CHAPTER I
INTRODUCTION

Garlic (*Allium sativum*) is an important foreign exchange earning cash crop commercially grown in India. Garlic, a bulbous perennial plant of the lilly family is grown globally in one million hectares with a production of 10 million tonnes.

India is the second largest producer of garlic after China with a share of about 13.2 percent of world’s area and 9.5 percent of world’s production. Area under garlic production in India in the year 2002 was 1.20 lakh hectares with a total production of 5 lakh tonnes (www.fao.org). Madhya Pradesh, Gujarat, Orissa, Maharashtra, Uttar Pradesh and Rajasthan are the major garlic growing states of India. More than 50 percent of the production however comes from Madhya Pradesh and Gujarat only. Indore and Mandsour in Madhya Pradesh; Angul in Orissa; Junnar Taluka in Maharashtra; Mainpuri, Etah and Etawa in Uttar Pradesh; Sikar, Jhunjhunun, Ajmer and Udaipur in Rajasthan are major garlic growing pockets of India (Chadha K.L, 2006). In Rajasthan, area under garlic was 20 thousand hectares with a production of 90 thousand tonnes in the year 2003-04 (Vital Agricultural Statistics, 2004-05).

Garlic has been used through recorded history for both culinary and medicinal purposes. It has a characteristic pungent, spicy flavour that mellows and sweetens considerably with cooking. It has long been recognized all over the world as a valuable spice for food. Garlic is consumed as green as well as dried in the spice form and used as ingredient to flavor various vegetarian and non-vegetarian dishes and pickles. Good tasty pickles, chutneys, curry powders are prepared from garlic cloves. Garlic is also used to disguise the smell and flavor of salted meat and fish.

Nutritive value of garlic varies from variety to variety. The soil, climate, cultural practices, agro techniques and nutrient application are reported to affect the chemical composition to a larger extent. Garlic has higher nutritive value, rich in proteins, phosphorus, potash, calcium, magnesium and carbohydrates. Nutritional composition of freshly peeled garlic is given in Table 1.1

As stated earlier, India is one of the leading countries in the world producing garlic of high quality. Garlic is exported mostly to Bangladesh, Philippines,
Singapore, United Kingdom, and The United States of America to cater to the ethnic population settled in these countries thereby earning substantial foreign exchange.

**Table: 1.1 Nutritive value of garlic**

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>Value per 100g of fresh garlic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>62 g</td>
</tr>
<tr>
<td>Protein</td>
<td>6.3 g</td>
</tr>
<tr>
<td>Fat</td>
<td>0.1 g</td>
</tr>
<tr>
<td>Minerals</td>
<td>1.0 g</td>
</tr>
<tr>
<td>Fibre</td>
<td>0.8 g</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>29.8 g</td>
</tr>
<tr>
<td>Energy</td>
<td>145 kcal</td>
</tr>
<tr>
<td>Calcium</td>
<td>30 mg</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>310 mg</td>
</tr>
<tr>
<td>Iron</td>
<td>1.2 mg</td>
</tr>
<tr>
<td>Thiamine</td>
<td>0.060 mg</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>0.23 mg</td>
</tr>
<tr>
<td>Niacin</td>
<td>0.4 mg</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>13 mg</td>
</tr>
<tr>
<td>Magnesium</td>
<td>71 mg</td>
</tr>
<tr>
<td>Copper</td>
<td>0.63 mg</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.86 mg</td>
</tr>
<tr>
<td>Zinc</td>
<td>1.93 mg</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.02 mg</td>
</tr>
</tbody>
</table>

(Source: www.indianspices.com/magazine/archive/octt_05_eng.pdf)

Growth in popularity of convenient foods in many countries has stimulated increasing demand for high quality dehydrated garlic products like garlic flakes, garlic oil and garlic powder and the same are exported to Japan, United Kingdom, Italy, Turkey, Germany and France.

The local demand and supply has a great impact on exports. Exports are allowed only after domestic requirements are met which is the cause of the price fluctuations from year to year.
Garlic is a semi-perishable spice, the moisture content of the bulb and surrounding relative humidity play an important role in maintaining its quality. It has a tendency to lose its moisture on storage, which causes weight loss and shriveling of cloves to an extent of 40-50 percent (Prakash et al., 1994).

Among the processing techniques of fruits and vegetables, drying is the most important process because dried products require less packaging material. Drying of foods is aimed at producing high density product, which when adequately packaged enhances shelf life after which the food can be rapidly and simply reconstituted without substantial loss of flavour, taste, colour and aroma. Mostly, the cost of food product is dependent on the drying process. So it is necessary to dry the product at minimum cost, energy and time.

The best way to stabilize the qualities of garlic is to dry it when it is at its best flavor. Moisture content of garlic at harvest is 60-65 percent and it should be dried to 6 percent for safe storage and for production of different dehydrated garlic products (Anonymous, 1987). The quality of the dehydrated product is affected by a number of factors like quality and nature of the raw-material, method of preparation and processing treatments, loading time, temperature and drying technique adopted.

In mechanical drying, the temperature of drying air greatly affects not only the time required for drying but also the quality of the finished product. In order to obtain large capacity and minimum operating costs, it is very essential to use the highest temperature for drying. The critical temperature is defined as the temperature at which a nearly dry product is seriously injured in quality when exposed for a certain period of time. At temperatures above the critical temperature, the dried product is likely to scorch the sugars present and likely to caramelize. Therefore, colour, flavor and aroma of the product are adversely affected. Critical temperature for garlic dehydration is 60°C. It was found that drying above 60°C resulted in reduction of flavor in garlic considerably (Pruthi et al. 1959).

Although hot air drying is the simplest and economic method of drying garlic, certain problems such as cell collapse, structural changes due to local hardening and unfavorable changes in colour, texture, flavour and nutritive value are likely to occur in dehydrated product. Fluidized bed drying technique is a very convenient method of drying for heat sensitive food materials as it prevents them
from overheating (Giner and Cavelo, 1987). Bobic et al. 2002 dried potatoes, parsley roots, celery roots and carrots in a fluidized bed dryer and found that product of excellent quality in a much shorter time than in continuous belt dryers which are generally used for drying.

Fluidized bed drying is a technique where a stream of gas is passed upward through a bed of material at a certain velocity. At this point of time the bed first expands then becomes suspended and agitated by the gas stream to form a fluidized bed. This has the appearance of the boiling liquid due to the formation of many small bubbles. At higher velocities, large size bubbles are formed resulting in a more violent type of fluidization called slugging or spouting.

Therefore, an attempt has been made for a comparative study between tray drying and fluidized bed drying of garlic cloves and slices. Thus, this project embraces the following specific objectives;

1. To study the drying characteristics of garlic cloves and slices in tray and fluidized bed dryer.

2. To evaluate the quality of the final dried product.
CHAPTER II
REVIEW OF LITERATURE

A comprehensive review of literature is a must in any research endeavour. It gives an excellent overview of work done in any particular field and helps in keeping up with recent developments. The available review related to the present study has been organized and presented hereunder.

2.1 General

Garlic (*Allium sativum*) is a perennial herb and is grown in tropical and subtropical plains for its pungent flavor, as a seasoning or condiment. Depending on the form of cooking, the flavor is either mellow or intense. Not all garlic has the same taste or flavor or other eating characteristics. There are wide variations from variety to variety and also the taste and flavor of any given garlic bulb will vary greatly depending on the time of harvest. Any given bulb of garlic is as mild as it will ever be at the time it is harvested and cured (dried down enough to trim roots and leaves without getting a garlicky smell). From the moment of harvest, garlic slowly loses moisture and dehydrates. On drying, garlic loses its size and weight and there is an increase in pungency as its mass decreases. Neither mild onions nor garlic stay mild, they all lose mildness with age (www.gourmetgarlicgarden.com)

2.2 Composition and uses of garlic

Indian standard specifications for fresh garlic recommend that the bulbs of garlic should have the shape and natural colour characteristics of that particular variety. The bulbs should be mature, well cured, well filled and fairly plump. Dried and cured garlic bulbs should have the characteristic pungent taste and flavor. They should be free from moulds, decay, diseases, insect attack, etc (IS specifications for garlic, 1965. IS: 3240)

The phytochemicals responsible for the characteristic flavor of garlic are produced when the plant’s cells are damaged. When a cell is ruptured by chopping, chewing, or crushing, enzymes stored in cell vacuoles trigger the breakdown of several sulfur-containing compounds stored in the cell fluids. The resultant compounds are responsible for the sharp or hot taste and strong smell of garlic. Some
of the compounds are unstable and continue to evolve over time. Among the members of the lily family, garlic has by far the highest concentrations of initial reaction products, making garlic much more potent than onions. Diallyl disulfide is believed to be an important odour component. Allicin has been found to be the compound most responsible for the spiciness of raw garlic.

Garlic is said to have anti-bacterial, anti-fungal, anti-inflammatory, antimicrobial, antiseptic, antiviral, antioxidant, antitumour and diuretic properties. Aristotle suggested its use for cure against rabies. During the early 1990’s and the onset of World War I, British army surgeons used garlic as a bactericide. It has long been recognized all over the world as a valuable spice for food. Garlic is consumed as green as well as dried in the spice form and used as ingredient to flavor the various vegetarian and non-vegetarian dishes and pickles. Good tasty pickles, chutneys and curry powders are prepared from garlic cloves. Garlic is also used to disguise the smell and flavor of salted meat and fish. (V. Sankar et al. 2005)

2.3 Drying theory

Drying as a means of preserving the safety and quality of foods has been at the forefront of technological advancements in the food industry. It has greatly extended the consumer-acceptable shelf life of commodities from a few days and weeks to months and years. The lower storage and transportation costs associated with the reduction of weight and volume due to water removal have provided additional economic incentives for widespread use of dehydration processes. The expanding variety of commercial dehydrated foods available today has stimulated unprecedented competition to maximize their quality attributes.

Drying involves simultaneous transfer of heat, mass and momentum in which heat penetrates into the product and moisture is removed by evaporation into an unsaturated gas phase. Owing to the complexity of the process, no generalized theory yet exists to explain the mechanism of internal moisture movement (Rao et al. 2005). The drying process depends on many factors such as the initial moisture content, desired final moisture content, temperature, relative humidity of drying air, and the air velocity (Azharul Karim et al. 2005). Knowledge of temperature and moisture distribution in the product is vital for equipment and process design, quality control, choice of appropriate storage and handling practices (Murat Ozdemir et al. 1999). The
moisture removal processes and their dependence on the process variables are expressed in terms of the drying kinetics, and therefore, the determination of the drying rate is an essential factor for development of reliable process models (Guine et al. 2002).

