STUDIES ON POST HARVEST PROCESSING OF GARLIC

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CERTIFICATE –IV

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This is to certify that **Mr. Anoop Kumar Dave** student of **Doctor of Philosophy**, Department of Farm Machinery and Power Engineering, College of Technology and Engineering, Udaipur has made all the corrections/ modifications in the thesis entitled **"Soil Puddle Characterization for Mechanized Transplanting of Rice in Vertisols"** which were suggested by the external examiner and the advisory committee in the oral examination held on 10.12.2004. The final copies of the thesis duly bound and corrected were submitted on 11.12.2004.

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ABSTRACT

Garlic (*Allium sativum* L.) has been used as a food, a condiment and medicinal purposes for over many centuries. The combination of allin and allinase present within the mesophyl cells of garlic cloves produces allicin and other thiosulphonates, which are responsible for typical garlic flavour. Garlic processing involves unit operations such as curing, grading, storage, bulb breaking, clove separation, peeling, dehydration, product development and packaging. The separation and peeling of garlic cloves requires special care and skill due to its typical physical characteristics and presence of essential volatile oils in the epidermal cells. Looking in to the increasing demand of garlic and its products in domestic and export market, the present investigation was taken to study on the post harvest processing of garlic.

The average initial moisture content and bulk density were observed to be 198.5 kg water per kg of dry matter and 332.2 kg/m^3, respectively. Sphericity of garlic clove was ranged from 0.38 - 0.48. Survey study on the existing methods of garlic processing revealed that most of the farm practices are performed with traditional methods. The garlic bulb breaker was found to be used for separation of cloves for seed purpose or further processing. It was found to work satisfactorily with clove separation efficiency of 93%. The existing garlic peeler was observed unsatisfactory as there was crushing/ bruising of cloves. The 30 min heating at 70 ^{o}C in cabinet tray dryer was found to be the best among chemical treatment, hydrothermal and thermal treatments as minimum time (12.10 min) for peeling of garlic cloves was required.

Preliminary trials on clove peeling were conducted to optimise the process parameters on the basis of maximum peeling recovery and peeling efficiency with minimum damage of cloves. The optimized attributes *viz.* diameter of peeling chamber (130 mm), air jet pressure (10 kg/cm^2) and air jet position (60 mm) were taken to develop batch type clove peeler for peeling of 500 g garlic cloves with the assistance of compressed air. The extensive trails for performance evaluation of developed garlic clove peeler were conducted and found that developed peeler worked satisfactory with peeled recovery of 94.8 % and peeling efficiency of 97.6 % for 70 seconds peeling time.

The drying time required to reach the safe moisture level (7.5 % db)for unpeeled and peeled garlic cloves was found to be 50 and 40 h in open Sun and 33 and 28.5 h

in solar cabinet drying, respectively. The convective drying behaviour of dehydrated garlic cloves at drying air temperature of 40, 50 and 60°C and velocities of 1.0, 1.5 and 2.0 m/s were studied. The drying time ranged from 570 to 1200 min and entire drying was taken place in falling rate period. Moisture diffusivity was found to vary in the range of 3.03- 8.64×10^{-10} m²/s. The garlic slices were also dehydrated in fluidized bed dryer at air temperature of 40, 50 and 60°C with air velocity of 3.0 m/s. The drying time for garlic slices was found to be 306, 274 and 180 min. Freeze dryer required 48 h for garlic slice drying to the safe moisture content (7.8 %) at freezing temperature - 40°C.

The L value and flavour strength of fresh garlic was recorded to be 72.64 and 0.66, respectively. The L value and flavour strength was observed to be 52.32 & 0.17, 58.72 & 0.19, 64.79 & 0.30, 66.42 & 0.27 and 68.23 & 0.41 for the garlic samples dehydrated in open sun, solar, convective, fluidized bed and freeze drying method, respectively. The water activity of garlic cloves and slices dehydrated in different drying methods varied between 0.25 and 0.29. For garlic paste, the flavour strength was found to be 0.65, 0.49, 0.46, 0.45 and 0.44 at interval of 0, 30, 60, 90 and 120 days, respectively. The colour, flavour and overall acceptability of the garlic paste, dehydrated cloves and powder was found to be satisfactory up to the storage period of 90, 120 and 90 days, respectively. Technology packages for production of garlic paste, flakes and powder was developed. The developed Process Technology was observed to be techno-economic feasible. The cost of production of garlic paste and powder was worked out to be Rs 38.15 and 141.16 per kg, respectively.

CHAPTER-I

INTRODUCTION

India is known as the home of spices and boasts of a long history of trading with the ancient civilizations of India, Egypt, Mesopotamia, Rome and China. Today, Indian spices are the most sought-after globally, given their exquisite aroma, texture and taste. India is rightly the spice bowl of the world. India has the largest domestic market for spices in the world. Garlic (Allium sativum) is an important bulbous perennial plant grown and used throughout India primarily as a spice or condiment. The botanical name of garlic is Allium sativum, and it belongs to the Allium genus of the Alliaceae family. Throughout the history of garlic, the herb has been popular across the world for various reasons. It is also known by a lot of names, some of which are alho, knoblauch, toi, bawang, poondoo, ail, aglio, katiem, thum, knoflook, lasun, chesnok, gratiem, sarmisak, and lehsun; garlic is also referred to as Bronx vanilla and Italian perfume. Garlic bulb is composed of several small segments or cloves surrounded by a thin white or pinkish tough papery skin. The bulbs are valued for their flavour and command an extensive commercial importance because of their wide application in food and pharmaceutical preparations. Garlic bulbs are used either sliced or ground to flavour curries, soups, tomato sauces, stews, and salad dressings in southern European and Asian cuisines.

China is the highest producer of garlic, followed by India, South Korea, USA, Egypt and Spain. In India, garlic is being grown on about 2 lakh hectares area with total production of about 10.6 lakh tons. Madhya Pradesh, Uttar Pradesh, Gujarat, Rajasthan, Himachal Pradesh, Punjab, Orissa and Maharashtra are the main states where garlic is grown commercially. Madhya Pradesh, Rajasthan and Gujarat, produce 40% of country's garlic. Karnataka, Bihar, Tamil Nadu, Punjab, Haryana and Andhra Pradesh also produce sizeable quantity of garlic in cooler regions of the states. Garlic in plains is grown from October-March (Indian horticulture database–2011). The genotypes mostly grown in plains are tropical type, which have very low productivity. Himachal Pradesh, Uttaranchal and Jammu and Kashmir grow long day type garlic from September to June. Yield potential of this type of garlic per unit area is high but due to limited area, total production is less. India till recently was cultivating only smaller-clove types of garlic which found market in Bangladesh, Sri

Lanka and the Middle East. However, now bigger-clove types of garlic of 40-60 mm diameter containing 10 to 15 cloves are getting preference all over the world and India has also started cultivating the same.

The chemical composition of garlic includes enzymes, vitamin Bs, flavonoids and certain minerals. Overall, it is a good source of protein; minerals like calcium, copper, iron, manganese, phosphorus, potassium and selenium; as well as vitamins such as vitamin A, vitamin B1 (thiamine), vitamin B2 (riboflavin), vitamin B6 and vitamin C. Garlic also contains good levels of antioxidants. Garlic contains many powerful sulfur-containing compounds - one particular type of such substances is thiosulfinates, of which allicin is probably the most well-known and best studied.

Garlic has been used as a food, a condiment, and for medicinal purposes for over many centuries. Garlic is mainly used as aromatic spices and pickles as it has digestive, carminative and anti-rheumatic properties. Garlic finds medicinal usage especially in treating intestinal diseases. Garlic is being used in ayurvedic formulation since a long for curing lungs, healing intestinal ulcer and checking muscular pain and giddiness. It is recognized to have remarkable preventive and curative abilities. The consumption of garlic reduces the risk of cardiovascular disease and cancer (Arnault et al., 2005). The protective mechanism of the garlic against cancer and cardiovascular diseases has been well established. Garlic is considered the main source of allicin which appears to be effective against E. coli, Staphylococcus aureus, Clostridium perfringens and Salmonella spp. (Yu and Wu, 1989). It has been proved that garlic has different applications as antimicrobial, antitumor, antithrombotic, hypolipidaemic, antiarthritic and hypoglycemic agent (Abdel-Salam et al., 2008; Bali et al., 2011). The garlic bulbs are valued for their flavor and have wide applications in food industries (Mishra et al., 2011; Puranik et al., 2011and Dewi et al., 2011).

Many operations are being performed between cultivation of garlic in the field and reaching the quality bulbs to the consumers. Post harvest losses in garlic are to the tune of 10-20%. Post-harvest management practices i.e. curing, drying, sorting and grading, packaging, storage and transportation should be followed properly to avoid the losses occurring before reaching to the consumer. Curing of garlic is the process by which the outer leaf sheaths and neck tissues of the bulb are dried. Curing is essential to obtain maximum storage life and have minimal decay. Curing is an

additional process that helps in development of skin colour. Outer cloves of bulbs are easily damaged during mechanical harvest and these damaged areas discolour and decay during storage. Therefore, separation of damaged or infected garlic bulbs prior to storage is the basic requirement of proper storage of high quality garlic for the fresh market. Garlic storage requires good airflow to prevent moisture accumulation, low relative humidity (60-70%). Garlic can be kept in good condition for 1-2 months at ambient temperatures (20-30°C) under low relative humidity (60-70%). High humidity and improper curing can cause mould growth and rooting. Storage without tops in nylon-netted bags gives better performance at Nasik and Karnal. The same has been recommended for minimizing the decay and losses during storage of garlic bulbs (http://www. nhrdf.com/html).

The separation of garlic cloves requires special care and skill due to its typical physical characteristics and presence of essential volatile oils in the epidermal cells. Conventionally, separation of garlic cloves is performed manually by rubbing the bulb between palms, against jute bags or by beating with wooden stick. A prototype for garlic clove separation has been reported to be developed (Mudgal, 2009; Mudgal and Sahay, 2009). Typical shape of cloves makes the peeling to be very tedious and time-consuming operation. The peeling of garlic cloves requires special care and skill because of the typical physical characteristics and presence of essential volatile oils in the epidermal cells imparting garlic its characteristic aroma. Conventionally, peeling is performed by rubbing the cloves against jute bags on a hard surface.

Keeping the product fresh is the best way to maintain its nutritional value, but most storage techniques require low temperatures, which are difficult to maintain throughout the distribution chain. On the other hand, drying is a suitable alternative for post harvest management especially in countries like India where low temperature distribution and handling facilities are poorly established. 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. Fluidized bed drying technique is a very convenient method of drying for heat sensitive food materials as it prevents them from overheating. Drying of vegetables in a fluidized bed dryer produces dry vegetable pieces of excellent quality in a much shorter time than in continuous belt dryers which are generally used for drying (Bobic et al. 2002).

Freeze dehydration typically results in biological products with a porous crust and of superior rehydration capability whereas hot air drying results in a dense product with an impermeable crust. The nutrients are lost during different processing conditions while freeze drying in which the nutrient loss are minimized has the advantage over other methods and also it retains the flavour, sensory quality, wholesomeness and original structure of product. This is an improved method of preparing stable water-soluble product from aroma and flavour bearing materials (Kylink, 1990).

The dehydration with little induced degradation of nutritional properties while having higher retention of flavour/essential oils can be the valued technology for garlic preservation. Availability of raw garlic at cheaper prices during lean season offers a very attractive opportunity for entrepreneur in the field of garlic processing. The garlic paste, dehydrated flakes and powder being a good value added product can fetch good foreign exchange by exporting quality garlic products. Growth in popularity of convenient foods has stimulated increasing demand for high quality dehydrated garlic products like garlic flakes, garlic oil and garlic powder. Considering the increasing demand for garlic products in domestic and export market, an attempt has been made for a study on post harvest processing of garlic with the following specific objectives:

1. To study the existing mechanical methods of garlic processing for further improvement,
2. To study the process parameters of garlic processing,
3. To optimize the process parameters of garlic processing,
4. To develop a technology package for garlic processing and
5. To evaluate techno-economic feasibility.

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 literature related to the present study has been reviewed, organized and presented here under.

2.1 General

Garlic is a perennial herb and is grown in tropical and subtropical plains for its pungent flavour, as condiment. India is known as the home of spices and boasts of a long history of trading with the ancient civilisations of India, Egypt, Mesopotamia, Rome and China. India is rightly the spice bowl of the world. India has the largest domestic market for spices in the world. The uses of spices range from use in pharmaceuticals, medicines, beverages, food processing for flavouring and preserving food items and personal hygiene products, including cosmetics. India is the world's largest producer and exporter of spices of the 109 varieties listed by the International Organization for Standardization (ISO), as the country produces and exports about 75 varieties of spices.

Madhya Pradesh, Rajasthan and Gujarat, produce 40% of country's garlic. China is the highest producer of garlic, followed by India, South Korea, USA, Egypt and Spain. Garlic is being grown on about 2 lakh hectares area with total production of about 10.6 lakh tons. Madhya Pradesh, Uttar Pradesh, Gujarat, Rajasthan, Himachal Pradesh, Punjab, Orissa and Maharashtra are the main states where garlic is grown commercially. Karnataka, Bihar, Tamil Nadu, Punjab, Haryana and Andhra Pradesh also produce sizeable quantity of garlic in cooler regions of the states. Garlic in plains is grown from October-March (Indian horticulture database, 2011).

2.1.1 Garlic and its importance

The botanical name of garlic is *Allium sativum* L., and it belongs to the *Allium* genus of the family *Alliaceae*. Garlic is also referred to as Bronx vanilla and Italian perfume. India is the second largest producer of garlic. The chemical composition of garlic includes enzymes, vitamin Bs, flavonoids and certain minerals. Overall, it is a

good source of protein; minerals like calcium, copper, iron, manganese, phosphorus, potassium and selenium; as well as vitamins such as vitamin A, vitamin B_1 (thiamine), vitamin B_2 (riboflavin), vitamin B_6 and vitamin C. Garlic also contains good levels of antioxidants. Garlic contains crude protein (17.2%), dimethyl sulphite (1779 μg/kg) and essential oil contents (0.14%). In addition, K (21,378.84 mg/kg), P (6009.37 mg/kg), Mg (1056.15 mg/kg), Na (532.78 ppm) and Ca (363.61 ppm) were also reported as the major minerals in garlic (Haydar *et al.*, 2005). An important bit of garlic information is that it contains many powerful sulfur-containing compounds - some sources state that there are more than 80 of such compounds in garlic. One particular type of such substances is thiosulfinates, of which allicin is probably the most well-known and best studied.

Garlic is mainly used as aromatic spices and pickles as it has digestive, carminative and anti-rheumatic properties. Garlic finds medicinal usage especially in treating intestinal diseases. Garlic is being used in *ayurvedic* formulation since a long for curing lungs, healing intestinal ulcer and checking muscular pain and giddiness. It is recognized to have remarkable preventive and curative abilities. The consumption of garlic reduces the risk of cardiovascular disease and cancer (Arnault *et al.*, 2005). The protective mechanism of the garlic against cancer and cardiovascular diseases has been well established. Garlic is considered the main source of allicin which appears to be effective against *E. coli*, *Staphylococcus aureus*, *Clostridium perfringens* and *Salmonella* spp. (Yu and Wu, 1989).

2.1.2 Interesting garlic facts

History has documented a lot of interesting garlic facts and details about the uses of the herb. Some of this garlic information is as stated below:

- Mythology also indicates garlic was used as an evil repellent, especially of the vampire like Count Dracula!
- The ancient Indian healing system of *Ayurveda* describes garlic as a medicinal plant which was used to warm the body, improve blood circulation, and cure digestive problems, etc.
- The history of garlic involved a lot of the ancient cultures. For example, garlic was worshipped by ancient Egyptians, although they were also said to have had a strong

aversion towards cooking and eating it.

- Recorded history of garlic in Korea indicates that the traditional six-clove black garlic was given to women to bless them with supernatural powers and immortality!
- According to Cassell's Dictionary of Superstitions, there is an Islamic myth that considers that after Satan vanished from the Garden of Eden, garlic grew from his left footprint and onion grew from his right.
- Taoists believe that garlic enhances the vital life energy or chi energy.
- Hippocrates, who is regarded by many as being the father of modern medicine, was said to have used garlic to treat cancerous tumors.
- During the years of plague in Europe, many people ate garlic daily in an attempt to protect themselves from the deadly illness.
- The world wars also played a part in the history of garlic. During the war years, when the supply of sulphur drugs ran out, the British used garlic for effectively treating wounds. It was also used to deal with many other diseases.
- Garlic is a strong antiseptic-Louis Pasteur verified its antiseptic properties in 1858. Garlic is also a strong antibacterial, antifungal, antiviral and anti-parasitic herb - throughout the history of garlic, the herb has been used for such purposes and these properties have been verified in countless studies.
- Because of its pungent odour, garlic is sometimes called the 'stinking rose'.

2.1.3 Food value of garlic

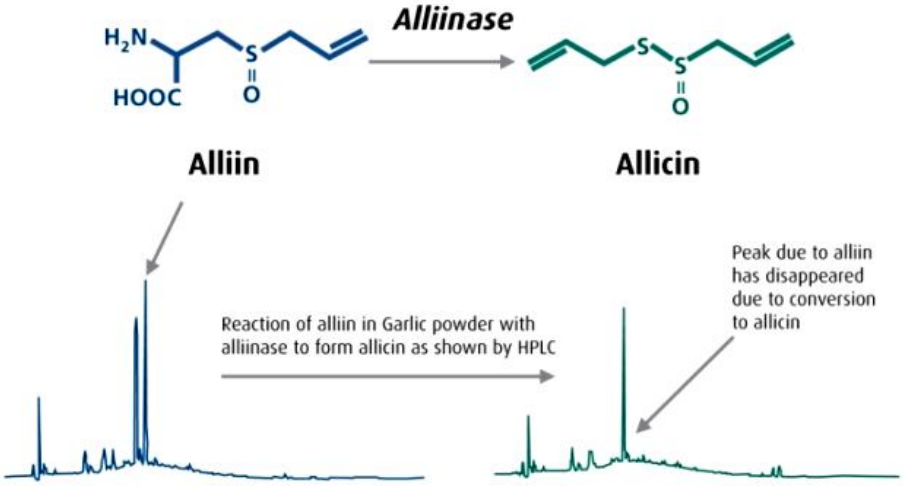
Nutritive value of garlic varies from variety to variety. Nutritional composition of freshly peeled garlic is given in Table 2.1. Bureau of Indian standard specification for fresh garlic recommend that the bulb of garlic should have the shape and natural colour characteristics of the variety. The bulb should be mature, well cured, compact, well filled and fairly plump. Dried and cured garlic bulbs should have the characteristic pungent taste and flavour. They should be free from mould, off-taste, decay, diseases, insect attack *etc*. If damaged bulbs are present, the proportion of such damaged bubs should not exceed 5 per cent (IS: 5452-1969).

Table 2.1 Nutritional values of garlic/100 g of garlic

Components	Garlic
Moisture	64.2 g
Energy	145 kcal
Carbohydrates	25.46 g
Dietary fiber	2.1 g
Fat	0.5 g
Protein	6.39 g
Thiamine (Vit.B_1)	0.2 mg
Riboflavin (Vit. B_2)	0.11 mg
Niacin (Vit. B_3)	0.7 mg
Vitamin C	31.2 mg
Calcium	181 mg
Iron	1.7 mg
Magnesium	25 mg
Phosphorus	153 mg
Potassium	401 mg
Sodium	17 mg
Zinc	1.16 mg
Manganese	1.672 mg
Selenium	14.2 µg

(Source: http://en.wikipedia.org)

Garlic flavour



Garlic flavor is due to the formation of organosulfur compounds when the main odorless precursor alliin is converted by the enzyme alliinase to allicin and other flavor compounds. This occurs at low rates unless the garlic cloves are crushed or damaged. Alliin content decreases during storage of garlic bulbs, but the effect of time, storage temperatures and atmospheres has not yet been well documented. If garlic has been kept cold it soon begins to sprout when brought to room temperature.

2.1.4 Post-harvest management of garlic

Many operations are being performed between cultivation of garlic in the field and reaching the quality bulbs to the consumers. Post-harvest management practices i.e. curing, drying, sorting and grading, packaging, storage and transportation are the main unit operations being used as post harvest activities.

2.1.4.1 Curing and drying of bulbs

Garlic is harvested when the bulbs are well mature. Normally it is harvested when 50 per cent of the plants have shown neck fall. Garlic is harvested by uprooting the entire plant by taking firm hold of the dry leaves. After garlic is harvested it needs to be cured naturally in the field. Curing of garlic, as shown in Plate 2.1, is the process by which the outer leaf sheaths and neck tissues of the bulb are dried.

Plate 2.1 Curing of garlic bulbs

Curing is essential to obtain maximum storage life and have minimal decay. Normally it takes about a week for drying of foliage and outer scales. Drying is necessary to remove excess moisture from the outer skin and neck. The roots are removed completely. Remove any chunks of dirt from the roots, being careful not to bruise the garlic. The curing in field till foliage turns yellow should be done. Artificial curing can be done by passing hot air at 27-35ºC through the curing room. It takes about 48 hours for complete curing process if humidity is between 60- 75%.

2.1.4.2 Grading and sorting of bulbs

Outer cloves of bulbs are easily damaged during mechanical harvest and these damaged areas discolour and decay during storage. Therefore, separation of damaged or infected garlic bulbs prior to storage is the basic requirement of proper storage of high quality garlic The drudgery of human labour involved for grading of garlic has been reduced by hand operated as well as motorized grader (Plate 2.2). There have been 5 and 20 times increased efficiency achieved in grading operations by these machines. The precision of grading achieved by graders is 98% as against 50% in hand grading. The thick-necked, splitted, injured and diseased bulbs with hollow cloves are sorted out. Size grading is done after sorting. It is very much necessary for getting better price and to minimize losses and decay. Cleaning consists of trimming the leaves and roots and removing the dirty outer wrappers. During trimming the tops one should be careful that skins protecting the individual cloves should not to be damaged and enough stem on hard necks be left to make cracking easy. Many machines are used for cleaning and grading of spices, such as vibratory sieve separators; gravity separators; colour and size graders and de-stoners. Vibratory sieve separators for cleaning and sorting and centrifugal aspirator for removing light husk are commonly used in garlic processing industries.

