater antioxidant activity than non-oxidized polyphenols (Nora *et al*., 2014). In addition, increases in antioxidant capacity after drying may be related to the Maillard reaction products (MRPs), which can be formed as a consequence of heat treatment and which generally exhibit strong antioxidant properties (Kamiloglu and Capanoglu, 2014; Kamiloglu *et al*. 2016).

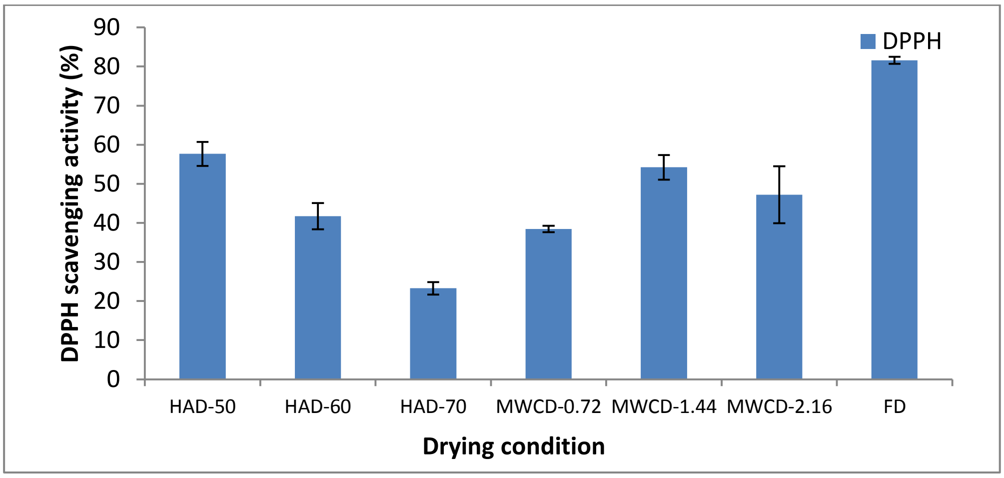


Fig.4.23 Variation of DPPH at different drying conditions

4.8 Minerals

Table 4.11 shows the level of eight essential minerals, i.e. selenium, manganese, iron, zinc, calcium, magnesium, sodium and potassium for paddy straw mushroom powder. Potassium was found to be the most abundant mineral with a value of 271.438±0.687 mg per 100g d.m., while manganese was the least abundant with a value of 2.348±0.043 mg per 100g d.m. Mushrooms are said to be good biological accumulators of zinc and zinc is biologically very vital to the human body (Bano *et al*. 1981). The Zinc content of mushroom powder was 5.659±0.260 mg per 100 g (d.m.). Selenium was in fairly good concentrations, and selenium is known for fighting against cancer (Lipinski, 2005). This is organic selenium as found in the mushroom fruiting body, and mushrooms are known for bioconversion of such minerals from the growth substrate from inorganic form to organic form (Falandysz, 2008). However, sodium is relatively less in mushroom species, thus, mushrooms are said to be good for patients with hypertension Rajarathnam, 1998). Similar observations were found in result reported by Mallikarjuna *et al*. (2014).

Not much change in the mineral content of the samples were observed after drying. Thus it may be concluded that drying does not change any mineral content of mushroom and the thus can be used as a food and mineral supplement for other value added products. Mazza (2007) has also mentioned that the loss of mineral contents could be due to interaction of saponins with minerals before processing or diffusion of micronutrients into intercellular spaces especially at high temperatures (Ruales and Nair, 1993; Bhargava *et al.* 2006).

Table 4.11 Mineral composition of mushroom powder after drying

Minerals content	**values**
Selenium	4.234±0.342
Zinc	5.659±0.260
Iron	88.076±0.155
Manganese	2.348±0.043
Magnesium	136.527±0.459
Calcium	45.087±0.195
Sodium	61.988±0.55
potassium	271.438±0.687

4.3.4 Functional Quality

4.3.4.1 Water absorption index (WAI)

Water absorption index of paddy straw mushroom powder is shown in figure 4.24. The value of water absorption index was maximum (3.96±0.06 g starch/ g dry matter) in freeze dried sample and minimum (3.05±0.06) in microwave convective drying at 1.44 W/g. Ignoring freeze drying, the maximum WAI was obtained for sample dried in hot air at 50°C. It was observed that there is no significant difference between hot air dried sample at 50° and 60°C (Table 4.11). Ahmed *et al*. (2010) and Carvalho *et al*. (2016) also observed that higher drying temperature yielded higher WAI values in sweet potato flour and in potato pulp, respectively. There is a relationship between the content of hydrophilic property of protein and water absorption capacity, which means that the edible mushroom powder being rich in protein might have hydrophilic groups exposed to water, causing more water to be absorbed by the solid matrix of the dried sample after drying (Hall *et al.*1996). The water absorption capacity is very dependent on the fibre structure as it plays important role on the kinetics of water uptake (Tawatsinlapasorn *et al*. 2017).Water retention capacity is directly associated to the amount and type of fibre, damaged starch and protein content present in the dehydrated powder (Rasper, 1979).

4.3.4.2 Water solubility index (WSI)

Water solubility index of mushroom powder have been shown in Fig. 4.25. It was observed that water solubility index of freeze dried sample was maximum (0.39±0.02 g/100g) and it was minimum (0.23±0.05g/100g) in hot air dried sample (50°C). Samples dried with hot air at 60°C and 70°C had higher WSI than those dried at 50°C. Ahmed *et al*. (2010) found significant increase in WSI with increasing drying temperature of sweet potato which is same as the result shown in Table 4.9.

4.3.4.3 Oil absorption index (OAI)

The oil absorption index of microwave convective (2.16 W/g) dried sample was maximum (2.57±0.086g/g) and that of freeze dried sample was minimum (2.34±0.067g/g) (Fig. 4.26). However, there was no significant difference between microwave convective dried sample and hot air dried samples as shown in Table 4.12**.**

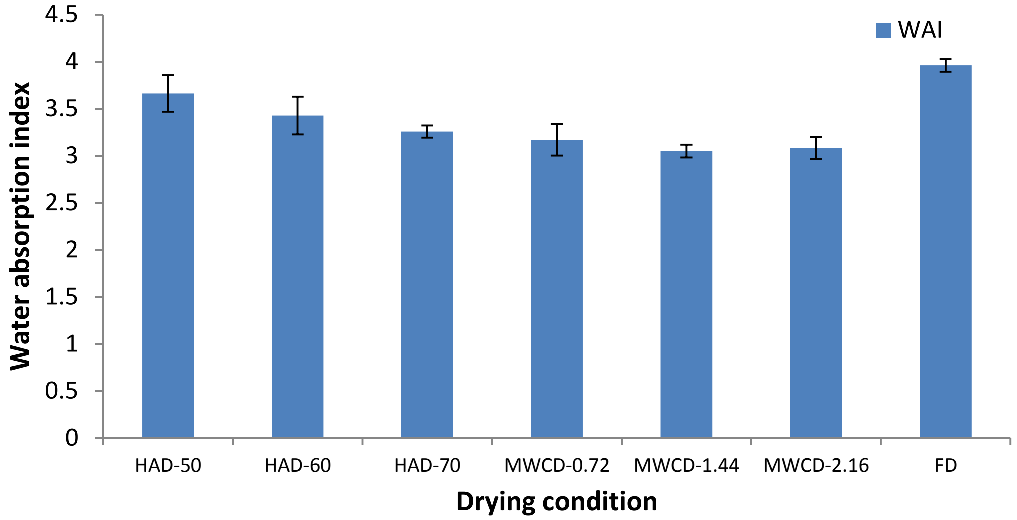


Fig.4.24 Variation of water absorption index at different drying conditions

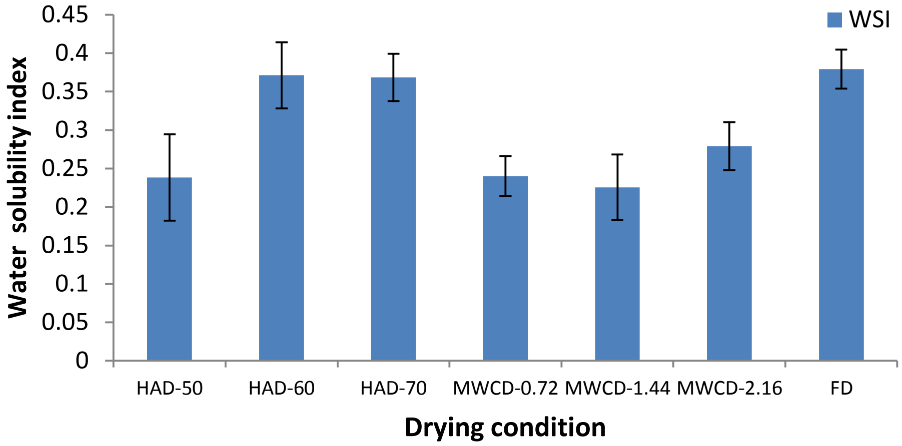


Fig.4.25 Variation of water solubility index at different drying condition

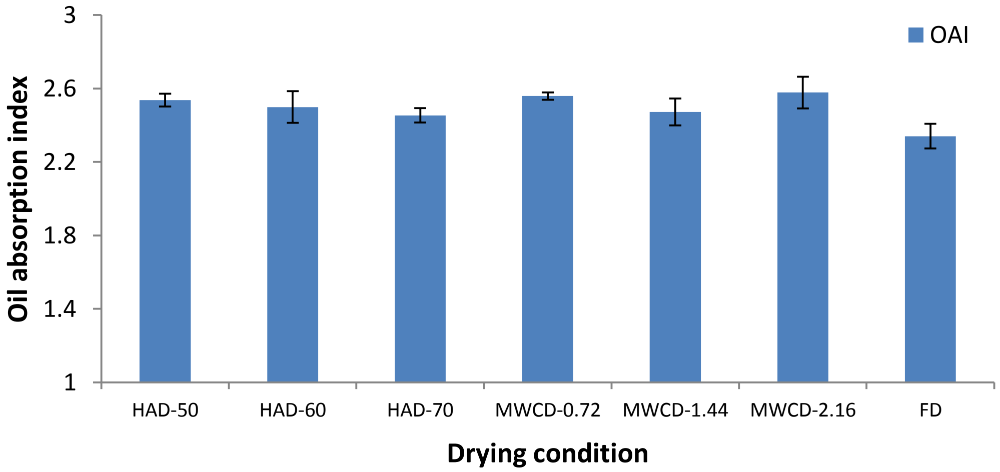


Fig.4.26 Variation of oil absorption index at different drying conditions

Table 4.12 Comparison between drying temperatures for WAI, WSI and OAI during hot air drying, microwave convective drying and freeze drying

Parameter	WAI(g starch/g dry sample)	WSI(g/g)	OAI(g/g)
HAD-50	3.66±0.19^{b}	0.23±0.05^{b}	2.53±0.035^{a}
HAD-60	3.42±0.20^{bc}	0.37±0.04^{a}	2.49±0.086^{a}
HAD-70	3.25±0.06^{cd}	0.36±0.03^{a}	2.45±0.038^{a}
MWCD-0.72W/g	3.16±0.16^{d}	0.24±0.02^{b}	2.55±0.020^{a}
MWCD-1.44W/g	3.05±0.06^{d}	0.22±0.04^{b}	2.47±0.073^{a}
MWCD-2.16W/g	3.08±0.11^{d}	0.27±0.03^{b}	2.57±0.086^{a}
FD	3.96±0.06^{a}	0.39±0.02^{a}	2.84±0.067^{b}

Oei (2003) observed that the high value of the oil absorption capacity of freeze dried samples could be due to the stability of the hydrophobic and peptide groups of the protein present in them. It can be used as flavour render in food system. This liquid retention is an index of the ability of the mushroom to absorb and retain oil, which in turn influences the texture and mouth feel of foods.

4.3.5 Effect of Temperature and Power Level on Texture

The hardness of dried paddy straw mushroom for stem and cap have been shown in Figs. 4.27 and 4.28. It was observed that hardness of dried mushroom decreased with increased temperature and power level. The hardness of mushroom varied in the range of 2058.87±586.10g to 5529.11±1560.08g for stem and 4363.51±496.62g to7493.08±1897.67g for cap. The freeze dried sample had the minimum hardness and the microwave dried sample at 0.72 W/g had the maximum hardness. However, if the freeze dried samples are kept aside, there was no significant difference in hardness of the samples dried by other methods. The reason for the soft mushroom in the case of freeze-drying may be due to the fact that during freeze drying, the original dimensions of the product are maintained. The ice is then sublimed, usually under a high vacuum. Since there is no aqueous phase, there is no migration of water to the surface but, instead, a receding interface between frozen and dry layer. The effect of concentration of water-soluble components due to the mobility of the aqueous phase is thereby prevented and hence the resulting product is of tender texture (Soto *et al.* 2001). Kotwaliwale *et al.* (2007) also reported an increase in hardness during hot air drying of oyster mushroom.

Referring to the Figs. 4.29 and 4.30, it was observed that chewiness of dried mushroom decreased with increase in both temperature and power level in MWCD. The value of chewiness of both stem and cap were maximum in hot air drying at 50°C and minimum in freeze dried sample as in shown in Table 4.10. However, there was no significant difference between hot air and microwave dried samples for stem. For cap there was no significant difference for hot air dried samples (50, 60°C) and microwave convective dried sample. This result is agreement with Bansal *et al.* (2013).

Table 4.13 Comparison between drying methods for hardness and Chewiness of dried mushroom

Parameter	**Hardness(g) -Stem**	**Hardness(g) -Leaf**	**Chewiness-Stem**	**Chewiness-cap**
HAD-50	5529.11±1560.08^{a}	7282.99±1105^{b}	2263.40±804.35^{a}	3771.84±1135.84^{b}
HAD-60	4980.24±2073.78^{a}	5305.60±473.70^{b}	1965.72±812.82^{ab}	1930.67±356.57^{b}
HAD-70	4635.77±980.58^{a}	4566.64±312.56^{a}	1912.48±622.03^{ab}	1625.95±386.17^{a}
MWCD-0.72W/g	5457.24±2102.46^{a}	7493.08±1897.67^{a}	1748.01±738.56^{ab}	2315.06±1042.77^{b}
MWCD-1.44W/g	4377.78±2133.31^{ab}	7108.68±1260.54^{a}	1409.98±397.32^{ab}	2194.59±633.04^{b}
MWCD-2.16W/g	3915.96±1033.25^{abc}	5931.36±1896.51^{ab}	1283.48±1042.69^{ab}	2190.67±447.60^{b}
FD	2058.87±586.10^{c}	4196.85±607.76^{ab}	1161.82±282.69^{b}	2268.64±316.69^{b}