2.4 Air drying process

A brief review of the work done by various researchers related to air drying of foods is presented hereunder.

Madamba et al. (1996) investigated the thin-layer drying characteristics of garlic slices (2–4 mm) for a temperature range of 50–90°C, a relative humidity range of 8–24%, and an airflow range of 0.5–1 m/s. An analysis of variance (ANOVA) revealed that temperature and slice thickness significantly affected the drying rate while relative humidity and airflow rate were insignificant factors during drying. Effective diffusivity of water varied from 2 to $4.2 \times 10^{-10} \text{ m}^2/\text{s}$ over the temperature range investigated, with energy of activation of 989 kJ/kg. Four mathematical model were fitted to the experimental drying data, with the Page and the two-compartment models giving better predictions than the single-term exponential and Thompson's model.

Karathanos (2002) examined the effect of drying 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 was a 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 and 70°C) was fitted to GAB equation. The parameters of the model considered were found to be greatly affected by the air conditions and sample size. In particular, the temperature increment increased the drying constant and decreased the equilibrium moisture content of the dehydrated products.

Sharma et al. (2003) studied drying kinetics of garlic cloves under convective drying conditions. Convective drying of garlic cloves was carried out at drying temperature of 40, 50, 60 and 70 °C at air velocities of 1-2 m/s. The cloves were almost uniform in size having length of 20.1 mm and diameter 7.2 mm. It was
observed that the drying rate increased with increase in drying air temperature, thus reducing the drying time. Air velocity showed no significant effect on the drying time and moisture diffusivity increased with increase in air temperature and velocity.

Sacilik et al. (2005) investigated the dehydration characteristics of the Kastamonu garlic (*Allium sativum* L.) in a convective hot-air dryer. The dehydration characteristics of garlic slices were examined at air temperatures of 40, 50 and 60 °C and sample thicknesses of 3 and 5 mm. During the dehydration experiments, air velocity was held stable at 0.8 m s\(^{-1}\). The effects of air temperature and sample thickness on the dehydration characteristics and quality parameters of the dehydrated garlic slices were determined. The transport of water during dehydration was described by Fick's equation and the effective diffusivity was between 195 and 335 μm\(^2\) s\(^{-1}\). The effect of temperature on the effective diffusivity was described by the Arrhenius-type relationship. The activation energy was found as 23.48 kJ mol\(^{-1}\). Rehydration capacity was found to be in the range between 2.37 and 2.84. In the experiments, samples with a lighter colour were obtained at lower air temperatures.

Sharma et al. (2005) developed a laboratory scale infrared-convective dryer. The effects of process variables such as infrared power, drying air temperature and drying air velocity on drying time, moisture diffusivity and re-hydration characteristics of onion slices were studied. It was observed that the drying time reduced by as much as 2.25 times in infrared power range of 300 to 500 W, air temperature 35 to 45°C at velocity 1.0 to 1.5 m/s. The drying rates were lower at higher air velocity. Effective moisture diffusivity increased with decrease in moisture content. The re-hydration ratio of dehydrated onion slices was found to be in the range of 4.5 and 5.3.

### 2.5 Fluidized bed drying process

Singh et al. (1997) studied the dehydration of button mushroom and found discoloration and poor re-hydration characteristics of dehydrated product. To overcome these problems, button mushrooms were given different pre-treatments such as blanching, soaking in 0.5% KMS; soaking in 1% KMS, 0.2% citric acid, 6% sugar and 3% salt solution separately prior to dehydration. The pre-treated samples were then dried in fluidized bed dryer at different temperatures viz. 50, 60, 70, 80 and 90°C. Dehydrated mushrooms were evaluated for colour, texture, flavor and overall.
acceptability. The quality of dehydrated mushrooms was significantly influenced by pretreatments as well as temperature of drying. It was found that samples soaked in 1 percent KMS, 0.2 percent citric acid, 6 percent sugar and 3 percent salt solution and dried at 50 °C gave satisfactory results.

Bobic et al. (2002) investigated fluid bed drying of vegetable pieces. The vegetables used were potatoes, parsley roots, celery roots and carrots of various dimensions. Temperatures of fluidized air were varied from 60°C to 100°C at velocities of 0.71m/s. The goal was to obtained dry vegetables with 6 percent to 10 percent of water content and of good rehydration quality. The results have shown that drying of vegetables in a fluidized bed produces dry vegetable pieces of excellent quality in a much shorter time than in continues belt-dryers which are generally used.

Dhingra and Paul (2005) studied the effect of temperature (55-65°C), slice thickness (3-6mm), air velocity (6-9m/s) and concentration of sodium metabisulphite as pre-treatment (0.1-0.3 percent) on the colour, rehydration ratio and final moisture content in a fluidized bed drying of garlic slices. It was found that drying air temperature and slice thickness significantly affected colour, rehydration ratio and final moisture content. Further, it was found that air velocity affected rehydration ratio while no effect was observed for concentration of sodium metabisulphite. An optimum drying temperature of 60°C for drying 3mm garlic slices pre-treated with 0.1% sodium meta bisulphate solution at an air velocity of 9m/s was found to be significant factors affecting drying.

2.6 Moisture diffusivity in drying

In drying, the diffusion coefficient or diffusivity is used to indicate the flow of moisture or mass out of the material. The diffusion coefficient of the food material varies with its moisture content. Many researchers have tried to correlate effective moisture diffusivity with temperature and moisture content; and some of that have been reviewed hereunder.

Fakuoka et al. (1994) studied the moisture diffusion process for soybean seed using pulsed field gradient NMR method. A constant coefficient of 4.3 x 10^{-10} m²/s was obtained for diffusion times ranging from 18.5 to 28.5 m²/s. This value was 10 times larger than literature values measured by a gravimetric method of seed hydration, and was 100 times larger than that calculated using absorption data. It was
reported that a dry soybean seed had considerable freely movable water which was centered at the inter-cotyledon face surrounded by an oil layer.

Sharma and Prasad (2003) dried fresh garlic cloves using microwave convective technique. It was reported that moisture diffusion increased for the same values of drying air temperature and velocities as applied microwave power increased. However the parameter decreased at all temperatures and applied microwave powers with increase in air velocity.

2.7 Modeling of drying behaviour of foods

Noomborn et al. (1986) examined non linear regression technique to model drying of foods. Data of moisture content and time were collected for long grain rough rice representing on-farm and commercial drying conditions. Four different drying models were evaluated for single layer rice drying data. The first two were based on the solution of diffusion equation and others were empirical. The two term Exponential form of diffusion model and second empirical model were determined the best and generalized form was developed. For commercial drying conditions the second empirical model proved to be the best for generalized model.

Pathak et al. (1991) developed mathematical model of the form of Page’s equation. Thin layer drying rates of rapeseed were experimentally determined at eight levels of drying air temperature, four in conventional drying temperature range of 50°C- 60°C and four at the elevated temperatures up to 200°C. The model predicted the moisture ratios well at conventional as well as elevated drying temperatures.

Rossello et al. (1992) developed simple mathematical model to describe the drying kinetics of potato cubes. The influence of both air temperature and air flow rate on the drying of 1cm potato cubes was studied. The critical value above which air flow rates have no effect on drying rates was approximately of 800 kg/h m². The agreement between calculated and experimental average moisture content was satisfactory.

Palipane et al. (1994) used two criterion for adequacy of the model fit in the thin-layer drying behaviour of macadamia in-shell nuts and kernels for a temperature range of 26–56°C and 21–48°C, respectively and relative humidity range of 15–75% and 14–63%, respectively. The two-term exponential model predicted accurately the drying behaviour of in-shell nuts and kernels. The temperature dependence of the
drying rate constants was best explained by an Arrehenious-type relationship. At low moistures, the removal of moisture from the kernel was faster when in-shell nuts were dried than when extracted kernels were dried.

Abe and Afzal (1997) studied four mathematical models to describe the thin layer infrared drying characteristics of rough rice. The models considered were Exponential model, Page model, Diffusion model based on a spherical grain shape, and an approximation of the Diffusion model. Tests were conducted using four levels of radiation intensity, three levels of inlet air velocity and three levels of grain initial moisture content. The Page model was reported to be the most adequate one in describing thin-layer infrared radiation drying of rough rice.

Karathanos and Belessiots (1999) applied Page equation to air drying data of high sugar-containing agricultural plant products such as currants, sultanas, figs and plums. A good linear relationship was found and two parameters of the Page equation were evaluated. The Page equation was successful in modelling of drying fresh fruits. However, it failed to predict the drying behaviour when the drying was continued for moisture contents below 15 % (db), which was required to attain shelf stability. This was attributed to the Page equation being accurate only in cases where weight reduction was mainly due to water evaporation. Deviation from the Page equation occurred where there is a further reduction in weight due to the decomposition of sugars at relatively high drying temperatures and moisture contents lower than typical of dried fruits (below 15% db).

Sogi et al. (2004) studied tomato seeds dried in fluidized bed dryers at 50, 70 and 90°C using tray load of 4, 8 and 12 kg/m². Sorption isotherms were obtained at 30, 40, 50, 60 and 70°C by the static method using saturated salt solutions. They concluded that drying rates in the drying of tomato seeds took place under the falling rate period and the drying behaviour was well described by Page's model.

2.8 Quality evaluation

Consumption of food is directly related to the quality. Important attributes identified with food are color and flavor. Small and medium sized processing businesses all over the world increasingly have to consider the production of good quality products. Quality commonly thought of as a degree of excellence, is one of the major positioning tool of the producer for marketability and for consumers
satisfaction. It is the combination of attributes or characteristics of a product that have significance in determining the degree of acceptability of the product to the user. To retain its quality and nutritive value, it is essential to ensure the integrity and safety of food throughout the food chain. Any measure taken to ensure all above will also add to its value as a commodity and create better demand, both at domestic and international level. Some reviews related flavor strength and colour are presented hereunder.

Shankarnarayana et al. (1981) reported that the characteristic flavor of alliums was due to the volatile oil which consisted chiefly of sulfur compounds. The volatile oil content in fresh onion was about 0.03 percent. An oxidimetric method of determination of the volatile oil in small samples of onion and garlic has been developed based on the reaction between the volatile oil and chloramines-T in acid medium. A relationship has been found between the volatile oil content and the consumption of chloramine-T by the steam distillates of onion and garlic. The consumption of N chloramine-T per gram of garlic oils was found to be 90.

Colour plays an important role and it has become a vital aspect in judging food. Perhaps, it is the first character perceived by the senses and is indispensable for rapid identification and ultimate acceptance of the product to the modern day consumer. The most important characteristic by which quality of the food is judged is its appearance and in turn, the important characteristic of the appearance is colour.