Plate 2.2 Different garlic bulb grader

2.1.4.3 Packaging of garlic bulbs

Packaging is an integral part of the preservation and can also minimize many of the potential spoilage changes, imparting improved keeping quality and increased shelf life to the packaged food. In India, the garlic bulbs are packed in open mesh jute bags for domestic use. These are packed in bags of 90 and 40 kg capacity each in Andhra Pradesh, Karnataka and other garlic growing states respectively. As per the garlic grading and packing rules, 18 and 25 kg packing are done in perforated 10 ply corrugated cardboard boxes for export. Nylon-netted bags used for packing and further storage cause minimum losses in storage (Plate 2.3) (http://www.nhrdf.com/ html).

Plate 2.3 Packaging practices of garlic bulbs

2.1.4.4 Storage of garlic bulb

Post harvest losses in garlic are to the tune of 10-20%. Storage of these commodities is a function of genotypes, cultural practices adopted and the environment under which the bulbs are stored. Storage in bottom and side ventilated structures help in reducing storages losses from 20 to 10% in garlic.

Plate 2.4 Storage structures for garlic

Low cost model of 5 to 10 tons capacity and high cost model of 25 to 50 tons capacity with bottom and side ventilation very well designed and tested (Plate 2.4) have become popular among the farmers.

Top and bottom ventilated storage structure

This distinct type storage structure (25 to 50 tonnes capacity) is constructed with G.I. framework. The floor is ventilated and constructed with wooden bantams. The sidewalls are made of bamboo and plastered with clay and cow dung paste. The ventilation is provided at lower portion of western sidewall and upper portion of the eastern sidewall. The lower portion ventilator of western sidewall has control flaps to regulate the entry hot winds in summer and high humid wind sin rainy season. Plastered sidewalls control humidity in rainy days, while maintains inside temperature during summer. The storage losses in this structure are 28-30% for four months of storage. This structure may better suit to humid and high temperature areas.

Storage facilities require adequate ventilation in order to help extend shelf life and maintain produce quality. Ventilation in storage structures is improved if air inlets are located at the bottom of the store, while air outlets are at the top. A simple, light-proof exhaust vent is a pressure-relief flap. Garlic storage requires good airflow is required to prevent moisture accumulation, low relative humidity (60-70%). Cloves sprout quickly at 4.4ºC and therefore prolonged storage in this temperature range should be avoided. Garlic stored at humidity higher than 70% at any temperature develop mould and start rotting. Cold storage of garlic is possible at 0-4°C and 60-70% relative humidity. The storage loss of 12.5% is recorded in garlic stored at 1-5ºC and 75% relative humidity as compared to 42.4% losses in ambient temperature (http://www. nhrdf.com/html).

2.2 Physical Characteristics

Important physical characteristics of garlic which influence their suitability for dehydration include bulb weight, diameter, height, neck diameter, colour and shape. Wide variation in these characteristics has been reported between variety and even within the same variety (Kalra *et al.,* 1987).These differences have been attributed primarily to the differences in varieties. Agro-climatic conditions, cultural practices, maturity, method of planning and storage conditions (Kalra *et al.,* 1987).

2.3 Separation and Peeling Garlic Clove

The separation and peeling of garlic cloves requires special care and skill due to its typical physical characteristics and presence of essential volatile oils in the epidermal cells.

2.3.1 Garlic clove separation

The separation of cloves from garlic bulb can achieved by the striking the bulbs or by rubbing on hard surface. During the separation of the clove most of the energy observed on detaching the clove from the root, inner stem and husk lining. The principal of threshing process in classical rasp bar and toothed threshing unit was used as basic tool for designing and development of garlic clove separator (Kanafojski and Karwowski, 1976). Bharti and Jain (1986) developed garlic breaking cum peeling machine and reported 26 per cent peeling efficiency. Jain *et al.* (1998) developed hand operated garlic bulb breaker and about 9-10 per cent clove were reported in the form of clump. Conventionally separation of garlic cloves is performed manually by rubbing the bulb between palms or against jute bag or by beating with wooden stick. Traditional methods are very laborious and time consuming (Mudgal *et al.*, 1998). Jain *et al.* (1998) developed power operated machine for garlic clove separation and reported 50 per cent breaking efficiency. Sahay (2000) worked on development of mechanical mechanism for clove separation and reported 95-98 per cent separation efficiency with a intake capacity of 700 kg/h.

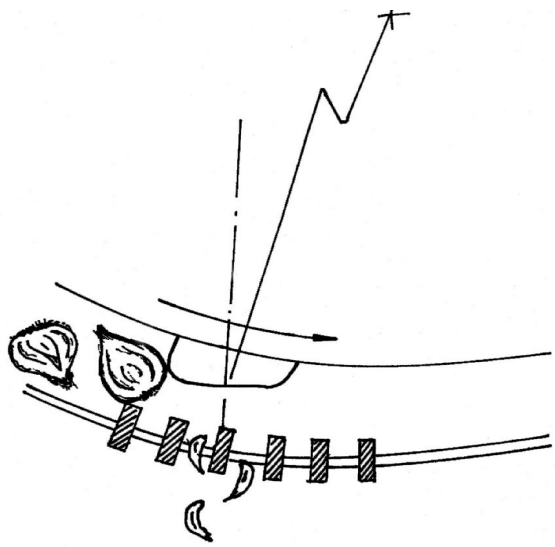


Fig. 2.1 Cloves separation

2.3.2 Garlic peeling

Peeling of cloves is the unit operation through which papery outer skin is removed to facilitate further processing. The peeling of garlic cloves requires special care and skill, due to the typical physical characteristics and presence of essential

volatile oils in the epidermal cells imparting garlic its characteristic aroma. The natural compound of alliicin as found in garlic loses its beneficial properties within hours because it begins to react with garlic's other components as soon as the clove is crushed. Conventionally, peeling is performed by rubbing the cloves against jute bags on a hard surface. This method is very laborious and unhygienic. Typical size and shape of cloves makes the peeling to be very tedious and time-consuming operation. The abrasion gadgets developed earlier were found infeasible as the cloves were crushed. The garlic clove peeling machine was tried to develop at Post Harvest Technology Scheme, College of Technology and Engineering, Udaipur. The developed machine has many problems in its basic concepts of abrasion. The skins of peeled cloves adhered to the lining material and impart smoothness to the abrasive surfaces in due course of time, thereby adversely affect the performance (Mudgal *et al*., 1998). Mandot and Vyas (1987) attempted to develop garlic peeling unit based on reciprocating mechanism. The device consisted of two rubber padded inclined wooden plates. The cloves slide between the two plates due to action of gravity.

Lye treatment, flame peeling and mechanical peeling are the common peeling methods used in modern processing industry. Lye peeling and flame peeling methods are harsh and are not suitable for garlic and onion like products (Wang, 1993, Srivastava *et al.*, 1997 and Naik *et al.*, 2007). Naik *et al.* (2007) developed a batch type multiplier onion peeling machine (50-60kg/h) suitable for farm-level operation. Interaction studies were carried out between the speeds of rotation versus peeling efficiency. Damage percentage, unpeeled samples and operational parameters were optimized. The peeling efficiency was about 92 % with unpeeled and damaged percentages of 6 and 2 %, respectively.

Srivastava *et al*. (1997) designed and tested a medium-size onion peeling machine. The machine consists four scoring blades assisted by compressed air jets to slit the outer layers of the onion skin. Tests were made to determine peeling performance as affected by onion size, onion shape, compressed-air pressure, and onion feeding rate. The performance of the machine was characterized by peeling efficiency, peeling losses, and throughput rate. Feeding chain speed and air pressure significantly affected the machine’s performance.

Adnan (2010) reported to construct an onion skin peeling machine based on the concept of friction on the surface of the onion and topped with the use of water to

helps soften the surface of the onions before peeling process. Srivastava *et al.* (1997) reported to design and developed an onion peeling machine suitable for farm-level operation. The peeling machine (750 kg/h) was found to work satisfactorily with 89%peeling efficiency and 17% peeling losses.

Guldas (2003) found that hand peeling of kiwi fruit has some disadvantages such as difficulty during peeling, increase of loss in weight and nutritional value. Weight (fruit tissue) loss in hand peeling was higher than alkali peeling.

Fujita (2000) patented a method as well as device for skin peeling of garlic using forced agitation of reserve water and garlic cloves. The garlic disintegrating and peeling apparatus patented by Sakata (2002) has a hollow main body provided with a rotary disk having a plurality of vertical rods to form a step on the upper faces, a cylindrical peeling vessel having an uneven face and granular grinding face on the inner side face and a driving means to drive the rotary disk.

Nagarajan (2006) developed a garlic-peeling machine with a capacity 200 kg/h. The pressurized air pushed the garlic entering the peeling chamber from the big blower to the rotating blade. Since the blades were rotating, they hit the garlic towards the serrated wall of the peeling chamber and there it gets peeled.

Manjunatha *et al.* (2012) fabricated and evaluated an experimental garlic peeler. Prototype garlic peeler was evaluated with the optimized crop-machine parameters. The peeling efficiency, yield of peeled garlic and unpeeled garlic, damage and peel separation were 86.6, 86.2, 4.7, 9.15 and 96 %, respectively with a machine throughput capacity of 27 kg/h and the energy requirement of 1.15 kw-h. Operation cost of the peeler was determined on the basis of fixed and variable cost and found to be INR 22.9/h.

2.4 Garlic Drying

Drying as a means of preserving the safety and quality of foods has been at the fore front 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*. 2007). 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).

Singh and Gupta (1998) analyzed bulbs of fifteen varieties of garlic for quality parameters for dehydration purposes. Studies revealed that garlic collection G-189 recorded significantly highest TSS (43.42%), dry matter (44.24%), drying ratio (2.26:1), pyruvic acid content (28.35 micro mole/g) and re-hydration ratio (1:5.06). Garlic collection G-189 was found to be the most suitable for dehydration purpose on account of better recovery and colour of dehydrated product. 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).

2.4.1 Solar drying

Nyati *et al.* (1988) studied on dehydration of garlic peeled and unpeeled cloves with solar and sun drying. The rate of drying was faster in direct type of solar dryer with minimum shrinkage but colour was of poor quality. Jain and Singh (1992) conducted experiment on dehydration of peeled garlic cloves using open, indirect and indirect solar dryer. Direct type of solar dryer found suitable for dehydration of garlic with quality parameters. Ambrose and Sreenarayanan (1998) dehydrated fresh garlic clove using sun, solar mechanical and fluidized bed dryer. It was found that drying at 60ºC for 4 hrs in a fluidized dryer give good quality powder. Bisnoi *et al*. (2008) carried out study to evaluate the dehydration characteristics of garlic treated by different methods. The effect of pre-treatments viz., control, sample blanched in hot water at a temperature of 80-85ºC for duration of 5 minutes and sample treated with 0.5 per cent sodium meta-bisulphite for a duration of 20 minutes and dehydration

methods *viz.*, open sun drying, solar cabinet drying, electric tray drying, microwave drying was studied. The results of the study showed that the product quality of blanched sample for 55ºC and sodium meta-bisulphite treated sample for 65ºC in electric tray dryer was best as compared to rest of the samples.

2.4.2 Mechanical drying

Madamba *et al.* (1996) investigated the thin-layer drying characteristics of garlic slices (2– 4 mm) for a temperature range of 50–90ºC, 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 4.2×10^{-10} m^2/s over the temperature range investigated, with energy of activation as 989 kJ/kg. Four mathematical models 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 (1997) 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 70ºC) 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 70ºC 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 in a convective hot-air dryer. The dehydration characteristics of garlic slices were examined at air temperatures of 40, 50 and 60ºC and sample thicknesses of 3 and 5 mm. During the dehydration experiments, air velocity was held stable at 0·8 m/s. 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 $\mu m^2 s^{-1}$. 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 45ºC 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.

Dash and Bhatnagar (1991) developed multistage de-hydration process for garlic. Garlic cloves were dehydrated at 60, 70, 80 and 90°C up to 20, 30, 40 and 50% cut-off moisture levels; the remaining moisture up to 5% level for storage was removed at a control temperature of 6qoc. A 2-stage and 3-stage dehydration process was recommended for garlic dehydration, as it resulted in a saving of about 16 and 17% of the total drying time respectively, compared with single stage drying at 60ºC.

2.4.3 Fluidized bed drying process

Denloy *et al*. (1978) determined heat transfer coefficients from an immersed cylindrical heater to a fluidized bed from the quiescent bed condition to beyond the conditions for maximum bed to surface heat transfer. The experiments were carried out with a range of particles of different thermal and physical properties. Air, argon, carbon dioxide and Freon were used as the fluidizing gases. Correlations were

developed to describe the two components of the overall coefficient: (i) the particle convective component and (ii) the inter phase gas convective component.

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 to 100ºC at velocities of 0.71 m/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 (55-65ºC), slice thickness (3-6 mm), air velocity (6-9 m/s) and concentration of sodium metabisulphite as pre-treatment (0.1-0.3 per cent) 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 60ºC for drying 3 mm garlic slices pre-treated with 0.1% sodium meta bisulphate solution at an air velocity of 9 m/s was found to be significant factors affecting drying.

2.4.4 Freeze drying

There are three stages in the freeze drying process *viz*., freezing, primary drying, and secondary drying. Freeze-drying causes less damage to the substance than other dehydration methods using higher temperatures. Freeze-drying does not usually cause shrinkage or toughening of the material being dried. In addition, flavours, smells and nutritional content generally remain unchanged, making the process popular for preserving food. However, water is not the only chemical capable of sublimation, and the loss of other volatile compounds such as acetic acid (vinegar) and alcohols can yield undesirable results. Freeze-drying is a relatively expensive process. The equipment is about three times as expensive as the equipment used for other separation processes, and the high energy demands lead to high energy costs.

Furthermore, freeze-drying also has a long process time, because the addition

of too much heat to the material can cause melting or structural deformations. The low operating temperature of the process leads to minimal damage of these heat-sensitive products. Experimental shelf freeze dryer without samples on shelves is capable of cooling at a rate of approximately 0.5ºC/minute and can heat at approximately 1.3ºC/minute. The cooling ramp rate will be slower as the temperature approaches -40ºC. Garlic clove were sliced 4 mm slice and kept for freeze drying at -40ºC with 0.01 mbar vacuum pressure. In this step, it is important to cool the material below its triple point, the lowest temperature at which the solid and liquid phases of the material can coexist. This ensures that sublimation rather than melting will occur in the following steps. Larger crystals are easier to freeze-dry. To produce larger crystals, the product should be frozen slowly or can be cycled up and down in temperature. This cycling process is called annealing. However, in the case of food, or objects with formerly-living cells, large ice crystals will break the cell walls, resulting in the destruction of more cells, which can result in increasingly poor texture and nutritive content. In this case, the freezing is done rapidly, in order to lower the material to below its eutectic point quickly, thus avoiding the formation of ice crystals.

During the primary drying phase, the pressure is lowered (to the range of a few mill bars), and enough heat is supplied to the material for the water to sublime. In this phase, pressure is controlled through the application of partial vacuum. The vacuum speeds sublimation, making it useful as a deliberate drying process. The secondary drying phase aims to remove unfrozen water molecules, since the ice was removed in the primary drying phase. This part of the freeze-drying process is governed by the material's adsorption isotherms. In this phase, the temperature is raised higher than in the primary drying phase, and can even be above 0 ºC, to break any physico-chemical interactions that have formed between the water molecules and the frozen material. Thermal processing causes degradation of nutritional content and give a cooked flavor to food, while non-thermal processes have emerged as a sound approach for preservation of foods with little induced degradation of nutritional and sensory properties (Barbosa-Canovas and Swanson, 1994). Out of various dehydration techniques used freeze dehydration typically results in biological products with a porous crust and of superior rehydration capability whereas hot air drying results in a dense product with an impermeable crust. The nutrients are lost during different processing conditions while freeze drying in which the nutrient loss

are minimized has the advantage over other methods and also it retains the flavor, sensory quality, wholesomeness and original structure of product.

Lee *et al.* (1989) studied drying rate of garlic during freeze-drying by measuring garlic moisture content as a function of drying time. Drying conditions were vacuum chamber pressure of 0.1-1.0 torr, -10ºC back face temperature, and 0ºC surface temperature of the product. Drying rate of 0.5- 1.25 cm thick samples in vacuum chamber pressure of 0.4 torr was faster than that at 0.1 or 0.2 torr of vacuum chamber.

2.4.5 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 4.3×10^{-10} m^2/s was obtained for diffusion times ranging from 18.5 to 28.5 m^2/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.

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 50-60ºC and four at the elevated temperatures up to 200ºC. 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 m^2. The agreement between calculated and experimental average moisture content was satisfactory.

Palipane *et al.* (1994) used two criterions for adequacy of the model fit in the thin-layer drying behaviour of macadamia in-shell nuts and kernels for a temperature range of 26–56ºC and 21–48ºC, 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 90ºC using tray load of 4, 8 and 12 kg/m^2. Sorption isotherms were obtained at 30, 40, 50, 60 and 70ºC 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.

Lin *et al.* (2007) experimented on dehydration of yam slices using far-infrared radiation (FIR)-assisted freeze drying and found that drying time and rehydration ratio were significantly affected by drying temperature and thickness. The coefficients of determination (R^2) of surface response models of drying time, rehydration ratio and total colour difference were found to be over 0.95. The optimum drying processing could be established at 50 mm distance from FIR plate and by controlling the drying temperature in the range of 34–37ºC and slices thickness of 7–8 mm for freeze drying with FIR heating of products.

Sablani *et al.* (2007) studied the freeze-drying of garlic at different shelf temperatures (-5, -15, and -25ºC). The moisture content of dried garlic and its temperatures at different locations within the sample were measured as a function of drying time. The apparent porosity of fresh garlic was 0.25 (±0.03), while 72 h dried samples showed about 0.700. Apparent porosity increased with the decrease of moisture content showing varied curvatures depending on the shelf temperatures. The estimated shrinkage-expansion coefficients were 0.313, 0.429 and 0.409 for shelf temperatures -5, -15 and -25ºC respectively. Samples dried at -5ºC showed significantly lower open pore porosity compared with the samples dried at -15 and -25ºC respectively.

2.5 Quality Evaluation

Consumption of food is directly related to the quality. Important attributes identified with food are colour and flavour. 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 per cent. 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 chlorarnine-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.

Jebson and Youzhang (1994) developed a new procedure to produce high-quality dried garlic powder in which most of the characteristic flavours are preserved. A two-part drying technique was tested, in which garlic samples were dried either as large pieces at high temperature, or as thin slices and at lower temp. in order to preserve the enzyme allinase. It was demonstrated by sensory panel trials that the new garlic powder was preferred to a commercially available garlic powder. Effects of sample size, air temperature, humidity, and flow rate on drying rate were studied in an air tunnel drier. At smaller sample sizes, the drying rate increased significantly. Higher air temperature and increasing air flow rates also significantly improved drying rates, but the effect of air humidity was more complex. Changing the drying air humidity did not have much direct effect on drying rates but had a negative effect (*i.e*. decreased the drying rates) if the drying temperature was high.

Ramalakshmi *et al.* (1997) studied the effects of storage on the quality of stabilized garlic powder. Garlic bulbs of var. Jamnagar were used to prepare dehydrated garlic powder, encapsulated garlic oil and stabilized garlic powder (encapsulated garlic oil-dehydrated garlic powder (23:77) with 2% tri-calcium phosphate as anti-caking agent). Products were analysed together with the raw material for moisture, volatile oil and colour (% whiteness). Stabilized garlic powder was packed in a polyester/ AI foil / polyethylene laminate, stored at ambient (27ºC,

65% RH) and accelerated (40ºC, 30-40% RH) conditions for up to 6 months and analysed at monthly intervals. It lost 6.20 and 9.85% of diallyl disulphide under ambient and accelerated conditions, respectively. Loss of colour value was 7.7 and 8.0% under ambient and accelerated conditions, respectively.

Pezzutti and Crapsite (1997) investigated the effects of drying temperature and water content on the sorption equilibrium, drying kinetics and aroma losses of garlic with a view to improving dryer simulation and design. Models for predicting the behaviour of these characteristics under different drying conditions were also developed. Adsorption and de-sorption isotherms were determined at 25, 45 and 65ºC and correlated with a four parameter equation. Temperature had a negligible effect on adsorption and there was some hysteresis effect, which decreased with temperature. Effective coefficient for water diffusion and energies of activation were determined from drying curves at varying conditions. The diffusion equation applied in two limit zones and a model which considered internal and external resistances to mass transfer had to be used. Effective diffusivity increased with temperature from 1.54 to 3:45 x 10^{-10} m^2/s in the wet zone and from 0.34 to 0.58 x 10-10 m^2/s in the dry zone. Activation energies were 27.8 and 16.9 kJ/mol for the wet and dry zones, respectively. Pyruvic acid content was used as a measure of garlic flavor and aroma, and changes during drying were modelled as a first order reaction. Enzymatic pyruvic acid decreased faster than total pyruvic acid at high temperature. It is concluded that this model can be used to predict quality deterioration during the drying of garlic under different conditions.

Ahmed *et al*. (2001) prepared garlic paste with a TSS and pH value of 33% and 4.1 respectively, from fresh garlic by addition of 10% NaC1 (w/w) and citric acid. Appearance of green pigment was noticed in the product during preparation. Paste was thermally processed at 70, 80 or 90ºC respectively for 15 minutes. Greening of paste decreased with increase in temperature. The product was found to be shelf stable at 25ºC for a period of at least 6 months.

Madamba (1997) examined the application of response surface methodology (RSM) to drying of garlic, for production of high quality flakes. Garlic was air dried in a forced-air pilot plant under various conditions of relative humidity, temperature, air flow rate, slice thickness, loading density and initial moisture content, in a 27-runBox and Behnken design. Independent variables used in optimization were

temperature, slice thickness, air speed and relative humidity. Quality factors evaluated were color (CIE L value and/or optical index), final moisture content and re-hydration ratio. Second order polynomial models for color parameters were significant while the rehydration ratio and final moisture content were not. By superimposing the contour plots, an optimum drying temperature of 70ºC was obtained, for 2 mm thick garlic slices, with predicted values close to experimental values.