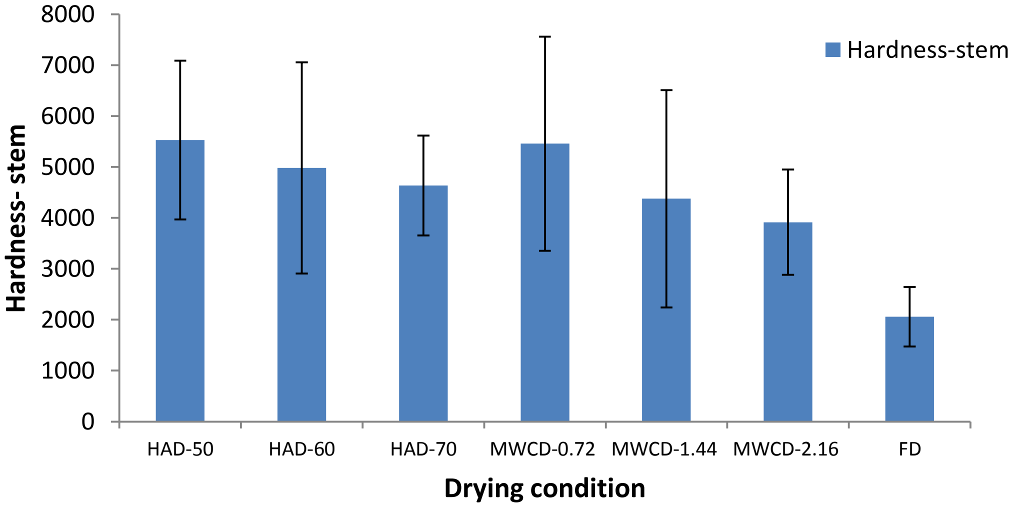


Fig.4.27 Variation of hardness of mushroom (stem) at different drying conditions

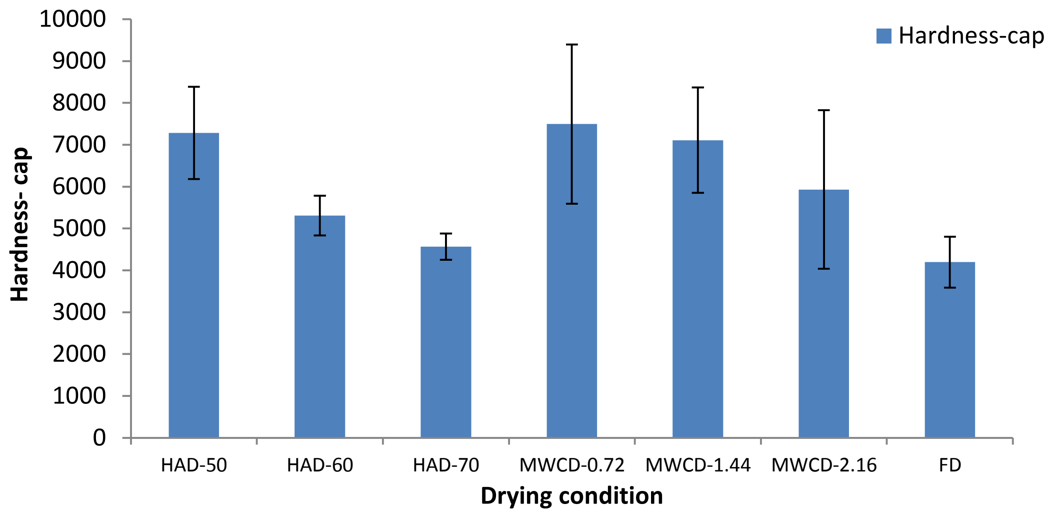


Fig.4.28 Variation of hardness of mushroom cap at different drying conditions

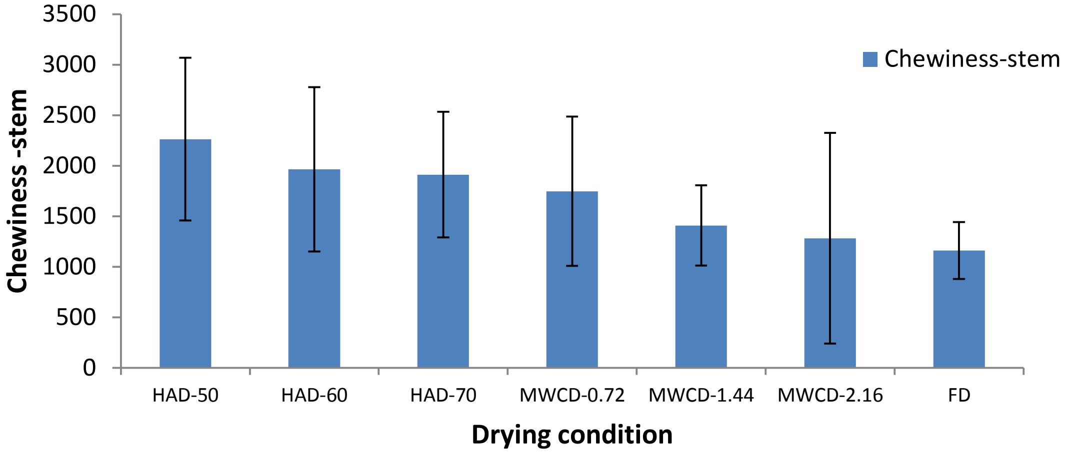


Fig.4.29 Variation of chewiness of mushroom (stem) at different drying condition

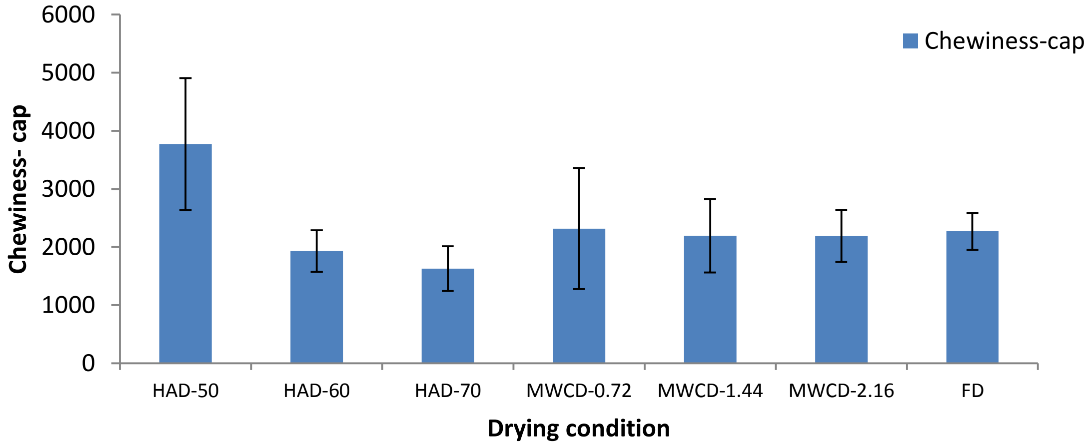


Fig.4.30 Variation of chewiness of mushroom (cap) at different drying condition

4.3.6 Microscopic structures

Fig.4.34 (a-h) to 4.45 (a-h) shows scanning electron microscope images of the microstructure of paddy straw mushroom samples dried by convective, combined microwave-convective drying and freeze drying methods at different magnification (100X,500X, 1000X and 2000X) of surface, inside and cross section image. Image of the microstructure of raw paddy straw mushroom was taken after dipping in liquid nitrogen. As can be seen in the microscopic images (4.34a to 4.34-f), the increased temperature and microwave power caused microstructural damage and destroyed the cell walls of dried samples. In the case of convective drying, samples dried at 50°C had more pore structure with smooth surface than that of the mushrooms dried at 60°C and 70°C. Combined microwave- convective drying (1.44W/g and 2.16W/g) resulted in more tissue shrinkage, collapse and more crushed formation compared to 0.72W/g. Freeze dried sample (1-g) was more close to raw sample(1-h). As we discussed earlier, rehydration ratio was more in freeze dried sample and convective dried (50°C) sample due to more porous structure and similar result can be seen from the microscopic structure at different magnification level.

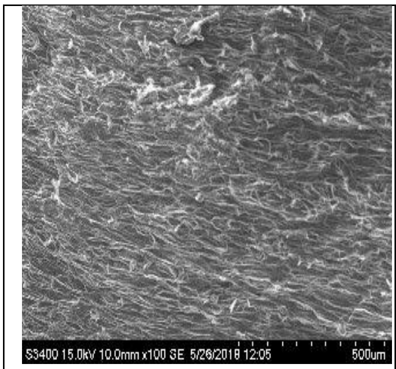


Fig.4.31a 50°C surface 100

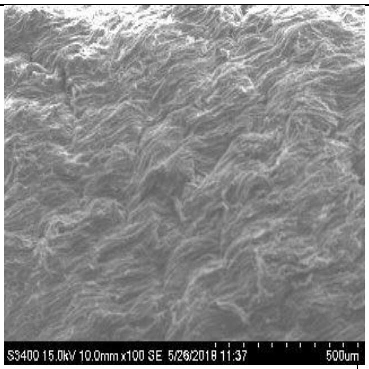


Fig.4.31b 60°C surface 100

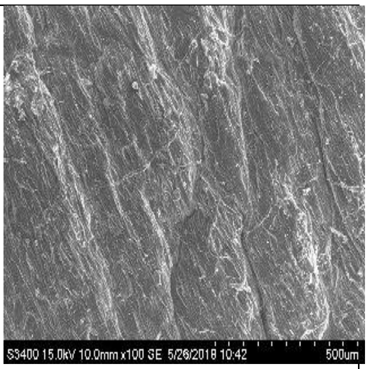


Fig.4.31c 70°C surface 100

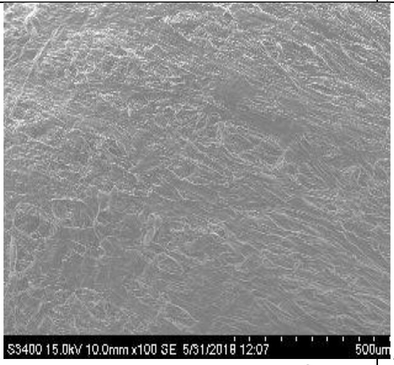


Fig. 4.31d 0.72W/g- Surface 100

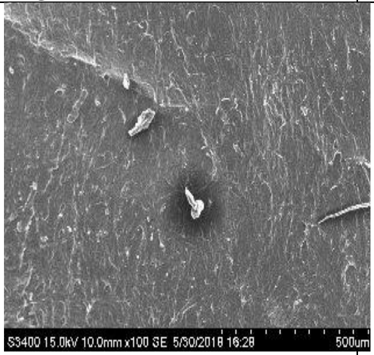


Fig. 4.31e 1.44W/g - Surface 100

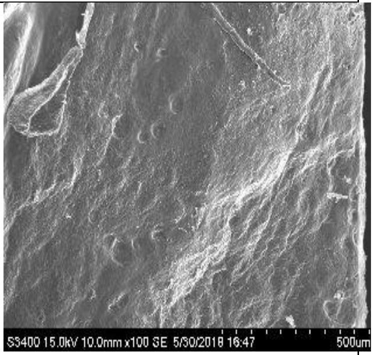
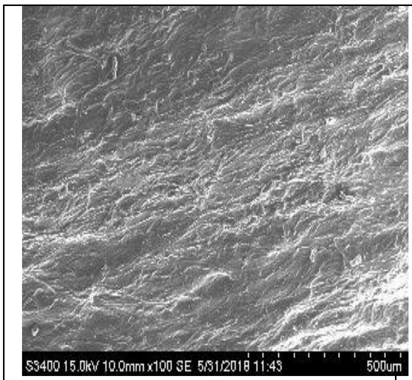
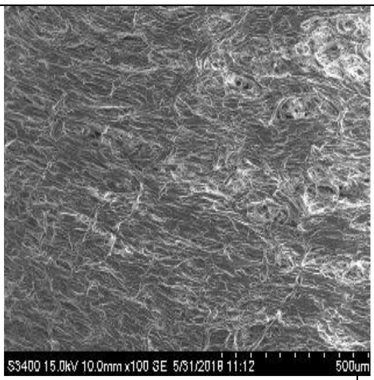
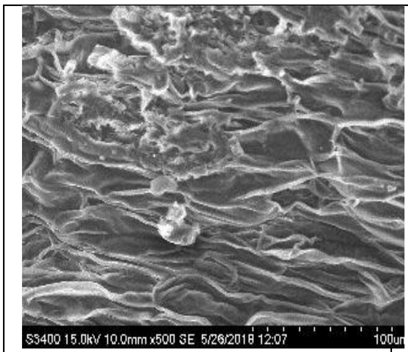
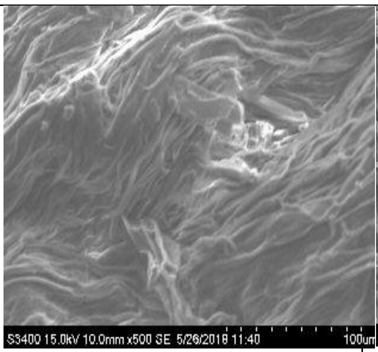
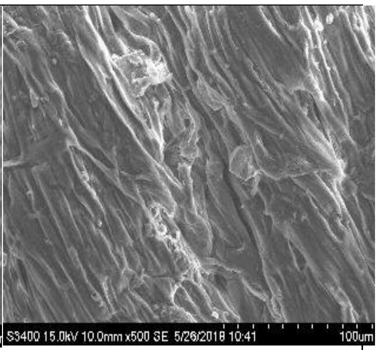
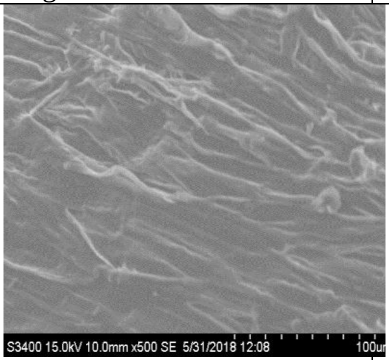
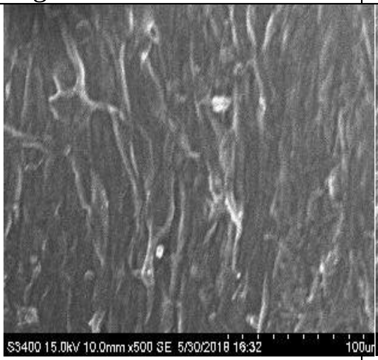
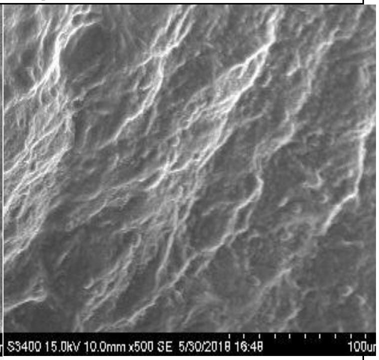
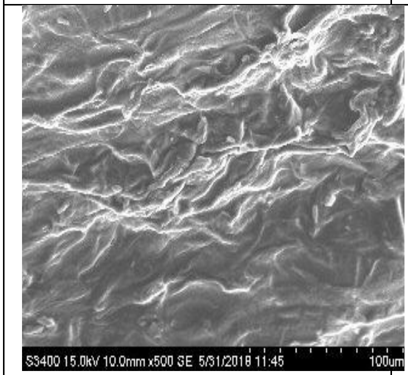
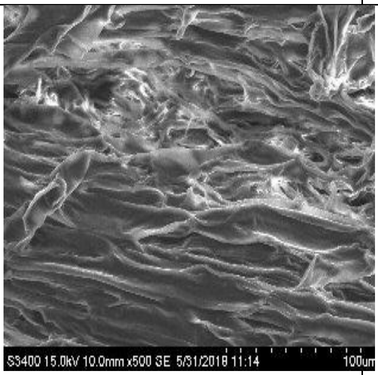


Fig. 4.31f 2.16W/g- Surface 100

 Fig. 4.31g FD Surface 100	 Fig. 4.31h Raw surface 100	

 Fig.4.32a 50°C surface 500	 Fig. 4.32b 60°C surface 500	 Fig. 4.32c 70°C surface 500
 Fig. 4.32d 0.72W/g- Surface 500	 Fig. 4.32e 1.44W/g- Surface 500	 Fig. 4.32f 2.16W/g- Surface 500
 Fig. 4.32g FD- Surface 500	 Fig. 4.32h Raw- surface 500	