Ranganath and Dubash (1981) isolated the major carotenoid pigments from spinach leaves and sweet potatoes were isolated and identified using column chromatography. The changes in content of carotenoids as well as ascorbic acid on dehydration and subsequent storage of the above vegetables were measured. The major changes in individual carotenoid patterns in spinach leaves due to dehydration were studied. It contains four major carotenoid pigments. The only hydrocarbon fraction, which was 3-carotene, amounted about 42-44 percent of the total carotenoids present. The oxy-carotenoids were neoxanthin 8 per cent, and lutein and violaxanthin to about 40 per cent of the total carotenoids present. Traces of zeaxanthin were also identified.
CHAPTER III
MATERIALS AND METHODS

This chapter deals with the materials used and procedure adopted to achieve the objectives of the present investigation. This includes the description of raw material, moisture content determination, experimental set up and methodology used in drying of garlic slices by tray dryer and fluidized bed dryer; and analysis of drying data.

3.1 Raw Material

Cured garlic bulbs (*Allium sativum*) were procured from local market of Udaipur. These garlic bulbs were stored in gunny bag for approximately one month. The weight of five bulbs and cloves were measured and average weight was found to be 24 g and 1 g respectively.

3.2 Sample preparation

The cloves were separated, peeled by hand and sliced to 5mm thickness using a micrometer having least count of 0.001mm. The cloves were sliced across the length. The slices from the middle of uniformly sized cloves were obtained. Each sample was dipped in sodium metabisulphite (0.1 percent) for 5 min at room temperature to prevent browning which might otherwise take place during drying. Garlic samples were removed from the solution and were spread on muslin cloth to remove excess solution from the surface.

3.3 Moisture content of peeled garlic cloves

The initial moisture content of garlic slices was determined by oven drying method (Ranganna, 2000). An amount equal to 20 g of freshly peeled garlic sample was placed in thoroughly washed, dried and pre-weighed moisture boxes. The initial weight of each sample was recorded. The moisture boxes were put in the oven at 80°C temperature for 24 hours. The samples were then taken out of oven and cooled in the dessicator and weighed using an electronic balance having capacity of 200 g and least count of 0.001 g. Initial and bone dried weights were used to calculate the initial moisture content which was expressed as g water per g dry matter. The initial moisture content of garlic was 1.819 g water per g dry matter.
Fig. 3.1 Flowchart for garlic drying

Raw Garlic

Peeling

Slicing (5mm)

Pretreatment (0.1% sodium meta bisulphite)

Drying

Peeled cloves

Tray drying (40, 50 & 60°C)

Fluidized bed drying (40, 50 & 60°C)

Grinding to powder

Quality evaluation
3.4 Experimental Plan

Experiments were planned to study the effect of process parameters on drying kinetics of garlic cloves and slices in a tray dryer and a fluidized bed dryer. Drying air temperature and air velocity were considered as variables choosing the values employed commonly for dehydration of fruits and vegetables. Flow chart for garlic drying is shown in Fig 3.1. The details of the variables of the present experiment are as follows;

3.4.1 Variables under study

Variables selected in this study were classified under two major categories as independent variable and dependent variable

I. Independent variable
   1. Drying air temperature: 40, 50 and 60 °C
   2. Drying air velocity
      (i) Tray drying : 1.5 m/s
      (ii) Fluidized bed drying : 2.5, 3.0 and 3.5 m/s

II. Dependent variable
   1. Drying time (h)
   2. Drying rate (g water / g dry matter-h)
   3. Water activity (a_w)
   4. Quality evaluation
      (i) Color
      (ii) Flavor strength.

3.5 Experimental set-up

A laboratory model convective tray dryer and fluidized bed dryer were used in this study.

3.5.1 Tray dryer

A convective tray dryer was used to conduct drying experiments. Its technical specifications are presented in Appendix A. Plate 3.1 shows the dryer. The dryer comprise of a drying chamber, heating unit, and a blower. The details of the dryer are described as follows.
Plate 3.1 Experimental tray dryer

a) Drying chamber: It comprised of an insulated box with a single door opening at front. An adjustable speed blower for regulation of air velocity was provided on left side of drying chamber. A heating unit for increasing the temperature of air is also provided. The air enters the dryer due to suction and transfers heat to the wet product for drying and simultaneously absorbs moisture from it. The moisture laden air leaves the dryer by opening of drying chamber.

The sample trays having size of 340 x 270 mm made of stainless steel were used in the dryer. The bottom of these trays comprises of SS wire mesh which permitted good flow of drying air through the product. The trays were stacked one over the other in a single column. The size of sample tray permitted amply to spread 100 g of garlic sample uniformly in a single layer. Garlic samples were spread uniformly in a single layer over the tray, thus resulted into loading density of 1.089 kg/m².

b) Heating unit: It consisted of an electric heater of 2.5 kW placed on inner right wall of drying chamber. A thermostatic controller was used on the heating unit for controlling the temperature of the drying air. The maximum temperature of the drying air which could be attained at highest air velocity of 1.5 m/s was 92 °C.
c) Fan: A fan provided at inner left side of drying chamber sucked the filtered atmospheric air inside and then through heating unit thereby forcing it to pass through the wet product placed in trays. This caused quick and effective drying of the product. The fan was operated by a single phase, 50 Hz, 0.375 kW AC motor.

The temperature of the drying chamber was pre-set through a temperature indicator cum controller provided on control panel of dryer. A thermostat controlled and maintained the temperature by switching ON or OFF the heating unit. The velocity of drying air was measured by using an anemometer, its technical specifications are presented in Appendix A. A constant air velocity of 1.5 (±0.1) m/s was maintained for all the experiments.

3.5.2 Fluidized bed dryer

A tabletop fluidized bed dryer (Make: Sherwood Scientific Ltd. Cambridge, England) was used in this present study; and the same is shown in Plate 3.2. The dryer is simple, compact, conveniently portable and easy to operate. The cabinet contains the air distribution system and electrical controls. Air is drawn in through a mesh filter in the base of the cabinet and blown by the centrifugal fan over a 2 kW electrical heater and through stainless steel filter gauze at the base of the dryer body.

The tube unit consisted of a container with a fine mesh distributor and stainless steel support. A filter bag, which fitted over the top of the tube, retained any particles expelled from the fluidized bed. The fluid bed dryer had PID controller in the range of 0-200ºC, which regulated the operation of the heater to maintain the desired temperature of the drying air.

a) Principles of fluidized beds

When a steam of gas is passed upwards through a bed of a material at a certain velocity the bed will first expand, then become suspended and agitated by the gas stream to form a fluidized bed. This has the appearance of the boiling liquid due to the formation of many small bubbles – the so called “bubbling fluidization”. At higher gas velocities, larger bubbles of the material are formed resulting in a more violent type of fluidization called slugging or spouting.
b) Drying process

If a bed of wet material is fluidized by a heated air stream, as in the laboratory batch dryer, the conditions are ideal for drying. The very efficient contact between gas and solid particles due to the turbulence of the bed results in high heat transfer rates causing rapid evaporation (mass transfer) of moisture which is carried away with the exit air. This process has a high thermal efficiency because most of the heat input is used in vaporizing the moisture. Because of the very good mixing of particles in the fluidized states, the conditions of temperature and moisture content are uniform throughout the bed; therefore a uniform quality product is obtained. Fluidization causes very little abrasion and the quality of food is not affected.

3.6 Drying characteristics

The initial weight of garlic cloves was recorded after 30 minute interval in first one hour. Subsequently the weight was recorded after every one hour till the end of drying in a tray dryer. In case of slices, initial weight was recorded after very 10 minute interval in first one hour. Subsequently the weight was recorded after every 15 minute interval for second hour and after that every 30 minute from third hour till the end of drying in a tray dryer. In case of slices, initial weight was recorded after very
10 minute interval in first one hour. Subsequently the weight was recorded after every 15 minute interval for second hour and after that every 30 minute from third hour till the end of drying. The drying was terminated at moisture content of about 6 per cent wet basis which was found safe for storage.

The moisture content of garlic cloves and garlic slices was determined by mass balance equations after periodic interval. The observed drying data i.e. weight loss of the sample with time for each drying run were converted to different drying parameters such as moisture content, drying rate and estimated effective moisture diffusivity using standard technique. The values of moisture content for three replications were averaged to get data for each of the drying run for studying the drying kinetics under a specific drying condition. To calculate moisture ratio (MR) under both convective as well as fluidized bed drying, the moisture content (0.06 g water per g dry matter) of the dried product was taken as equilibrium moisture content (EMC).

3.6.1 Moisture content of garlic samples during drying

Moisture content of garlic cloves and slices during drying experiments at various time intervals was determined by calculating mass of dry matter of the sample. Moisture contents at various times were calculated by the formula:

\[
\text{moisture content} = \frac{W_0 - DM}{DM}, \text{ g water per g dry matter}
\]

where,

\[W_0 = \text{weight of the sample at time } \theta, \text{ g}\]

\[DM = \text{dry matter of the sample, g}\]

3.6.2 Drying rate

The moisture content data in each of experiments were analyzed to determine the moisture lost by garlic sample in a known time interval. The drying rate was expressed as g water/g dry matter-min. The drying rate which changes in moisture content under various drying conditions is given in Appendix B.
3.7 Moisture diffusivity

In drying, diffusivity is used to indicate the flow of moisture out of material. In falling rate period of drying, moisture transfer within the food is mainly by molecular diffusion. Moisture diffusivity is influenced by shrinkage, case hardening during drying, moisture content and temperature of material. The falling rate period of drying for biological materials is best described by Fick’s second law of diffusion (Crank, 1975) as given below.

\[
\frac{\partial M}{\partial t} = D \frac{\partial^2 M}{\partial x^2}
\]  

3.2

The garlic cloves were assumed as infinite cylinders i.e. moisture diffusion occurring radially outwards only. Following assumptions were made for the infinite cylindrical shaped body of garlic clove and slice.

1. Moisture is initially uniformly distributed throughout the mass of a sample.
2. Mass transfer is symmetric with respect to the centre of the cylinder.
3. Surface moisture content of the sample instantaneously reaches equilibrium with the condition of surrounding air.
4. Resistance to the mass transfer at the surface is negligible compared to internal resistance of the sample.
5. Mass transfer is by diffusion only.
6. Diffusion coefficient is constant and shrinkage is negligible.