Ambrose and Sreenarayanan (1998) conducted studies to standardise the conditions for production of garlic powder and to evaluate its storage stability and other quality attributes. Fresh garlic cloves were dehydrated by 4 methods: sun drying; solar cabinet drying; mechanical drying; and fluidized bed drying. The dried material was powdered and evaluated for drying characteristics and sensory qualities. Drying at 60ºC for 4 h in a fluidized bed drier gave good quality powder with moisture content below 3%. Shelf life of the powder after three months of storage under ambient conditions was found to be better when aluminium laminate or brown glass bottles were used as packaging. The product prepared from garlic powder was highly acceptable as determined by sensory evaluation.

Hong *et al.* (1999) studied the effects of processing treatments (chopping, boiling and microwave treatment) on the composition and change of flavour compounds in garlic cloves and garlic extracts. 17 major flavour compounds were found in intact garlic cloves. The production and loss of volatiles was high when garlic was chopped. Microwave treatment was more effective in preventing the loss of non-protein sulphur compounds. The results suggest that microwave processing garlic is an effective method for preserving its functional compounds.

2.6 Value Added Garlic Products

The Bureau of Indian Standards specification IS: 5452 prescribes the requirements (Table 2.2) and methods of sampling and test for dehydrated garlic. According to this standard the dehydrated garlic should be of white to pale cream colour, and when in the powder form, it should be free flowing and free from agglomerates. It should have a marked and pungent odour, characteristic of the variety used, free from off-flavours, foreign odour, rancidity and mustiness. After steeping in water for 4 hr, it should reconstitute to form a product approximately akin to raw, freshly peeled, sliced or minced garlic of good quality.

Table 2.2 BIS specifications for dehydrated garlic

Compositions	Requirement (per cent by weight)
Moisture, max.	5.0
Total ash, max	6.5
Acid insoluble ash	0.5
Extraneous matter	3.0

The International Standard, ISO 5560 (1981) of the International Organization for standardization, applies to dehydrated garlic in its various commercial forms. Total proportion of extraneous matter shall not exceed 5 per cent (m/m) and specific requirements includes: moisture content, less than 8% (m/m) for garlic slices, rings, flakes, pieces, and less than 6% for garlic powder and grits; total ash, less than 5.5% on dry basis; and acid insoluble ash, less than 0.5% on dry basis. Sampling, testing, re-hydration, sensory evaluation, packaging (to protect from light and moisture), storage and transport (in dry, cool conditions) are also covered. The standard however does not specify microbiological requirements. The ADOGA (American Dehydrated Onion and Garlic Association) has also laid down specifications for different dehydrated garlic products. The dehydrated products are classified as sliced, large chopped, chopped, minced, ground, granulated, agglomerated coarse, agglomerated-fine and powdered products, on the basis of size.

Yamada Seiyaku Co. Ltd. (1973) patented the process of preparing garlic powder free of alliin decomposition. The method involves steeping ground garlic, lactose and potato starch in an aqueous solution of vinegar or acetic acid and sodium chloride.

Pruthi *et al*. (1974) patented improvements in or relating to the manufacture of garlic powder. In this process garlic bulbs are separated into the papery husk, roots and cloves using an aspirator. The cloves are dried and the meaty portion, which is separated from the husk in a pulper, is ground in a hammer mill to produce dehydrated garlic powder.

Koch *et al.* (1989) described a simple, fast and reliable procedure for determining allicin in garlic bulbs and in its preparations by static headspace gas chromatography. After enzymatic release, the allicin was quantitatively reduced by

Cleland's reagent (1, 4-dimercapto-2,3-butanediol) without prior isolation. The allylmercaptan formed was sampled from the headspace above the aqueous dispersion and injected into the gas chromatograph. Quantification is achieved either by addition of a suitable internal standard, e.g. 1-pentylmercaptan, or by using a homogenized garlic powder as external standard.

2.7 Techno Economic Feasibility of the Developed Technology

A feasibility study is an evaluation and analysis of the potential of the proposed project which is based on extensive investigation and research to support the process of decision making. Feasibility studies aim to objectively and rationally uncover the strengths and weaknesses of an existing business or proposed venture, opportunities and threats present in the environment, the resources required to carry through, and ultimately the prospects for success. In its simplest terms, the two criteria to judge feasibility are cost required and value to be attained. As such, a well-designed feasibility study should provide a historical background of the business or project, description of the product or service, accounting statements, details of the operations and management, marketing research and policies, financial data, legal requirements and tax obligations. Generally, feasibility studies precede technical development and project implementation. A feasibility study evaluates the project's potential for success; therefore, the perceived objectivity is an important factor in the credibility to be placed on the study by potential investors and lending institutions. It must therefore be conducted with an objective, unbiased approach to provide information upon which decisions can be based.

Economic of mustard processing unit has been studied by Sriniwas *et al.* (1989) and they concluded that the estimated cost of processing per quintal of mustard seed for oil mill , expeller and kohlu were Rs. 8.17, Rs. 9.24 and Rs. 11.22, respectively. Schiavone *et al.* (2013) described in detail about the design, construction, and performance evaluation of a natural-convection, solar dryer. They observed that the operating capacity of the dryer was 9.5 kg of fresh mango slices per 36 h, lowering the moisture content from 84.5% (w.b.) to 10.3% (w.b.) under a continuous mode of operation. The collector efficiency, pick-up efficiency, and system efficiency were 26.7%, 20.4%, and 25.9% respectively.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the experimental set-up, methods and techniques adopted to study the physical properties of garlic bulb and clove, existing mechanical methods of garlic clove separation and clove peeling, design and development of low cost and highly efficient clove peeler, drying kinetics of garlic clove, slices, product development, quality evaluation and techno-economics feasibility of garlic processing.

3.1 Physical Properties of Garlic Bulb and Clove

The physical properties of garlic bulb and clove are important in the design of processing equipments. The physical characteristics of garlic bulb and cloves *viz.*, moisture content (%), bulk density (kg/m^3), bulb diameter (mm), length and thickness of garlic clove (mm), number of cloves per garlic bulb were evaluated. Weight of garlic bulb and cloves (g) was determined by electronic balance and bulb diameter (mm), length and thickness of clove (mm), were measured using Vernier calipers. The true density of both garlic bulb and cloves (kg/m^3) was found out by toluene displacement method (Mazza, 1983). Moisture content was determined by oven drying method (Ranganna, 2000).

3.2 Existing Garlic Processing Trends

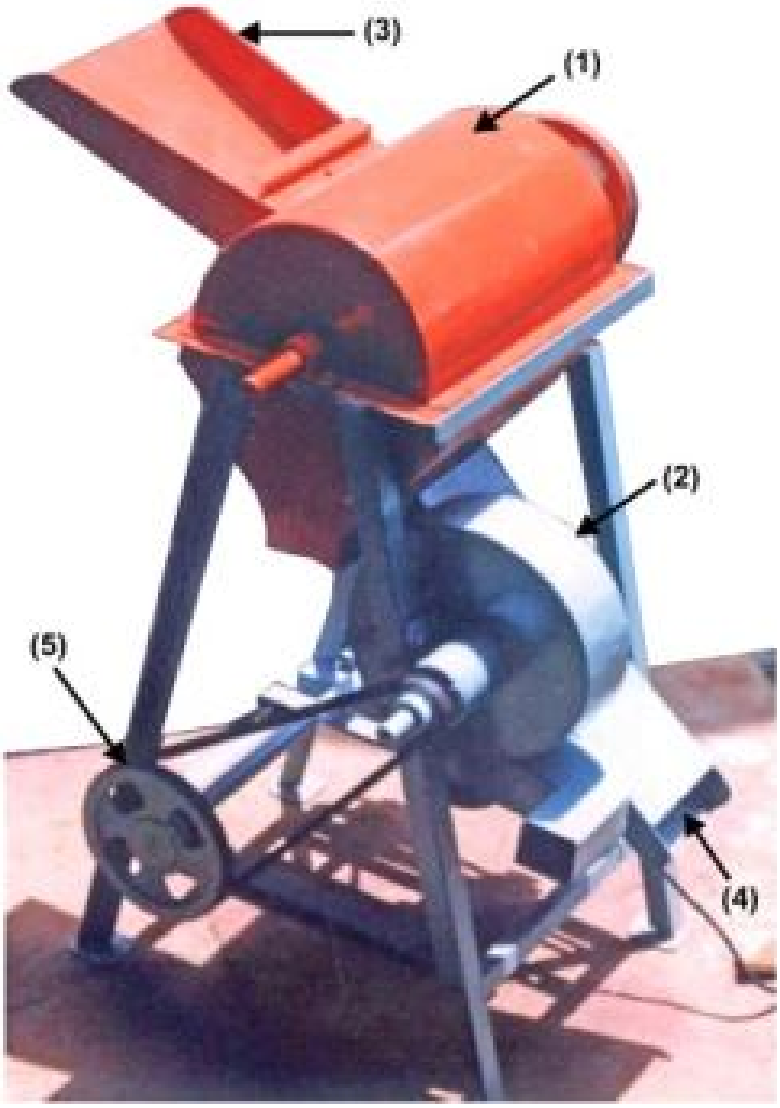
A survey was conducted to study and analyze the existing methods of garlic processing in the major garlic producing districts *viz.*, Baran, Kota, Pratapgarh Chittorgarh, Bundi and Jhalawar of Rajasthan state using the survey questionnaire developed for this purpose as given in Appendix A-1. The information in the questionnaire was collected from 60 respondents *viz.*, farmers, entrepreneurs and processor of the production catchment.

3.3 Existing Garlic Processing Prototypes

The survey conducted in the production catchment revealed that most of the on farm processing is done manually or by conventional methods whereas graders, bulb breakers, flakers, solar as well as mechanical dryers and grinder are in process of adoption in small scale processing industries. It was observed that open mesh jute, plastic and nylon-netted bags of 20-40 kg capacity are used for packaging of garlic bulbs for further marketing and storage.

3.3.1 Garlic bulb breaker

Bulb breaker or clove separator performs the separation of single cloves to facilitate further processing *i.e.* flaking, slicing, peeling, dehydration and development of various products. The garlic bulb breaker or clove separator, identified prototype, was developed by Mudgal (2009) is shown in Plate 3.1.



(1)Beater (2) Blower (3) Hopper (4) Outlet (5) Belt & Pulley

Plate 3.1 Existing garlic bulb breaker

It consists of cylindrical beater, grated concave, aspirator, power transmission unit and feed hopper. The cylindrical beater (Plate 3.2) was made of mild steel (MS) sheet and flat. Six numbers of concave shape MS blades were provided between batons in opposite direction so that the garlic bulbs could be spread evenly over the entire length of cylindrical beaters. The top of batons and concave blades were covered with rubber strip padding material to reduce the injuries to the clove. The grated concave was made up of MS bar of 6 mm diameter. The spacing between concave bars varied from 15-20 mm as the thickness of garlic cloves varies from 12-18 mm. A single phase, 0.75 kW, 1440 rpm AC motor was required as prime mover for operation of cylindrical beater and aspirator.

Plate 3.2 Cylindrical beater

Healthy garlic bulbs of 30 mm or more in size of *Yamuna Safed* variety were selected and a test sample of 5 kg was used for experimental trials. The garlic bulb breaker was operated at recommended process parameters *viz.* beater and blower speed of 340 and 135 rpm, respectively. Jain *et al.* (1998**)** recommended the above process parameters on the basis of minimal crushing and maximal separation of cloves. The performance of the existing garlic clove separator was evaluated by conducting experimental trials (10 replications). The material collected from the trough was separated into different fractions *i.e.* single cloves (Plate 3.3), clamp of cloves, crushed cloves, husk, stem and roots and weighed and recorded for each experiment and mean values of three replications were used for further calculations to determine the bulb breaking and clove separation efficiency. The bulb breaking and separation time was recorded for each trial. The weight of husk and roots was observed to be 110 g/kg of garlic bulbs. The bulb breaking and single clove separation efficiency were calculated as

$$\eta_{BB} = \frac{W_s + W_c}{W - W_w} \times 100$$

...3.1

$$\eta_{CS} = \frac{W_s}{W - W_w} \times 100$$

…3.2

Where,

η_{BB} = Bulb breaking efficiency, (%);

η_{CS} = Single clove separation efficiency, (%);

W_S = Weight of single separated cloves, g;

W_C =Weight of clumps of separated cloves, g;

W_W = Weight of husk and roots, g; and

W = Weight of garlic bulbs, g

Plate 3.3 Garlic bulb and separated single cloves

3.3.2 Existing clove peeling

Clove peeling is the unit operation through which papery outer skin is removed to facilitate for further processing. The typical shape of clove makes the peeling to be very tedious and time consuming unit operation. Peeling of garlic cloves required a special care and skill because of its typical physical characteristics and presence of essential volatile oils in an epidermal cells imparting garlic characteristics aroma. Conventionally peeling is performed by rubbing the cloves against jute bag on a hard surface. This method is laborious, unhygienic and time consuming. The china made rubber garlic peeler (Plate 3.4) makes it is easy to remove the skin of the garlic cloves without getting unpleasant smells on hands and being used in house hold kitchen.

Plate 3.4 Domestic rubber garlic peeler

The hand operated garlic clove peeler (Plate 3.5) consists of peeling cylinder with abrasive padding material of coir matting, outer cover with hopper, handle and frame structure. The cylinder was fixed on MS frame at 8 º

slope. The performance of the machine was evaluated with garlic cloves samples weighing 1000 g.

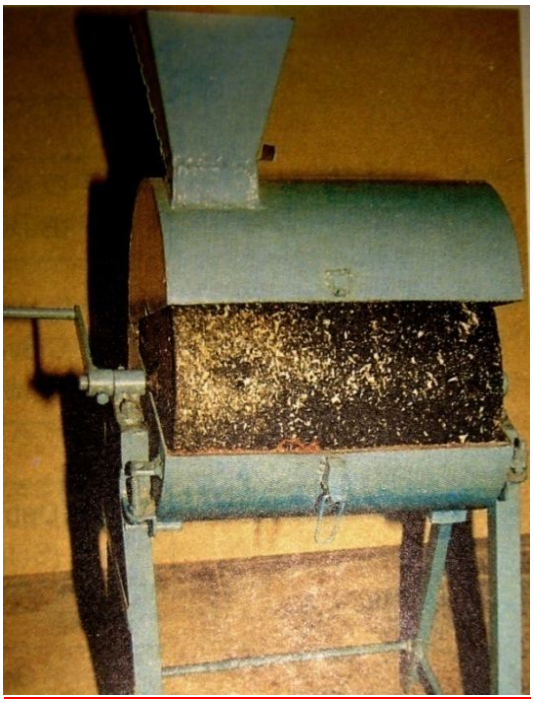


Plate 3.5 Hand operated garlic clove peeler

The graded garlic cloves were fed through the hopper and peeling cylinder was rotated manually at 50 rpm. The peeled, unpeeled and crushed garlic cloves with husk were collected at the discharge end. The performance was evaluated to determine the peeling efficiency and percentage recovery as per the following formula (Mudgal and Champawat , 2011):

$$PE = \frac{W_1}{W_1 + W_2 + W_3} \text{ x } 100 \qquad \text{....3.3}$$

$$PR = \frac{W_1}{W} \text{ x } 100 \qquad \text{....3.4}$$

Where,

PE = Peeling efficiency (%)

PR = Peeled clove recovery (%)

W_1= Weight of peeled cloves, g

W_2 = Weight of unpeeled cloves, g

W_3 = Weight of peeled but damaged cloves, g and

W = Weight of garlic cloves, g

3.4 Pre-Treatments Prior to Garlic Clove Peeling

The pre-treatments *viz.*, hydrothermal, thermal and chemical treatment were applied to the garlic cloves to facilitate the peeling operation. The hydrothermal pre-treatment was given by blanching the garlic cloves for 2, 6 and 10 minutes in boiling water. The surface water from blanched cloves was removed by gentle rubbing with muslin cloth prior to peeling. The garlic cloves were soaked in 0.1 per cent $NaHCO_3$ solution and kept at ambient temperature for 10 min. The solution decanted off using muslin cloth before peeling. The garlic cloves were treated with 2 per cent mustard oil and conditioned for 10 min at ambient temperature. The garlic cloves were heated in air dryer at three temperature levels (50, 60 and 70°C) for 10, 20 and 30 min. The manual peeling of all pre treated samples was carried out by ten labourers of different age group and gender. Time taken in peeling of 100 g sample by each worker was recorded and the average peeling time per kg of cloves was calculated.

3.5 Development of Clove Peeler

Considering the increasing demand for garlic products in domestic and export market, and losses occurring during abrasive and wet peeling as mentioned in review of literature, a garlic clove peeler was developed in which peeling of clove is performed with the assistance of compressed air.

3.5.1 Design considerations

The following criteria were considered in designing and developing of the peeler.

1. Easy to fabricate at local level.
2. Easy to operate by unskilled labour.
3. Capable of removing the outer skin (peel) from individual clove.
4. Minimum damage to the inner epidermis cells of the cloves.
5. Highly efficient,
6. Minimum processing cost.
7. Techno economically feasible.

3.5.2 Optimization of machine parameters

The height of peeling chamber was decided on basis of bouncing height of garlic cloves at the time of air jet pressure. The height of peeling chamber was kept 50 mm higher than the maximum bouncing height to safeguard the garlic clove carried

away along with the skin at husk outlet. The bouncing height of garlic clove was observed 350 mm so the cylinder height was kept 400 mm for the all observations. Bed depth was selected in such a way that all the material (garlic cloves) come in contact of swirling air and gets peeled. The bed depth of garlic cloves up to 60 mm produced the maximum peeling efficiency. Various combinations of process parameters *viz.*, diameter of peeling chamber, air jet pressure and air jet position as mentioned in Table-3.1 were taken into consideration. Preliminary trials on clove peeling were conducted for every possible combination of process parameters and data were recorded for all the 27 trials to optimize attributes on the basis of maximum peeling recovery and peeling efficiency with minimum damage of cloves.

Table 3.1: Parameter for preliminary trial

S. No.	Parameters	:	Attributes
1.	Peeling chamber diameter	:	100, 130 and 160 mm
2.	Air jet position	:	60, 80 and 100 mm
3.	Air pressure	:	5, 10 and 15 kg/cm^2

3.5.3 Software (Design expert) based optimization

Numerical multi response technique was carried out for optimization of process parameters such as peeling recovery and peeling efficiency. Design expert version 8.0.6 of STAT-EASE software (Stat ease Inc, Minneapolis, USA) was used for simultaneous optimization of the multiple responses. The constraints were set such that the selected variables (chamber diameter, pressure of air jet and jet position) would be optimum from economical point of view for the most important product attribute and close to the optimum for the others (Jain *et al.*, 2011). The main criteria for constraints optimization were maximum possible peeling recovery and peeling efficiency as most important economic attribute. The desired goals for each factor and response have been shown in Table 3.2. The process parameters for garlic clove peeling process were numerically optimized for desirability function having equal importance (+) to all the three process parameters and equal importance (+++++) to two responses. The goal setting begins at a random starting point and proceeds up the steepest slope on the response surface for a maximum value of peeling recovery and peeling efficiency.

Table 3.2: Range and responses of process parameters for optimization

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Impor tance
Chamber diameter, mm	In range	100	160	1	1	3
Air jet pressure, kg/cm^2	In range	5	15	1	1	3
Jet position, mm	In range	60	100	1	1	3
Peeling recovery, %	Maximum			1	1	3
Peeling efficiency, %	Maximum			1	1	3

3.5.4 Fabrication of garlic clove peeler

On the basis of findings of preliminary trials conducted, batch type garlic clove peeler (500 g capacity) consisting four main components *viz*. feed hopper, peeling chamber, air jet positions and husk discharge outlet was fabricated with optimized parameters (Plate 3.6).

Plate 3.6 Developed garlic clove peeler

The hopper was designed to accommodate a sample of 500 g garlic cloves. Provision of opening and closing of hopper was made by providing a movable check of MS plate at the bottom of the hopper, so that pressure inside the peeling chamber can be maintained during peeling operation. Considering the practical problem of availability of compressors, 10 kg/cm^2 air jet pressure was selected. Therefore, the peeling chamber of 130 mm diameter with air jet position at 60 mm height from the bottom was finalised at 10 kg/cm^2 air jet pressure for development of garlic clove peeler. The developed garlic peeler consists of 130

mm diameter, 400 mm long MS peeling chamber mounted on MS angle frame. The top portion of pressure chamber was connected with a 40 mm diameter reducer to separate thin husk from the peeled material. Galvanised iron pipe of 10 mm diameter was inserted and positioned at a height of 60 mm from the bottom of the peeling chamber to flow the air from the compressor. A hopper was provided at the upper portion of the peeling chamber for feeding separated garlic cloves. A circular mild steel plate was hinged at the bottom of the peeling chamber with a provision of clamping the bolt on the other side. Rubber ring gasket was provided under the chamber wall to prevent the air leakage.