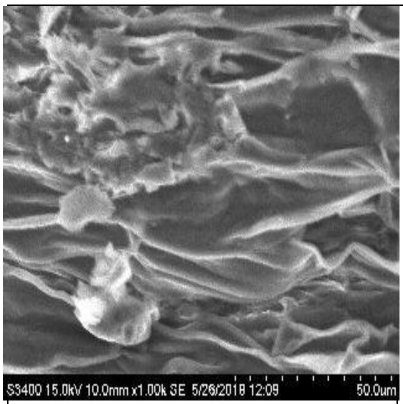


Fig.4.33a 50°C surface 1000

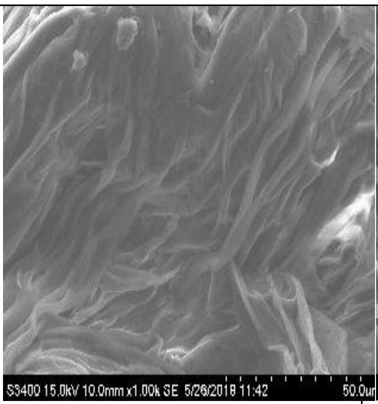


Fig. 4.33b 60°C surface 1000

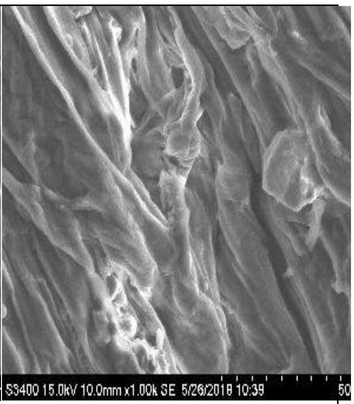


Fig. 4.33c 70°C surface 1000

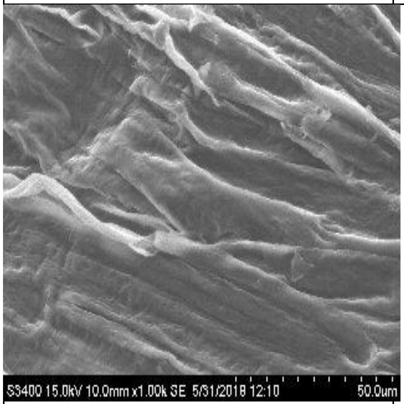


Fig. 4.33d 0.72W/g - Surface 1000

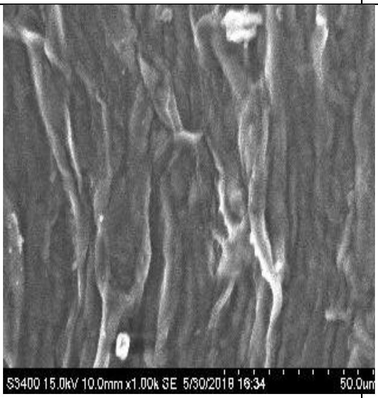


Fig. 4.33e 1.44W/g - Surface 1000

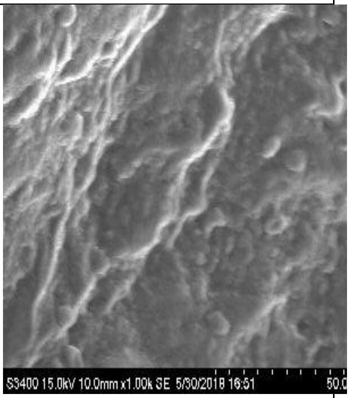


Fig. 4.33f 2.16W/g - Surface 1000

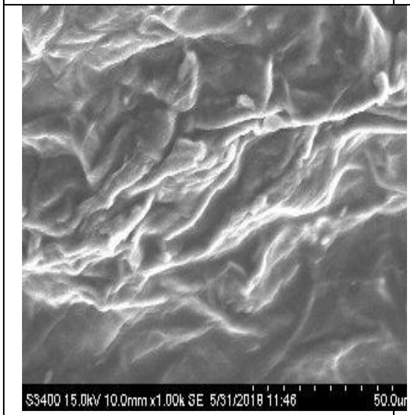


Fig. 4.33g FD- Surface 1000

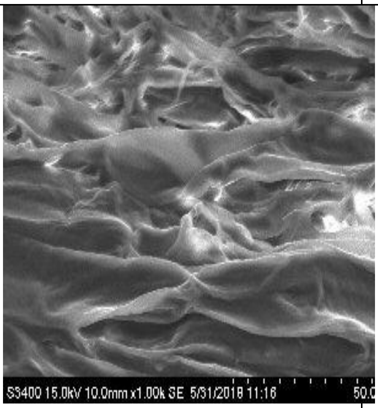
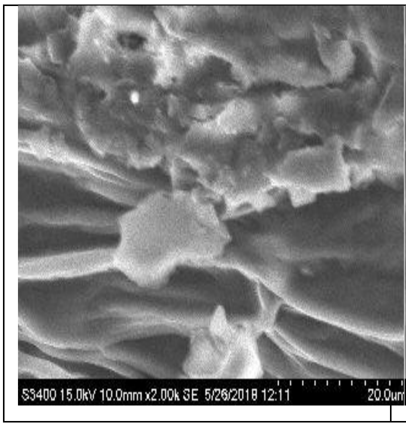
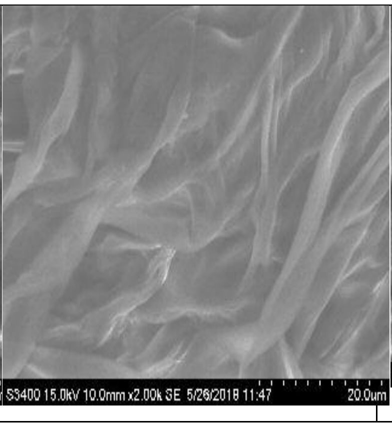