Following solution to Fickian equation was, therefore, used

\[
MR = \frac{M_i - M_e}{M_0 - M_e} = \frac{4}{\lambda_n^2} \exp\left[-\frac{\lambda_n^2 D t}{r^2}\right]
\]  

3.3

where,

- \(MR\) = moisture ratio, dimensionless
- \(M_0\) = moisture content at time \(t = 0\), g water/ g dry matter
- \(M_i\) = moisture content at time \(t\), g water/ g dry matter
- \(M_e\) = equilibrium moisture content, g water/ g dry matter
- \(D\) = moisture diffusivity, m\(^2\)/s
- \(r\) = radius of the cylinder, m
- \(t\) = drying time, s
- \(\lambda_n\) = nth root of the Bessel function of zero order, \(n = 1, 2, 3 \ldots\)
The final moisture content of the dehydrated garlic (0.06 g water/g dry matter) was assumed to be equilibrium moisture content $M_e$ in each run.

(For $n = 1$ and $\lambda_1 = 2.405$)

3.8 Modelling of drying behaviour of garlic

Modelling has been widely and effectively used for the analysis of drying behaviour of agricultural products. Many mathematical models have described the drying process, of them Exponential model is one of the basic model.

$$MR = \exp \left( - k_s t \right)$$ \hspace{1cm} 3.4

where,

- $MR =$ Moisture ratio, dimensionless
- $k_s =$ drying constant, min$^{-1}$
- $t =$ time, min

This model tends to predict the early stages of drying. To overcome the shortcomings of the Exponential model, the Page model is applied with an empirical modification to the time term by introducing an exponent ‘$n$’.

$$MR = \exp \left( - k_p t^n \right)$$ \hspace{1cm} 3.5

where,

- $k_p =$ Drying constant in Page model, min$^{-1}$
- $t =$ time, min

3.9 Water activity ($a_w$)

Water activity ($a_w$) has its most useful application in predicting the growth of bacteria, yeasts and molds. For a food to have a good shelf life without relying on refrigerated storage, it is necessary to control either its acidity level (pH) or the level of water activity ($a_w$) or a suitable combination of the two. This can effectively increase the product's stability and make it possible to predict its shelf life under known ambient storage conditions. Food can be made safe to store by lowering the water activity to a point that will not allow dangerous pathogens such as *Clostridium botulinum* and *Staphylococcus aureus* to grow in it. For example, food with a water activity below 0.6 will not support the growth of osmophilic yeasts. Similarly,
Clostridium botulinum, the most dangerous food poisoning bacteria, is unable to grow at a$_w$ of 0.93 and below.

A digital water activity meter used in measuring water activity of the dehydrated garlic samples is shown in Plate 3.3. Water activity was determined as a measure of storage stability using a FA-st lab water activity meter.

Plate 3.3. Water activity meter

3.10 Quality evaluation

Quality is one of the very important parameters in food processing to ensure the best quality finished products. Control should be exercised at every stage from pre-processing to packing, storing, etc. Quality of dehydrated garlic powder had been evaluated on the basis of colour and flavour strength.

3.10.1 Color measurement

Color is important to consumers as a means for identifying and judging quality for its basic esthetic value. Food is no exemption; colour is a vital constituent of the food. The overall objective of colour to the food is to make them appealing and
recognizable. The colorimeter used in the present investigation is presented in Plate 3.4. Colour of the dried garlic was measured using a Hunter Lab Colorimeter (Model CFLX/DIFF, CFLX-45). A cylindrical glass sample cup (6.35 dia. x 4 cm deep) was placed at the light port (3.175 cm dia). Each sample was measured for colour value thrice. The instrument was initially calibrated with a black as well as with standard white plate (L = 91.09) provided along with the equipment. The color values are obtained as lightness (L), on L a b scale.

Plate 3.4 Hunterlab colorimeter

3.10.2 Flavor strength

Compounds such as sugars and organic acids can contribute to the organoleptic experience. It is a special class of biologically active organo-sulfur compounds, which give garlic their distinctive flavor and aroma.

Flavor in garlic (*Allium sativum* L.) is dominated by organosulfur compounds arising from the enzymatic decomposition of S-alk(en)yl-L-cysteine S-oxide flavor precursors. Allyl cysteine sulfoxide is the primary flavor precursor of garlic. Differences in flavor intensity within a species are due to differences in the precursors concentrations. Higher concentration of the flavor precursors will increase the flavor
strength. Difference in flavor among the vegetable alliums results from the presence of the different flavor precursors and the ratio in which they accumulate.

The flavor strength of dried garlic was determined by chloramine-T method (Shankarnarayana et al. 1981). An aliquot (75 g, corresponding to 5 g dry garlic powder) was used for the determination of flavor strength. It was transferred to one litre round bottom flask. Antifoam and glass beads were added to the above flask to prevent frothing. Sample was let into the flask and about 250 ml of the sample was collected in a solution containing 35 ml 10 N sulfuric acid, 15 ml water and 20 ml chloramine-T taken in a 1-litre Erlenmeyer flask. The aliquot of the slurry was subjected to chloramine-T oxidation. The excess chloramine-T was determined by adding 10 ml potassium iodide solution and titrating the liberated iodine with sodium thiosulfate using starch as indicator. The titre values of thiosulfate for the experiment and the blank were determined. A reagent blank was carried out simultaneously under the same conditions. The difference in the values between the blank and the experimental corresponds to the chloramine-T consumed by the garlic oil.

The flavor strength of garlic powder was calculated using the following formula.

\[
\text{Flavor strength, } (\%) = \frac{V \times N \times 100}{W \times F} \quad 3.6
\]

where,

- \( V \) = difference in volume (ml) of thiosulfate between blank and the experiment.
- \( N \) = normality of thiosulfate.
- \( W \) = weight of garlic powder used for oxidation
- \( F \) = factor, i.e. the experimental value of (ml) Chloramine – T per g of garlic oil (90 for garlic).

3.10.3 Rehydration Characteristics

Rehydration tests for the dehydrated garlic samples were carried out by immersing the conventionally dried as well as fluidized bed dried garlic samples in water. Approximately 5 g dried garlic sample was put in 50 ml distilled water at 35°C in a 100 ml beaker kept in a hot water bath to maintain a water temperature of 35°C for 5h (Kim and Toledo, 1987; Nsonzi and Ramaswamy, 1998). The water of the
beaker was drained and samples were collected. Surface moisture of the samples was removed gently by wiping it off with a tissue paper and the weight was taken. Dehydrated garlic samples were evaluated for rehydration ratio, from the weight before and after the rehydration.

Rehydration ratio \( RR = \frac{C}{D} \)

where,

\( C = \) weight of rehydrated sample, g
\( D = \) test weight of dehydrated sample, g
This chapter deals with the results and their interpretations in context to the objectives framed for the investigation. Results obtained during the course of investigation have been systematically presented hereunder.

4.1 Tray drying of garlic cloves and slices

The primarily processed garlic cloves and slices having initial moisture content of 62% were pre-treated with 0.1 percent sodium metabisulphate. Garlic cloves were uniformly spread on trays and were dehydrated in a tray dryer to a safe moisture content of 6-9%. The drying experiment was carried out with drying air temperatures of 40, 50 and 60°C. The velocity of the drying air was kept constant as 1.5 m/s throughout the drying period. Similarly, the slices were dried in a tray dryer with drying air temperatures of 40, 50 and 60°C and at constant air velocity of 1.5 m/s. The data of each drying experiment is presented in Appendix-B.

4.1.1 Effect of process variables on drying curve

The change in moisture content of garlic cloves and slices with elapsed drying time, at each of drying temperature 40, 50 and 60°C at air velocity of 1.5 m/s are presented in Figs 4.1 and 4.2.

The moisture content of both garlic cloves and slices decreased exponentially with drying time under all drying conditions. The drying followed a typical trend of drying behaviour for food materials as reported earlier (Singh, 2001). As the drying air temperature increased, the drying curves exhibited steeper slope indicating that the drying rate increased with increase in drying air temperature. This resulted into substantial decrease of drying time. In case of garlic cloves, drying time at 40, 50 and 60°C was 18, 14 and 12 h, respectively and for slices the drying time was 7, 5.5 and 4 h at 40, 50 and 60°C respectively. As drying air temperature was increased from 40 to 60°C, the drying time reduced by about 33% and 43% for garlic cloves and slices, respectively. Size reduction in garlic causes shortening of drying time due to
increased surface area for heat and mass transfer. The drying time observed under various drying conditions is presented in Table 4.1.

Fig. 4.1 Drying curves of garlic cloves obtained at different air temperatures with air velocity of 1.5m/s in tray drying

Fig. 4.2 Drying curves of garlic slices obtained at different air temperatures with air velocity of 1.5m/s in tray drying
Table: 4.1 Drying time for garlic samples in a tray dryer

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Air temperature (°C)</th>
<th>Drying time, min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cloves</td>
</tr>
<tr>
<td>01</td>
<td>40</td>
<td>1080</td>
</tr>
<tr>
<td>02</td>
<td>50</td>
<td>840</td>
</tr>
<tr>
<td>03</td>
<td>60</td>
<td>720</td>
</tr>
</tbody>
</table>

An analysis of variance was carried out to study the effect of process variables on the drying time and the same is presented in Table 4.2. ANOVA shows that air temperature has no significant effect on drying time whereas the size of garlic has been found to have significant effect on drying time at 5% level of significance.

**Table: 4.2. ANOVA for the effect of process variables on the drying time of garlic samples in a tray dryer**

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>$F_{cal}$</th>
<th>$F_{tab}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>74100</td>
<td>2</td>
<td>37050</td>
<td>7.96 (NS)</td>
<td>19.00</td>
</tr>
<tr>
<td>Size</td>
<td>453750</td>
<td>1</td>
<td>453750</td>
<td>97.58*</td>
<td>18.51</td>
</tr>
<tr>
<td>Error</td>
<td>9300</td>
<td>2</td>
<td>4630</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>537150</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 5% level of significance

**4.1.2 Drying rate curves of pretreated garlic cloves and slices for tray drying experiments**

The drying rate for the garlic cloves and slices was estimated from the difference in its moisture content in a known time interval and expressed as g of moisture evaporated per g of dry matter-min. The drying rate of garlic cloves and slices under different convective drying conditions is represented in Appendix B. The drying rate as a function of moisture content at different drying air conditions are shown in Figs 4.3 and 4.4.
From both the plots, it was inferred that drying of garlic occurred only in falling rate period of drying. Constant rate drying period was absent throughout the garlic drying process under all the air temperatures studied. This result was in agreement with that observed by other researchers previously (Sankat and Castaigne, 1992). This may be due to fact that in vegetable products, moisture is transferred to the surface during initial period only by capillary mechanism. Due to the shrinkage of product, the rate of drying was not constant. It was also observed that drying rate was higher at higher moisture content and it decreased with decrease in moisture content. This trend was observed for garlic cloves as well as for slices dried at all the three temperature levels. This happened because higher air temperature resulted into higher temperature of the product, which increased vapor pressure inside the product and forcing the moisture to move faster towards surface. It was also observed that at all air temperatures, drying rates were higher for slices as compared to that for garlic cloves.