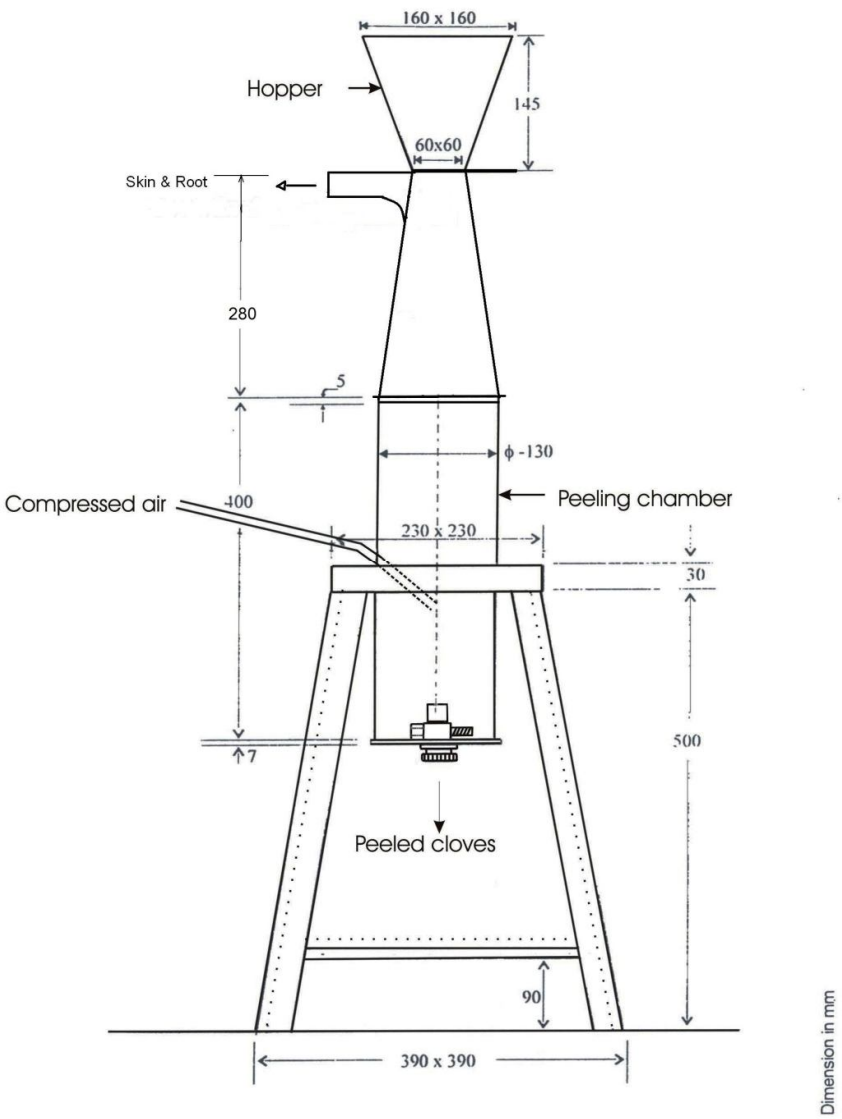


Fig. 3.1 Detailed drawing of developed garlic clove peeler

Healthy garlic bulbs of 30 mm or more in size of *Yamuna Safed* variety were selected for experimental trials. The bulb breaking and clove separation was performed by garlic bulb breaker. The graded healthy garlic cloves were selected for conducting extensive trials to evaluate the performance of developed garlic clove peeler (Fig. 3.1). The cloves were pre-treated as per optimised process of section 3.5.2 to facilitate the peeling operations. Test samples of 500 g treated garlic cloves were taken for conducting performance evaluation trials. The peeling operation was carried out by applying compressed air in the peeling chamber for peeling time of 40, 50, 60, 70, 80 and 90s. The observations *viz*. weights of peeled, unpeeled and peeled but damaged cloves were recorded to determine the peeling efficiency and percentage recovery for each peeling trial as per equation no. 3.3 and 3.4 mentioned earlier.

3.6 Drying of Garlic Cloves

Keeping the product fresh is the best way to maintain its nutritional value, but most storage techniques require low temperatures, which are difficult to maintain throughout the distribution chain. The drying of garlic can be performed easily by using solar dryer, cabinet or tray, fluidized bed, vacuum, freeze, microwave drying methods or combination of these. The choice of drying method depends on various factors such as the type of product, availability of dryer, cost of dehydration and final quality of desiccated product. Energy consumption and quality of dried products are other critical parameters in the selection of a drying process. 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.

3.6.1 Solar drying

The study on open sun drying was carried out with a sample size of 1000 g samples of peeled and unpeeled garlic cloves. Garlic cloves were placed in single layer on cement concrete floor on plastic sheets separately. The moisture content of samples was recorded at a regular interval of 60 min till the desired moisture (6-7% db) was attained according to IS: 5425.

The solar drying of peeled and unpeeled garlic cloves was carried out in the solar cabinet dryer (Plate 3.7) by placing the weighed samples of 1000 g on trays inside the solar cabinet dryer. The weight of trays along with samples was recorded at

the interval of 90 min till completion of drying (6-7%, db).

Plate 3.7 Solar cabinet dryer

3.6.2 Convective drying of garlic cloves and slices samples

Garlic cloves do not have moisture content low enough to be considered as shelf stable. It is therefore, needed it to be dried to obtain a shelf stable product *i.e.* stable with respect to prevention of microbial growth and enzymatic colour changes.

3.6.2.1 Experimental set-up

A laboratory model convective tray dryer (Plate 3.8) was used in all the dehydration experiments. The technical specifications of the convective tray dryer used in dehydration studies of garlic cloves and slices have been given in Appendix A-2. The dryer comprised of a drying chamber, heating unit, and a fan. The details of the dryer are described here under:

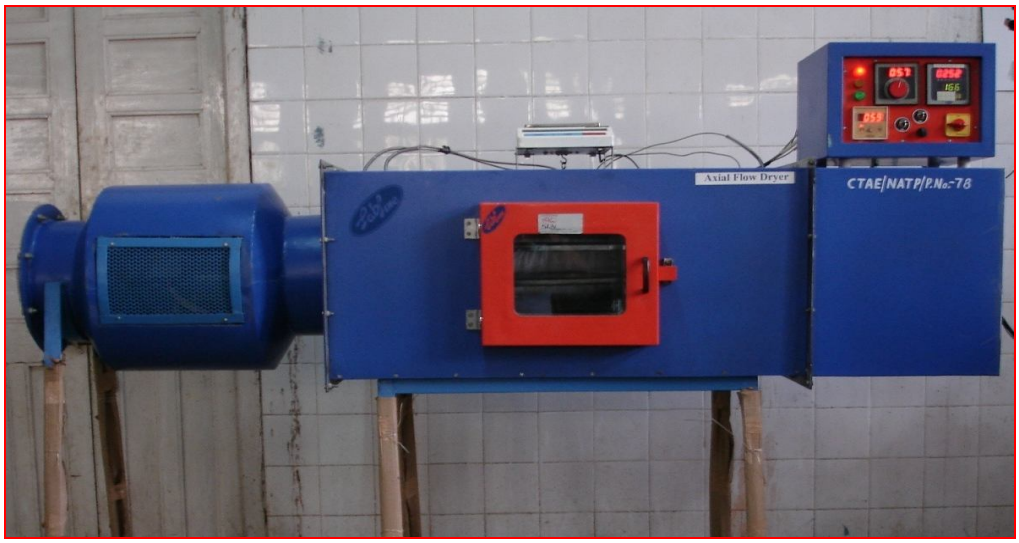


Plate 3.8 Experimental convective tray dryer

Drying chamber: It comprised of an insulated box with a single door opening at front. An adjustable speed axial flow fan for regulation of air velocity is 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 another opening of drying chamber. The sample trays having size of 340 x 270 mm made of stainless steel (SS) 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 enough space to spread the sample of 100 g garlic cloves and slices uniformly in a single layer. The garlic cloves and slices samples were uniformly spread over the tray thus resulted into loading density of 1.089 kg/m^2. A continuous weighing scale of 0.01 g least count is also fitted in the dryer. The sample trays were hanged with the weighing scale to continuously weigh the sample at a selected time interval without interrupting the system.

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 inside the dryer. The maximum temperature of the drying air which could be attained at highest air velocity of 1.5 m/s was 90°C (at no load).

Fan: An axial flow fan provided at inner left side of drying chamber sucks the filtered

atmospheric air inside and then through heating unit; forcing it to pass through the wet product placed in trays. This caused quick and effective drying of product. The fan was operated by a single phase, 50 Hz, 0.375 kW AC motor. The drying air velocity was changed with a fan speed regulator provided at the control panel.

The temperature of the drying chamber was pre-set through a temperature indicator cum controller provided on control panel of the dryer. It controlled and maintained the temperature of air by controlling the supply to the heating unit.

3.6.2.2 Convective drying experiments

Drying process is influenced by temperature, velocity, relative humidity, time of drying, loading density, *etc.* Among these parameters listed above, the drying air temperature (T) and air velocity (V) were selected to study drying characteristics of the garlic cloves and slices samples. The dehydration experiments were conducted in 3 replications at 40, 50 and 60ºC drying air temperatures and air velocity of 1.0, 1.5 and 2.0 m/s. Air velocity was measured with the help of a digital anemometer, while drying air temperature was adjusted by temperature indicator cum controlling unit and conditions were allowed to stabilize at desired temperature. The relative humidity of the ambient air was measured by a hygrometer. The garlic cloves and slices samples were spread over the drying trays in single layer and inserted into the dryer. The samples were weighed at 15 min interval for the first 1 h, at 30 min interval for the next 3 h at 60 min interval for the next 4 h and at 90 min interval for remaining period till attainment of final moisture content of 7%. These data are given in Appendices C1-C9. The data were used to analyze the moisture movement characteristics *viz* moisture ratio, drying rate, moisture diffusivity and to estimate activation energy.

3.6.3 Fluidized bed dryer

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.

Plate 3.9 Fluidized bed dryer

The laboratory model fluidized bed dryer (Make: Sherwood Scientific Ltd. Cambridge, England) consisting air distribution system and electrical controls was used for experimental trials (Plate 3.9). 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 fluidized bed dryer had the range of 0-200ºC; which regulated the operation of the heater to maintain the desired preset temperature of the drying air.

3.6.3.1 Fluidized bed drying of garlic slices

The terminal velocity of white garlic cloves is 9.89 m/s at 34.9 and 12.22 at 64.21 per cent 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 4 mm thickness were dried in fluidized bed dryer.

Cloves were separated, peeled by hand and sliced across its length to thickness of 4 mm. The dryer was run idle for about 15 min to achieve steady state before each

drying experiment. Drying of garlic slices were carried out at 40, 50 and 60°C at air velocity of 3.0 m/s. The sample weights (50g) were recorded after every 4 min interval for first 32 min., 8 min interval up to 72 min, 12 min. interval up to 132 and 16 min. interval up to 306 min till the moisture content reached to 6-7% (wb). The moisture content of garlic slices was determined by mass balance equations. The observed drying data *i.e.* weight loss of the sample with time for each drying run were analyzed to study the drying kinetics of garlic slices.

3.6.4 Drying characteristics

3.6.4.1 Moisture ratio

The moisture ratio (MR) at each moisture content level was determined by the following equation:

$$MR = \frac{M - M_{\infty}}{M_o - M_{\infty}} \qquad \ldots 3.5$$

Where,

MR : Moisture ratio

M : Moisture content at any time (d.b.), %

M_o : Initial moisture content (d.b.), %

M_{∞} : Equilibrium moisture content (d.b.), %

3.6.4.2 Moisture content during drying

Moisture content of garlic cloves and slices (db) during drying experiment was determined by the following equation:

$$\text{Percent moisture content (db)} = \frac{W_{\theta} - DM}{DM} \times 100 \qquad \ldots 3.6$$

Where,

W_{θ} : Mass of the sample at time θ, g

DM : Dry matter of the sample, g

3.6.4.3 Drying rate

The moisture content data recorded during experiments were analyzed to determine the moisture lost by sample of garlic cloves and slices in particular time interval. The drying rate of sample was calculated by following mass balance equation.

$$R = \frac{\text{WML (kg)}}{\text{Time interval (min) x DM (kg)}} \quad \ldots 3.7$$

Where,

R : Drying rate at time θ

WML : (Initial mass of sample – Mass of sample after time θ)

3.6.4.4 Dry matter

It is the matter left after complete removal of moisture from the product. The initial moisture content of untreated and various pre-treated samples were determined by oven drying method, as described earlier. The dry matter (per cent) and mass of dry matter in sample were calculated as follows:

$$\text{DM (per cent)} = 100.0 - \text{Initial moisture content (wb)} \quad \ldots 3.8$$

$$\text{Weight of DM} = \text{Initial mass of sample} \times \frac{DM\ (\%)}{100} \quad \ldots 3.9$$

3.6.4.5 Moisture diffusivity

In drying, diffusivity is used to indicate the rapidness of flow of moisture or moisture out of material. In falling rate period of drying, moisture is transferred mainly by molecular diffusion. Diffusivity is influenced by shrinkage, case hardening during drying, moisture content and temperature of material (Singh, 2001; Karim and Hawaldar, 2005).

The falling rate period in drying of biological materials is best described by simplified mathematical Fick's second law diffusion. (Crank, 1975) as given below.

$$\frac{\delta M}{\delta t} = D \frac{\delta^2 M}{\delta X^2} \quad \ldots 3.10$$

Where,

D = Diffusion coefficient, m^2/s

M = Moisture content, g water per g dry matter

X = characteristic dimension i.e. distance of surface from the centre line of product

T = Time elapsed during the drying, s

The garlic slices were considered as infinite slab as the thickness of the slices

i.e. 4 mm. The certain assumptions were considered in estimation of moisture diffusivity during drying process, which are given herewith as follows (Crank, 1975).

1. Moisture is initially uniformly distributed throughout the mass of a sample.
2. Mass transfer is symmetric with respect to the centre.
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. Moisture transfer is by diffusion only.
6. Diffusion coefficient is constant and shrinkage is negligible

Equation 3.5 can be written for infinite slab as follows.

$$MR = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left[\frac{-(2n+1)^2 \pi^2 D_{eff} t}{L^2} \right] \quad \text{... 3.11}$$

Where,

D_{eff} = Effective diffusivity in m^2/s

MR = Moisture ratio, dimensionless

M = Moisture content g water per g dry matter

M_0 = Initial moisture content, g H_2O/g dry matter

M_e = Equilibrium moisture content, g H_2O/g dry matter

L = Characteristic dimension i.e. thickness of slab

T = Time elapsed during the drying (s).

The equation can be simplified to the first term of the series only and results into following equation.

$$MR = \left(\frac{M - M_e}{M_0 - M_e} \right) = \frac{8}{\pi^2} \exp\left(-\pi^2 \frac{D_{eff} t}{L^2} \right) \quad \ldots 3.12$$

Taking logarithm and rearranging the equation (3.12)

$$\ln[MR] = \ln\left(\frac{M - M_e}{M_0 - M_e} \right) = \ln \frac{8}{\pi^2} - \left(\frac{\pi^2 D_{eff} t}{L^2} \right) \quad \ldots 3.13$$

$$\ln[MR] = -0.21 - \left(\frac{\pi^2 D_{eff} t}{L^2} \right) \quad \ldots 3.14$$

A general form of above eq^n could be written in semi-logarithmic form, as follows.

$$\ln(MR) = A - Bt \quad \ldots 3.15$$

Where, A is constant and B is slope

Experimental values of the effective diffusivity were typically calculated by plotting experimental drying data in terms of ln (*MR*) versus drying time "t". It gave a straight line and the slope of the line was used to measure the moisture diffusivity (Eq. 3.15). This approach was a simplified one and shrinkage of the material was not taken into consideration, i.e. thickness of the material L was assumed constant throughout the drying process.

$$\text{Slope} = \frac{\pi^2 \mathrm{D_{eff}}}{\mathrm{L}^2} \quad \ldots 3.16$$

3.6.7 Freeze drying

Freeze-drying causes less damage to the substance than other dehydration methods using higher temperatures. The flavor, smell and nutritional content generally remain unchanged, making the process popular for preserving food.

3.6.7.1 Freeze dryer

The shelf freeze dryer (Plate 3.10) having dimension 1100×850×650 mm equipped with a microprocessor based controller that permits temperature to be programmed using as many as eight different segments. A detailed specification of freeze dryer used for dehydrating the garlic slices has been elaborated in Appendix, A-3.

Garlic slices (4 mm thick) of 100g sample size were placed inside the chamber and set point was adjusted to -40°C freezing temperature. Drying of slices occurred under vacuum after completion of the freezing process. On the completion of drying process the vacuum was released by opening the air admittance valve. The chamber door was opened and dried slices were removed only after the chamber attained the atmospheric pressure. The time required for drying of garlic slices was taken as average value of three replications.

Plate 3.10 Freeze dryer

3.6.8 Optimization of drying methods

The drying methods *viz.*, open sun drying, solar drying, convective drying, fluidized bed drying and freeze drying were employed for the dehydration of garlic cloves and slices. The dehydrated garlic cloves and slices were subject to analysis for flavor strength, colour, water activity (a_w) and rehydration ratio. On the basis of above quality parameters the best suited drying method for production of acceptable quality of dehydration garlic cloves and slices was selected and recommended for dehydration by garlic processors.

3.7 Product Development and Shelf life Study

Availability of raw garlic at cheaper prices in many developing nations offers a very attractive opportunity for processors to produce the garlic products at competitive prices. The powder being a good value added product, transportation cost to far distances becomes negligible and good export earnings are possible. Dehydrated

garlic slices; garlic powder and garlic paste is used mainly as a condiment in various preparations, for flavoring in food industry and also serves as carminative and stimulant in many medical preparations.

3.7.1 Garlic paste

Garlic paste was prepared as per method described by Mudgal *et al.* (1998). The peeled garlic cloves were ground in domestic grinder. At the time of grinding, preservatives *viz.* sodium chloride (1.5%), citric acid (0.5%), sodium benzoate (0.05%) was added. Garlic paste (15 g) was packed in air tight plastic food grade bottles and polyethylene pouches and stored at room temperature for conducting storage studies. The shelf life studies were carried out by conducting quality evaluation of the garlic paste at regular interval of 30 days.

3.7.2 Dehydrated garlic cloves, slices and powder

The conventional technique of making garlic powder consists in manual removal of outer papery skin of the garlic bulb, separation and peeling of cloves by hand, dehydration in open Sun or shade, powdering them using hammer or attrition mill and finally packaging. This technique is tedious, laborious and time consuming and hence uneconomical.

The dehydrated garlic cloves, slices, powder was prepared by employing the optimized process parameters and developed technology/equipments. The samples weighing 50 g of dehydrated garlic slices and powder were packed in air tight plastic food grade bottles and polyethylene pouches and stored at ambient temperature for conducting storage studies. The shelf life studies were carried out by conducting quality evaluation of the dehydrated garlic slices and powder at regular interval of 30 days.

3.7.3 Shelf life study

The quality of garlic paste, dehydrated garlic flakes and powder was evaluated on the basis of color value, flavor strength, and organoleptic parameters. The color value, flavor strength, and organoleptic score of garlic paste, dehydrated garlic flakes and powder were evaluated by the panel of 10 judges at storage period of 0, 30, 60, 90 and 120 days (at time interval of 30 days) for shelf life studies.

3.8 Quality Analysis

As quality is an important parameter in food processing. The quality control is one of the very important in food processing to **e**nsure best quality finished products. The quality control should be exercised at every stage commencing from pre-processing to packing and storing, etc.

3.8.1 Color measurement

Colour is one of the most important qualities of acceptance for products, reflects sensation to the human eye. Colour is important to consumer as a means of identification, as a method of judging quality and for its basic aesthetic value. Dried products are usually darker in colour, but darker colour does not mean better quality. Too dark may imply that the product is over dried. The advantage is that this parameter can be visually determined for assessing dryness quality. The colorimeter used in the present investigation Hunter Lab Colorimeter (Model CFLX/DIFF, CFLX-45) is shown in Plate 3.11.

Plate 3.11 Hunter lab colorimeter

Plate 3.12 Colour scale representing relationship of colour index (L*, a*, b*)

The technical specification of Hunter Lab Colorimeter used in experimentation has been given in Appendix A-4. A cylindrical glass sample cup (63.5 mm in diameter x 40 mm height) was placed at the light port (31.75 mm diameter). The instrument was initially calibrated with a black as well as with standard white plate supplied with the equipment. The 3-dimensional scale L*, a* and b* were used in a Hunter Lab Colorimeter. The L* is the lightness coefficient, ranging from 0 (black) to 100 (white) on a vertical axis. The a* is redness (positive a* value) and greenness (negative a* value) on a horizontal axis. A second horizontal axis is b*, that represent yellow (positive b* value) or blue (negative b* value) colour (Plate 3.12). Hunter L-value, which denotes the degree of whiteness, was chosen to represent the colour value of sample.

3.8.2 Flavor strength

The biologically active organo-sulfur compounds gives a distinctive flavor and aroma in garlic. Flavor in garlic 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 garlic products were 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 titrated values of thiosulfate for the experiment and the blank were determined. A reagent blank was carried out under the same conditions. The difference in the values between the blank and the experimental corresponds to the chloramines-T consumed by the garlic oil.

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

$$\text{Flavor strength}(\%) = \frac{V \text{ x } N \text{ x } 100}{W \text{ x } F} \qquad \ldots 3.17$$

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).

3.8.3 Water activity (a_w)

Moisture plays an important role in the stability of fresh, frozen and dried foods. It acts as a solvent for chemical, microbiological and enzymatic reactions. Water activity (a_w) is a measure of the availability of water to participate in such reactions. Moisture in a food will exert a vapour pressure. The extent of this pressure will depend on the amount of moisture present, the temperature and the composition of the

food. Different food components will lower the water vapour pressure to different extents, with salts and sugars being more effective than starches or proteins. Thus two different foods with similar moisture contents may not necessarily have the same a_w. Water activity can be defined as the ratio of the vapour pressure exerted by the food to the saturated vapour pressure of water at the same temperature.

$$a_w = \frac{P_A}{P_{A_{sat}}} \qquad \text{... 3.18}$$

Where,

a_w = Water activity

P_A = Vapour pressure of water exerted by food.

P_{Asat}= Saturated vapour pressure of water at the same temperature

Water activity is a function of moisture content in the food and the temperature (Ratti and Mujumdar, 1996). Bound molecule of water in food can be defined by water activity (Barbosa-Cánovas and Vega-Mercado, 1996):

- Tightly bound water $a_w < 0.3$
- Moderately bound water $0.3 < a_w < 0.7$
- Loosely bound water $a_w > 0.7$
- Free water $a_w = 1.0$.

Most of bacteria do not grow at water activities below 0.91 and most molds cease to grow at water activities below 0.80 (Leung, 1986). By measuring water activity, it is possible to predict which micro-organisms will or will not be potential sources of spoilage. Lower water activity of a dried product implies better potential for storage.

A digital water activity meter was used in measuring water activity of the dehydrated samples shown in Plate 3.13. Water activity was determined using a hygrolab-3 water activity meter. The sample used was just enough (about 20-25 g) to cover the filling indicator of the sample cup. The filled sample cup was kept in contact with sensor probe of water activity meter and values of water activity were recorded.

Plate 3.13 Water activity meter

3.8.4 Organoleptic parameters

Sensory evaluation is important to assess the consumer's requirements. It is difficult to quantify the sensory characteristics of product 100 per cent by machine because it is a subjective factor. Sensory analysis provides marketers with an understanding of product quality, directions for product quality and profiles of competing products and evaluations of product reformulations from a consumer perspective. The sensory analysis of garlic products *viz*, garlic paste, garlic powder and dehydrated flakes were carried out by numerical sensory card (BIS-6273) as given in Appendix A-5 from excellent to poor.

The prepared garlic products *viz.* paste, powder and slices (flakes) were evaluated for its sensory characteristics such as colour, taste, appearance and overall acceptability and compared with sensory characteristics of dried product. The products were served for the evaluation to fifteen panelists at a time. The score sheet was provided with product and panelists were requested to mark the product according to their liking. The average scores of all the panelists were computed.