Fig. 4.33h Raw surface 1000





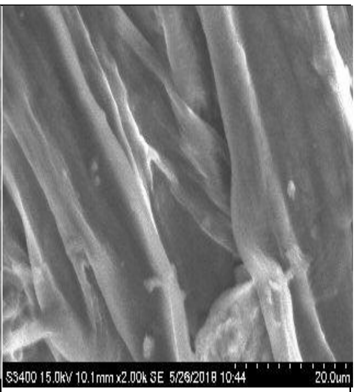


Fig. 4.34 c 70°C surface

Fig. 4.34 a 50°C surface 2000

Fig. 4.34 b 60°C surface 2000

2000

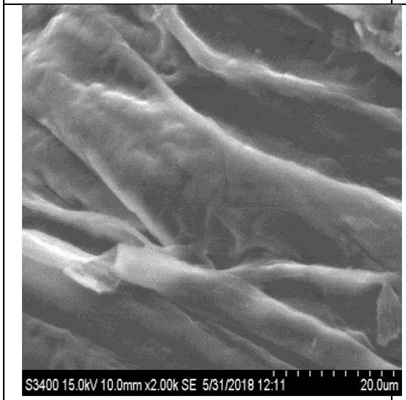


Fig. 4.34 d 0.72W/g - Surface 2000

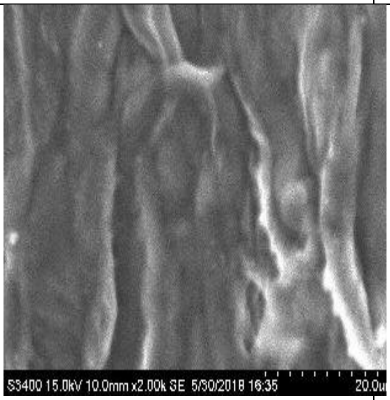


Fig. 4.34 e 1.44W/g - Surface 2000

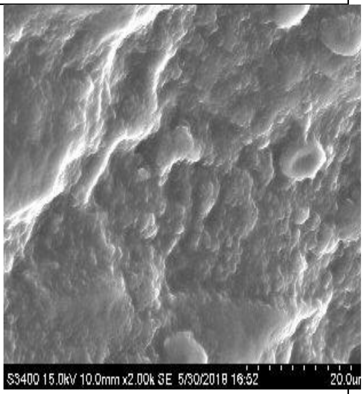


Fig. 4.34 f 2.16W/g - surface 2000

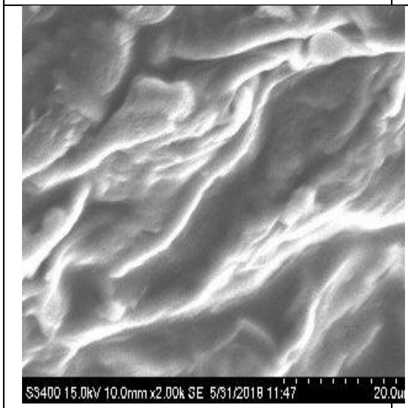


Fig. 4.34 g FD- Surface 2000

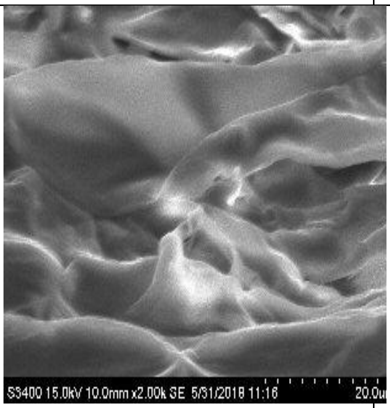


Fig. 4.34 h Raw- Surface 2000

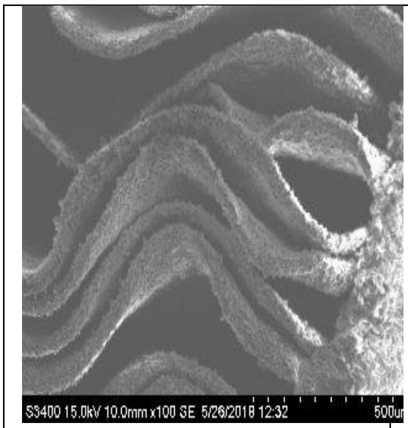


Fig. 4.35 a 50°C Inside 100

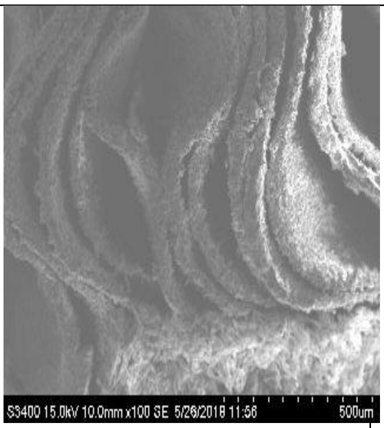


Fig. 4.35 b 60°C Inside 100

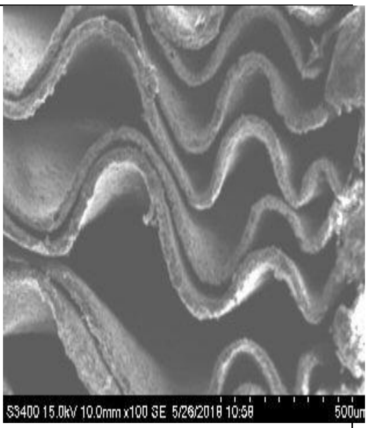


Fig. 4.35 c 70°C Inside 100

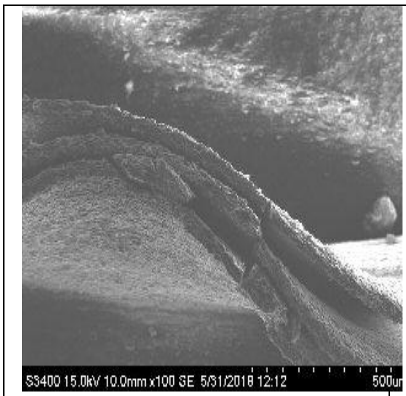


Fig. 4.35 d 0.72W/g - Inside 100

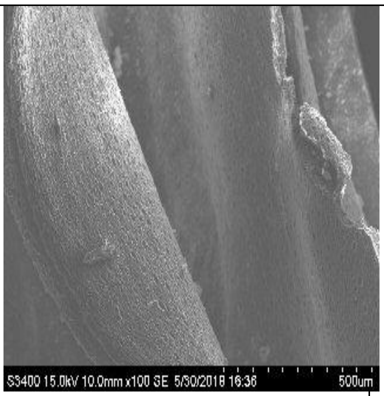


Fig. 4.35 e 1.44W/g - Inside 100

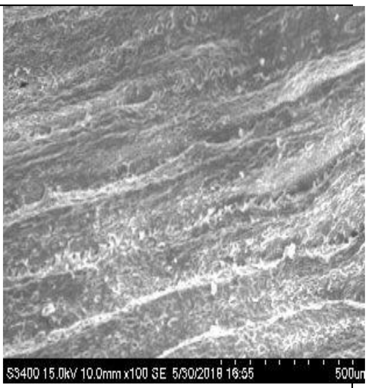


Fig. 4.35 f 2.16W/g - Inside 100

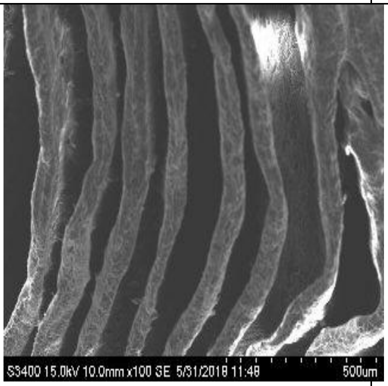


Fig. 4.35 g FD- Inside 100

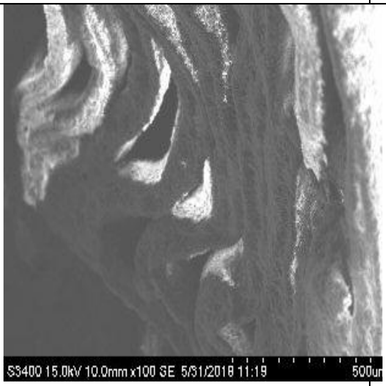


Fig. 4.35 h Raw –inside 100

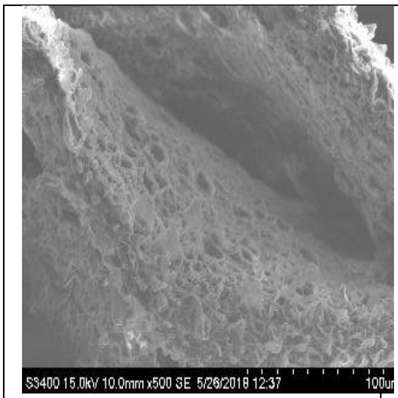


Fig.4.36 a 50°C Inside 500

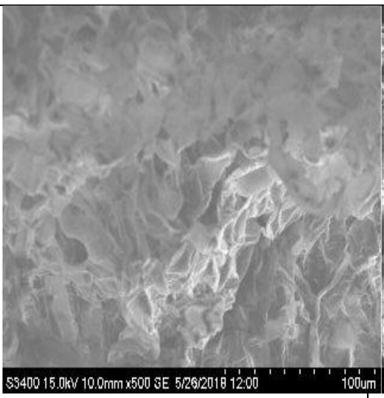


Fig. 4.36 b 60°C Inside 500

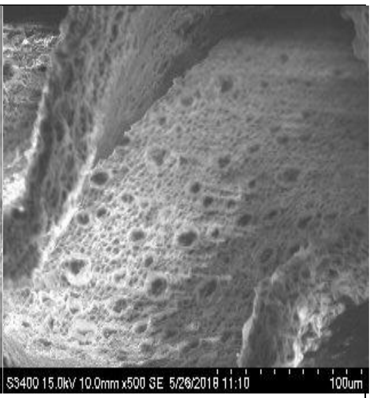


Fig. 4.36 c 70°C Inside 500

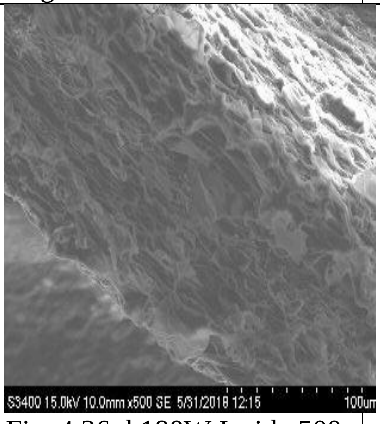


Fig. 4.36 d 180W Inside 500

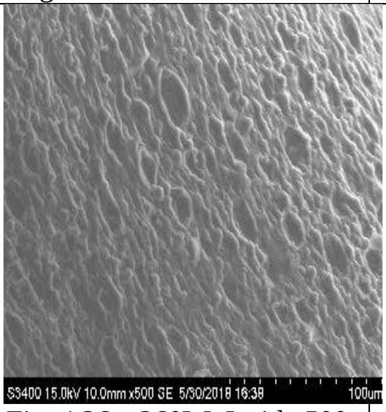


Fig. 4.36 e 360W Inside 500

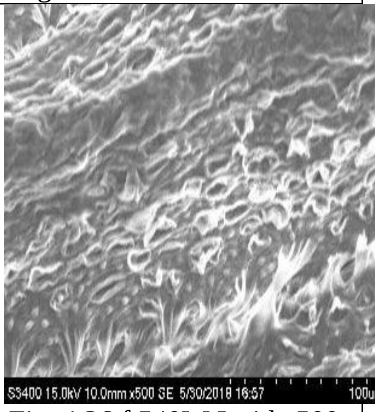


Fig. 4.36 f 540W Inside 500

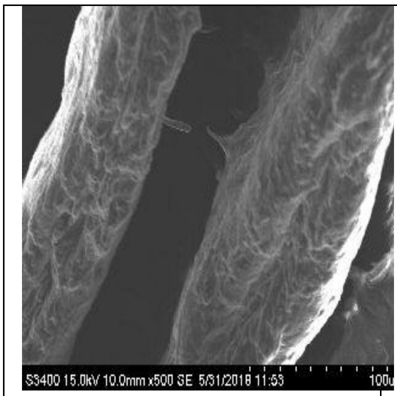


Fig. 4.36 g FD- Inside 500

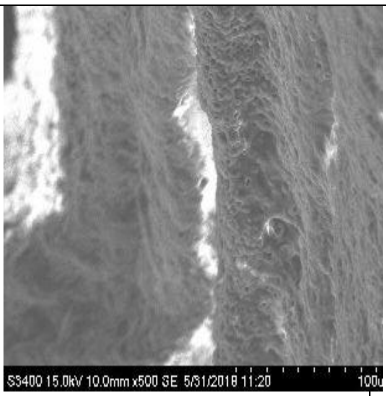


Fig. 4.36 h Raw- Inside 500

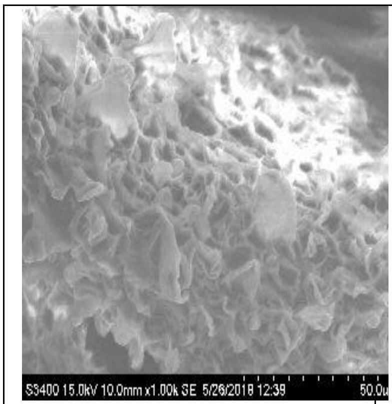


Fig. 4.37 a 50°C Inside 1000

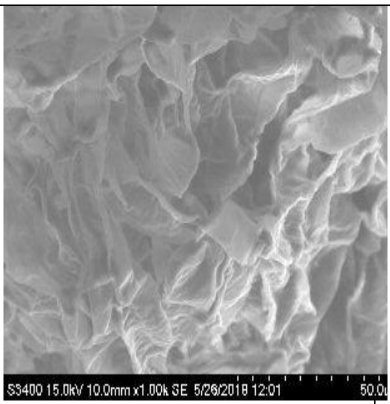


Fig. 4.37 b 60°C Inside 1000

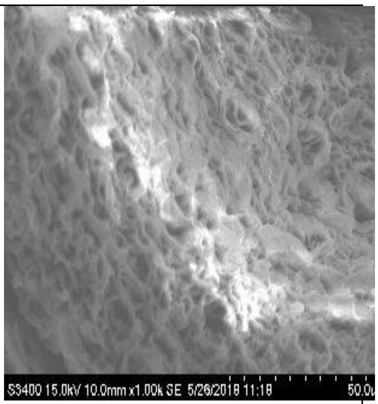


Fig. 4.37 c 70°C Inside 1000

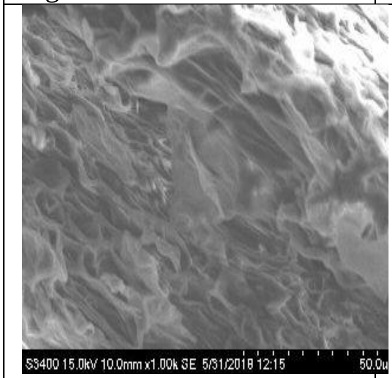


Fig. 4.37 d 0.72W/g Inside 1000

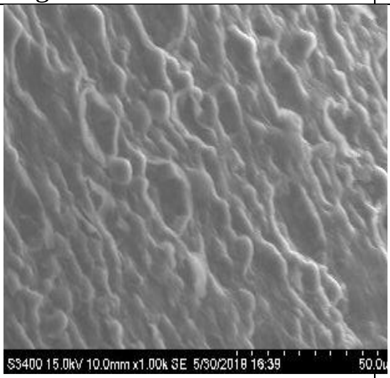


Fig. 4.37 e 1.44W/g Inside 1000

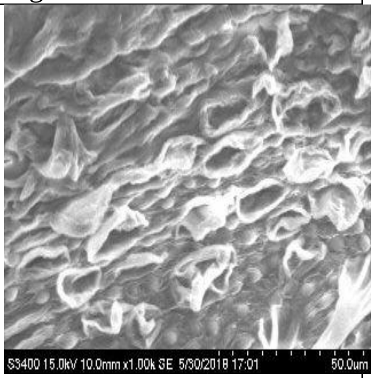


Fig. 4.37 f 2.16W/g Inside 1000

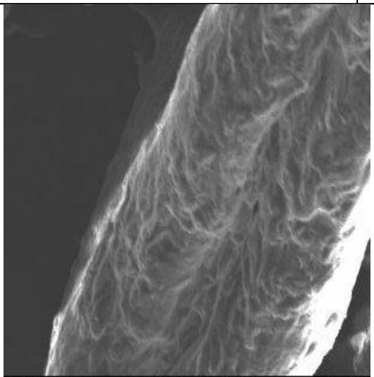


Fig. 4.37 g FD- Inside 1000

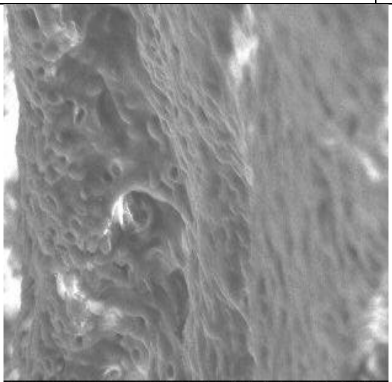


Fig. 4.37 h Raw inside 1000

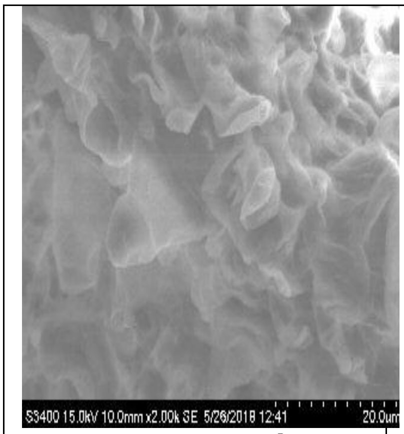


Fig. 4.38 a 50°C Inside 2000

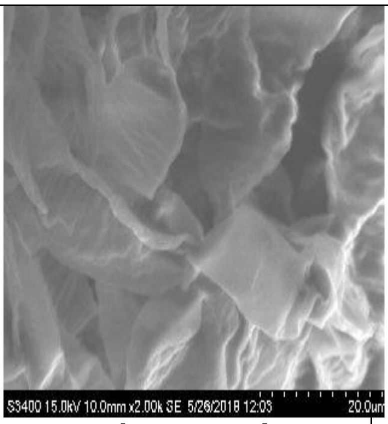


Fig. 4.38 b 60°C Inside 2000

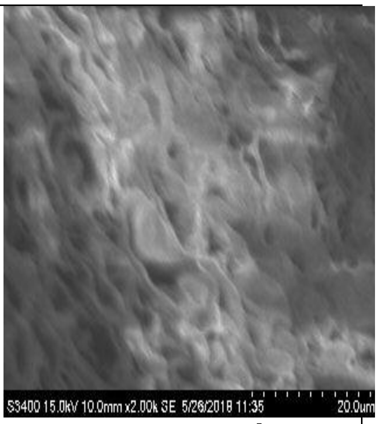


Fig. 4.38 c 70°C Inside 2000

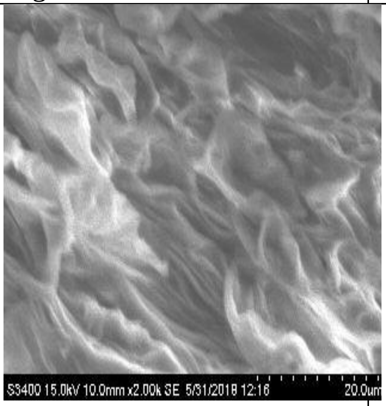


Fig. 4.38 d 180W Inside 2000

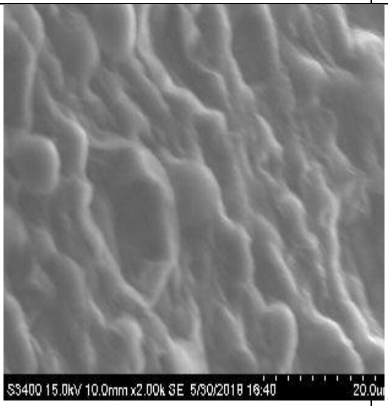


Fig. 4.38 e 360W Inside 2000

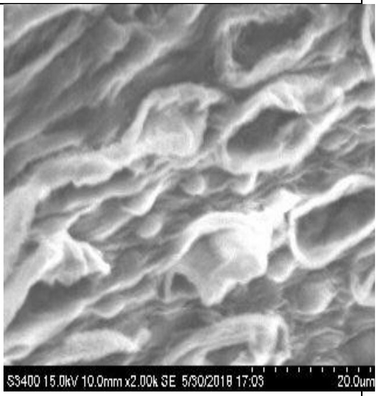


Fig. 4.38 f 540W Inside 2000

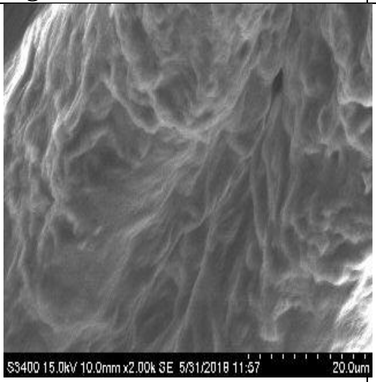


Fig. 4.38 g FD- Inside 2000

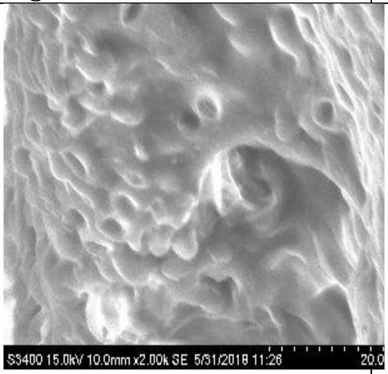


Fig. 4.38 h Raw – inside 2000

Fig. 4.39 a 50°C cross section 100

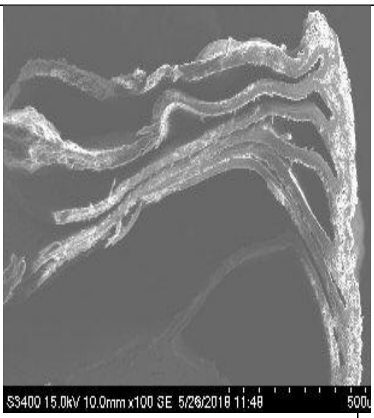


Fig. 4.39 b 60°C cross section 100

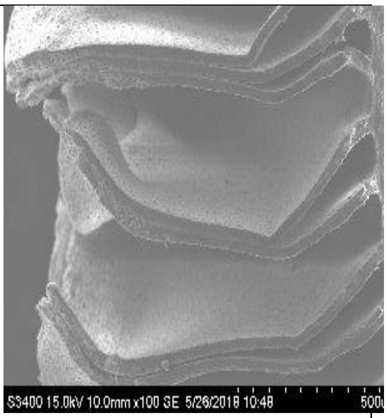


Fig. 4.39 c 70°C cross section 100

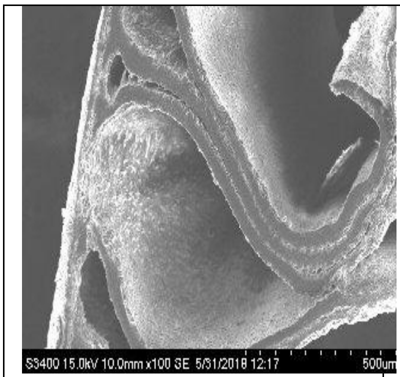


Fig. 4.39 d 180W Cross section 100

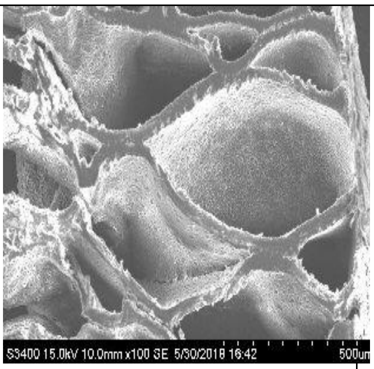


Fig. 4.39 e 360W Cross section 100

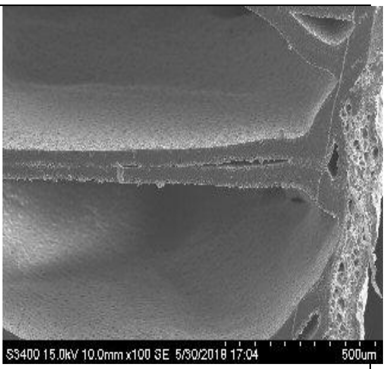


Fig. 4.39 f 540W Cross section 100

Fig. 4.39 g FD- Cross section 100

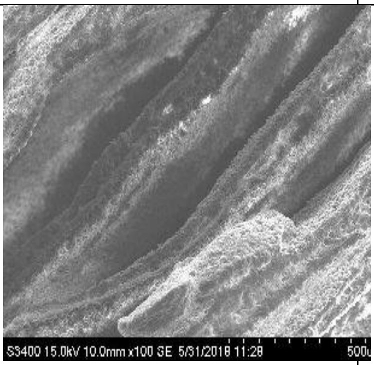


Fig. 4.39 h Raw- Cross section 100

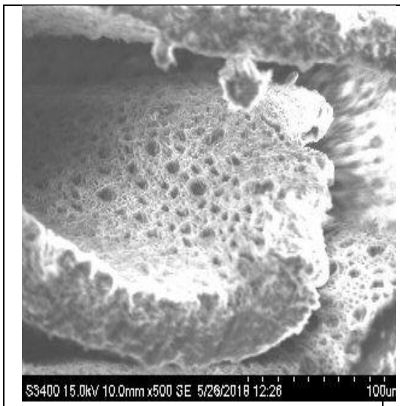


Fig. 4.40 a 50°C cross section -500

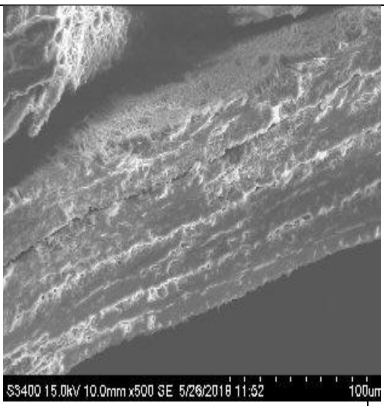


Fig. 4.40 b 60°C cross section-500

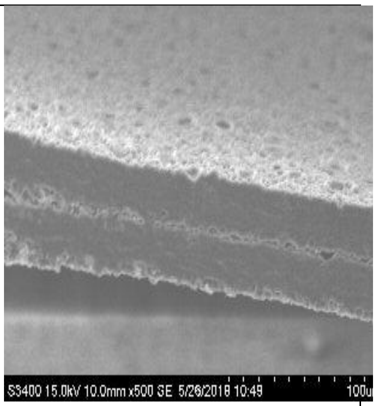


Fig. 4.40 c 70°C cross section-500

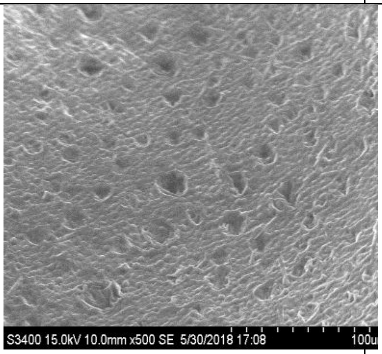


Fig. 4.40 d 0.72W/g - Cross section 500

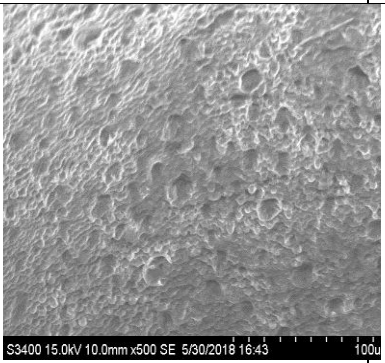


Fig. 4.40 e 1.44W/g -Cross section 500

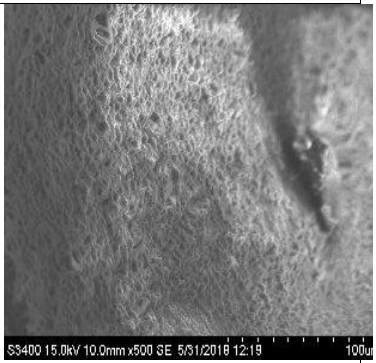


Fig. 4.40 f 2.16W/g - Cross section 500

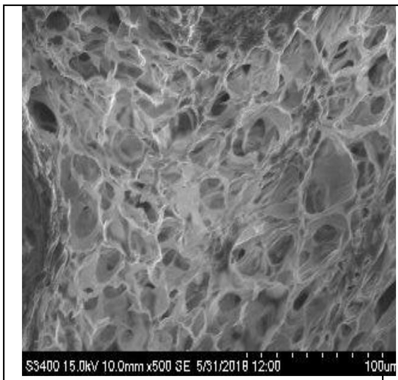


Fig. 4.40 g FD- cross section-500

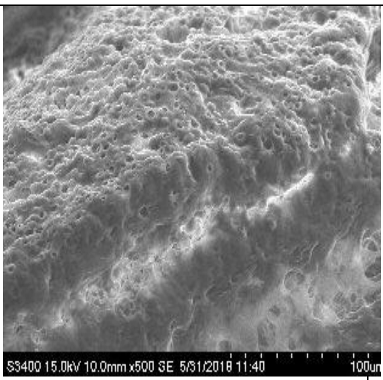


Fig. 4.40 h Raw- cross section-500

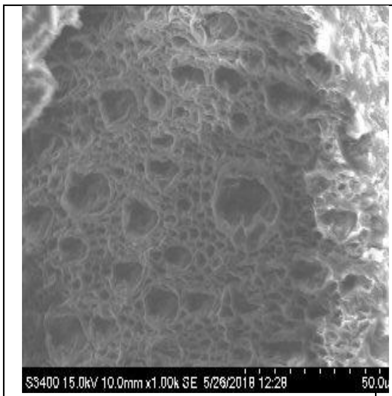


Fig.4.41 a 50°C cross section-1000

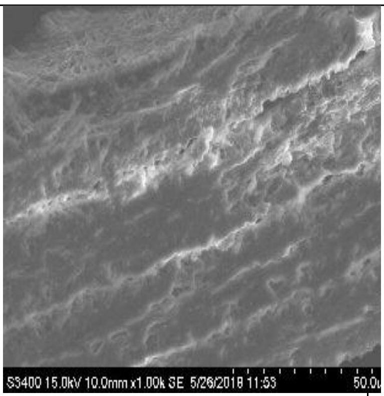


Fig. 4.41 b 60°C cross section-1000

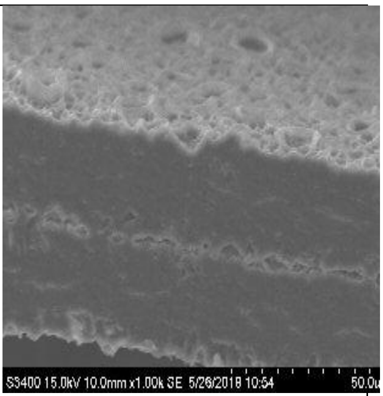


Fig. 4.41 c 70°C cross section-1000

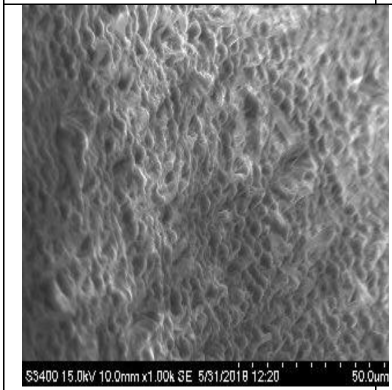


Fig.4.41 d 0.72W/g -cross section-1000

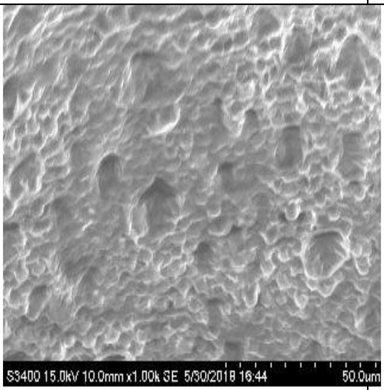


Fig.4.41 e 1.44W/g - cross section-1000

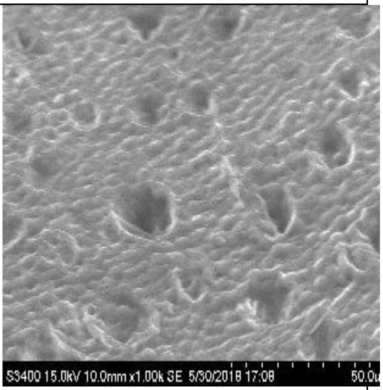


Fig. 4.41 f 2.16W/g-cross section-1000

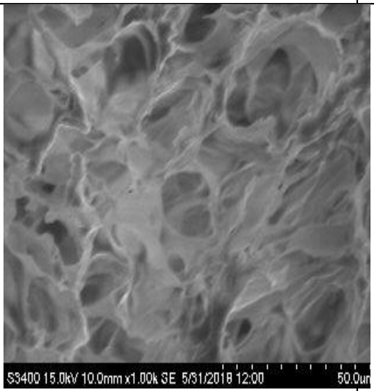