A second order polynomial relationship was found to have fitted adequately to desirable variations in the drying rates with moisture content at all three experimental temperatures and is represented by equation 4.1 with their coefficient of correlation values presented in Table 4.3.

\[ R = A x^2 + B x + C \]  

4.1

Where, \( R \) is the rate of drying in g water evaporated per g dry matter-min. A, B and C are constants and \( x \) is the moisture content in g water per g of dry matter. It is also seen that the values of coefficient of correlation are more than 0.95 at all the process temperatures that shows the good correlation among the predicted and observed values.

| Table: 4.3. Regression coefficients of equation 4.1 during tray drying of garlic |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Size  | Air temperature (°C) | Regression coefficients | Coefficient of correlation (\( r^2 \)) |
| Cloves |                 | A   | B   | C   |                  |
| 40    | 0.0007           | 0.0014 | 0.002 | 0.955 |
| 50    | 0.0008           | 0.0004 | 0.002 | 0.955 |
| 60    | -3x10^{-5}       | 0.0012 | 0.001 | 0.962 |
| Slices |                 | A   | B   | C   |                  |
| 40    | 0.0008           | 0.0037 | 0.003 | 0.977 |
| 50    | 0.0011           | 0.0057 | 0.005 | 0.970 |
| 60    | 0.0029           | 0.0137 | 0.007 | 0.980 |
Fig. 4.3 Drying rate curves of garlic cloves obtained at different air temperatures with air velocity of 1.5m/s

Fig. 4.4 Drying rate curves of garlic slices obtained at different air temperatures with air velocity of 1.5m/s

4.1.3 Moisture diffusivity

The variation in moisture diffusivity with moisture content is a complex phenomenon. The effective moisture diffusivity ($D_{eff}$) of a food material characterizes its intrinsic mass transport property of moisture, which includes molecular diffusion,
liquid diffusion, vapor diffusion, hydrodynamic flow and other possible mass transport mechanisms (Karathonos et al., 1990).

The moisture diffusivity during the hot air drying of treated garlic cloves and slices at various temperatures of drying air were calculated by using equation as described in section 3.7 of chapter III. The slopes of curves and intercept of straight line were determined. The estimated values of moisture diffusivity are presented in Table 4.4.

The variations in $D_{eff}$ with moisture content of garlic during convective drying are presented in Fig. 4.5 and 4.6. The $D_{eff}$ value of food material was affected by moisture content as well as temperature. It can be observed from the Table 4.4 that for garlic cloves, the moisture diffusivity increased from $1.94 \times 10^{-10}$ to $4.10 \times 10^{-10} \text{ m}^2/\text{s}$ as the drying air temperature increased from 40 to 60 $^\circ$C. Similar values of moisture diffusivities have been reported by some researchers for the food products (Madamba et al. 1996). Drying at 60$^\circ$ C gave the highest $D_{eff}$ value. For garlic slices, the effective moisture diffusivity increased from $5.47 \times 10^{-10}$ to $9.57 \times 10^{-10} \text{ m}^2/\text{s}$ with increase in air temperature from 40 $^\circ$C to 60 $^\circ$C. Moisture diffusivity increased with the increase in drying air temperature during drying. This may be due to increase in the product temperature with increase in drying air temperature, which ultimately increased the water vapour pressure inside the product.

<table>
<thead>
<tr>
<th>Sl. no</th>
<th>Air temperature ($^\circ$C)</th>
<th>Moisture diffusivity x10$^{-10}$ ($\text{m}^2/\text{s}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cloves</td>
</tr>
<tr>
<td>01</td>
<td>40</td>
<td>1.94</td>
</tr>
<tr>
<td>02</td>
<td>50</td>
<td>2.44</td>
</tr>
<tr>
<td>03</td>
<td>60</td>
<td>4.10</td>
</tr>
</tbody>
</table>

Table: 4.4. Effective moisture diffusivity of garlic cloves and slices dried in a tray dryer
The ANOVA was carried out to study the effect of process variables i.e. drying air temperature and size on the moisture diffusivity and the same is presented in Table 4.5. It was inferred that size has significant effect at 5% level on moisture diffusivity of garlic samples during drying process. The effect of temperature was found non-significant.
Table: 4.5. ANOVA showing the effect of process variables on moisture diffusivity of garlic samples dried in a tray dryer

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>$F_{cal}$</th>
<th>$F_{tab}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>9.82</td>
<td>2</td>
<td>4.91</td>
<td>6.13 (NS)</td>
<td>19.00</td>
</tr>
<tr>
<td>Size</td>
<td>36.96</td>
<td>1</td>
<td>36.96</td>
<td>46.2*</td>
<td>18.51</td>
</tr>
<tr>
<td>Error</td>
<td>1.6</td>
<td>2</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>48.38</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 5% level of significance

4.1.4. Activation Energy

Activation energy is required for flow of fluids and is determined by using Arrhenius equation (equation 4.2), using moisture diffusivity values obtained at different drying air temperatures.

$$D_{\text{eff}} = D_0 \exp \left[ \frac{-E_a}{R(T+273.15)} \right]$$  \hspace{1cm} (4.2)

where,

$E_a$ = Activation Energy (kJ/mol)

$D_{\text{eff}}$ = Moisture diffusivity ($m^2/s$)

$D_0$ = Reference diffusion co-efficient at infinite temperature

$T$ = Absolute temperature, (K)

$R$ = Universal gas constant (Joule/mol.K)

The dependence of moisture diffusivity on drying air temperature is presented in Fig. 4.7. The activation energy estimated from the slopes of straight line is presented in Table 4.6.

Table: 4.6 $E_a$ values for garlic cloves and slices

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Size</th>
<th>Activation Energy (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cloves</td>
<td>32.47</td>
</tr>
<tr>
<td>2</td>
<td>Slices</td>
<td>24.66</td>
</tr>
</tbody>
</table>
The activation energy for garlic cloves and slices was 24.66 and 32.47 kJ/mol respectively. Thermodynamically, activation energy is the relative ease with which the water molecules pass the hurdle when migrating within the product. Conventionally heating activation energy values for diffusivity for vegetables may be 9.00 kJ/mol (Yusheng and Poulsen, 1988) and as high as 280 kJ/mol (Feng and Tang, 1999). The values estimated in this study for garlic are well within the range for convective drying process. Lower activation energy translates to higher moisture diffusivity in the drying process.

4.1.5 Modeling of drying behaviour of garlic

Experimental results of moisture ratio with drying time was fitted into Exponential and Page model as discussed under section 3.8 of chapter III. The average moisture content was expressed as non-dimensional moisture ratio and used to model the drying curves with time (min). Initial moisture content was used as critical moisture content due to absence of constant drying rate period (Karathanos, 1997). Equilibrium moisture, $M_e$ at different drying air temperatures was taken as 0.06 g H$_2$O/g dry solid i.e. the moisture content at which drying was terminated. The goodness of fit of the model was determined by estimating the coefficient of determination, $R^2$ (Madamba et al, 1996). The estimated parameters of exponential as
well as Page model are given in Table 4. 7. Figs 4.8 and 4.9 show the variation of moisture ratio at different temperature levels. As the duration of drying increased, moisture ratio decreased which was expected also. Comparison of $R^2$ value of both the models showed that Page model gave better fit than the Exponential model.

4.1.5.1 Effect of size on drying constant, $k$

The drying constant, $k$ depended on size of garlic. The $k$ value was lower for garlic cloves compared to slices. For cloves, the highest value of drying constant $k_s$ (Exponential model) and $k_p$ (Page model) was observed as $0.006 \text{ min}^{-1}$ and $0.001 \text{ min}^{-1}$. In case of slices, the highest value of drying constant $k_s$ (Exponential model) and $k_p$ (Page model) was observed as $0.018 \text{ min}^{-1}$ and $0.009 \text{ min}^{-1}$, respectively.

4.1.5.2 Effect of temperature on drying constant, $k$

Temperature affected the drying constant in Exponential ($k_s$) and Page model ($k_p$). The drying constant in Exponential ($k_s$) and Page model ($k_p$) increased with increase in drying temperature for both garlic cloves and slices. For cloves as temperature increased from $40^\circ\text{C}$ to $60^\circ\text{C}$, $k_s$ and $k_p$ increased from $0.004 \text{ min}^{-1}$ to $0.0066 \text{ min}^{-1}$ and $0.0008 \text{ min}^{-1}$ to $0.0015 \text{ min}^{-1}$, respectively. In case of slices, the value of $k_s$ and $k_p$ increased from $0.0076 \text{ min}^{-1}$ to $0.0183 \text{ min}^{-1}$ and $0.0064 \text{ min}^{-1}$ to $0.0091 \text{ min}^{-1}$, respectively for similar rise in temperature from $40^\circ\text{C}$ to $60^\circ\text{C}$.

**Table: 4.7. Drying constants of Exponential and Page model under various drying conditions**

<table>
<thead>
<tr>
<th>Size</th>
<th>Temperature ($^\circ\text{C}$)</th>
<th>Exponential model</th>
<th>Page model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$k_s$</td>
<td>$R^2$</td>
<td>$n$</td>
</tr>
<tr>
<td>Cloves</td>
<td>40</td>
<td>0.004</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.005</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.0066</td>
<td>0.91</td>
</tr>
<tr>
<td>Slices</td>
<td>40</td>
<td>0.0076</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.0115</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.0183</td>
<td>0.98</td>
</tr>
</tbody>
</table>
Fig. 4.8 Effect of drying air temperature on moisture ratio of garlic cloves

Fig. 4.9 Effect of drying air temperature on moisture ratio of garlic slices
4.1.6. **Water activity of dehydrated garlic samples**

The water activity scale extends from 0 (bone dry) to 1 (pure water) but most foods have a water activity level in the range of 0.2 (very dry foods) to 0.99 (moist fresh foods). The water activity \( (a_w) \) represents the ratio of the water vapor pressure of the food to the water vapor pressure of pure water under the same conditions and it is expressed as a fraction. By multiplying this ratio by 100, the equilibrium relative humidity (ERH) can be measured that the foodstuff would produce if enclosed with air in a sealed container at constant temperature.

The water activity of the garlic samples was measured by a digital water activity meter at room temperature and the same are presented in Table 4.8. The water activity ranged between 0.269-0.280 for garlic cloves and 0.272-0.281 for garlic slices, which is within safe limit.