3.8.5 Rehydration characteristics

According to Ranganna (1986), there is no standard time for rehydration of fruits and vegetables. It varies from product to product. Rehydration time was therefore standardized through trial runs conducted for the purpose. A value of 1 hour was observed to be adequate as there was no weight gain beyond this point. The

rehydration ratio of dehydrated garlic flakes and slices product were determined by standard methods.

Two 250 ml glass beakers were used for rehydration of dehydrated garlic flakes and slices samples in water. Five gram dehydrated garlic flakes and slices samples were taken in each beaker and kept in a water bath at ambient temperature for one hour. Samples were withdrawn after 1 h and then sample surface was dried with filter paper and weighed to determine the moisture content. Various rehydration characteristics were evaluated using following relations:

$$\text{Rehydration ratio } (RR) = \frac{C}{D} \qquad \ldots 3.19$$

$$\text{Coefficient of rehydration } (CR) = \frac{C \times (100 - A)}{\left(D - \frac{BD}{100}\right) \times 100} \qquad \ldots 3.20$$

Where,

A = Moisture content of samples before dehydration, IMC, % (wb)

B = Moisture content of dehydrated sample, % (wb)

C = Drained weight of rehydrated sample, g

D = Test weight of dehydrated samples, g

3.9 Technology Package for Garlic Processing

Process technology for production of flakes and powder was optimized on the basis of finding of study conducted. Technology package for processing of the garlic products, *viz.* technology package for production of garlic paste; fakes and powder, were developed and recommended for on farm processing with quality assurance for augmenting prosperity of producers as well as processors.

3.9.1 Cost economics of the developed technology

It is pertinent to study the cost involved in production, since it enables to comprehend the intricate issues involved in processing. Cost of production is an important indicator of efficiency of the process. Therefore, the costs analysis was carried out to understand economic perspective of production of garlic paste, flakes and powder. The various cost components involved in establishment and running of processing unit has been taken into account to work out the production cost (Rs/kg) of garlic paste, flakes and powder. Generally, a processor can increase the profitability

either by increasing the production turnover by running the plant at full capacity or by reducing cost of production by efficiently utilization of machinery, technology and available resources.

3.9.2 Techno economic feasibility of developed technology

Generally, feasibility studies precede technical development and project implementation. A feasibility study is an evaluation and analysis of the potential of the developed technology based on efficiently utilization of equipment, utility and resources to support the process of decision making. The quality parameters in each step of production of garlic paste, flakes and powder is also an important factor to be considered for quality assurance and consumer satisfaction. In its simplest terms, the feasibility of the developed technology can be judged by the cost of production with quality assurance and the profit attained. Techno economic feasibility of garlic processing technology was carried out by considering the cost economics, efficiency of the equipments to provide information for establishment on farm processing units for production of garlic paste; fakes and powder with quality assurance for augmenting prosperity of producers.

CHAPTER IV

RESULTS AND DISCUSSION

The results of the investigations carried out on physical properties of garlic bulb and garlic clove, performance evaluation of exiting garlic bulb breaker and clove peeler, optimization of pre peeling treatments and process parameterfor clove peeling, performance evaluation of developed clove peeler, drying studies of garlic cloves and slices and quality analysis of developed products have been described in this chapter.

4.1 Physical Properties of Garlic Bulb and Clove

The results related to physical parameters of garlic *viz.* number of cloves/ bulb, weight of garlic bulb and clove (g); length of garlic clove (cm) and bulk density of clove (kg/m^3) have been presented in Table 4.1 and 4.2. The data depicted in Table 4.1 revealed that the number of cloves in a garlic bulb varied from 16-52. The weight of garlic bulbs and cloves were found to vary from 22.40 to 52.22 g and 0.8 g to 1.32 g, respectively. The present findings are in conformity with that of Bhatt *et al*. (1998) and Singh (1993).

Table 4.1 Physical parameters of garlic

Parameters	:	Range
Number of cloves/ bulb	:	16-52
Weight of garlic bulb (g)	:	22.40-52.22
Weight of garlic clove (g)	:	0.8 -1.32 g
Length of garlic clove (cm)	:	1.92-3.78
Bulk density of clove (kg/m^3)	:	332.2 kg/m^3

The diameter of garlic bulb of the variety in use was found to vary from 32 mm to 38 mm. The clove length ranged from 1.92 cm to 3.78 cm. The thickness of garlic clove ranged from 5.25 to 9.23 mm. The average thickness was recorded as 7.07 mm. Sphericity of garlic clove ranged from 0.38 - 0.48. The mean value of sphericity of garlic bulb was calculated as 0.42. Average bulk density was observed to be 332.2 kg/m^3 (Table 4.2). The present results are in conformity with findings of other researchers.

Table 4.2 Physical parameters of garlic bulb and cloves

S.	Garlic bulb	Garlic clove

No.	diameter (mm)	Length (mm)	Width (mm)	Thickness (mm)	Sphericity
1.	35.96	25.26	11.10	8.10	0.48
2.	36.52	36.21	14.15	9.23	0.43
3.	56.65	29.30	10.20	7.12	0.44
4.	43.68	34.52	12.32	7.14	0.40
5.	41.26	28.15	9.26	6.23	0.42
6.	39.50	33.24	12.28	5.25	0.41
7.	54.25	36.42	14.32	6.24	0.38
8.	48.75	32.14	10.28	7.30	0.43
Mean ± S.D	**44.57 ± 7.86**	**31.90 ± 4.01**	**11.74 ± 1.85**	**7.07 ± 1.22**	**0.42 ± 0.29**

4.2 Existing Garlic Processing Practices

The result of survey conducted regarding the existing methods of garlic processing in the production catchment area has been presented in Table 4.3. The curing and drying of bulbs is being performed in the field itself. It is very well clear from Table 4.3 that 95 per cent curing, drying and storage, 97 per cent grading, 91 per cent processing, 90 per cent clove separation, 99 per cent peeling, 95 per cent drying of cloves and 70 per cent processed product storage of garlic is done manually on farm by conventional methods whereas graders, bulb breakers, flakers, solar as well as mechanical dryers and grinder are in process of adoption in small scale processing industries. The survey conducted in the production catchment revealed that most of the on farm practices are performed with traditional methods. The most of the on farm practices *viz.* curing; drying and storage of bulbs were being performed with traditional methods, only few farmers have adopted the improved recommendations for curing, drying and storage of bulbs. The most of the processors were found to using well ventilated structures for storage of garlic bulbs. The grading of garlic bulbs is not popular in the area surveyed, only 2-3% graded bulbs were being marked in the *mandis*. It was observed that jute, plastic and nylon-netted bags 20-40 kg capacity is used for packaging of garlic bulbs for further storage and marketing. The separation of cloves for purpose of seed or further processing was being performed by the

available garlic bulb breaker. The peeling of cloves for the purpose of paste making or others was being done manually.

Table 4.3 Existing garlic processing practices

Respondents = 60

S. No.	Parameters	Response (%)	
1.	Curing, drying and storage of garlic bulbs	95 (Traditional methods)	5 (Improved methods)
2.	Grading of garlic bulbs	97 (Traditional methods)	3 (Improved methods)
3.	Processing garlic	91 (Consumed as raw)	9 (Processed)
4.	Garlic clove separation	80 (Manually)	20 (Garlic bulb breaker)
5.	Garlic clove peeling	99 (Manually)	1 (Peelers)
6.	Drying of cloves	95 (Solar drying)	5 (Mechanical drying)
7.	Product storage	70 (HDPE, LDPE polyethylene)	30 (Bottling and jar)

4.3 Existing Prototypes for Garlic Processing

The survey conducted in the production catchment revealed that most of the on farm practices are performed with traditional methods. The garlic bulb breaker was the only prototype reported in survey as being used for separation of cloves for purpose seed or further processing. Some attempts were also made for development of garlic clove peeler for the purpose of paste making or others. Therefore, the performance evaluation studies of garlic bulb breaker and clove peeler was performed.

4.3.1 Garlic bulb breaker

The weight of different separated fractions *i.e.* single cloves, clamp of cloves, crushed cloves, husk, stem and roots, during performance eveluation of existing garlic bulb breaker, for each experiment and their mean values are depicted in Table 4.4. The capacity of the existing garlic bulb breaker was found to vary between 720 and 780 kg/h. Clove separation efficiency of the same prototype was estimated in the range of 92.80- 93.37%. It has been observed that the existing garlic bulb breaker works with output capacity of 750 kg/h with 93 per cent clove separation efficiency and 0.5-2 per cent crushing losses as shown in Table 4.4.

Table 4.4 Performance evaluation of garlic bulb breaker

Speed of beater =340 rpm
Speed of blower =135 rpm
Thickness of padding material =15 mm
Padding material= Rubber strip
Weight of garlic bulbs=5.0 kg

S.	Separa-	Weight of separated fraction (g)*	Clove	Capacity

No.	tion time (s)	Single cloves	Clumps cloves	Crushed cloves	Cloves with husk	Husk & stem	separation efficiency (%)	(kg/h)
1.	24	4472	265	43	18	196	93.08	750
2.	25	4480	290	34	15	178	92.90	720
3.	23	4510	270	30	12	170	93.37	780
4.	24	4488	285	30	14	173	92.93	750
5.	25	4478	264	38	16	192	93.13	720
6.	24	4476	285	37	13	177	92.80	750

*Average of three replications

4.3.2 Existing clove peeler

The peeling efficiency was observed to range from 49.25-52.13 per cent. The maximum peeling efficiency of 52.13 per cent with a large amount of crushed cloves to 48.23 per cent was obsereved (Table 4.5). The average peeling efficiency of 50.79 per cent were recorded. The peeling time (min) was found in the range of 11 -12.5 min/1000g of garlic cloves. The average peling time was found as 11.6 min/1000g of garlic cloves. This poor performance indicates that machine was not technically viable for garlic processing. The peeling per cent was observed to be very low and there was crushing/ bruising of garlic cloves. The slippery problem in the prototype was also recorded. The crushed cloves adhered to the lining material, imparting smoothness to the abrasive surfaces in due course of time; thereby adversely affect the performance of the machine. The performance of the garlic peeling prototype was thus found unsatisfactory. Therefore, an improved garlic peeler was developed for garlic peeling operation. The results are in confirmity with that of previous researchers, support the present findings (Mudgal and Champawat, 2011).

Table 4.5 Peeling efficiency of existing garlic clove peeler

Angle of inclination: 8º Clearance: 10 mm

RPM: 100 Padding material: coir matting

Weight of sample=1000 g

S. No.	Wt of peeled garlic (g)	Wt of unpeeled garlic (g)	Peeling efficiency (%)	Peeling time (min)
1.	510	484.0	51.30	12.0
2.	490	504.8	49.25	11.5
3.	520	474.7	52.13	11.0
4.	505	489.4	50.78	11.0
5.	502	491.5	50.52	12.5

Mean	**505.40**	**488.88**	**50.79**	**11.6**

Initially machine works smoothly for 15 minutes thereafter peeling cylinder gets slipery and peeling of clove stoped automatically. Garlic cloves started crushing and machine was choked. Therefore, it was concluded that prototype for peeling of garlic cloves was not suitable.

4.4 Pre-treatments Prior to Garlic Clove Peeling

The results of different pretreatments *viz.* hydrothermal, chemical and thermal treatment given prior to peeling of cloves have been presented and discussed in this section. Untreated garlic cloves were taken as control sample. The time required for peeling of 100 g untreated cloves and weight of husk has been presented in Table 4.6. The time required for peeling of 100 g garlic cloves varied beetween 28.0 and 29.3 min with average peeling time of of 28.7 min. The average weight of peel husk was found to be 9.0 g per 100 g of cloves.

Table 4.6 Peeling of garlic clove without treatment (Control)

S. No.	Weight of peeled clove (g)	Weight of husk removed (g)	Peeling time (min)
1	91.20	8.40	28.30
2	88.30	10.0	29.50
3	89.80	9.60	28.00
4	90.20	8.23	28.60
5	90.10	8.78	29.20
Mean	**89.92**	**9.002**	**28.71**

4.4.1 Hydrothermal treatment

The 100 g garlic cloves were blanched for 2, 6 and 10 min in hot water and peeling time has been given in Table 4.7. The peeling time was observed to be 23.7 min in 2 min blanching, 25 min in 6 minute blanching and 26.7 min in 10 min blanching. The maximum peeling time (26.7 min) was recorded in 10 min blanching. The increase in peeling time may be due to higher absorbtion of moisture by the cloves (Table 4.7).

Table 4.7 Effect of hydrothermal treatment on garlic peeling time

Sample size = 100g garlic clove

S. No.	Peeling time (min.)		
	Blanching(2 min)	Blanching(6 min)	Blanching(10 min)

1.	24.5	25.4	26.2
2.	23.9	25.0	27.0
3.	22.8	24.7	26.8
Mean ± S.D	**23.73 ± 0.86**	**25.03 ± 0.35**	**26.67 ± 0.42**

4.4.2 Chemical treatment

The peeling time required for chemically treated cloves has been given in Table 4.8. Peeling time was found to be 30.37 min at room tempearture for 10 min. soaking. The garlic cloves were also treated with 2% edible oil (mustard oil) and kept for 10 min for tempering and manual peeling time was recorded**.** The peeling time in this method was observed to be 28.75 min (Table 4.8).

Table 4.8 Effect of $NaHCO_3$ solution and mustard oil on peeling time

Sample size = 100 g cloves

S. No.	Peeling time (min)	
	$NaHCO_3$ solution (0.1%) for 10 min	**Mustard oil (2 %) for 10 min**
1.	30.5	28.5
2.	29.5	29.5
3.	29.5	29.0
4.	32.0	28.0
Mean ± S.D	**30.37 ± 0.71**	**28.75 ± 1.05**

4.4.3 Thermal treatment

The garlic cloves were kept at 50, 60 and 70 °C for 10 min, 20 min and 30 min in hot air oven and then peeled manaully. The peeling time data of thermally treated garlic cloves has been presented in Table 4.9.

Table 4.9 Effect of thermal pre-treatment on garlic peeling time

Sample size = 100 g cloves

Treatment temperature(^oC)	Peeling time (min)		
	Treatment time (10 min)	**Treatment time (20 min)**	**Treatment time (30 min)**
50	23.87	17.95	16.05
60	22.40	16.48	14.57
70	20.22	14.33	12.10

The peeling time was found minimum at 30 min in 70°C as compared

to 10 min and 20 min. At 30 min treatment time the bonds between the skin and clove werer found to be weaker due to this reason time required for peeling was less as compared to 10 and 20 minute of drying. At higher temperature the elasticity of garlic cloves was also increased which results in reduction of peeling time and peeling damage (Table 4.9).

4.4.4 Optimization of pretreatment

The pretreatment was optimised on the basis of minimun time requirement for peeling of pretreated cloves. The peeling time in thermal tratment was observed as minimum as compared to the other treatments *i.e.* chemical treatment, hydrothermal treatment and control treatment. Hence the thermal treatment was selected for the further studies of garlic peeling. The peeling time at thermal treatment temperature of 70ºC for 30 min was minimum in comparison to 50 and 60ºC at time 10 and 20 min treatment times. Hence, combination of both 70ºC air temperature and 30 min thermal treatment in air oven was finally selected for peeling of garlic cloves for further investigations. These combinations of temperature and thermal treatment were used in the performence evalution of developed garlic peeler.

4.5 Development of Clove Peeler

The results of preliminary trials on clove peeling for optimization (Design expert software) of attributes on the basis of maximum peeling recovery and peeling efficiency with minimum damage of cloves and performance evaluation of developed clove peeler have been described and discussed in this section.

4.5.1 Preliminary trials for optimization of machine parameters

The weight of fractions of peeled, unpeeled and damaged garlic cloves in each preliminary trial on clove peeling for various combinations of process parameters has been presented in Table 4.10. The percentage peeling recovery was observed to increase with increase in air jet pressure while decreased with increase in diameter of peeling chamber and position of air jet. Similar trend was observed in case of peeling efficiency. The peeling recovery was observed in the range of 49.12 – 96.20 per cent with maximum of 96.20 per cent and minimum of 49.12 per cent in all combinations of process parameters in the study. Similarly peeling efficiency was also found in the range of 50.30 – 98.16 per cent with maximum of 98.30 per cent and minimum of 50.30 per cent in all preliminary trails conducted (Table 4.10).

Table 4.10 Performance of clove peeler at various levels of machine parameters

Chamber height- 400 mm; Bed depth- 60 mm

S. No.	Chamber diameter (mm)	Pressure of air jet (kg/cm^2)	Jet position (mm)	Weight of cloves (g)	Weight of fractions (g)		Peeled recovery (%)	Peeling efficiency (%)
					Peeled	Unpeeled, damaged		

1.	100	5	60	250	155.20	92.02	62.00	62.75
2.	100	5	80	250	152.50	87.02	61.12	63.50
3.	100	5	100	250	142.54	98.05	57.01	59.25
4.	100	10	60	250	237.13	7.04	94.80	97.13
5.	100	10	80	250	230.25	10.00	92.00	95.80
6.	100	10	100	250	220.14	20.03	88.30	91.66
7.	100	15	60	250	227.58	15.01	91.04	92.31
8.	100	15	80	250	225.36	17.05	90.05	92.9
9.	100	15	100	250	217.52	19.07	87.12	91.9
10.	130	5	60	500	295.05	189.20	59.12	60.95
11.	130	5	80	500	280.12	200.30	56.12	58.33
12.	130	5	100	500	270.36	211.21	54.12	56.13
13.	130	10	60	500	475.23	13.21	95.36	97.3
14.	130	10	80	500	477.10	12.03	95.40	97.54
15.	130	10	100	500	445.24	35.04	89.12	92.70
16.	130	15	60	500	475.06	12.07	95.12	97.13
17.	130	15	80	500	480.08	9.23	96.20	98.16
18.	130	15	100	500	455.29	25.03	91.32	94.79
19.	160	5	60	900	477.15	406.0	53.12	54.02

20.	160	5	80	900	459.13	404.90	51.02	53.13
21.	160	5	100	900	441.34	454.15	49.12	50.30
22.	160	10	60	900	738.01	131.86	82.13	89.0
23.	160	10	80	900	720.02	129.30	80.52	84.8
24.	160	10	100	900	702.04	164.12	78.39	81.06
25.	160	15	60	900	801.03	65.13	89.34	92.27
26.	160	15	80	900	855.05	19.04	87.65	97.84
27.	160	15	100	900	868.01	15.06	81.12	98.30

4.5.1.1 Effect of peeling chamber diameter

The size of peeling chambers did not produce any effect on bed depth of cloves for all diameters (100, 130 and 160 mm) of peeling chambers. Suitable bed depth was observed to be 60 mm. Though the peeling capacity was increased with increase in diameter of peeling chamber as the quantity of cloves processed was observed to be 250, 500 and 900 g for peeling chambers of diameters 100, 130 and 160 mm, respectively. With the increase in diameters of peeling chamber the position (height) of air jet and the required pressure of compressed air was found to be increased. For peeling chambers of diameters 100, 130 and 160 mm the suitable jet position (*i.e.* the height from the top surface of garlic bed) were observed to be 60, 80 and 100 mm, respectively. The air pressure required for proper peeling of garlic cloves were observed to be 10, and 10 to 15 kg/cm^2 for peeling chambers of diameters 100, 130 and 160 mm, respectively. The peeling chambers of 160 mm diameters produced good peeling effect at 15 kg/cm^2 air pressure at all positions of air jet.

4.5.1.2 Effect of air jet pressure

The jet air pressure of 5 kg/cm^2 was not found suitable, as it could not produce required peeling effect in all the peeling chambers even at minimum height of air jet. The 10 kg/cm^2 air pressure produced good peeling results with chambers of 100 and 130 mm diameter with 60 mm air jet height, but the same could not produce the peeling phenomenon with chamber of 160 mm diameter. The time taken in peeling was same in all the cases but injuries to

cloves were less at 60 mm bed depth and 60 mm air jet height. For all the jet position, the jet pressure of 10 to 15 kg/cm^2 produced good peeling of garlic with 130 and 160 mm diameter chambers. Surface injuries to most of the peeled cloves were noticed in case of higher pressure range.

4.5.1.3 Effect of air jet position

The jet position at 60 mm height above the cloves produced good peeling results with chamber of 100 mm diameter and 10 kg/cm^2 pressure of air jet, but the same could not produce the peeling phenomenon with chamber of 160 mm diameter. The jet position at 60 mm height from bed surface was observed best suitable, as it produced required peeling effect in all the peeling chambers with the following combinations of chamber diameter and air jet pressure *viz.* (1)100 mm chamber diameter and air jet pressure of 10 kg/cm^2; (2) 130 mm chamber diameter and air jet pressure of 10-15 kg/cm^2; and (3) 160 mm chamber diameter and air jet pressure of 15 kg/cm^2. For the jet position 100 mm height from bed surface, the jet pressure of 15 kg/cm^2 produced good peeling of cloves with 160 mm diameter chamber. The best possible air jet position for peeling chamber of diameter 130 mm was found to be 60 mm above the bed surface.

4.5.2 Optimization of process parameters using design expert software

A graphical multi response optimization technique of Design expert version software was adapted to determine the workable optimum values of machine parameters garlic clove peeler to be developed. The graphical representations of all responses are shown in Fig. 4.1 to 4.3.