Fig.4.41g FD- cross section-1000

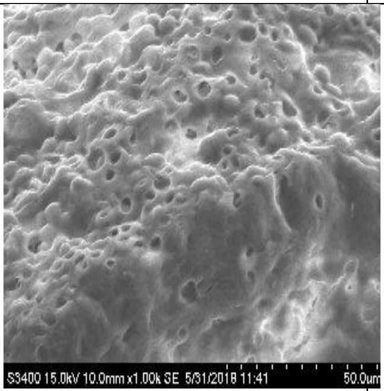


Fig.4.41h Raw-cross section-1000

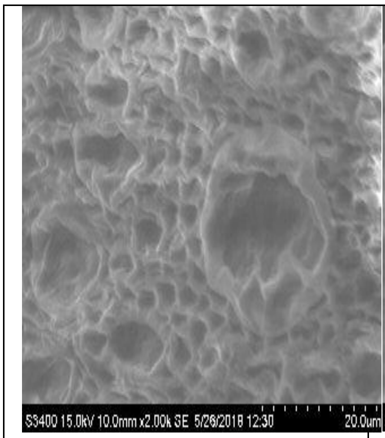


Fig. 4.42 a 50°C cross section-2000

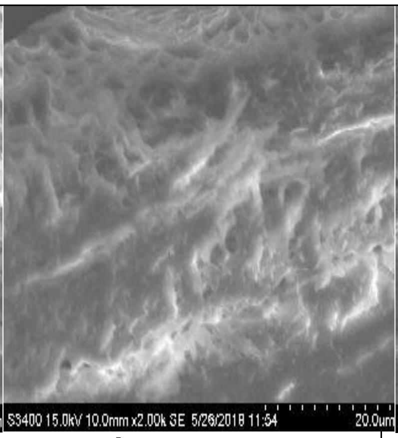


Fig. 4.42 b 60°C cross section-2000

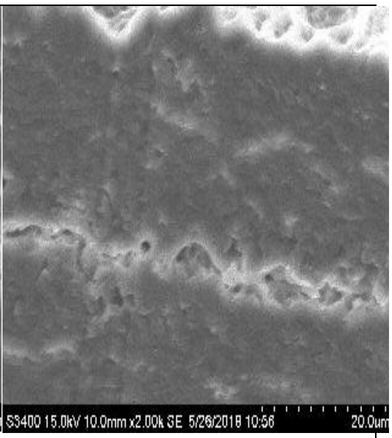


Fig. 4.42 c 70°C cross section-2000

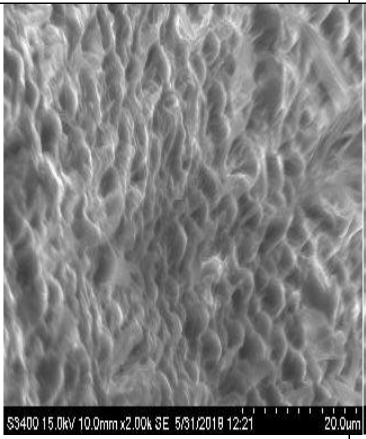


Fig. 4.42 d 0.72W/g - cross section-2000

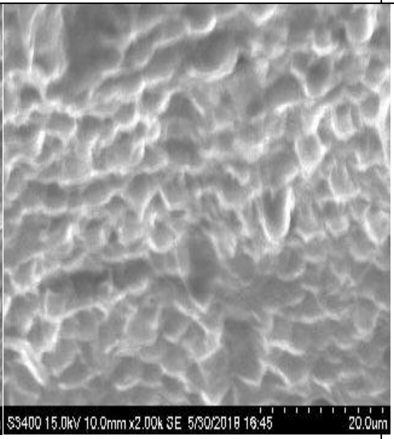


Fig. 4.42 e 1.44W/g - cross section-2000

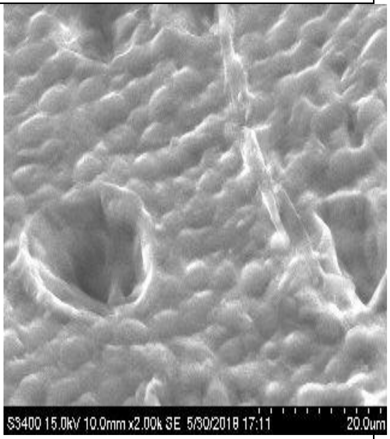


Fig. 4.42 f 2.16W/g- cross section-2000

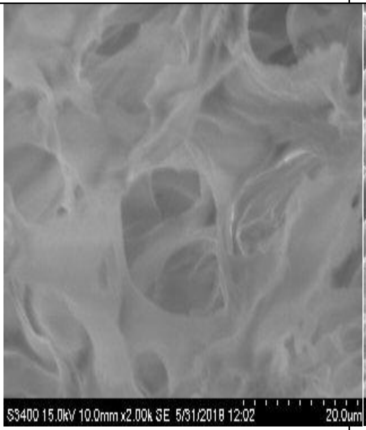


Fig. 4.42 g FD - cross section-2000

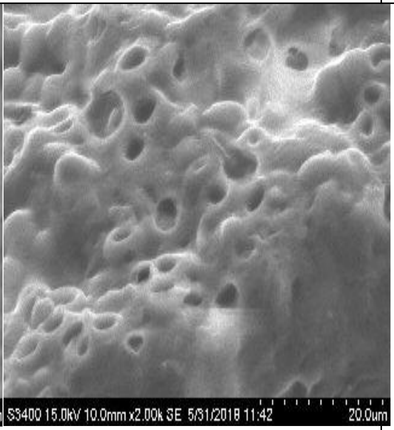


Fig. 4.42 h Raw- cross section-2000

4.4 Standardisation of process parameters for mushroom drying

From the above discussions it is observed that freeze drying offered the best quality attributes for mushroom among the different methods studied. The freeze dried samples showed better rehydration ratio, better colour, higher DPPH scavenging activity, better rehydration ratio, more water absorption index and less shrinkage ratio. The freeze drying also showed excellent retention of the different minerals. However, freeze drying is an energy intensive and expensive method, which cannot be commonly afforded by the small mushroom growers. The microwave assisted convective drying was also found suitable for drying of mushroom and can be recommended for drying of mushroom in less time. However, for a commercial enterprise, a continuous microwave dryer would be required.

The hot air drying method at 50°C also yielded dehydrated mushroom with acceptable product quality, which was not significantly different from microwave assisted convective drying. Thus, it is recommended to dry paddy straw mushroom at 50°C in hot air dryer for commercial production of dried mushroom. However, in case the dehydrated mushroom has to be specifically used for its mineral content or for medicinal purpose, it is recommended to use the freeze drying method.

4.5 Changes in quality parameters during storage

As the hot air drying at 50°C was considered the best for drying of mushroom in view of its quality and adaptability, the mushroom dried with hot air at 50°C was used for the storage study. The changes in quality attributes of the dehydrated product was studied for three months period, which are presented in Figs. 4.43 to 4.49. As discussed in Chapter 3, the samples were stored in different packaging materials, viz. low density polythene (LDPE), metalized polyester polyethylene (MPP) and polyethylene terephthalate (PET) bottle.

4.5.1 Moisture content

The change in moisture content of the dehydrated mushroom during the three months storage period has been shown in Figs. 4.43 and 4.44. It was observed that moisture content of dried samples increased during the storage period. Initial moisture content of dried paddy straw mushroom flakes was 9.89±0.38% (d.b.) and that for powder was 6.82±0.01%. After 90 days storage, it was observed that moisture content of dried flakes stored in LDPE and MPP were 12.08±0.03% (d.b.) and 11.15±0.27% (d.b.), respectively and powder stored in MPP and PET bottle were 9.09±0.02% (d.b.) and 9.27±0.04% (d.b.). There was a significant difference in moisture contents in samples stored in different packaging materials. Thus, in view of moisture absorption, it is recommended to store the mushroom powder and flakes in MPP pouches. Hanlon (1992)

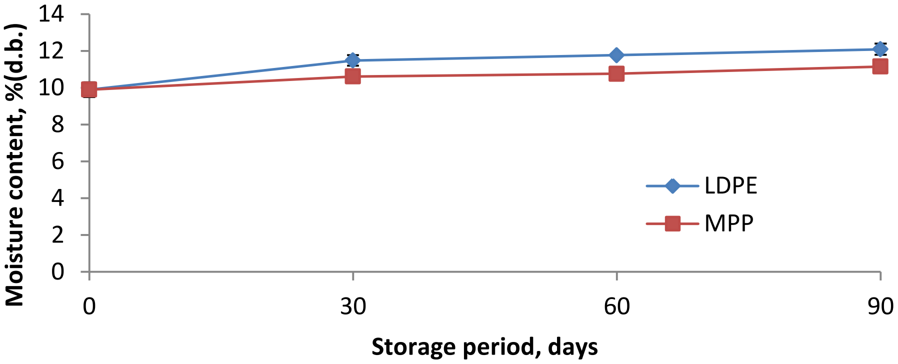


Fig.4.43 Variation of moisture content of mushroom flakes in different packaging materials

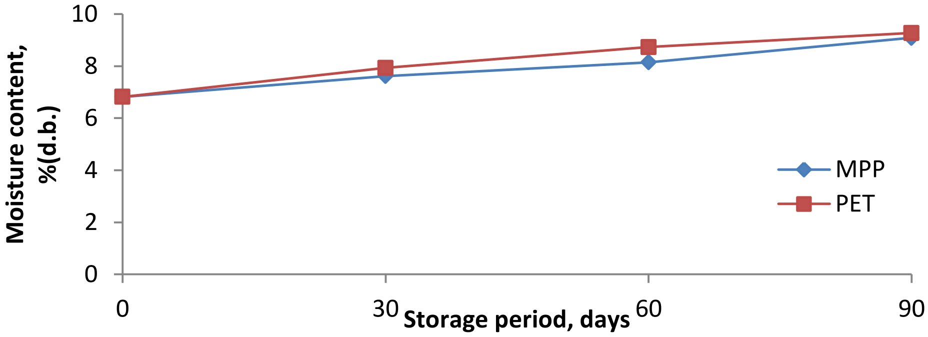


Fig. 4.44 Variation of moisture content of mushroom powder in different packaging materials

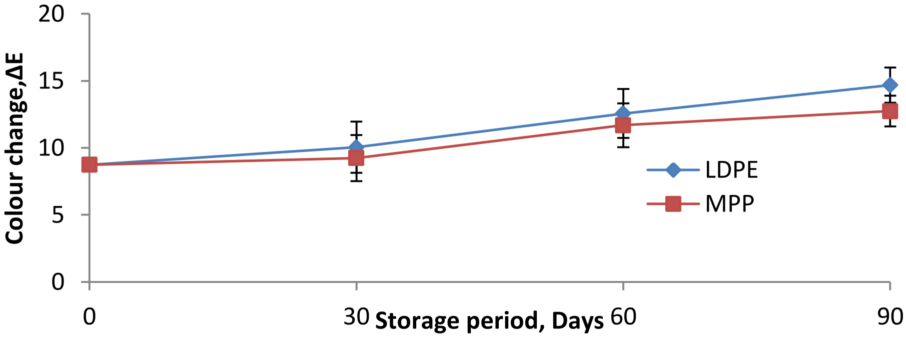


Fig. 4.45 Variation of colour change of mushroom flakes in different packaging materials

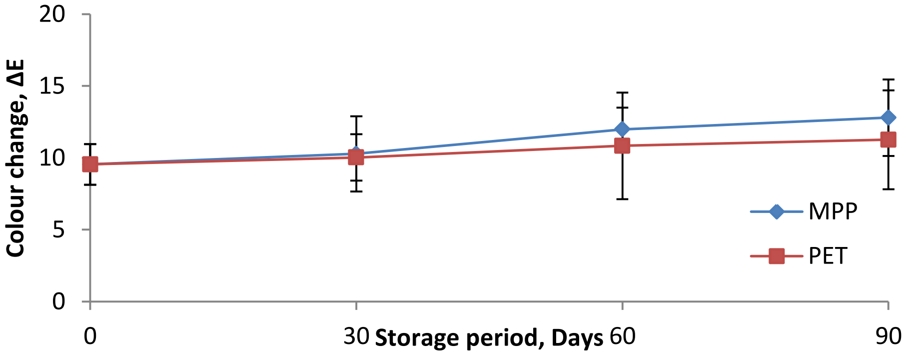


Fig. 4.46 Variation of colour change of mushroom powder in different packaging materials

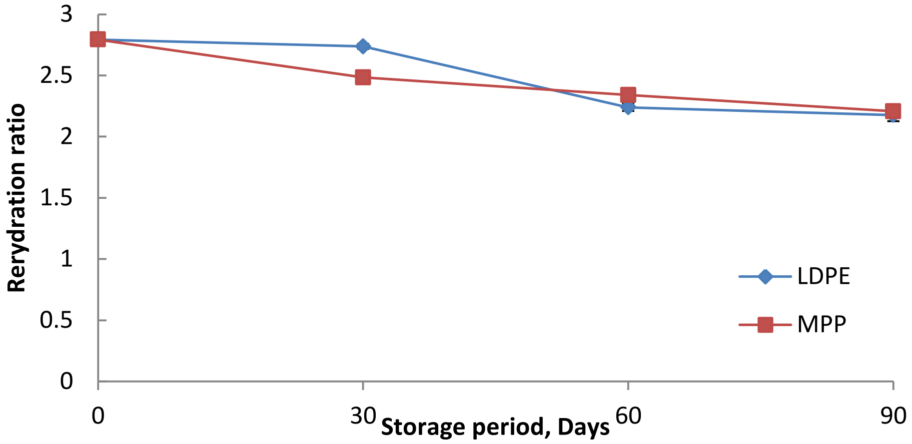


Fig. 4.47 Variation of rehydration ratio of mushroom flakes in different packaging materials

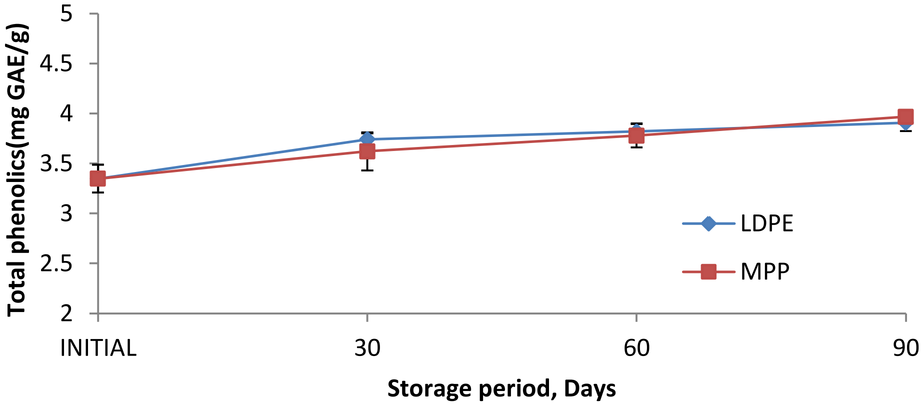


Fig. 4.48 Variation of total phenolic of flakes in different packaging materials

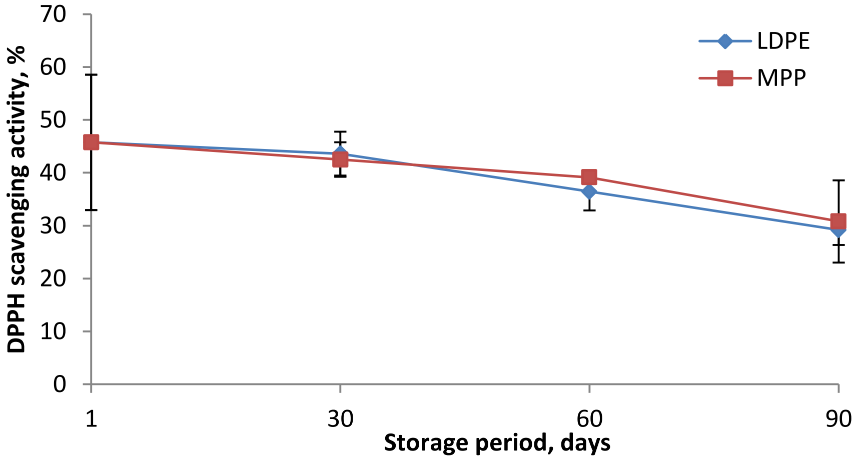


Fig. 4.49 Variation of DPPH scavenging activity of mushroom flakes in different packaging materials

has also recommended to store powders in MPP pouches due to the less water permeability in MPP pouch (i.e 0.8 g/m^2.day).