**Table: 4.8 Water activity \((a_w)\) of tray dried garlic cloves and slices**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Temperature (^{\circ}\text{C})</th>
<th>Water activity((a_w))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>cloves</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>0.27</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>0.26</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>0.28</td>
</tr>
</tbody>
</table>

4.1.7 **Quality analysis of tray dried garlic cloves and slices.**

The quality of the dehydrated garlic cloves and slices were evaluated on the basis of color and flavor strength adopting the standard procedures as discussed before. The results of the study are presented in the following section;

4.1.7.1 Color

Color values measured using a Colourflex Hunterlab Colorimeter was relative to the absolute values of perfect reflecting diffuser as measured under the same geometric conditions (ASTM method). Readings were recorded at room temperature. L-value measured with colorimeter indicated the lightness of product color. The L-values for garlic samples dried under various conditions are represented in Table 4.9.
It is inferred from the observations that L-value reduced when drying air temperature was increased from 40 to 60 °C for both cloves and slices. This could possibly be due to exposure of product to high temperature which could have darkened the surface of the dried product. The L-values obtained for slices was more than that of cloves for all the drying air temperatures studied. It may be because of less exposure of the slices to the drying air in comparison to cloves.

Table: 4.9 Lightness (L-values) of tray dried garlic samples

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Temperature (°C)</th>
<th>Cloves</th>
<th>Slices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>78.36</td>
<td>87.44</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>77.32</td>
<td>85.72</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>73.14</td>
<td>83.94</td>
</tr>
</tbody>
</table>

The ANOVA was carried out to study the effect of process variables i.e. drying air temperature and size on color of garlic samples and the same is presented in Table 4.10. It was inferred that size has significant effect at 5% level on color of garlic samples during drying process. The effect of temperature was found non-significant.

Table: 4.10. ANOVA for the effect of process variables on color of tray dried garlic samples

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F_cal</th>
<th>F_tab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>19.86</td>
<td>2</td>
<td>9.93</td>
<td>12.6(NS)</td>
<td>19.00</td>
</tr>
<tr>
<td>Size</td>
<td>133.29</td>
<td>1</td>
<td>133.29</td>
<td>169.79*</td>
<td>18.51</td>
</tr>
<tr>
<td>Error</td>
<td>1.57</td>
<td>2</td>
<td>0.785</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>154.72</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 5% level of significance

4.1.7.2 Flavor

Flavor strength of dehydrated garlic powder was determined with the chloramine-T method (Shankarnarayana et al. 1981) as described in section 3.10.2 of chapter III. Flavor strength was found in the range of 0.004 to 0.01 percent for cloves and 0.001 to 0.004 percent for slices. The lowest value of flavor strength is 0.001 percent for slices dried at 60°C temperature. Garlic cloves dried at 40°C had the
highest value of flavor strength compared to slices dried at 40\(^0\)C. As the temperature increased the flavour strength of dehydrated product decreased which may be due to loss of volatile oil at higher temperature. It was also found that flavour strength was less for dehydrated slices in comparison to cloves dehydrated at same temperature which may be due to the exposure of larger surface area.

Table: 4.11 Flavor strength of garlic samples dried in a tray dryer

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Temperature (^0)C</th>
<th>Flavor strength (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cloves</td>
<td>slices</td>
</tr>
<tr>
<td>1.</td>
<td>40</td>
<td>0.010</td>
</tr>
<tr>
<td>2.</td>
<td>50</td>
<td>0.008</td>
</tr>
<tr>
<td>3.</td>
<td>60</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Flavor strength of fresh garlic is 0.06 percent

An analysis of variance was carried out to study the effect of process variables i.e. temperature and size on flavor strength for drying of garlic samples and the same is presented in Table 4.12. Since \(F_{\text{cal}}\) is less than \(F_{\text{tab}}\) at 5\% level of significance for temperature and size. Statistically it is shown that there is no effect of temperature and size on flavor strength of dehydrated garlic samples.

Table: 4.12 ANOVA showing the effect of process variables on flavor strength of tray dried garlic samples

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>(F_{\text{cal}})</th>
<th>(F_{\text{tab}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>15.22</td>
<td>2</td>
<td>7.61</td>
<td>2.57(NS)</td>
<td>19.00</td>
</tr>
<tr>
<td>Size</td>
<td>36.01</td>
<td>1</td>
<td>36.01</td>
<td>12.20(NS)</td>
<td>18.51</td>
</tr>
<tr>
<td>Error</td>
<td>5.9</td>
<td>2</td>
<td>2.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>57.13</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 5\% level of significance

4.1.7.3 Rehydration studies

Rehydration ratio was determined as explained in section 3.10.3 of chapter III and is presented in Table 4.13. The minimum rehydration ratio was obtained for garlic cloves dried at 60 \(^0\)C and maximum rehydration ratio was obtained for slices dried at 40\(^0\)C.
Table: 4.13. Rehydration characteristics of garlic sample dried in tray dryer

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Temperature (^{\degree}C)</th>
<th>Dehydrated weight (g)</th>
<th>Rehydrated weight (g)</th>
<th>Rehydration ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cloves</td>
<td>Slices</td>
<td>Cloves</td>
</tr>
<tr>
<td>01</td>
<td>40</td>
<td>5</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>02</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>03</td>
<td>60</td>
<td>5</td>
<td>5</td>
<td>09</td>
</tr>
</tbody>
</table>
4.2 Fluidized bed drying of garlic slices

The primarily processed and treated garlic slices were dehydrated in fluidized bed dryer. The drying experiment was carried out at air temperature of 40, 50 and 60°C with air velocity of 2.5, 3.0 and 3.5 m/s.

The terminal velocity of white garlic cloves is 9.89 m/s at 34.9 percent moisture content (Masoumi, 2004) and this value is much higher than the maximum drying air velocity at which the fluidized bed dryer can operate. Therefore, it was practically impossible to conduct drying experiment for garlic cloves in a fluidized bed dryer as garlic cloves could not be brought under fluidization. Due to the above constraint, only slices of 5 mm thickness were dried in fluidized bed dryer. The data of each drying experiment is presented in the following section.

4.2.1 Effect of process variables on drying curve

The change in moisture content of garlic slices with elapsed drying time, at three drying temperature levels of 40, 50 and 60°C at three air velocity level of 2.5, 3.0 and 3.5 m/s is presented in Figs 4.10, 4.11 and 4.12. The moisture content of garlic slices decreased exponentially with drying time under all drying conditions. As the drying air temperature increased, the drying curves exhibited steeper slope indicating that the drying rate increased with increase in drying air temperature. This resulted into substantial decrease in drying time. The drying time for garlic slices at 40, 50 and 60°C with air velocity of 3.5 m/s was 6, 5 and 4 h, respectively. Similarly, the drying time for garlic slices dried at 40, 50 and 60°C was found to be 6, 5.5 and 4.5 h for air velocity of 3.0 m/s and 6, 5.5 and 5 h for air velocity of 2.5 m/s. As the drying air temperature was increased from 40 to 60°C, the drying time reduced by about 33.3, 25 and 16.5 percent for air velocity of 2.5, 3.0 and 3.5 m/s, respectively. The drying time observed under various drying conditions is presented in Table 4.14. The drying curves of garlic slices under all conditions indicated that the drying process is unaffected by air velocity, but temperatures play a major role in drying.

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Air temperature (°C)</th>
<th>Drying time, min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2.5 m/s</td>
</tr>
<tr>
<td>01</td>
<td>40</td>
<td>360</td>
</tr>
<tr>
<td>02</td>
<td>50</td>
<td>330</td>
</tr>
<tr>
<td>03</td>
<td>60</td>
<td>300</td>
</tr>
</tbody>
</table>
Fig. 4.10 Drying curves of garlic slices at different temperatures with air velocity of 2.5m/s

Fig. 4.11 Drying curves of garlic slices at different temperatures with air velocity of 3.0m/s

Fig. 4.12 Drying curves of garlic slices at different temperatures with air velocity of 3.5m/s
Fig. 4.13 Drying curves of garlic slices at different air velocities with constant air temperature of 40°C

Fig. 4.14 Drying curves of garlic slices obtained at different air velocities with constant air temperature of 50°C

Fig. 4.15 Drying curves of garlic slices obtained at different air velocities with constant air temperature of 60°C
An analysis of variance was carried out to study the effect of process variables on the drying time and is presented below in Table 4.15. ANOVA shows that temperature has significant effect on drying time and air velocity was non significant at 5% level of significance.

Table: 4.15 ANOVA showing the effect of process variables on drying time for garlic slices in a fluidized bed dryer

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>$F_{cal}$</th>
<th>$F_{tab}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>12200</td>
<td>2</td>
<td>6100</td>
<td>24.4*</td>
<td>6.94</td>
</tr>
<tr>
<td>Air velocity</td>
<td>1400</td>
<td>2</td>
<td>700</td>
<td>2.8(NS)</td>
<td>6.94</td>
</tr>
<tr>
<td>Error</td>
<td>1000</td>
<td>4</td>
<td>250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14600</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 5% level of significance

4.2.2 Drying Rate curves for garlic slices in fluidized bed drying experiments

The drying rate for the garlic slices was estimated from the difference in its moisture content in a known time interval and expressed as g water evaporated per g of dry matter-min (Appendix B). The drying rate as a function of moisture content at different drying air conditions is shown in Fig 4.16 through 4.21. From all the three plots, it was inferred that drying of garlic occurred only in falling rate drying period. Constant rate drying period was absent through out the drying process. This result was in agreement with those observed by other researchers previously (Sankat and Castaigne, 1992).

It was observed that drying rate was higher at higher moisture content and it decreased with decrease in moisture content. The drying air temperature affected the drying rate at different drying air conditions. The increase in drying air temperature resulted in increase in drying rate. This trend was observed for garlic slices dried with air velocity of 2.5, 3.0 and 3.5m/s at all the three temperature levels of 40, 50 and 60°C. From Fig 4.19, 4.20 and 4.21, it is evident that air velocity has significant influence in the initial period of drying with a drying rate of 0.054 g of water evaporated/ g of dry matter-min for 3.5m/s compared to 0.0035 g of water evaporated/ g of dry matter-min for air velocity of 2.5m/s, implying that the evaporation process took place in the surface and was therefore more directly affected by the velocity.
Subsequently and after a short period of time (2-3h), the predominance of air velocity variation on the drying rate became less important.

A second order polynomial relationship was found to have fitted adequately to desirable variations in the drying rates with moisture content at all the three experimental temperatures and is represented by equation 4.1 with their coefficient of correlation values presented in Table 4.16.

\[ R = A x^2 + B x + C \]  \hspace{2cm} 4.1

It has also been observed that coefficient of correlation is more than 0.95 at all the process temperatures which indicates that there is good correlation among the predicted and observed values.