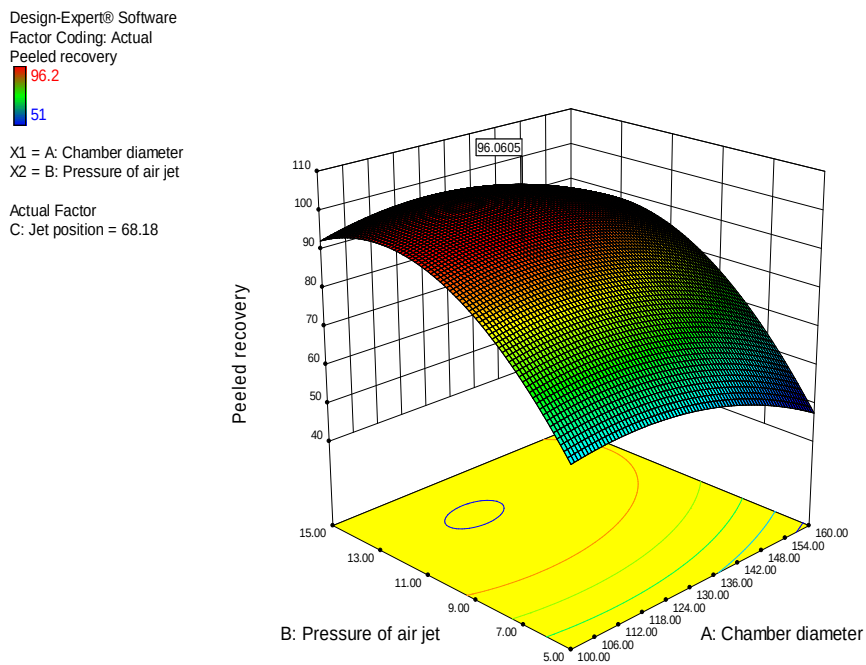


Fig. 4.1 Variation in peeling recovery with air jet pressure & chamber diameter

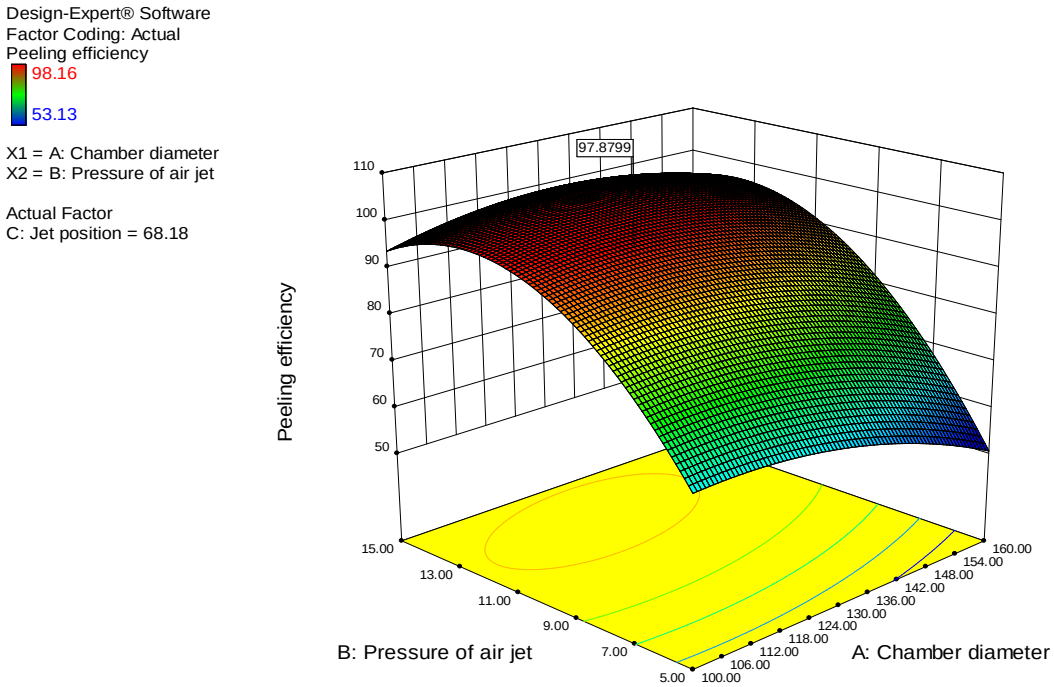


Fig. 4.2 Variation in peeling effeciency with air jet pressure and chamber diameter

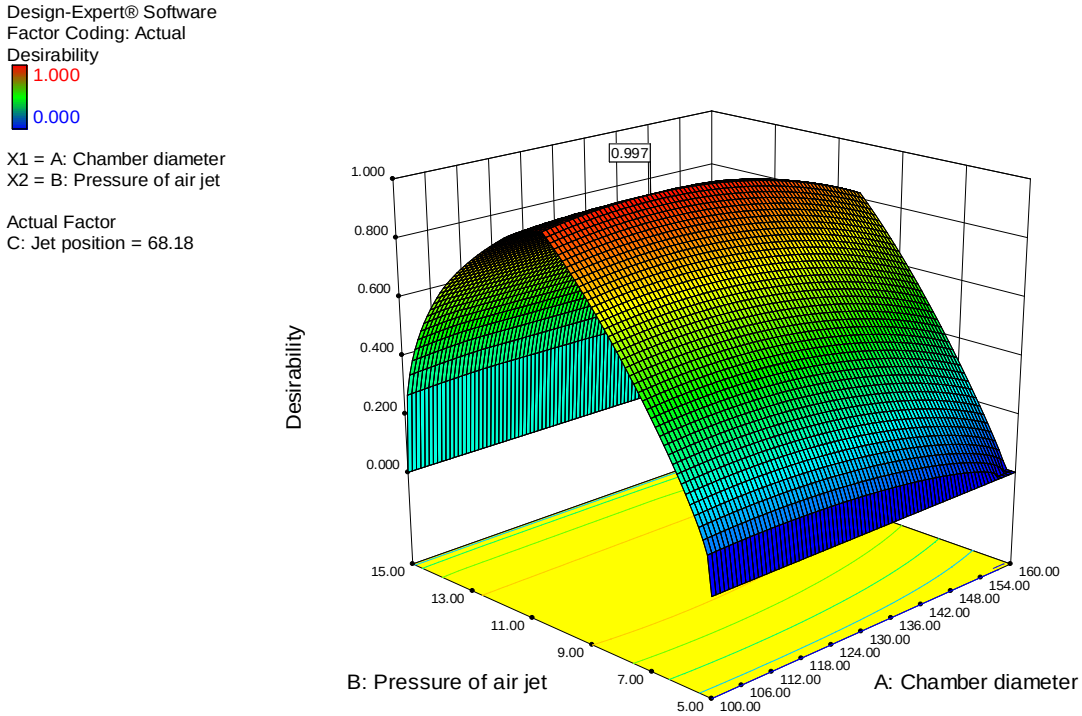


Fig. 4.3 Variation in desirability with air jet pressure and chamber diameter

Predicted values of air jet pressure air jet position, and chamber diameter for

maximum recovery and peeling efficiency by using design expert version software have been given in Table 4.11

Table 4.11 Predicted responses for maximum peeling recovery and efficiency

Factor	Name	Level	Low level	High level
A	Chamber diameter	118.78	100	160
B	Pressure of air jet	10.00	5	15
C	Jet position	68.17	60	100

The observed experimental values (mean of three replications) and values predicted by the equations of the model are presented in Table 4.12. The experimental values were found to be very close to the predicted values for peeling recovery and peeling efficiency, with the value of C.V. as 1.54 per cent and 1.89 per cent, respectively. Statistically it can be seen that the optimised machine parameters are quite adequate for design and development of garlic peeler with maximum peeling recovery and efficiency.

Table 4.12 Peeling recovery and peeling efficiency at optimum process conditions

Response	Predicted value	*Experimental value (±SD)	C.V. (%)
Peeling recovery, %	96.06	95.36	1.54
Peeling efficiency, %	97.87	97.30	1.89

* Average of three replications

4.5.2.1 Verification of the model for garlic peeling process

Garlic peeling experiments were conducted at the optimum process conditions (x_1 = 130, x_2 = 10 and x_3 = 60) for testing the adequacy of model equations for predicting the response values. The optimum values of process variables obtained by numerical optimization:

Chamber diameter, mm: 118.78 ≈ 130

Pressure of air jet, kg/cm^2: 10 ≈ 10

Jet position, mm: 68.17 ≈ 60

4.5.3 Performance evaluation of developed clove peeler

The developed garlic clove peeler was observed to be very simple in

construction and easy in operation. The extensive trials were conducted for evaluating the performance of the developed garlic peeler. The observed data *viz.* time required for peeling, weight fractions of peeled (Plate 4.1), unpeeled and peeled but damaged cloves have been presented in the Table 4.13. The peeling recovery (%) and efficiency (%) of the developed clove peeler was estimated using above recorded observations.

The recovery of peeled cloves was observed to be 50.4, 73.4, 88.4, 94.8, 85.4 and 75.8 %) for the peeling time of 40, 50, 60, 70, 80 and 90 s, respectively. Similarly, the peeling efficiency was found to be 51.8, 74.89, 90.38, 97.55, 87.14 and 77.50 % for the peeling time of 40, 50, 60, 70, 80 and 90 s, respctively (Table 4.13). Both the peeled recovery and peeling efficiency were observed in increasing trend with increase in the peeling time up to 70s. The maximum peeling efficiency (97.6 %) was observed with peeling time of 70 s. With increase in the peeling time after 70 s the peeling recovery and peeling efficiency were observed to decrease because of abrasive damage to the skin of peeled cloves. With 60 s of peeling time, the peeling efficiency was recorded to be 90.4 %. No damage to the surface of peeled garlic was noticed for peeling time of 60 s though 9.4 % cloves remained unpeeled. Therefore, 70 s peeling time was found most suitable for peeling garlic cloves with 97.6 % peeling efficiency.

Plate 4.1 Sample of cloves peeled in developed peeler

Table 4.13 Performance evaluation of developed garlic peeler

Chamber diameter =130 mm	Chamber height = 400 mm
Pressure of air jet = 10 kg/cm^2	Jet position = 60 mm
	Weight of cloves = 500 g

S. No.	Peeling time (s)	Weight fractions of cloves (g)			Peeled recovery (%)	Peeling efficiency (%)
		Peeled	Unpeeled	Peeled but damaged		
1	40	252	237	--	50.4	51.80
2	50	367	123	--	73.4	74.89
3	60	442	47	--	88.4	90.38
4	70	479	06	06	94.8	97.55
5	80	427	05	57	85.4	87.14
6	90	379	03	107	75.8	77.50

4.6 Garlic Drying

The results of studies carried out on different drying methods namely solar drying, mechanical drying, fluidized bed drying and freeze drying have been described and discussed in this section.

4.6.1 Open sun drying

It can be seen from the moisture loss curves (Figs. 4.4 to 4.5) that open sun drying of unpeeled garlic cloves required nearly 50 h of exposure to reduce the moisture content from 198.5 % to 7.82 % (db) whereas only 40 h were required for samples peeled cloves to reach the moisture level of 7.46 % (db)**.** Therefore, 20 % time could be saved in drying if peeling of cloves is performed prior to drying in open sun.

Fig. 4.4 to 4.5 shows the effect of drying time on moisture content for drying of garlic peeled and unpeeled cloves in open sun drying. Drying rate was found higher at initial stage and decreased with reduction in moisture content. The present findings are in conformity with that of Bisnoi *et al*. (2008) who reported similar results.

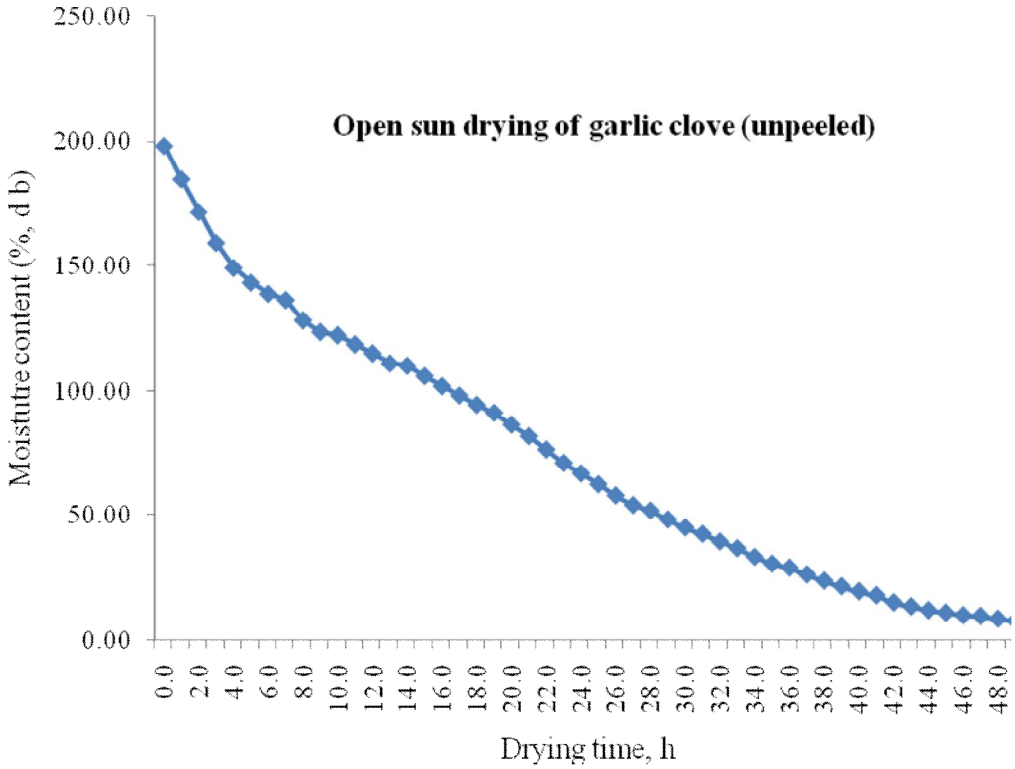


Fig. 4.4 Variation in moisture content of unpeeled garlic clove with drying time

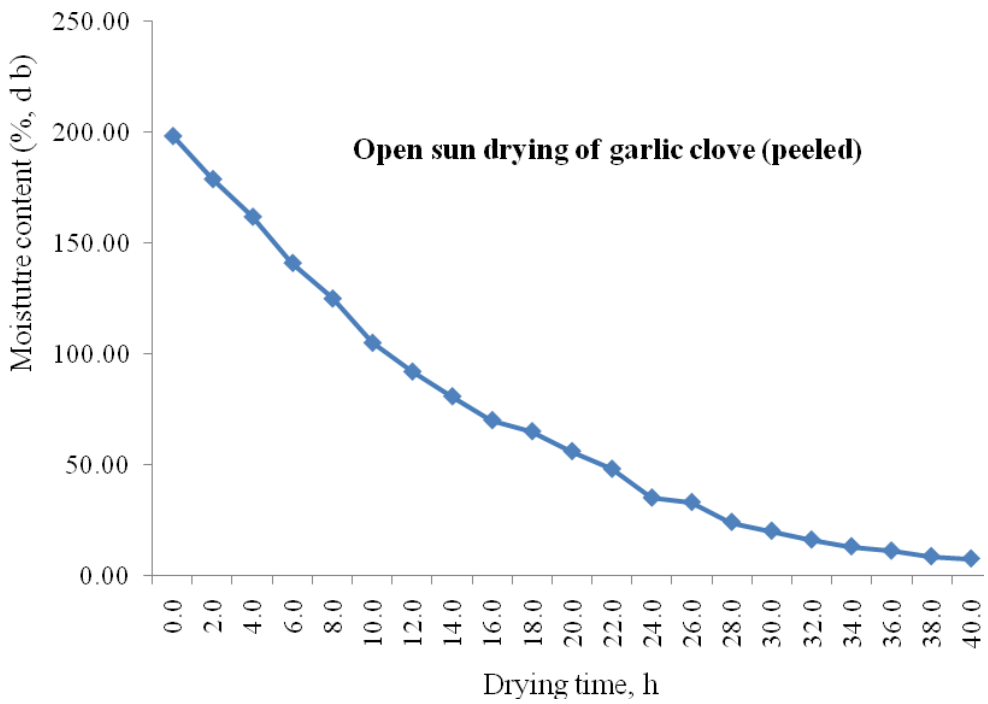


Fig. 4.5 Variation in moisture content of peeled garlic cloves with drying time

4.6.2 Solar drying

The moisture loss curves for drying the unpeeled and peeled garlic cloves have been presented in Fig. 4.6 and 4.7.

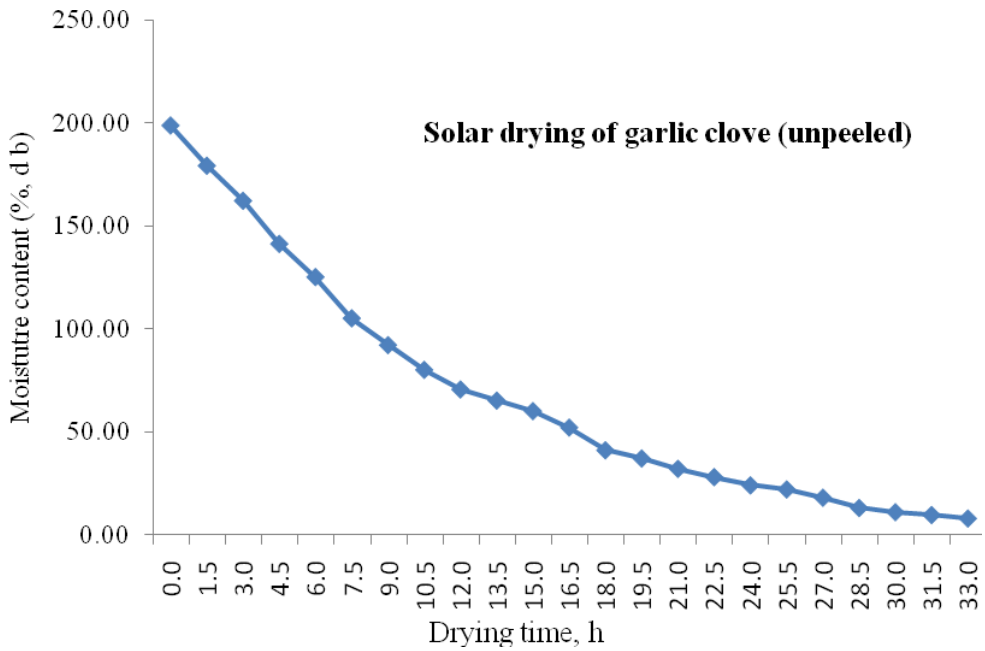


Fig. 4.6 Variation in moisture content of unpeeled garlic cloves with drying time

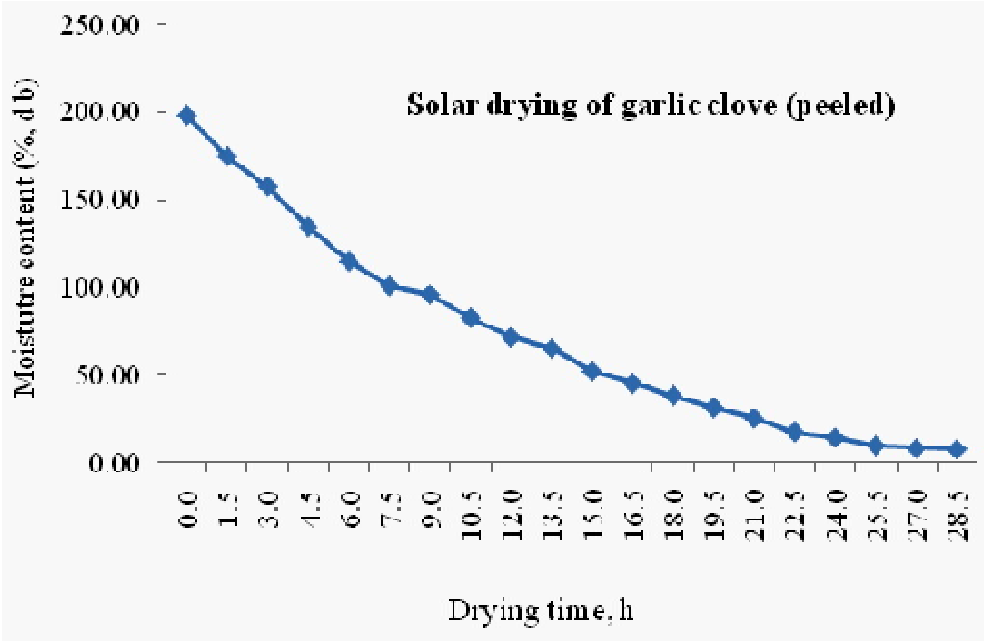


Fig. 4.7 Variation in moisture content of garlic (peeled) with drying time

It is clear that 33 h was required for solar drying of unpeeled garlic cloves (up to moisture content of 7.9 %) whereas only 28.5 h was. required for peeled samples to reach the 7.5 per cent moisture level from initial moisture content of 198.5 % (db)**.** The drying rate of garlic cloves for solar cabinet dryer was found higher at initial stage and it decreased with reduction in moisture content. It also shows that drying rate remained higher in solar drying than that of open sun drying. The present findings are in conformity with that of Bisnoi *et al*. (2008) who reported similar results

4.6.3 Mechanical tray drying of garlic cloves

The results of investigations carried out for drying characteristics and estimation of effective moisture diffusivity during the convective drying of garlic cloves have been described and discussed in this section.

4.6.3.1 Drying characteristics

The average initial moisture content of the garlic samples was observed to be 198.5 per cent (db) for all the samples. The convective drying behaviour of dehydrated garlic cloves at drying air temperature of 40, 50 and 60°C and velocities of 1.0, 1.5 and 2.0 m/s have been given in Fig. 4.8 - 4.10. The experimental data are presented in Appendices C1-C9. The variation in moisture content of dehydrated garlic samples with drying time, drying rate and effective moisture diffusivities as well as effect of air velocities are analysed in following sections.

4.6.3.2 Variation in moisture content with time

Moisture content of garlic samples decreased exponentially with drying time under all drying conditions (Fig. 4.8- 4.10).

The drying data of garlic cloves sample were analysed and regression equations of exponential form were predicted as

$$MC = Ae^{(-kt)} \qquad \text{... 4.1}$$

Where, MC is moisture content of the garlic samples and t is time in min and A, k are constants. The values of regression coefficients A and k are given in Table 4.14 with R^2 value.