4.5.2 Colour Change

The changes in colour values for flakes and powder sample stored in different packaging materials have been shown in Figs. 4.45 and 4.46. It was observed that all the samples darkened during the storage period. The higher colour change for flakes was observed in LDPE (14.67±1.31) and for powder it was in MPP (12.79±2.66). However, there was no significant difference in the colour change on 60th and 90th days of storage for both flakes and powder.

4.5.3 Rehydration Ratio

The change in rehydration ratio of dried mushroom during three months of storage is shown in Figure 4.47. The rehydration ratio of dried samples stored in different packaging materials decreased during storage. The value of rehydration ratio after 60th days of storage in LDPE and MPP were 2.24±0.03 and 2.34±0.017, respectively, and after 90th days the values were 2.17±0.05 and 2.20±0.041, respectively. Higher rehydration ratio was obtained for the MPP pouch as compared to LDPE. The statistical analysis revealed that there was significant difference after 60 days storage, but there was no significant difference after 90 days storage period.

Table 4.14 Moisture content of mushroom flakes and powder in different packaging material during three months of storage

	Packaging materials	**0**	**30**	**60**	**90**
Flakes	LDPE	9.89±0.38	11.48±0.29	11.76±0.04^a	12.08±0.03^a
	MPP	9.89±0.38	10.61±0.25	10.75±0.34^b	11.15±0.27^b
Powder	MPP	6.82±0.01	7.62±0.02	8.15±0.04^a	9.09±0.02^a
	PET	6.82±0.01	7.93±0.04	8.73±0.02^a	9.27±0.04^a

Table 4.15 Colour change of mushroom flakes and powder in different packaging material during three months of storage

	Packaging materials	0	30	60	90
Flakes	LDPE	8.73±0.17	10.04±1.90	12.56±1.82^{a}	14.67±1.31^{a}
	MPP	8.73±0.17	9.23±1.72	11.68±1.63^{a}	12.74±1.14^{b}
Powder	MPP	9.54±1.41	10.27±2.62	11.97±1.50^{a}	12.79±2.66^{a}
	PET	9.54±1.41	10.02±1.61	10.83±3.70^{a}	11.25±3.44^{a}

Table 4.16 Rehydration ratio in mushroom flakes and powder in different packaging material during three months of storage

	Packaging materials	0	30	60	90
Flakes	LDPE	2.79±0.005	2.73±0.02	2.24±0.03^{a}	2.17±0.05^{a}
	MPP	2.79±0.005	2.48±0.005	2.34±0.017^{b}	2.20±0.041^{a}

Table 4.17 Total phenolics of mushroom flakes in different packaging material during three months of storage

	Packaging materials	0 (mg GAE/g)	30 (mg GAE/g)	60 (mg GAE/g)	90 (mg GAE/g)
Flakes	LDPE	3.34±0.13	3.74±0.06	3.81±0.08a	3.90±0.08a
	MPP	3.34±0.13	3.62±0.19	3.77±0.11a	3.96±0.04a

Table 4.18 DPPH scavenging activity of flakes in different packaging material during three months of storage

	Packaging materials	0 (%)	30 (%)	60 (%)	90 (%)
Flakes	**LDPE**	**45.74±12.79**	**43.60±4.14**	**36.44±3.55a**	**29.19±2.81a**
	MPP	**45.74±12.79**	**45.74±3.27**	**39.13±0.61a**	**30.81±7.76a**

4.5.4 Total Phenolic content

Initial value of total phenolics in mushroom at the start of storage were 3.34±0.13 mg GAE/g. The total phenolic value of dried sample during the three months storage is shown in Figure 4.48. It was observed that total phenolics increased with storage period. The value of total phenolics after 60 days were 3.81±0.08 and 3.77±0.11 mg GAE/g. The values after 90 days storage 3.90±0.08 and 3.96±0.04 mg GAE/g, respectively in LDPE and MPP pouch. However, there was no significant difference between samples stored in different packaging materials after 60 and 90 days storage. Choi et al. (2011) studied the effect of storage on phenolic compounds of citrus peels, and concluded that long term storing originated an increase in total phenols and bioactivity.

4.5.5 DPPH Scavenging activity

The DPPH scavenging activity of dried mushroom sample during three months storage have been shown in Fig. 4.49. DPPH scavenging activity of dried samples stored in different packaging materials decreased during storage. The value of DPPH after 60 days storage in LDPE and MPP were 36.44±3.55% and 39.13±0.61% respectively. The values after 90 days storage were 29.19±2.81% and 30.81±7.76% respectively. The statistical analysis revealed that there was no significant difference in the DPPH scavenging activity of mushroom samples in different packaging materials.

In view of the above, it is recommended to store the dehydrated mushroom flakes and powder in MPP pouches.

4.6 Sensory evaluation

The sensory evaluation of the paddy straw mushroom was done after three month storage. The dehydrated mushroom flakes from LDPE and MPP packages were taken and rehydrated as per the method described in section 3.5.2 (water approximately 30 times the weight of sample and soaking for 20 minutes). Then the samples were taken for cooking along with the fresh sample. After cooking, the three samples were put to sensory test on a nine-point Hedonic scale. The quality attributes selected for sensory evaluation were colour, flavour, taste, texture and overall acceptability.

The observations of the consumer panel are shown in Table. 4.19. The raw sample had the best overall acceptability (8.27±0.46) followed by MPP packaged sample (7.36±0.67) and it was observed that the dehydrated samples could be used for cooking and other applications in absence of fresh mushroom.

Table 4.19 Sensory analysis of paddy straw mushroom

Sample	Colour	Flavour	Taste	Texture	OA
Fresh sample	8.63±0.50	8.09±0.53	8.54±0.68	8.27±0.46	8.27±0.46
MPP packaged sample	6.9±0.94	7±0.84	7.63±0.80	7.00±0.63	7.363±0.67
LDPE packaged sample	6.45±0.52	6.63±1.02	7.27±0.64	6.81±0.98	7.18±0.75

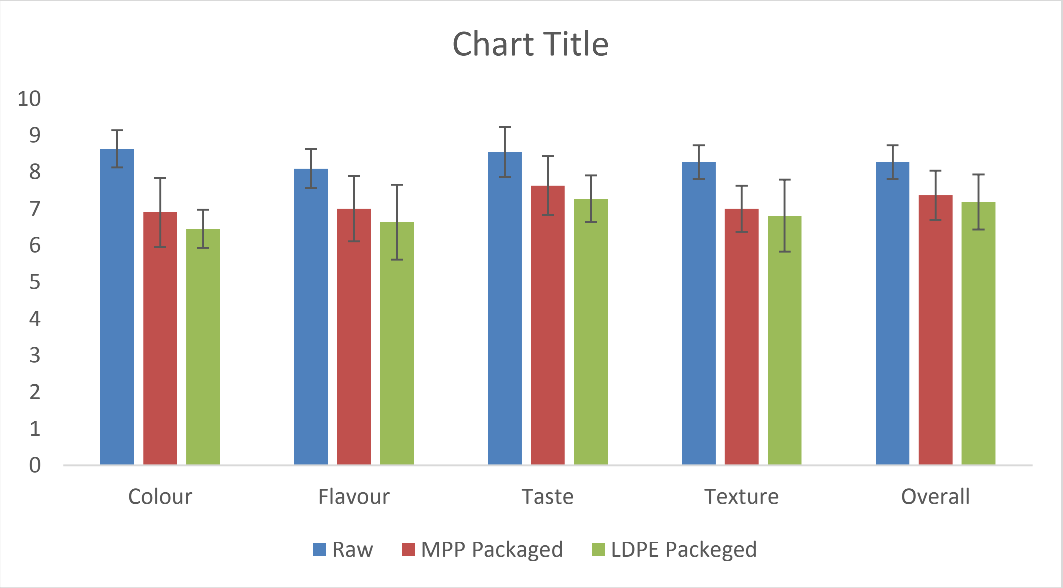


Fig 4.50 Sensory analysis of paddy straw mushroom (raw and rehydrated samples)

Chapter-5

SUMMARY AND CONCLUSIONS

Drying can be used for preparation of dehydrated mushroom flakes, which has good shelf life, marketability, export potential, thus yielding higher income to farmers. Though many drying technologies are available, but limited study has been carried out on analysing the effect of different drying methods and the operational parameters on the quality of straw mushroom. It is very important to know the nutritional status of the dehydrated paddy straw mushroom as the mushrooms are valued for their nutrition benefits. In view of the above, this study was planned to investigate the effects of different drying methods and the operational parameters on the quality of dehydrated paddy straw mushroom and to suggest some drying solution to the farmers without compromising on the nutritional value of *Volvariella volvacea*. The present study has been undertaken with following objectives:

- To study the drying kinetics of paddy straw mushroom under different drying conditions.
- To have the comparative evaluation of drying methods based on physico-chemical properties of dehydrated product.
- To assess the storability of the dehydrated mushroom in flakes and powder form using different packaging materials.

The paddy straw mushroom was dried in hot air dryer (HAD at three temperatures, viz. 40°C, 50°C and 60°C with constant air velocity of 1 m), microwave assisted convective dryer (MWCD at three microwave power levels, viz. 0.72, 1.44 and 2.16W/g at constant air temperature of 50°C) and freeze dryer (FD) to study the drying kinetics and end product quality. The initial moisture content of sample was 837.20% (d.b.) and the final moisture content of the samples were kept as 9% (d.b.). The dependent parameters to study the product quality included moisture content, total drying time, drying rate, moisture ratio, effective moisture diffusivity and activation energy for the study of drying kinetics. The product quality characteristics studied in the work included the change in colour, rehydration ratio and shrinkage ratio, nutritional quality (ash, protein, carbohydrate, fibre, ascorbic acid and reducing sugar, DPPH, total phenolics), functional quality (water solubility index, water absorption index, oil absorption index), minerals (Ca, Mg, Mn, Na, K, Se, Fe and Zn), texture (hardness, chewiness) and microscopic structure.

The following salient conclusions have been drawn:

- The moisture ratio decreased with increase in drying time. There was no constant rate drying period.
- The effective moisture diffusivities during hot air drying at 50, 60 and 70°C were 3.057×10^{-10}, 4.076×10^{-10} and 8.152×10^{-10} m^2s^{-1}, respectively. The activation energy (E_a) was 44.97 kJ mol^{-1}. The Page Model gave better prediction than other models for hot air drying characteristics of mushrooms.
- The microwave power level affected the drying rates for all conditions and the drying rate increased with the increase in microwave power levels.
- The effective diffusivities for microwave assisted convective drying at 0.72, 1.44 and 2.16 W/g were 4.99×10^{-9}, 6.14×10^{-9} and 6.35×10^{-9} m^2s^{-1}, respectively The activation energy (E_a) was 0.336 W/g. It was observed that the valuee of effective diffusivities were higher than that of hot air drying.
- The freeze drying took maximum time of 17 hours, whereas the hot air drying took a time of 180-450 minutes. The microwave assisted convective drying required only 27-30 minutes for drying of mushroom slices to the desired moisture level.
- Among the models examined, the Wang and Singh (1978) gave the best fit for the experimental data for microwave assisted convective drying with higher R^2 value and lower standard error and RSS.
- The total carbohydrate content of paddy straw mushroom was estimated as 32.17 ± 0.46% on dry weight basis. The protein content was 40.23±1.14% on dry weight basis. The crude fibre and ash content (on dry weight basis) were 17.48± 0.024 g/100g and 7.86±0.015 g/100g, respectively.
- The different drying conditions significantly affected the final colour of the dehydrated mushroom. However, considering that paddy straw mushroom initially had a higher moisture content, which also exhibited higher L values, the change in colour through instrumental analysis could not give any conclusive result. The freeze dried samples exhibited the maximum change in colour, and there was significant difference between the freeze dried samples

and the samples dried with microwave at low power levels and hot air at 50-60°C air temperature.

- The rehydration ratio of dried paddy straw mushroom varied in the range of 2.48±0.087 to 2.94±0.059. The freeze dried product had the maximum rehydration ratio of 2.94 ± 0.059 and that dried with microwaves at 1.44 W/g had minimum. There was no significant difference in rehydration ratios of freeze dried samples and those dried with hot air at 50°C.
- The freeze dried sample had the minimum shrinkage ratio of 0.11± 0.005 and 50°C hot air dried product had maximum 0.21±0.25. There was no significant difference in shrinkage ratios of microwave dried samples and those dried with hot air dryer.
- The maximum protein content was found in hot air (50°C) dried product and minimum in microwave convective (2.16W/g) dried ones. However, there was no significant difference between the freeze dried samples and the samples dried with microwave (0.72W/g) and that dried with hot air at 50°C.
- The maximum carbohydrate content was found in MWCD (0.72 W/g) product (30.82±1.15%) and minimum (28.51±2.23%) in MWCD (2.16 W/g) product; however, there was no significant effect on the final carbohydrate content of the samples dried under different conditions.
- The ash content of dried paddy straw mushroom varied in the range of 7.78±0.54 to 9.18 ± 0.23 g/100g. The maximum ash content was observed in the samples dried in freeze dryer, however, it was not significantly different from the samples dried under MWCD at 0.72 W/g.
- The maximum fibre content of 16.56 ± 1.65 g/100g was in 50°C hot air drying and the minimum (12.40 ± 0.05 g/100g) was in freeze drying. There is no significant difference between hot air dried sample at 50°C and that at 60°C.
- The ascorbic acid content of mushroom reduced during drying; it decreased from an initial value of 60.13±0.26 mg/100g (dry basis) to 6.92±1.60 mg/100g, when dried in hot air (50°C). The ascorbic acid retention was maximum in freeze dried sample and minimum in hot air dried samples.
- The maximum reducing sugar (3.68±0.17g/100g) was in microwave convective dried sample (0.72W/g) and the minimum (1.39± 0.15 g/100g) in hot air drying (70°C). There was no significant difference in reducing sugars

of FD sample and MWCD sample in power levels of 1.44 and 2.16 W/g, but these values were much lower than the MWCD at 0.72 W/g.