**Table 4.16 Regression coefficients of equation 4.1 during fluidized bed drying of garlic slices**

<table>
<thead>
<tr>
<th>Air Velocity (m/s)</th>
<th>Air temperature (°C)</th>
<th>Regression coefficients</th>
<th>Coefficient of correlation (r²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>2.5</td>
<td>40</td>
<td>-0.0063</td>
<td>0.0178</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>-0.0105</td>
<td>0.0269</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>-0.0094</td>
<td>0.028</td>
</tr>
<tr>
<td>3.0</td>
<td>40</td>
<td>0.0017</td>
<td>0.0114</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>-0.0007</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>-0.006</td>
<td>0.0283</td>
</tr>
<tr>
<td>3.5</td>
<td>40</td>
<td>0.0035</td>
<td>0.0091</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>-0.0032</td>
<td>0.0242</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.019</td>
<td>0.0095</td>
</tr>
</tbody>
</table>
Fig 4.16 Drying rate curves of garlic slices at different air temperatures with air velocity of 2.5m/s

Fig 4.17 Drying rate curves of garlic slices at different air temperatures with air velocity of 3.0m/s

Fig 4.18 Drying rate curves of garlic slices at different air temperatures with air velocity of 3.5m/s
Fig 4.19 Drying rate curves of garlic slices at different air velocities and constant air temperature of 40°C

Fig 4.20 Drying rate curves of garlic slices at different air velocities and constant air temperature of 50°C

Fig 4.21 Drying rate curves of garlic slices at different air velocities and constant air temperature of 60°C
4.2.3 Moisture diffusivity of garlic slices during fluidized bed drying

The moisture loss data during fluidized bed drying were analyzed and moisture ratio was calculated. The data of moisture ratio versus drying time are presented in Appendix B. The variation in ln(MR) with drying time under various process conditions is presented in Fig 4.22 through 4.24. The variation in each case was found to be linear with inverse slope. The slope became steeper with increase in drying air temperature. The effective moisture diffusivity $D_{eff}$ for garlic slices varied from $1.02 \times 10^{-09}$ to $1.40 \times 10^{-09}$ m$^2$/s for different drying conditions as shown in Table 4.17. The value lies in the range of $10^{-10}$ to $10^{-11}$ m$^2$/s for food materials (Zogzas et al. 1996).

Table 4.17. Effective moisture diffusivity of garlic slices in a fluidized bed dryer

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Air temperature ($^\circ$C)</th>
<th>Moisture diffusivity x$10^{09}$ (m$^2$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2.5m/s</td>
</tr>
<tr>
<td>01</td>
<td>40</td>
<td>1.02</td>
</tr>
<tr>
<td>02</td>
<td>50</td>
<td>1.11</td>
</tr>
<tr>
<td>03</td>
<td>60</td>
<td>1.35</td>
</tr>
</tbody>
</table>

ANOVA was carried out to study the effect of process variables i.e. drying air temperature and velocity on the moisture diffusivity and the same is presented in Table 4.18. It was inferred that neither air temperature nor air velocity has significant effect at 5% level on moisture diffusivity of garlic samples during drying process.

Table 4.18. ANOVA showing the effect of process variables on moisture diffusivity of garlic slices dried in a fluidized bed dryer

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>ss</th>
<th>df</th>
<th>MS</th>
<th>$F_{cal}$</th>
<th>$F_{tab}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature</td>
<td>0.177</td>
<td>2</td>
<td>0.0885</td>
<td>5.53(NS)</td>
<td>6.94</td>
</tr>
<tr>
<td>Air Velocity</td>
<td>0.048</td>
<td>2</td>
<td>0.024</td>
<td>1.5(NS)</td>
<td>6.94</td>
</tr>
<tr>
<td>Error</td>
<td>0.064</td>
<td>4</td>
<td>0.016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.289</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 5% level of significance
Fig. 4.22 Variation in ln [MR] with time for garlic slices dried at air velocity 2.5m/s

Fig. 4.23 Variation in ln [MR] with time for garlic slices dried at air velocity 3.0m/s

Fig. 4.24 Variation in ln [MR] with time for garlic slices dried at air velocity 3.5m/s
4.2.4 Activation energy

The dependence of average effective moisture diffusivity ($D_{eff}$) on drying air temperature is obtained by the Arrhenius-type relationship and is shown in Fig 4.25. The activation energy estimated from the slopes of straight line is presented in Table 4.19.

**Table: 4.19 $E_a$ values for garlic slices at different air velocities**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Air velocity (m/s)</th>
<th>Activation Energy (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.5</td>
<td>12.81</td>
</tr>
<tr>
<td>2</td>
<td>3.0</td>
<td>12.44</td>
</tr>
<tr>
<td>3</td>
<td>3.5</td>
<td>12.16</td>
</tr>
</tbody>
</table>

The activation energy for garlic slices ranged between 12.16 and 12.81 kJ/mol for different air velocity levels. Activation energy value for garlic slices dried in fluidised bed drying process is much lower than convective drying process thereby indicating higher moisture diffusivity in fluidised bed drying process.

![Fig. 4.25 Effect of temperature on effective diffusivity of garlic slices](image)

4.2.5 Modeling of drying behaviour of garlic

Experimental data on drying of garlic slices were fitted into Exponential model and the Page model as discussed under section 3.8 of chapter III. The goodness of fit of each model was determined by estimating the coefficient of determination, $R^2$.
(Madamba et al. 1996). The estimated parameters of Exponential as well as Page model are given in Table 4.20 for all process conditions along with the corresponding values of $R^2$. Fig 4.26 through 4.28 shows the variation of moisture ratio at different temperature levels. Comparison of $R^2$ of both the models showed that Page model gave better fit than the Exponential model.

4.2.5.2. Effect of temperature on drying constant, $k$

Temperature affected the drying constant in Exponential ($k_s$) and Page model ($k_p$). The drying constant in Exponential ($k_s$) and Page model ($k_p$) increased with increase in drying air temperature. For both Exponential and Page models, the highest value of drying constants, $k_s$ and $k_p$ was observed as 0.23 and 0.44 min$^{-1}$ respectively.

**Table: 4.20 Drying constants of Exponential and Page model under various drying conditions**

<table>
<thead>
<tr>
<th>Air velocity(m/s)</th>
<th>Temperature ($^\circ$C)</th>
<th>Exponential model</th>
<th>Page model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$k_s$</td>
<td>$R^2$</td>
</tr>
<tr>
<td>2.5</td>
<td>40</td>
<td>0.011</td>
<td>0.979</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.012</td>
<td>0.980</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.018</td>
<td>0.985</td>
</tr>
<tr>
<td>3.0</td>
<td>40</td>
<td>0.012</td>
<td>0.904</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.015</td>
<td>0.977</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.023</td>
<td>0.978</td>
</tr>
<tr>
<td>3.5</td>
<td>40</td>
<td>0.011</td>
<td>0.955</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.014</td>
<td>0.967</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.023</td>
<td>0.988</td>
</tr>
</tbody>
</table>
Fig. 4. 26 Effect of temperature on moisture ratio of garlic slices at 2.5 m/s

Fig. 4. 27. Effect of temperature on moisture ratio of garlic slices at 3.0 m/s

Fig. 4. 28. Effect of temperature on moisture ratio of garlic slices at 3.5 m/s
4.2.6 Water activity of dehydrated garlic powder

The water activity of garlic slices was measured by a digital water activity meter at room temperature and the same is presented in Table 4.21. The water activity ranged between 0.279 and 0.298, which is within safe limits.

Table: 4.21 Water activity ($a_w$) of dried garlic slices

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Temperature ($^\circ$C)</th>
<th>2.5m/s</th>
<th>3.0m/s</th>
<th>3.5m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>0.298</td>
<td>0.297</td>
<td>0.285</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>0.291</td>
<td>0.299</td>
<td>0.284</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>0.289</td>
<td>0.291</td>
<td>0.279</td>
</tr>
</tbody>
</table>

4.2.7 Quality analysis of garlic slices

The quality of garlic slices were evaluated on the basis of color and flavor strength adopting the standard procedures as discussed before. The results of the study are presented as following.

4.2.7.1 Color

The L-values for garlic slices dried under various conditions are represented in Table 4.22. It is inferred from the observations that L-value reduced when drying air temperature was increased from 40 to 60 $^\circ$C for different levels of air velocity. This could possibly be due to the exposure of product to high temperature which could have darkened the surface of the dried product during drying.

Table: 4.22 Lightness (L-values) of fluidized bed dried garlic slices

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Temperature ($^\circ$C)</th>
<th>Color index(L-values)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2.5m/s</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>87.23</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>84.43</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>84.40</td>
</tr>
</tbody>
</table>
The ANOVA was carried out to study the effect of process variables on color of garlic samples and the same is presented in Table 4.23. It was inferred that temperature has significant effect on color of garlic samples while the effect of air velocity was found non significant at 5% level of significance.

**Table: 4.23 ANOVA showing the effect of process variables on the color of fluidized bed dried garlic slices**

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>$F_{cal}$</th>
<th>$F_{tab}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature</td>
<td>23.86</td>
<td>2</td>
<td>11.93</td>
<td>10.7*</td>
<td>6.94</td>
</tr>
<tr>
<td>Air Velocity</td>
<td>6.96</td>
<td>2</td>
<td>3.48</td>
<td>3.14(NS)</td>
<td>6.94</td>
</tr>
<tr>
<td>Error</td>
<td>4.43</td>
<td>4</td>
<td>1.107</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>35.25</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 5% level of significance

4.2.7.2 Flavor

Flavor strength of dehydrated garlic powder was determined by chloramine-T method (Shankarnarayana et al. 1981) as explained in section 3.10.2 of chapter III. It was found to lie in the range of 0.002 and 0.006 percent at various levels of air velocity and air temperature. The lowest value of flavor strength is 0.002 percent which is for garlic slices dried at 60°C.

**Table: 4.24 Flavor strength of garlic powder dried in fluidized bed dryer.**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Temperature ($^{0}C$)</th>
<th>Flavor strength (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2.5m/s</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>0.0065</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>0.0043</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>0.0021</td>
</tr>
</tbody>
</table>

The ANOVA was carried out to study the effect of process variables on flavor strength of dried garlic samples and the same is presented in Table 4.25. It was inferred that temperature has significant effect on flavor strength of dried garlic samples but the effect of air velocity was found non-significant at 5% level of significance.
Table: 4.25 ANOVA showing the effect of process variables on flavor strength of fluidized bed dried garlic slices

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>$F_{cal}$</th>
<th>$F_{tab}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature</td>
<td>28.76</td>
<td>2</td>
<td>14.38</td>
<td>63.34*</td>
<td>6.94</td>
</tr>
<tr>
<td>Air Velocity</td>
<td>0.16</td>
<td>2</td>
<td>0.08</td>
<td>0.352(NS)</td>
<td>6.94</td>
</tr>
<tr>
<td>Error</td>
<td>0.91</td>
<td>4</td>
<td>0.227</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28.83</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 5% level of significance

4.2.7.3 Rehydration studies

The rehydration ratio was determined as explained in section 3.10.3 of chapter III. Rehydration characteristic of dehydrated sample is presented in Table 4.26. The minimum rehydration ratio was obtained for garlic slice dried at 60 $^0$C and maximum rehydration ratio was obtained for slices dried at 40 $^0$C for all levels of air velocity.