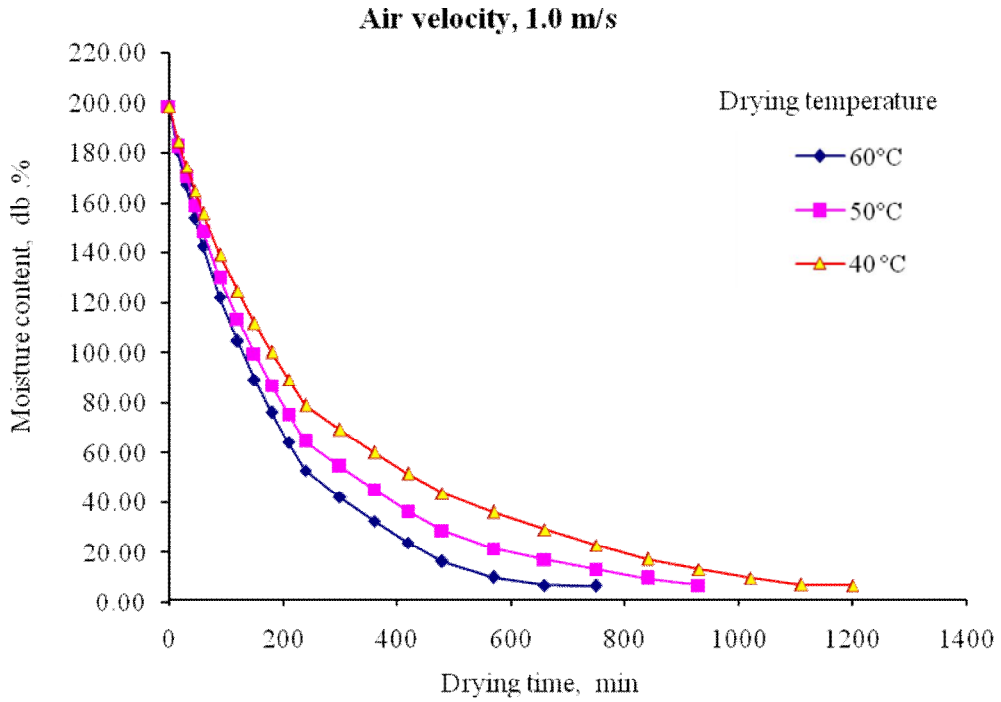


Fig. 4.8 Drying curves for garlic cloves at different air temperatures for 1.0 m/s drying air velocity in tray drying

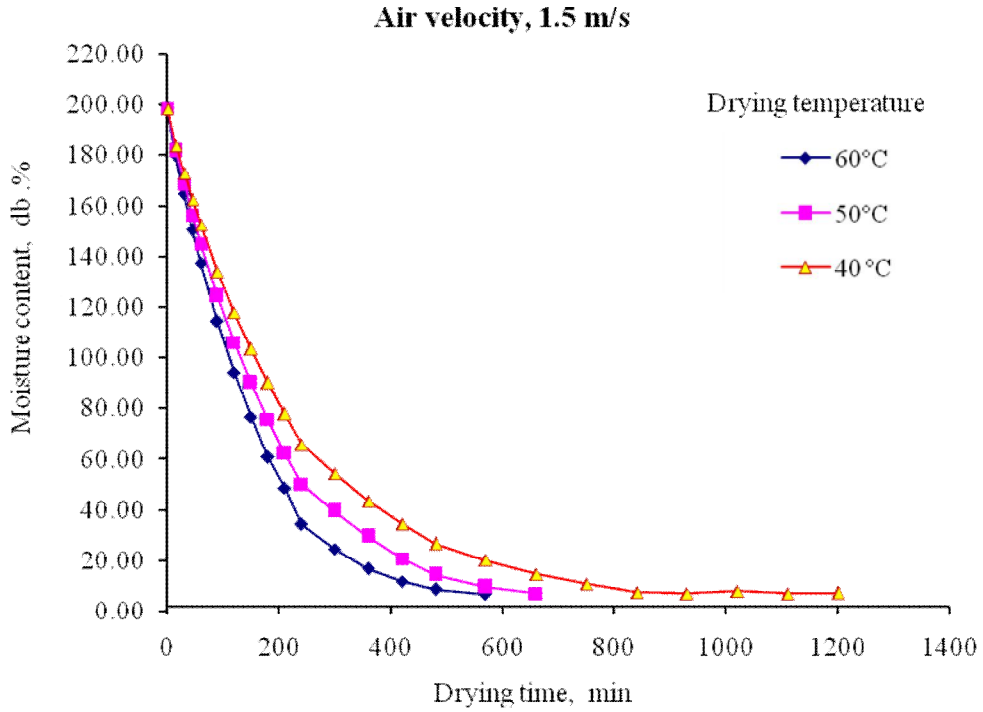


Fig. 4.9 Drying curves for garlic cloves at different air temperatures for

1.5 m/s drying air velocity in tray drying

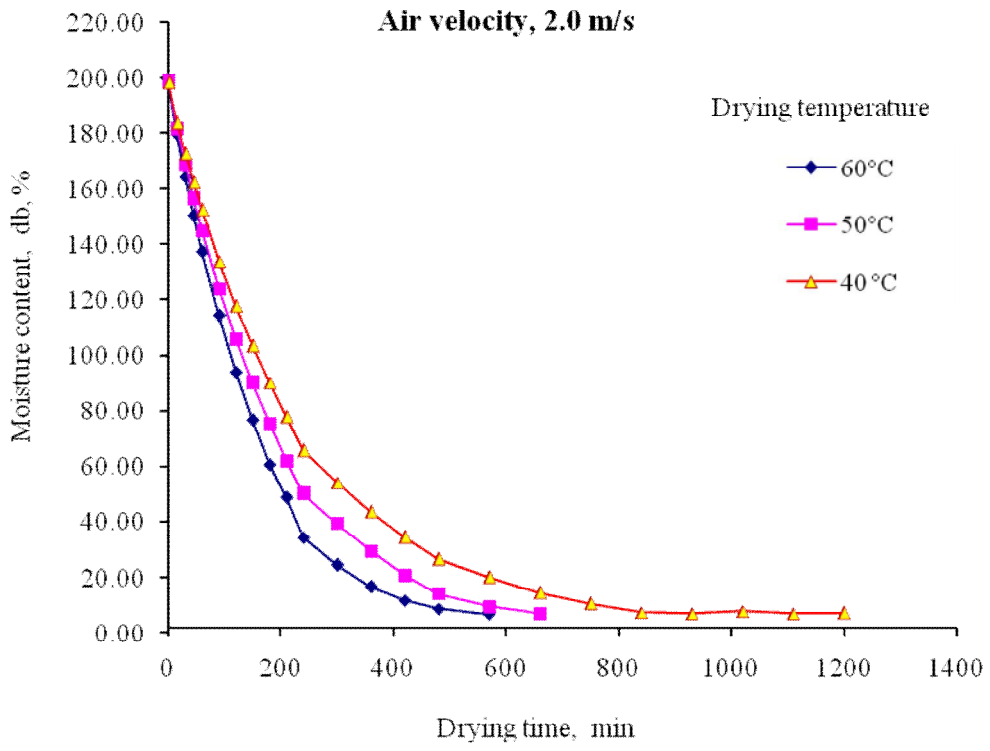


Fig. 4.10 Drying curves for garlic cloves at different air temperatures for 2.0 m/s drying air velocity in tray drying

It can also be seen from Fig 4.8 – 4.10 that minimum time in drying was observed at higher air temperature (60ºC) and maximum time was recorded for low

air temperature (40ºC) for all air velocities.

It can be seen from the Table 4.14 that for all experiments the coefficients of determination is in between 0.9662 to 0.9899 showing good correlation between the observed and predicted values. It can also be seen that values of overall regression coefficients (A and k) of the Eqn. (4.1) varied with variation in drying air temperature.

The total drying time for convective drying of dehydrated garlic cloves is shown in Table 4.15. It can be seen that there was a wide variation in drying time from 570 to 1200 min for the range of drying air temperatures and air velocities taken for study. Drying time in general decreased with increase in drying air temperature as well as increase in drying air velocity but the effect of air temperature was more pronounced as compared to air velocity.

Table 4.14 Regression coefficient of Eqn. (4.1) with R^2

S. N0.	Drying air velocity, m/s	Drying air temperature, °C	Regression coefficient		Coefficient of correlation, R^2
			A	K	
1		40	175.70	0.0002	0.9662
2	1.0	50	178.44	0.0004	0.9712
3		60	181.73	0.0006	0.9807
Average regression coefficient at 1.0 m/s air vel.			**178.6**	**0.0004**	**0.9727**
4		40	177.6	0.0003	0.971
5	1.5	50	181.1	0.0006	0.977
6		60	184.9	0.0008	0.986
Average regression coefficient at 1.5 m/s air vel.			**181.2**	**0.00056**	**0.978**
7		40	182.18	0.0004	0.9788
8	2.0	50	186.92	0.0007	0.9883
9		60	187.96	0.001	0.9899
Average regression coefficient at 2.0 m/s air vel.			**185.68**	**0.0007**	**0.985**

Table 4.15 Effect of temperature, velocity and their interaction with drying time

Temperature (°C)	Velocity, m/s			Mean
	1.0	1.5	2.0	
	Drying time (min)			
40	1200	1100	930	**1080**

50	930	840	660	**810**
60	750	660	570	**660**
Mean	**960**	**870**	**720**	**-**

Second order regression model for total drying time was fitted to experimental data (Table 4.14). The typical curves showing variation in drying rate with moisture content of dehydrated garlic cloves dried with air temperature of 40, 50 and 60ºC for air velocities of 1.0, 1.5 and 2.0 m/s, respectively are shown in Fig. 4.11- 4.13. The drying rates were determined from the mass balance calculations at various moisture contents.

The convective drying of garlic cloves followed a typical trend. 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. According to kinetic theory the energy of water molecules is increased with increase in temperature causing the movement of water molecules faster. It has been reported by Prabhanjan *et al.* (1995) that the higher temperature provide a larger water vapour pressure deficit (the difference between the saturated water vapour pressure and partial pressure of water vapour in air at a given temperature), which is one of the driving forces for the outward moisture diffusion process (drying). It was also found that the drying rate increased with increase in drying air velocity that might be due to modification in cellular structure, which minimized the effect of superficial hardening.

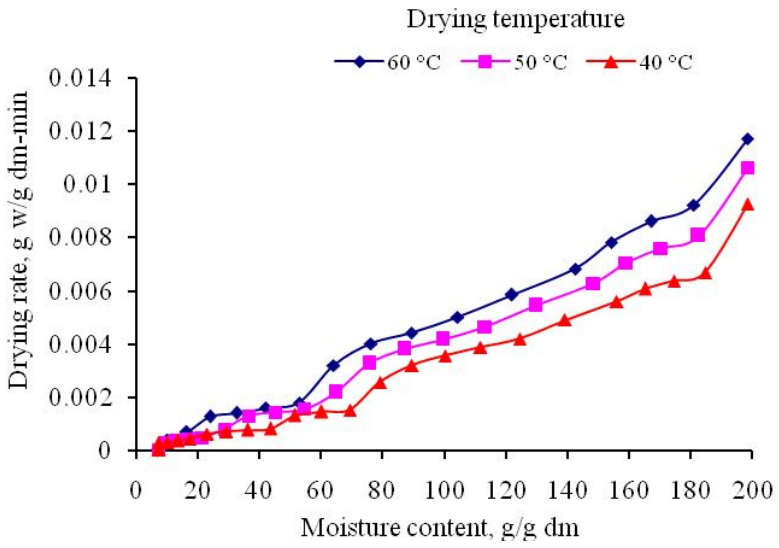


Fig 4.11 Variation in drying rate with moisture content for different drying temperature and 1.0 m/s drying air velocity

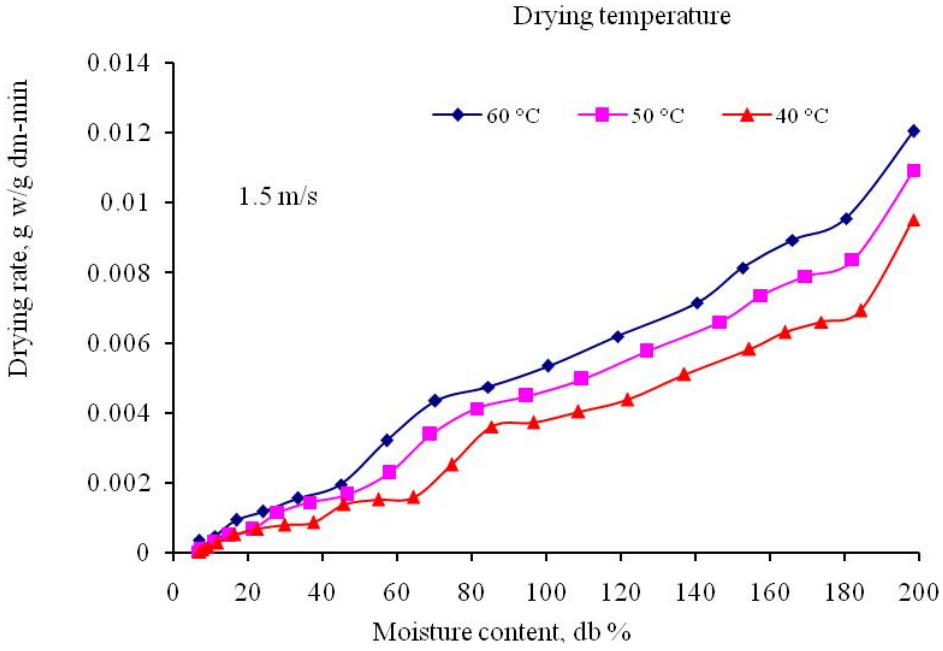


Fig 4.12 Variation in drying rate with moisture content for different drying temperature and 1.5 m/s drying air velocity

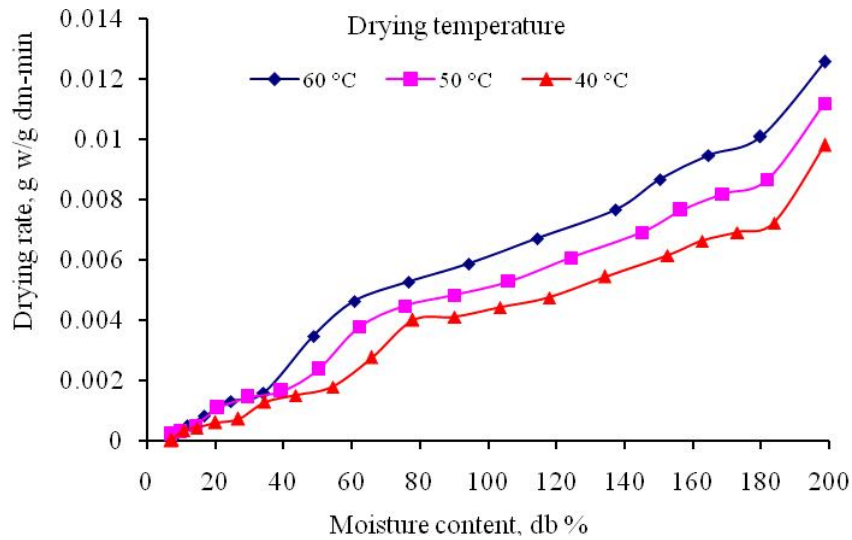


Fig 4.13 Variation in drying rate with moisture content for different drying temperature and 2.0 m/s drying air velocity

It can be observed from the Fig. 4.11-4.13 that as the drying proceeded, the moisture content of the sample decreased and the rate of drying also decreased. It can also be seen from the figure that the rate of drying was higher for high drying air temperature. This was expected also because high temperature of drying will remove moisture quickly from the sample which resulted in high drying rate. Further, it can be seen from the figures that no constant rate period was found during convective drying of dehydrated garlic cloves and entire drying had taken place in falling rate period.

4.6.3.3 Effect of air velocity

The effect of air velocities on moisture content of dehydrated garlic cloves during air drying is shown in Fig. 4.14 - 4.16 for air temperature of 40, 50 and 60°C. The figure revealed that under the prevailing conditions, the three drying curves at different air velocities are not very different from each other and the slopes of the lines are almost identical, especially at higher moisture levels, but effect becomes more pronounced in the later stage of drying where higher flow rate helps in attaining the final moisture content quickly in comparison to the lower air velocity.

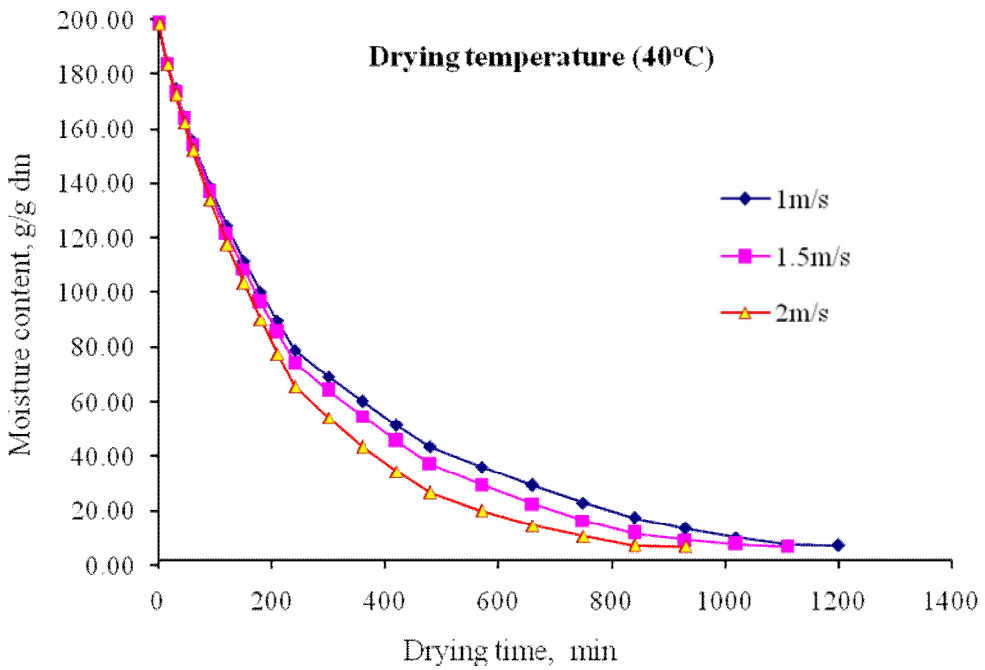


Fig. 4.14 Effect of drying air velocity on drying of garlic cloves at 40°C drying air temperature

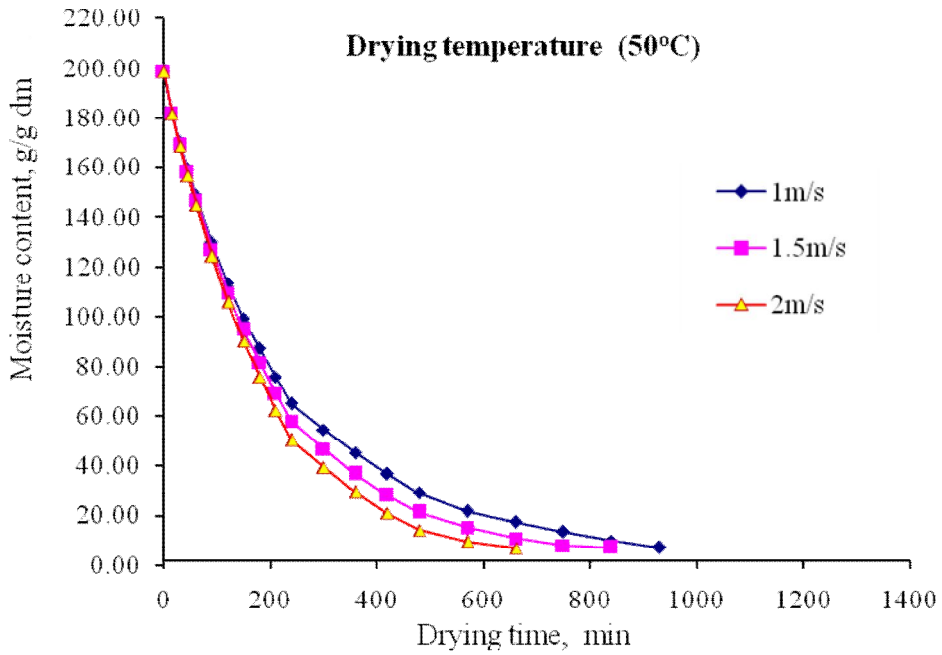


Fig. 4.15 Effect of drying air velocity on drying of garlic cloves at 50°C drying air temperature

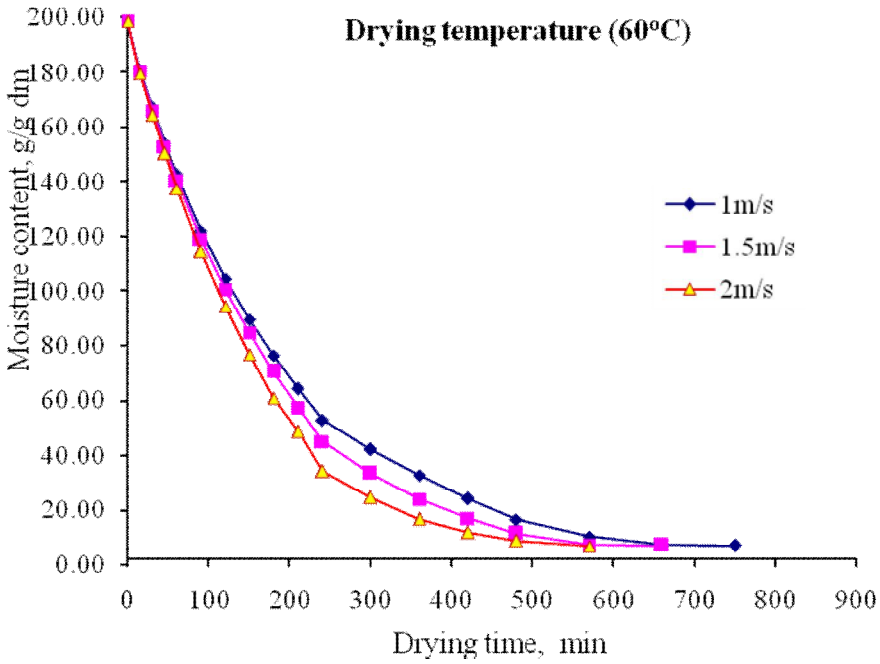


Fig. 4.16 Effect of drying air velocity on drying of garlic cloves at 60°C drying air temperature

4.6.3.4 Average moisture diffusivity (D_{eff})

The moisture loss data from convective drying were analyzed and moisture ratios at various time intervals were determined. The moisture ratio (MR) was plotted with drying time in order to find out moisture diffusivity for garlic cloves Fig 4.17-4.19.