- The total phenolic compounds in fresh paddy straw mushroom was 13.77±0.02 mg GAE/g on dry basis. The total phenolic compounds were maximum in freeze dried sample (4.88±0.08 mg GAE/g) and minimum (4.0±0.15 mg GAE/g) in hot air (70°C) dried sample. However, there was no significant difference between hot air (50°C) and microwave convective (1.44 W/g and 2.16 W/g) dried samples.
- It was observed that the minimum value (23.28 ± 1.58 %) of DPPH was in hot air (70°C) dried mushrooms and maximum value (81.58 ± 0.89 %) was in freeze dried sample. If the freeze drying is ignored, the maximum DPPH activity was observed in samples dried in hot air at 50°C. However, there was no significant difference between hot air dried sample at 50°C and microwave convective dried sample at 1.44 W/g.
- The level of eight essential minerals, i.e. selenium, manganese, iron, zinc, calcium, magnesium, sodium and potassium for paddy straw mushroom powder indicated that not much change in the mineral content of the samples were observed after drying.
- Thus it may be concluded that drying does not change any mineral content of mushroom and the thus can be used as a food and mineral supplement for other value added products.
- The value of water absorption index was maximum (3.96±0.06 g starch/ g dry matter) in freeze dried sample and minimum (3.05±0.06) in microwave convective drying at 1.44 W/g. Ignoring freeze drying, the maximum WAI was obtained for sample dried in hot air at 50°C. It was observed that there is no significant difference between hot air dried sample 50°and 60°C.
- Water solubility index of freeze dried sample was maximum (0.39±0.02 g/100g) and minimum (0.23±0.05g/100g) in hot air dried sample (50°C). Samples dried with hot air at 60°C and 70°C had higher WSI than those dried at 50°C.
- The oil absorption index of microwave convective (2.16 W/g) dried sample was maximum (2.57±0.086g/g) and that of freeze dried sample was minimum

(2.34±0.067g/g). However, there was no significant difference between MWCD sample and hot air dried samples.

- The hardness of dried mushroom decreased with increased temperature and power levels; it varied in the range of 2058.87±586.10g to 5529.11±1560.08 g for stem and 4363.51±496.62g to7493.08±1897.67g for cap. The freeze dried sample had the minimum hardness and the microwave dried sample at 0.72 W/g had the maximum. However, if the FD samples are kept aside, there was no significant difference in hardness of the samples dried by other methods.
- Higher temperatures and microwave powers caused more microstructural damage and ruptured the cell walls that those at lower levels. In case of convective drying, product dried at 50°C had more pores with smooth surface than that dried at 60°C and 70°C. MWCD at 1.44W/g and 2.16W/g resulted in more tissue shrinkage, collapse and more crushed formation compared to that at 0.72W/g.
- Thus, freeze drying offered the best quality product among the different methods studied. The FD samples showed better rehydration ratio, better colour, higher DPPH scavenging activity, better rehydration ratio, more water absorption index and less shrinkage ratio. The FD also showed excellent retention of minerals. The hot air drying at 50°C also yielded product with acceptable product quality, which was not significantly different from MWCD. Thus, it is recommended to dry paddy straw mushroom at 50°C in hot air dryer for commercial production of dried mushroom.
- In case the dehydrated mushroom has to be specifically used for its mineral content or for medicinal purpose, it is recommended to use freeze drying.
- The storage study indicated that after 90 days, the moisture content of dried flakes stored in LDPE and MPP were 12.08±0.03% (d.b.) and 11.15±0.27% (d.b.), respectively and the powder stored in MPP and PET bottle were at 9.09±0.02% (d.b.) and 9.27±0.04% (d.b.).
- The samples darkened during the storage and the higher colour change for flakes was observed in LDPE (ΔE value 14.67±1.31). For powder, the maximum change in colour was for MPP (ΔE value 12.79±2.66). However, the difference in colour change was not significant in different packages.

- The value of rehydration ratio after 90 days was 2.17±0.05 and 2.20±0.041, respectively. Higher rehydration ratio was obtained for the MPP pouch as compared to LDPE. The statistical analysis revealed that there was significant difference after 60 days storage, but no significant difference was observed after 90 days of storage.
- Total phenolics increased with storage period. The value of total phenolics after 60 days were 3.81±0.08 and 3.77±0.11 mg GAE/g. The values after 90 days storage were 3.90±0.08 and 3.96±0.04mg GAE/g, respectively in LDPE and MPP packages. However, there was no significant difference between samples stored in different packaging materials after 60 and 90 days storage.
- The values of DPPH after 90 days storage were 29.19±2.81% and 30.81±7.76% respectively. There was no significant difference in the DPPH scavenging activity of mushroom samples in different packaging materials.
- In view of the above, it is recommended to store the dehydrated mushroom flakes and powder in MPP pouches.

On the basis of this comprehensive study, it is recommended to dry paddy straw mushroom at 50°C in hot air dryer for commercial production of dried mushroom. The microwave assisted convective dehydration can also be used at a power level of 0.72 W/g if commercial microwave assisted convective dryer is available. However, if the dehydrated mushroom has to be specifically used for its mineral content or for medicinal purpose, the freeze drying is recommended.

Chapter-6

SUGGESTION FOR FUTURE WORK

In view of the present study the following future work are suggested.

1. A complete nutritional analysis of mushroom and dehydrated mushroom needs to be conducted for establishing the loss of nutrients and functional ingredients during dehydration of mushroom.
2. Low cost dryers need to be developed for on-farm dehydration of mushroom.
3. Studies should be conducted on the energy utilisation in dehydrating mushroom to establish the cost economics of mushroom dehydrated products.
4. Studies should be conducted for incorporating mushroom powder in different secondary foods for enriching their nutritional value and for the economic benefit of the mushroom growers.

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Annexure 1

Hot air drying of paddy straw mushroom at 50°C

Drying time	**wt.of sample**	**Dry weight**	**Amount of moisture**	**M.C (db)**	**Average M.C**	**Drying rate**	**moisture ratio**	**ln moisture ratio**
0	650.3	52.024	598.276	1150			1	0
15	589.2	52.024	537.176	1032.554	1091.277	7.829719617	0.897873	-0.10773
30	535.1	52.024	483.076	928.5637	980.559	6.932697729	0.807447	-0.21388
60	430.6	52.024	378.576	727.6949	828.1293	6.695627659	0.632778	-0.45764
90	353.4	52.024	301.376	579.3019	653.4984	4.946434979	0.503741	-0.68569
120	278.1	52.024	226.076	434.561	506.9314	4.824696294	0.377879	-0.97318
150	218.9	52.024	166.876	320.7673	377.6642	3.793121124	0.278928	-1.2768
210	123.4	52.024	71.376	137.1982	228.9828	3.059485366	0.119303	-2.12609
270	87.6	52.024	35.576	68.38382	102.791	1.146906556	0.059464	-2.82238
330	72.7	52.024	20.676	39.7432	54.06351	0.47734379	0.034559	-3.36508
390	68.9	52.024	16.876	32.43887	36.09103	0.121738685	0.028208	-3.56816
450	67.9	52.024	15.876	30.51668	31.47778	0.032036496	0.026536	-3.62924

Hot air drying of paddy straw mushroom at 60°C

Drying time	wt.of sample	Dry weight	Amount of moisture	M.C (db)	Average M.C	Drying rate	moisture ratio	ln moisture ratio
0	686.6	54.928	631.672	1150			1	
15	589.4	54.928	534.472	973.0411	1061.521	10.49252355	0.846123	-0.16709
30	513.7	54.928	458.772	835.2243	904.1327	10.77167686	0.726282	-0.31982
60	411.9	54.928	356.972	649.8908	742.5575	8.151786581	0.565122	-0.57071
90	278	54.928	223.072	406.1171	528.0039	6.672371104	0.353145	-1.04088
120	192	54.928	137.072	249.5485	327.8328	4.114477134	0.216999	-1.52786
150	142.4	54.928	87.472	159.2485	204.3985	3.031240897	0.138477	-1.97705
210	92.1	54.928	37.172	67.67405	113.4613	1.057444898	0.058847	-2.83281
270	72.7	54.928	17.772	32.35508	50.01456	0.320116031	0.028135	-3.57075
330	71	54.928	16.072	29.26012	30.8076	0.513460045	0.025444	-3.67129

Hot air drying of paddy straw mushroom at 70°C

Drying time	wt.of sample	Dry weight	Amount of moisture	M.C (db)	Average M.C	Drying rate	moisture ratio	ln moisture ratio
0	672	60.48	611.52	1150			1	0
15	542.4	60.48	481.92	796.8254	903.9683	14.28571429	0.894035	-0.11201
30	449.9	60.48	389.42	643.8823	720.3538	10.19620811	0.712438	-0.33906
60	255.7	60.48	195.22	322.7844	483.3333	9.70326279	0.478022	-0.7381
90	154.4	60.48	93.92	155.291	239.0377	5.583112875	0.236411	-1.44218
120	92.4	60.48	31.92	52.77778	104.0344	3.417107584	0.102891	-2.27408
150	71.4	60.48	10.92	18.05556	35.41667	1.157407407	0.035027	-3.35162
180	65.4	60.48	4.92	8.134921	13.09524	0.330687831	0.012951	-4.34656

Microwave convective drying of paddy straw mushroom at 0.72W/g

Drying time	**wt.of sample**	**Dry weight**	**Amount of moisture**	**M.C (db)**	**Average M.C**	**Drying rate**	**moisture ratio**	**ln moisture ratio**
0	204.8	16.384	188.416	900			1	0
5	146.2	16.384	129.816	792.334	971.167	51.81884766	0.688986	-0.37253
10	91.6	16.384	75.216	459.082	625.708	41.19873047	0.399202	-0.91829
15	56.2	16.384	39.816	243.0176	351.0498	23.52905273	0.21132	-1.55438
18	40.2	16.384	23.816	145.3613	194.1895	20.29418945	0.126401	-2.06829
21	29.6	16.384	13.216	80.66406	113.0127	12.51220703	0.070143	-2.65722
24	23.8	16.384	7.416	45.26367	62.96387	6.256103516	0.03936	-3.23501
26	21.4	16.384	5.016	30.61523	37.93945	4.463195801	0.026622	-3.62602
28	19.9	16.384	3.516	21.45996	26.0376	2.059936523	0.018661	-3.98133
30	19.6	16.384	3.216	19.62891	20.54443	7.704162598	0.017069	-4.07051

Microwave convective drying of paddy straw mushroom at 1.44W/g

Drying time	wt.of sample	Dry weight	Amount of moisture	M.C (db)	Average M.C	Drying rate	moisture ratio	ln moisture ratio
0	253.3	25.33	227.97	900			1	0
5	190.8	25.33	165.47	653.257	776.6285	49.3485985	0.725841	-0.32042
10	126.6	25.33	101.27	399.8026	526.5298	50.69088038	0.444225	-0.81142
15	83	25.33	57.67	227.6747	313.7386	34.42558231	0.252972	-1.37448
18	58.9	25.33	33.57	132.5306	180.1026	31.7146993	0.147256	-1.91558
21	36.7	25.33	11.37	44.88749	88.70904	29.21437031	0.049875	-2.99824
24	29.8	25.33	4.47	17.64706	31.26727	9.080142124	0.019608	-3.93183
26	28.6	25.33	3.27	12.90959	15.27833	4.168732728	0.014344	-4.24442
28	26.5	25.33	1.17	4.619029	8.764311	2.345282274	0.005132	-5.27221

Microwave convective drying of paddy straw mushroom at 2.16W/g

Drying time	**wt.of sample**	**Dry weight**	**Amount of moisture**	**M.C (db)**	**Average M.C**	**Drying rate**	**moisture ratio**	**ln moisture ratio**
0	201.5	20.15	181.35	900			1	0
5	134.4	20.15	114.25	566.9975	733.4988	66.60049628	0.629997	-0.462039836
10	79.9	20.15	59.75	296.5261	431.7618	54.0942928	0.329473	-1.110259675
15	49.1	20.15	28.95	143.6725	220.0993	30.5707196	0.159636	-1.834858662
18	34.2	20.15	14.05	69.72705	106.6998	24.64846981	0.077474	-2.55780647
21	26.5	20.15	6.35	31.51365	50.62035	12.73779983	0.035015	-3.351974053
24	22.1	20.15	1.95	9.677419	20.59553	7.278742763	0.010753	-4.532599493
27	21.6	20.15	1.45	7.19603	8.436725	0.827129859	0.007996	-4.828865309

Annexure 2

Statistical Analyses of Data

Lightness

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	14152.21371	2358.70229	1.04	0.4192
Error	28	63319.97600	2261.42771		
Corrected Total	34	77472.18971			

R-Square	CoeffVar	Root MSE	l Mean
0.182675	121.9435	47.55447	38.99714

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	14152.21371	2358.70229	1.04	0.4192

Alpha	0.05
Error Degrees of Freedom	28
Error Mean Square	2261.428
Critical Value of t	2.04841
Least Significant Difference	61.608

Means with the same letter are not significantly different.

t Grouping		Mean	N	Treat
	A	31.16	5	HAD60
	A			
B	A	37.32	5	FD
B	A			
B	A	33.92	5	HAD50
B	A			
B	A	33.54	5	MW180
B	A			
B	A	31.16	5	MW360
B	A			
B	A	25.64	5	MW540
B				
B		24.46	5	HAD70

Hardness

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	50670350.0	7238621.4	2.72	0.0234
Error	34	90332230.5	2656830.3		
Corrected Total	41	141002580.5			

R-Square	CoeffVar	Root MSE	hardness Mean
0.359358	36.84274	1629.979	4424.152

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	7	50670350.03	7238621.43	2.72	0.0234

Alpha	0.05
Error Degrees of Freedom	34
Error Mean Square	2656830
Critical Value of t	2.03224
Least Significant Difference	2191
Harmonic Mean of Cell Sizes	4.571429

Means with the same letter are not significantly different.

t Grouping	Mean	N	Treat
A	5529	6	HAD50
A			
A	4377	6	MW360
A			
A	4635	6	HAD70
A			
A	4980	6	HAD60
A			
B A	5457	6	MW180
B A			
B A C	3916	6	MW540
B C			
B C	2241	2	FD1
C			
C	2058	4	FD

Hardness of cap

Alpha	0.05
Error Degrees of Freedom	34
Error Mean Square	2003309
Critical Value of t	2.03224
Least Significant Difference	2133.2
Harmonic Mean of Cell Sizes	3.636364

Means with the same letter are not significantly different.				
t Grouping		Mean	N	Treat
	A	5931	6	MW540
	A			
	A	7493	6	MW180
	A			
	A	4566	6	HAD70
	A			
B	A	7108	6	MW360
B	A			
B	A	5401	1	FD1
B	A			
B	A	4196	5	FD
B				
B		5305	6	HAD60
B				
B		7282	6	HAD50

Change in colour

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	84.0411886	14.0068648	7.80	<.0001
Error	28	50.3096800	1.7967743		
Corrected Total	34	134.3508686			

R-Square	CoeffVar	Root MSE	colour Mean
0.625535	14.04398	1.340438	9.544571

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	84.04118857	14.00686476	7.80	<.0001

Alpha	0.05
Error Degrees of Freedom	28

Alpha	0.05
Error Mean Square	1.796774
Critical Value of t	2.04841
Least Significant Difference	1.7366

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**Treat**
A	11.860	5	FD
A			
B A	9.840	5	MW360
B A			
B A C	7.850	5	HAD70
B C			
B D C	8.230	5	MW540
D C			
E D C	8.6520	5	HAD60
E D			
E D	10.980	5	MW180
E			
E	8.730	5	HAD50

Chewiness of stem

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	5686742.88	812391.84	1.55	0.1843
Error	34	17824892.24	524261.54		
Corrected Total	41	23511635.12			

R-Square	CoeffVar	Root MSE	chewiness Mean
0.241869	43.01291	724.0591	1683.353

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	7	5686742.883	812391.840	1.55	0.1843

Alpha	0.05
Error Degrees of Freedom	34
Error Mean Square	524261.5
Critical Value of t	2.03224
Least Significant Difference	1091.3
Harmonic Mean of Cell Sizes	3.636364

Means with the same letter are not significantly different.

t Grouping		Mean	N	Treat
	A	2263.4	6	HAD70
	A			
B	A	1965.7	6	HAD50
B	A			
B	A	1912.5	6	HAD60
B	A			
B	A	1748.0	6	MW360
B	A			
B	A	1410.0	6	MW180
B	A			
B	A	1388.2	1	FD1
B	A			
B	A	1283.5	6	MW540
B				
B		1162.8	5	FD

Chewiness of cap

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	17362013.23	2480287.60	6.63	<.0001
Error	34	12724069.40	374237.34		
Corrected Total	41	30086082.63			

R-Square	CoeffVar	Root MSE	chewiness Mean
0.577078	26.85778	611.7494	2277.736

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	7	17362013.23	2480287.60	6.63	<.0001

Alpha	0.05
Error Degrees of Freedom	34
Error Mean Square	374237.3
Critical Value of t	2.03224
Least Significant Difference	922
Harmonic Mean of Cell Sizes	3.636364

Means with the same letter are not significantly different.

t Grouping	Mean	N	Treat
A	3771.8	6	HAD70
B	2286.8	5	FD
B			

Means with the same letter are not significantly different.			
t Grouping	Mean	N	Treat
B	2194.6	6	MW180
B			
B	2190.7	6	MW540
B			
B	2178.0	1	FD1
B			
B	1961.8	6	MW360
B			
B	1930.7	6	HAD60
B			
B	1626.0	6	HAD50

Ash

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	4.74186514	0.79031086	2.15	0.1116
Error	14	5.14524867	0.36751776		
Corrected Total	20	9.88711381			

R-Square	CoeffVar	Root MSE	ash Mean
0.479601	7.413960	0.606232	8.176905

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	4.74186514	0.79031086	2.15	0.1116

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.367518
Critical Value of t	2.14479
Least Significant Difference	1.0616