Table: 4.26 Rehydration ratio of fluidized bed dried garlic slices

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Temperature ($^0$C)</th>
<th>Dehydrated weight (g)</th>
<th>Rehydrated weight (g)</th>
<th>Rehydration Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.5 m/s 3.0 m/s 3.5 m/s</td>
<td>2.5 m/s 3.0 m/s 3.5 m/s</td>
<td>2.5 m/s 3.0 m/s 3.5 m/s</td>
<td>2.5 m/s 3.0 m/s 3.5 m/s</td>
</tr>
<tr>
<td>01</td>
<td>40</td>
<td>5 5 5</td>
<td>16.0 16.0 15.5</td>
<td>3.2 3.2 3.1</td>
</tr>
<tr>
<td>02</td>
<td>50</td>
<td>5 5 5</td>
<td>15.0 15.0 15.0</td>
<td>3.0 3.0 3.0</td>
</tr>
<tr>
<td>03</td>
<td>60</td>
<td>5 5 5</td>
<td>14.5 14.5 14.5</td>
<td>2.9 2.9 2.9</td>
</tr>
</tbody>
</table>
CHAPTER V
SUMMARY AND CONCLUSIONS

Garlic is a wonder spice. It is used all over the world as a spice in food preparation because of its unique flavor. Growth in popularity of convenient foods in many countries has stimulated increasing demand for high quality dehydrated garlic products like garlic flakes, garlic oil and garlic powder and the same are exported to Japan, United Kingdom, Italy, Turkey, Germany and France.

Among all the processing techniques of fruits and vegetables, drying is the most important process because dehydrated products require inexpensive packaging and transportation and less energy during transportation. Drying of foods is aimed at producing high density product, which when adequately packaged has longer shelf life after which the food can be rapidly and simply reconstituted without substantial loss of flavor, taste, colour and aroma. Mostly, the cost of food product is dependent on the drying process. So it is necessary to dry the product at minimum cost, energy and time for techno-econ-socio compatibility. The study of drying kinetics helps in the design, simulation and optimization of drying processes. The present research work was therefore undertaken to study the drying kinetics of garlic during tray drying and fluidized bed drying. The specific objectives of the study were as follows;

1. To study the drying characteristics of garlic cloves and slices in tray and fluidized bed dryer.

2. To evaluate the quality of the final dried product.

In the present experiment, garlic was procured from the local market. The cloves were separated, peeled by hand and sliced to 5mm thickness. Both cloves and slices weighing 50 g were dried in tray dryer and fluidized bed dryer from initial moisture content of 1.8 g of water/ g of dry matter to a safe level of about 0.06 g of water/ g of dry matter. The experiments were conducted at air temperature levels of 40, 50, 60°C at air velocity of 1.5m/s for tray dryer. In case of fluidized bed drying process, experiments were conducted at three temperature levels (40, 50, 60°C) and three levels of air velocity (2.5, 3.0 and 3.5m/s).

It was observed that for cloves and slices dried in tray dryer, the drying time
was higher for cloves compared to slices for all the three levels of drying air temperature. ANOVA carried out to study the effect of process variables on drying time showed that the effect of size was significant on drying time. The drying rates decreased for garlic cloves compared to slices at different drying air temperature.

The effective moisture diffusivity increased with increase in temperature for both cloves and slices. It was observed that moisture diffusivity increased with the increase in drying air temperature during drying. This may be due to increase in the product temperature with increase in drying air temperature, which ultimately increased the water vapour pressure inside the product. With the increase in drying air temperature from 40 to 60 °C, effective moisture diffusivity varied from 1.9410x10^-10 to 4.10x10^-10 m²/s for cloves and from 5.4710x10^-10 to 9.56x10^-10 m²/s for slices. ANOVA, carried out to study the effect of process variables on moisture diffusivity revealed that size had significant effect on moisture diffusivity.

Activation energy was estimated for cloves and slices dried under tray drying conditions. Activation energy for cloves and slices was found to be 32.47 and 24.66 kJ/mol respectively. Lower value of activation energy translates to higher moisture diffusivity in the drying process.

For the prediction of drying kinetics in a suitable model, Exponential and Page models were selected. Necessary experimental data were fitted to Exponential and Page models using Marquardt method of non-linear regression procedure in Sy-stat (12.00) to calculate value of drying constant in Exponential and Page model. Drying constant was higher for slices compared to cloves in both Exponential and Page models. Drying constants in both the models varied from 0.0008 min⁻¹ - 0.006 min⁻¹ and 0.006 min⁻¹ - 0.018 min⁻¹ for cloves and slices respectively.

Water activity of dehydrated cloves and slices was measured by a digital water activity meter at room temperature. Water activity of both dehydrated cloves and slices was found in the range of 0.27-0.28, which was within safe limits.

L-values of dehydrated sample was measured using Hunterlab colorimeter. L-values measured with colorimeter indicated the lightness of the product’s colour. L – values for dehydrated cloves and slices was in the range of 73.14 – 78.36 and 83.94-87.44. It was inferred that the samples dried at lower 40°C were more lighter
compared to samples dried at 60°C and dehydrated slices were lighter compared to dehydrated cloves due to longer periods of drying. ANOVA carried out to study the effect of process variables on colour of dehydrated product showed that size has significant effect on colour.

Flavor strength of dehydrated garlic powder was determined by Chloromine-T method. Flavor strength was found in the range of 0.004 to 0.01 percent for cloves and 0.001 to 0.004 percent for slices. The lowest value of flavor strength is 0.001 percent for slices dried at 60°C temperature. The highest value of flavor strength was 0.01 percent for cloves dried at 50°C.

Rehydration studies of dehydrated sample were conducted using standard procedures. The minimum rehydration ratio was obtained for garlic cloves dried at 60°C and maximum rehydration ratio was obtained for slices dried at 40°C.

For garlic slices dried in fluidized bed dryer, the drying time reduced with increase in air temperature. As the drying air temperature was increased from 40 to 60°C, the drying time reduced by about 33.3, 25 and 16.5 percent for air velocity of 3.5, 3.0 and 3.5 m/s respectively. ANOVA shows that temperature has significant effect on drying time and air velocity was non significant at 5% level of significance. The drying rate increased with increase in air temperature.

The effective moisture diffusivity increased with increase in temperature at all the three levels of air velocity. With increase in drying air temperature from 40 - 60°C, effective diffusivity varied from 1.02-1.40x10^-9 m^2/s. ANOVA was carried on to study the effect of temperature and air velocity on effective moisture diffusivity, it was inferred that temperature had significant effect on moisture diffusivity.

Activation energy of garlic was estimated by using Arrhenius-type relationship. The activation energy for garlic slices ranged between 12.16 and 12.81 kJ/mol for different air velocity levels. Activation energy value for garlic slices dried in fluidized bed dryer process is much lower than convective drying process thereby indicating higher moisture diffusivity in fluidized bed drying process.

Experimental data were fitted to Exponential and Page models using Marquardt method of non-linear regression procedure in Sy-stat (12.00) to calculate
drying constant in Exponential and Page model. Temperature affected the drying constant in Exponential \(k_s\) and Page model \(k_p\). The drying constant in Exponential \(k_s\) and Page model \(k_p\) increased with increase in drying temperature. For both Exponential and Page models, the highest value of drying of \(k_s\) and \(k_p\) was observed as 0.23 min\(^{-1}\) and 0.44 min\(^{-1}\) respectively.

The water activity of garlic slices was measured by a digital water activity meter at room temperature. The water activity ranged between 0.279 and 0.298, which is within safe limits.

\[ L\text{-value of dehydrated slices was in the range of 81.02 to 87.23. L-value reduced when drying air temperature was increased from 40 to 60^0\text{C for different levels of air velocity. This could possibly be due to exposure of product to high temperature which could have darkened the surface of the dried product.} }\]

Flavor strength of dehydrated slices was found to lie in the range of 0.002 and 0.006 percent at various levels of air velocity and air temperature. The lowest value of flavor strength is 0.002 percent which is for garlic slices dried at 60\(^0\text{C. The ANOVA was carried out to study the effect of process variables on flavor strength of dried garlic samples and it was inferred that temperature has significant effect on flavor strength of dried garlic samples.} \]

Rehydration ratio of dehydrated slices was calculated. The minimum rehydration ratio was obtained for garlic slice dried at 60\(^0\text{C and maximum rehydration ratio was obtained for slices dried at 40\(^0\text{C for all levels of air velocity.} \]

The following specific conclusions could be drawn from this study.

1. The moisture content in garlic decreased with increase in drying air temperature for both tray drying and fluidized bed drying experiments.
2. Drying time is higher for cloves as compared to slices in all the three temperature levels of tray drying.
3. Drying rate of cloves is lower compared with that of slices in all the three temperature levels of tray drying.
4. Drying of garlic took place in falling rate period and constant rate period was completely absent in both tray drying and fluidized bed drying experiments.
5. Effective moisture diffusivity increased with increase in temperature. Moisture diffusivity of slices was higher compared to cloves in tray drying conditions.

6. Activation energy for cloves is higher compared to slices dried in tray dryer. Lower activation energy translates to higher moisture diffusivity in the drying process.

7. Drying constants in Exponential and Page models increased with increase in air temperature for both tray drying and fluidized bed drying conditions.

8. Garlic cloves had the highest flavor strength as compared to slices for tray drying conditions under study.

9. Moisture diffusivity of garlic slices dried under fluidized bed drying conditions was found in the range of 1.02 to 1.40 m²/s. Air velocity was statistically found to have no significant effect on moisture diffusivity of garlic slices.

10. Activation energy for garlic slices dried in fluidized bed drying process is much lower than convective drying process thereby indicating higher moisture diffusivity in fluidized bed drying process. The activation energy for garlic slices ranged between 12.16 and 12.81 kJ/mol for different air velocity levels.

11. Page model gave better fit than simple (Exponential) model for both tray drying and fluidized bed drying conditions.

12. Samples dried at lower temperature were of best quality in terms of color, flavor and rehydration ratio.

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