Means with the same letter are not significantly different.				
t Grouping		Mean	N	Treat
	A	9.1843	3	FD
	A			
B	A	8.4273	3	MW180
B	A			
B	A	7.780	3	MW540
B				

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**Treat**
B	7.9633	3	HAD60
B			
B	7.8780	3	MW360
B			
B	8.2763	3	HAD50
B			
B	7.7290	3	HAD70

Carbohydrate

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	14.64899048	2.44149841	0.65	0.6922
Error	14	52.83433333	3.77388095		
Corrected Total	20	67.48332381			

R-Square	CoeffVar	Root MSE	carbohydrate Mean
0.217076	6.498910	1.942648	29.89190

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	14.64899048	2.44149841	0.65	0.6922

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	3.773881
Critical Value of t	2.14479
Least Significant Difference	3.402

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**Treat**
A	30.820	3	MW180
A			
A	30.557	3	MW360
A			
A	30.533	3	FD
A			
A	30.213	3	HAD60
A			
A	29.790	3	HAD50
A			

Means with the same letter are not significantly different.			
t Grouping	Mean	N	Treat
A	28.813	3	HAD70
A			
A	28.517	3	MW540

Protein content

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	82.0686286	13.6781048	2.18	0.1073
Error	14	87.7062667	6.2647333		
Corrected Total	20	169.7748952			

R-Square	CoeffVar	Root MSE	protein Mean
0.483397	6.827543	2.502945	36.65952

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	82.06862857	13.67810476	2.18	0.1073

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	6.264733
Critical Value of t	2.14479
Least Significant Difference	4.3832

Means with the same letter are not significantly different.				
t Grouping		Mean	N	Treat
	A	38.520	3	MW180
	A			
	A	38.200	3	FD
	A			
	A	38.123	3	HAD50
	A			
	A	37.883	3	HAD60
	A			
B	A	36.147	3	HAD70
B	A			
B	A	34.890	3	MW360
B				
B		32.853	3	MW540

Fibre

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	31.19811429	5.19968571	7.18	0.0012
Error	14	10.13826667	0.72416190		
Corrected Total	20	41.33638095			

R-Square	CoeffVar	Root MSE	fibre Mean
0.754737	5.820257	0.850977	14.62095

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	31.19811429	5.19968571	7.18	0.0012

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.724162
Critical Value of t	2.14479
Least Significant Difference	1.4902

Means with the same letter are not significantly different.

t Grouping		Mean	N	Treat
	A	16.5667	3	HAD50
	A			
B	A	15.6167	3	HAD60
B				
B	C	15.0467	3	MW540
B	C			
B	C	14.3633	3	HAD70
B	C			
B	C	14.3467	3	MW180
	C			
	C	14.0033	3	MW360
	D	12.4033	3	FD

Total phenolic

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1.72219048	0.28703175	11.80	<.0001
Error	14	0.34053333	0.02432381		
Corrected Total	20	2.06272381			

R-Square	CoeffVar	Root MSE	phenolics Mean	
0.834911	3.449009	0.155961	4.521905	

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	1.72219048	0.28703175	11.80	<.0001

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.024324
Critical Value of t	2.14479
Least Significant Difference	0.2731

Means with the same letter are not significantly different.

t Grouping		Mean	N	Treat
	A	4.8733	3	FD
	A			
	A	4.8000	3	MW180
	A			
B	A	4.6767	3	MW360
B	A			
B	A	4.6067	3	MW540
B				
B	C	4.0033	3	HAD70
	C			
D	C	4.2700	3	HAD60
D				
D		4.4233	3	HAD50

DPPH activity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	6044.850067	1007.475011	43.85	<.0001
Error	14	321.620600	22.972900		
Corrected Total	20	6366.470667			

R-Square	CoeffVar	Root MSE	antioxidant Mean
0.949482	9.844595	4.793005	48.68667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	6044.850067	1007.475011	43.85	<.0001

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	22.9729
Critical Value of t	2.14479
Least Significant Difference	8.3936

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**Treat**
A	81.587	3	FD
B	57.653	3	HAD50
B			
B	54.220	3	MW360
C	43.873	3	MW540
C			
C	41.737	3	HAD60
C			
C	38.453	3	MW180
D	23.283	3	HAD70

Ascorbic acid

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	332.2847143	55.3807857	46.90	<.0001
Error	14	16.5308667	1.1807762		
Corrected Total	20	348.8155810			

R-Square	CoeffVar	Root MSE	ascorbic Mean
0.952609	8.589355	1.086635	12.65095

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	332.2847143	55.3807857	46.90	<.0001

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	1.180776
Critical Value of t	2.14479
Least Significant Difference	1.9029

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**Treat**
A	18.8633	3	FD
B	15.6967	3	MW360
B			
C B	14.8967	3	MW540
C			
C	13.4367	3	MW180
D	10.5733	3	HAD50
E	8.1667	3	HAD60
E			
E	6.9233	3	HAD70

Reducing sugar

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	12.57951429	2.09658571	45.97	<.0001
Error	14	0.63846667	0.04560476		
Corrected Total	20	13.21798095			

R-Square	CoeffVar	Root MSE	reducing Mean
0.951697	8.719827	0.213553	2.449048

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	12.57951429	2.09658571	45.97	<.0001

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.045605
Critical Value of t	2.14479
Least Significant Difference	0.374

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**Treat**
A	3.6800	3	MW180
B	3.0033	3	MW360
B			
B	2.967	3	MW540
B			
B	2.6367	3	FD
C	1.5667	3	HAD60

Means with the same letter are not significantly different.			
t Grouping	Mean	N	Treat
D	1.9800	3	HAD50
D			
D	1.3900	3	HAD70

Rehydration ratio

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.58032381	0.09672063	12.81	<.0001
Error	14	0.10573333	0.00755238		
Corrected Total	20	0.68605714			

R-Square	CoeffVar	Root MSE	rehydration Mean
0.845883	3.277646	0.086904	2.651429

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	0.58032381	0.09672063	12.81	<.0001

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.007552
Critical Value of t	2.14479
Least Significant Difference	0.1522

Means with the same letter are not significantly different.				
t Grouping		Mean	N	Treat
	A	2.93333	3	FD
	A			
	A	2.86333	3	HAD50
	B	2.65333	3	HAD70
	B			
C	B	2.60000	3	HAD60
C	B			
C	B	2.51667	3	MW540
C	B			
C	B	2.51000	3	MW180
C				

Means with the same letter are not significantly different.			
t Grouping	Mean	N	Treat
C	2.48333	3	MW360

Shrinkage ratio

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.01755895	0.00292649	40.25	<.0001
Error	14	0.00101800	0.00007271		
Corrected Total	20	0.01857695			

R-Square	CoeffVar	Root MSE	shrinkage Mean
0.945201	4.643999	0.008527	0.183619

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	0.01755895	0.00292649	40.25	<.0001

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.000073
Critical Value of t	2.14479
Least Significant Difference	0.0149

Means with the same letter are not significantly different.			
t Grouping	Mean	N	Treat
A	0.198333	3	HAD70
A			
A	0.197667	3	MW180
A			
A	0.197667	3	HAD50
A			
A	0.197667	3	MW360
A			
A	0.193000	3	MW540
A			
A	0.187667	3	HAD60
B	0.113333	3	FD

Water solubility index

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.08804533	0.01467422	9.95	0.0002
Error	14	0.02064333	0.00147452		
Corrected Total	20	0.10868867			

R-Square	CoeffVar	Root MSE	wsi Mean
0.810069	12.81408	0.038400	0.299667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	0.08804533	0.01467422	9.95	0.0002

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.001475
Critical Value of t	2.14479
Least Significant Difference	0.0672

Means with the same letter
are not significantly different.

t Grouping	Mean	N	Treat
A	0.37933	3	FD
A			
A	0.37000	3	HAD60
A			
A	0.36767	3	HAD70
B	0.27767	3	MW540
B			
B	0.24000	3	MW180
B			
B	0.23833	3	HAD50
B			
B	0.22467	3	MW360

Water absorption index

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	2.04300000	0.34050000	18.00	<.0001
Error	14	0.26480000	0.01891429		
Corrected Total	20	2.30780000			

R-Square	CoeffVar	Root MSE	wai Mean
0.885259	4.080986	0.137529	3.370000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	2.04300000	0.34050000	18.00	<.0001

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.018914
Critical Value of t	2.14479
Least Significant Difference	0.2408

Means with the same letter are not significantly different.

t Grouping		Mean	N	Treat
	A	3.9600	3	FD
	B	3.2500	3	HAD70
	B			
	B	3.6657	3	HAD50
C				
C	B	3.4257	3	HAD60
	D			
	D	3.1600	3	MW180
	D			
	D	3.0800	3	MW540
	D			
	D	3.0467	3	MW360

Oil absorption index

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.10509524	0.01751587	1.75	0.1808
Error	14	0.13973333	0.00998095		
Corrected	20	0.24482857			

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Total					

R-Square	CoeffVar	Root MSE	oai Mean
0.429261	4.007639	0.099905	2.492857

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	6	0.10509524	0.01751587	1.75	0.1808

Alpha	0.05
Error Degrees of Freedom	14
Error Mean Square	0.009981
Critical Value of t	2.14479
Least Significant Difference	0.175

Means with the same letter are not significantly different.

t Grouping	Mean	N	Treat
A	2.55333	3	MW180
A			
A	2.53667	3	HAD50
A			
A	2.53000	3	HAD60
A			
A	2.52000	3	HAD70
A			
A	2.51000	3	MW540
A			
A	2.47000	3	MW360
B			
B	2.33000	3	FD

Change in colour on 60th day

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1.30321000	1.30321000	0.58	0.4697
Error	8	18.10088000	2.26261000		
Corrected Total	9	19.40409000			

R-Square	CoeffVar	Root MSE	colour Mean
0.067162	12.81149	1.504197	11.74100

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	1	1.30321000	1.30321000	0.58	0.4697

Alpha	0.05
Error Degrees of Freedom	8
Error Mean Square	2.26261
Critical Value of t	2.30600
Least Significant Difference	2.1938

Means with the same letter are not significantly different.			
t Grouping	Mean	N	Treat
A	12.1020	5	ldpe
A			
A	11.3800	5	mpp

Colour on 90th day

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	9.35089000	9.35089000	6.18	0.0378
Error	8	12.11236000	1.51404500		
Corrected Total	9	21.46325000			

R-Square	CoeffVar	Root MSE	colour Mean
0.435670	8.978222	1.230465	13.70500

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	1	9.35089000	9.35089000	6.18	0.0378

Alpha	0.05
Error Degrees of Freedom	8
Error Mean Square	1.514045
Critical Value of t	2.30600
Least Significant Difference	1.7946

Means with the same letter
are not significantly different.

t Grouping	Mean	N	Treat
A	14.6720	5	ldpe

B	12.7380	5	mpp

Powder Colour on 60th day

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	3.27184000	3.27184000	0.41	0.5404
Error	8	63.99740000	7.99967500		
Corrected Total	9	67.26924000			

R-Square	CoeffVar	Root MSE	colour Mean
0.048638	24.80156	2.828370	11.40400

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	1	3.27184000	3.27184000	0.41	0.5404

Alpha	0.05
Error Degrees of Freedom	8
Error Mean Square	7.999675
Critical Value of t	2.30600
Least Significant Difference	4.125

Means with the same letter are not significantly different.			
t Grouping	Mean	N	Treat
A	11.976	5	mpp
A			
A	10.832	5	pet

Powder Colour on 90th day

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	5.88289000	5.88289000	0.62	0.4536
Error	8	75.85140000	9.48142500		
Corrected Total	9	81.73429000			

R-Square	CoeffVar	Root MSE	colour Mean
0.071976	25.61937	3.079192	12.01900

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	1	5.88289000	5.88289000	0.62	0.4536

.

Alpha	0.05
Error Degrees of Freedom	8
Error Mean Square	9.481425
Critical Value of t	2.30600
Least Significant Difference	4.4908

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**Treat**
A	12.786	5	mpp
A			
A	11.252	5	pet

Moisture on 60th day

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1.51001667	1.51001667	24.99	0.0075
Error	4	0.24166667	0.06041667		
Corrected Total	5	1.75168333			

R-Square	CoeffVar	Root MSE	moisture Mean
0.862037	2.183254	0.245798	11.25833

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	1	1.51001667	1.51001667	24.99	0.0075

Alpha	0.05
Error Degrees of Freedom	4
Error Mean Square	0.060417
Critical Value of t	2.77645
Least Significant Difference	0.5572

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**Treat**
A	11.7600	3	ldpe
B	10.7567	3	mpp

Moisture on 90th day

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1.30666667	1.30666667	15.59	0.0168
Error	4	0.33526667	0.08381667		
Corrected Total	5	1.64193333			

R-Square	CoeffVar	Root MSE	moisture Mean
0.795810	2.492204	0.289511	11.61667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	1	1.30666667	1.30666667	15.59	0.0168

Alpha	0.05
Error Degrees of Freedom	4
Error Mean Square	0.083817
Critical Value of t	2.77645
Least Significant Difference	0.6563

Means with the same letter are not significantly different.			
t Grouping	Mean	N	Treat
A	12.0833	3	ldpe
B	11.1500	3	mpp

Total phenolics on 60th day

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00281667	0.00281667	0.28	0.6243
Error	4	0.04013333	0.01003333		
Corrected Total	5	0.04295000			

R-Square	CoeffVar	Root MSE	phenolic Mean
0.065580	2.639434	0.100167	3.795000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	1	0.00281667	0.00281667	0.28	0.6243

Alpha	0.05

Error Degrees of Freedom	4
Error Mean Square	0.010033
Critical Value of t	2.77645
Least Significant Difference	0.2271

Means with the same letter are not significantly different.			
t Grouping	Mean	N	Treat
A	3.81667	3	ldpe
A			
A	3.77333	3	mpp

Total phenolics on 90th day

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00540000	0.00540000	1.22	0.3317
Error	4	0.01773333	0.00443333		
Corrected Total	5	0.02313333			

R-Square	CoeffVar	Root MSE	phenolic Mean
0.233429	1.692795	0.066583	3.933333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	1	0.00540000	0.00540000	1.22	0.3317

Alpha	0.05
Error Degrees of Freedom	4
Error Mean Square	0.004433
Critical Value of t	2.77645
Least Significant Difference	0.1509

Means with the same letter are not significantly different.			
t Grouping	Mean	N	Treat
A	3.96333	3	mpp
A			
A	3.90333	3	ldpe

DPPH on 60th day

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	43.09440000	43.09440000	6.36	0.0652
Error	4	27.08440000	6.77110000		

Corrected Total	5	70.17880000

R-Square	CoeffVar	Root MSE	dpph Mean
0.614066	6.651671	2.602134	39.12000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	1	43.09440000	43.09440000	6.36	0.0652

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treat	1	43.09440000	43.09440000	6.36	0.0652

Alpha	0.05
Error Degrees of Freedom	4
Error Mean Square	6.7711
Critical Value of t	2.77645
Least Significant Difference	5.8989

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**Treat**
A	41.800	3	mpp
A			
A	36.440	3	ldpe

DPPH on 90th day

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	3.93660000	3.93660000	0.60	0.4802
Error	4	26.04160000	6.51040000		
Corrected Total	5	29.97820000			

R-Square	CoeffVar	Root MSE	dpph Mean
0.131315	8.505162	2.551549	30.00000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	1	3.93660000	3.93660000	0.60	0.4802

Alpha	0.05
Error Degrees of Freedom	4
Error Mean Square	6.5104
Critical Value of t	2.77645
Least Significant Difference	5.7843

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**Treat**
A	30.810	3	mpp
A			
A	29.190	3	ldpe

Rehydration ratio on 60th day

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.01500000	0.01500000	25.00	0.0075
Error	4	0.00240000	0.00060000		
Corrected Total	5	0.01740000			

R-Square	CoeffVar	Root MSE	rehydration Mean
0.862069	1.069646	0.024495	2.290000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treat	1	0.01500000	0.01500000	25.00	0.0075

Alpha	0.05
Error Degrees of Freedom	4
Error Mean Square	0.0006
Critical Value of t	2.77645
Least Significant Difference	0.0555

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**Treat**
A	2.34000	3	mpp
B	2.24000	3	ldpe

Rehydration ratio on 90th day

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00135000	0.00135000	0.62	0.4756
Error	4	0.00873333	0.00218333		
Corrected Total	5	0.01008333			

R-Square	CoeffVar	Root MSE	rehydration Mean
0.133884	2.131992	0.046726	2.191667

Source	DF	Type I SS	Mean Square	F Value	Pr > F

Treat	1	0.00135000	0.00135000	0.62	0.4756

Alpha	0.05
Error Degrees of Freedom	4
Error Mean Square	0.002183
Critical Value of t	2.77645
Least Significant Difference	0.1059

Means with the same letter are not significantly different.			
t Grouping	**Mean**	**N**	**Treat**
A	2.20667	3	mpp
A			
A	2.17667	3	ldpe