The variation in ln (MR) with drying time of the garlic cloves have been presented in Fig 4.17 -4.19. The variation in ln (MR) with drying time for each case was found to be linear with inverse slope. At all levels straights lines were fitted satisfactory with coefficient of determination $R^2 > 0.90$. The slope became steeper with increase in air temperature and air velocity. Moisture diffusivities were calculated by using Eq. (3.16) from the slopes of these straight lines (Maskan *et al.* 2002; Doymaz, 2004) and are presented in Table 4.16. The moisture diffusivity varied in the range of 3.03×10^{-10} m²/s to 8.64×10^{-10} m²/s. during convective drying of (Table 4.16). These values are within the general range of 10^{-08} to 10^{-12}m²/s. for drying of food materials (McMinn and Magee, 1999).

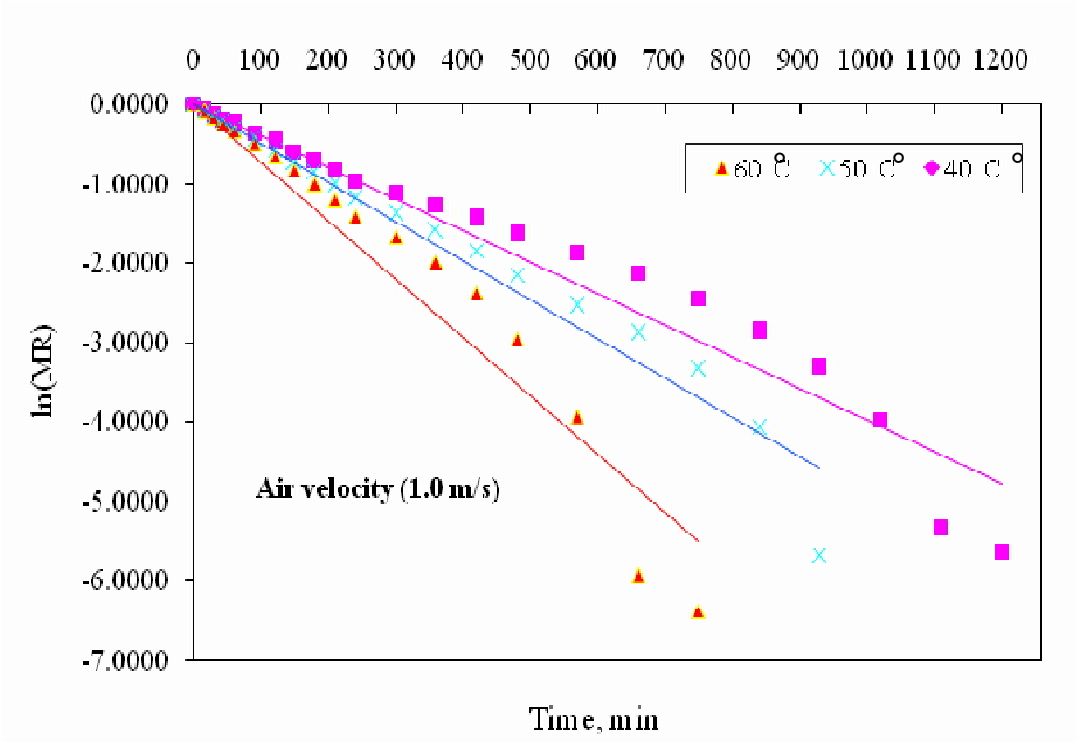


Fig. 4.17 Variation in ln (MR) versus time for 1.0 m/s drying air velocity in convective drying of garlic cloves

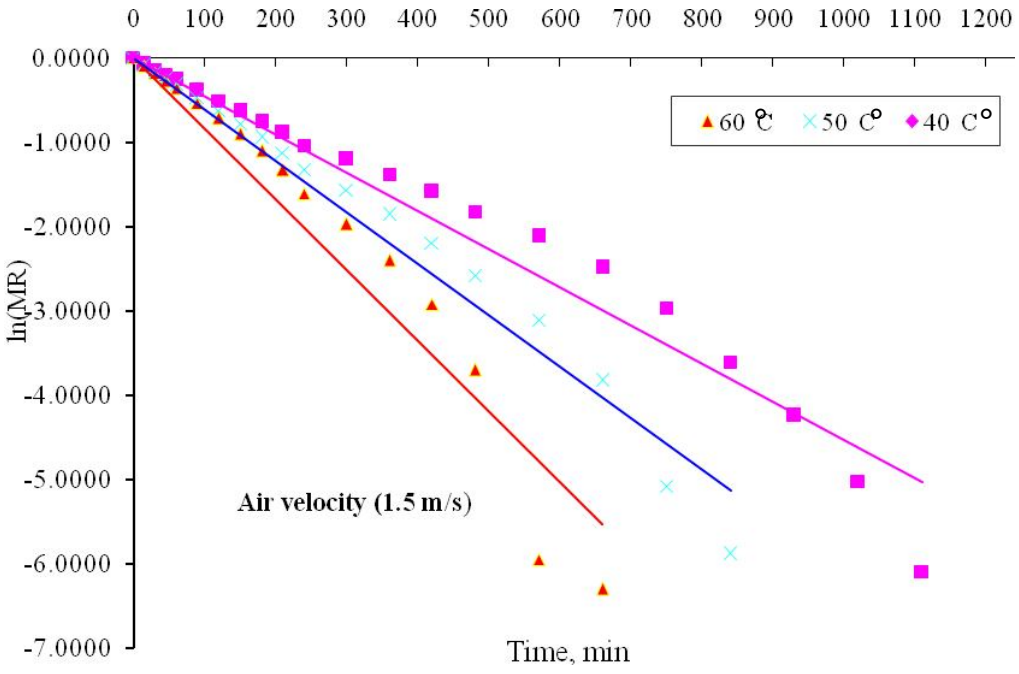


Fig. 4.18 Variation in ln (MR) versus time for 1.5 m/s drying air velocity in convective drying of garlic cloves

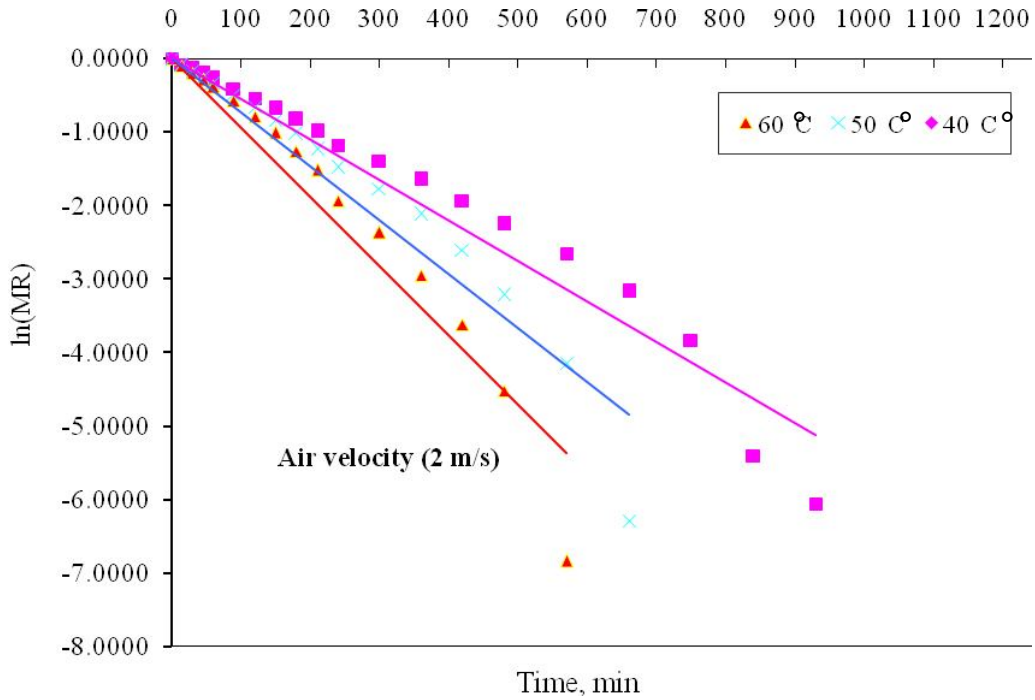


Fig. 4.19 Variation in ln (MR) versus time for 2.0 m/s drying air velocity in convective drying of garlic cloves

Table 4.16 Average moisture diffusivity of garlic cloves during Tray drying.

Air velocity, (m/s)	Air temp. (^{o}C)	Equation of straight line (y = mx + c)	Slope (m)	Diffusivity (m^2/s)	R^2
1	40	$y = -7\times10^{-05}x + 0.1154$	7×10^{-05}	3.03×10^{-10}	0.9545
1	50	$y = -8\times10^{-05}x + 0.0766$	8×10^{-05}	3.46×10^{-10}	0.9631
1	60	$y = -1\times10^{-04}x + 0.3242$	1×10^{-04}	4.32×10^{-10}	0.9496
1.5	40	$y = -8\times10^{-05}x + 0.156$	8×10^{-05}	3.46×10^{-10}	0.9666
1.5	50	$y = -1\times10^{-04}x + 0.1854$	1×10^{-04}	4.32×10^{-10}	0.976
1.5	60	$y = -2\times10^{-04}x + 0.3594$	2×10^{-04}	8.64×10^{-10}	0.9508
2	40	$y = -1\times10^{-04}x + 0.2151$	1×10^{-04}	4.32×10^{-10}	0.962
2	50	$y = -1\times10^{-04}x + 0.2933$	1×10^{-04}	4.32×10^{-10}	0.9417
2	60	$y = -2\times10^{-04}x + 0.3713$	2×10^{-04}	8.64×10^{-10}	0.9504

4.6.4 Fluidized bed drying

The garlic cloves were dried in fluidized bed dryer, but cloves required very high air velocity (12 m/s and above) for fluidization which was not possible in the existing dryer, therefore garlic cloves were sliced in 4 mm thickness and kept in fluidized bed dryer. The 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 3.0 m/s. The change in moisture content of garlic slices with elapsed drying time, at three drying temperature levels of 40, 50 and 60°C at air velocity level of 3.0 m/s is presented in Fig. 4.20. 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 dried at 40, 50 and 60ºC was found to be 306, 274 and 180 min for air velocity of 3.0 m/s The drying time observed under various drying conditions is presented in Table 4.17. The variation in drying rate measured for drying of garlic slices with moisture content during the fluid bed drying are presented in Fig. 4.21. It can be seen that the complete drying took place in falling rate period and constant rate period of drying is completely missing. Similar results are also reported by many researchers for fluid bed drying of various food materials.

Table 4.17 Drying time of garlic slices in a fluidized bed dryer

S. No	Air temperature (ºC)	Drying time, min (at air velocity 3.0 m/s)
1	40	306
2	50	274
3	60	180

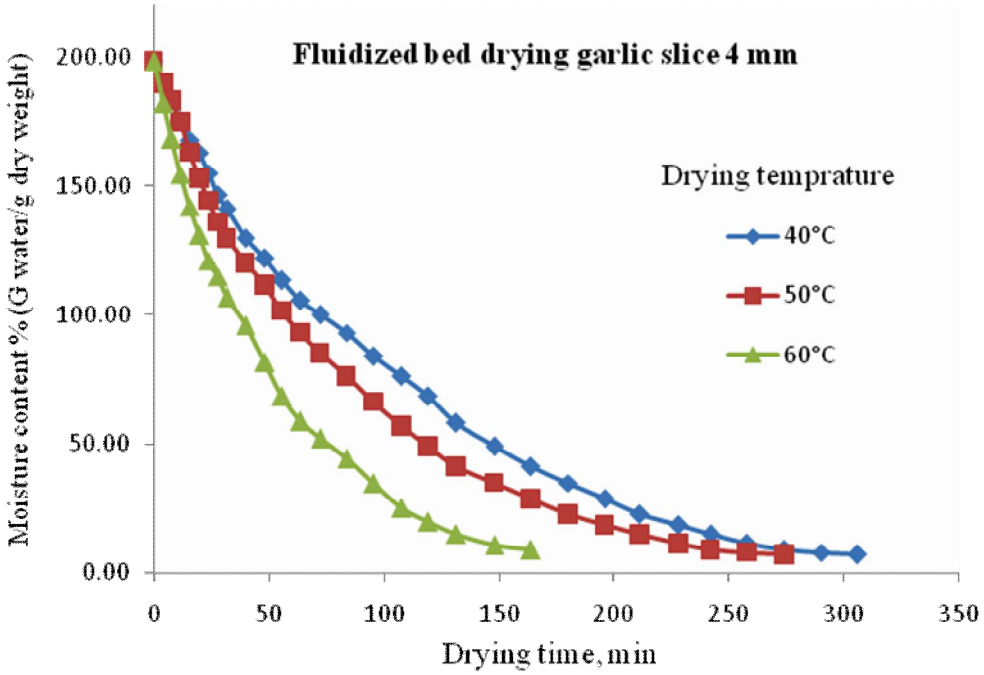


Fig. 4.20 Drying curves of garlic slice at different drying temperatures at air velocity (3.0 m/s) in fluidized bed drying

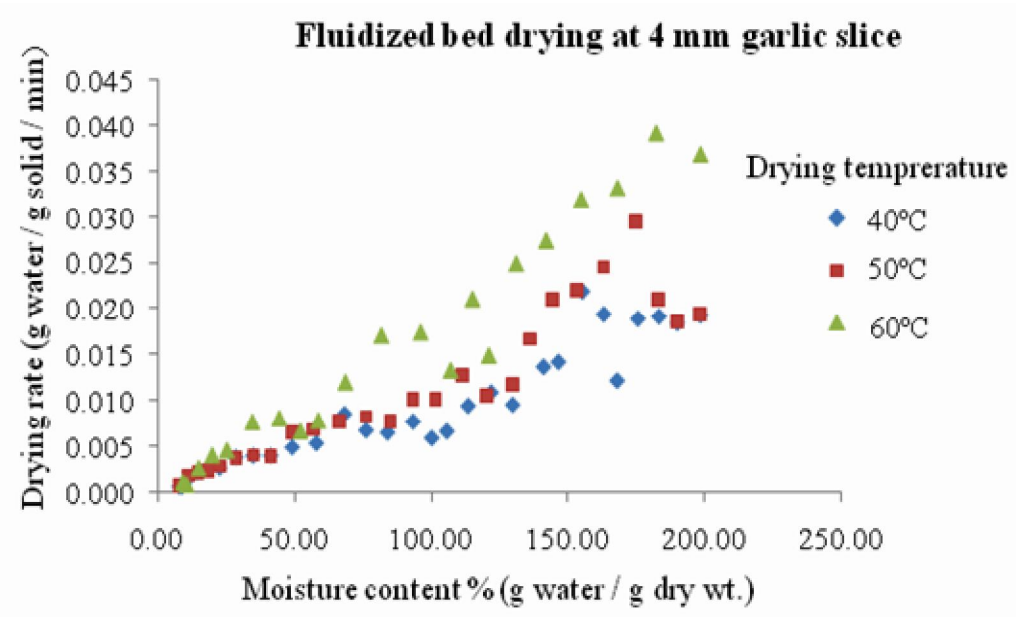


Fig. 4.21 Drying rate curves of garlic slice at different drying temperatures at air velocity (3.0 m/s) in fluidized bed drying

4.6.5 Freeze drying of garlic slices

The garlic cloves were dried in freeze dryer at freezing temperature of - 40°C. The drying period was too long for drying of cloves. Therefore, garlic cloves were sliced in 4 mm thickness and kept in freeze dryer for drying. To reduce the initial

moisture content of 198.50 per cent to 7.8 per cent in freeze drying 48 h were recorded. The sample of freeze dried slices and garlic powder has been shown in Plate 4.2. Drying rate increased due to crust formation on the surface of products during freezing by collapsing larger pores. This may have implication on formation of pores inside the material (Levine and Slade, 1989; Pan *et al*., 2008; Sablani *et al*., 2007).

Plate 4.2 Freeze dried garlic slices and powder

4.6.7 Optimization of drying methods for garlic dehydration

The samples of garlic cloves and slices dehydrated using various drying techniques (*viz.* open sun, solar, convective, fluidized bed and freeze drying method) were analyzed for flavor strength, colour, water activity (a_w) and rehydration ratio. The L value and flavor strength of fresh garlic was recorded to be 72.64 and 0.66, respectively. The respective values of quality attributes have been given in Appendix E. The data presented in Appendix E revealed that the colour value (L) of dehydrated samples ranged from 52.32- 68.23. The L value was observed to be 52.32, 58.72, around 64.79, 66.42 and 68.23 for the samples dried in open sun, solar, convective, fluidized bed and freeze drying method, respectively. The minimum and maximum colour value was found in open Sun and freeze dried garlic cloves and slices, respectively. It is also inferred from the observations that L-value reduced when drying air temperature was increased from 40 to 60°C. 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.

The flavor strength was found in the range of 0.17-0.41 per cent at different drying methods. The flavor strength was found to be 0.17, 0.19, 0.30, around 0.27 and 0.41 for the open sun, solar, convective, fluidized bed and freeze drying method,

respectively. The minimum (0.17) and maximum (0.41) flavor strength was found in open Sun and freeze drying method, respectively. The flavor strength was observed to decrease with increase in drying temperature in case of convective tray drying for all drying temperature and air velocities. The water activity of garlic cloves and slices dehydrated in different drying methods varied between 0.25 and 0.29. These results are in confirmation with Karathanos (2002), support the present findings. The data depicted in Appendix E revealed that the rehydration ratio of garlic dehydrated cloves and slices varied between 2.10 to 2.49. The present findings are in agreement with that of Sacilik *et al*. (2005) who has investigated the dehydration characteristics of the Kastamonu garlic in the range between 2·37 and 2·84, confirm the present results.

Drying of garlic cloves from initial moisture content of 198.5 to 7.0 % in open Sun and solar drying required about 40 and 28.5 h, respectively. The dehydration of the garlic cloves using convective tray dryer takes 12 h to dry from 198.5 to 7.0 %. In fluidized bed drying fluidization of garlic cloves was not possible in the equipment available because of requirement of higher air velocity (terminal velocity 12.5 m/s) so garlic cloves were sliced and garlic slices were dried in fluidized bed drier. The fluidized bed drying of garlic slice took 300 min to dry the garlic slice. The sensory characteristics and nutritional properties of freeze dried garlic slice were observed to be the best among all samples (Appendix E) but drying cost was in multifold of the convective and fluidized bed drying cost. The diffusivity was observed as 4.32, 8.64 and 8.64×10^{-10} m^2/s for drying air velocity of 1.0, 1.5 and 2.0 m/s for tray drying of garlic cloves. No significant effect on drying rate was observed with increase in diffusivity from 1.5 to 2.0 m/s therefore, drying air velocity of 1.5 m/s was selected for further studies. Hence mechanical tray drying at 60ºC temperature and drying air velocity of 1.5 m/s was recommended for garlic dehydration.

4.7 Product Development and Shelf life Study

The garlic paste prepared from fresh cloves; dehydrated garlic cloves, slices and ground powder dried in convective tray dryer (at 60 ºC temperature and drying air velocity of 1.5 m/s) were taken for the shelf life study. The effect of storage period on the flavor strength and organoleptic parameters of garlic paste, dried garlic cloves, slices (flakes) and powder were studied up to 120 days. The value of flavor strength and organoleptic score of above mentioned samples at 0, 30, 60, 90 and 120 days (interval of 30 days) have been shown in Table 4.18-4.23.

4.7.1 Garlic paste

The garlic paste was prepared, filled and sealed in plastic bottles and stored at ambient room temperature for shelf life study.

Table 4.18 Effect of storage period on the flavor strength of garlic paste

S. No.	Storage period (days)				
	0	**30**	**60**	**90**	**120**
1	0.65	0.50	0.47	0.46	0.45
2	0.64	0.48	0.45	0.44	0.43
3.	0.66	0.49	0.46	0.45	0.44
Mean±S.D.	**0.65 ± 0.01**	**0.49 ± 0.01**	**0.46 ± 0.01**	**0.45 ± 0.01**	**0.44 ± 0.01**

The samples were evaluated for its flavor strength and organoleptic parameters (colour, flavor, and texture and over all acceptability) at an interval of 30 days. The flavor strength was found to be 0.65, 0.49, 0.46, 0.45 and 0.44 at interval of 0, 30, 60, 90 and 120 days, respectively. The maximum value of flavor strength was obtained as 0.65 and it reduced to 0.44 after four months of storage (Table 4.18).

The prepared paste was tested organoleptically for colour, flavor, texture and overall acceptability and the result have been presented in Table 4.19. The colour, flavor and overall acceptability of the garlic paste was found to be good (sensory score of 70-80) up to the storage period of 60 days; satisfactory (sensory score of 60) up to the storage period of 90 days. After the end of four month it was not found suitable for consumption as the sensory score for colour, flavor and overall acceptability of the garlic paste was 50 only. No significant variation has been found in case of texture.

Table 4.19 Organoleptic score of garlic paste during storage

Storage period (Days)	Organoleptic parameters*			
	Colour	**Flavor**	**Texture**	**Overall acceptability**
0	70	80	70	70
30	70	80	60	70

60	70	70	60	70
90	60	60	60	60
120	50	50	60	54

*Average of ten replications

4.7.2 Dehydrated garlic clove/slices

The garlic cloves were dried in mechanical tray dryer at the optimized process parameters (60 ºC and 1.5 m/s air velocity). The dried cloves/slices (flakes) were packed in the food grade plastic pouches and stored for 4 months at ambient temperature for sensory evaluation for colour, flavor, texture and over all acceptability.

Table 4.20 Effect of storage period on the flavor strength of dehydrated garlic

S.No.	Storage period (Days)/				
	0	**30**	**60**	**90**	**120**
	Flavour strength				
1	0.30	0.28	0.27	0.26	0.24
2	0.29	0.26	0.25	0.24	0.23
3	0.31	0.27	0.26	0.25	0.22
Mean ± S.D.	**0.30 ± 0.01**	**0.27 ± 0.01**	**0.26 ± 0.01**	**0.25 ± 0.01**	**0.23 ± 0.01**

Samples were evaluated for flavor strength and found to be 0.30, 0.27, 0.26, 0.25 and 0.23 after 0, 30, 60, 90 and 120 days (at an interval of 30 days), respectively. It can be seen from the Table 4.20 that with duration of storage period flavor strength decreased for all the samples. The maximum value of flavor strength was obtained as 0.30 and it reduced to 0.23 after four months of storage.

The dried cloves/ slices were also evaluated organoleptically for colour, flavor, texture and over all acceptability by the panel of 10 judges and results have been presented in Table 4.21. It can be seen from the Table 4.21 that no significant variation has been found in all the orgnoleptic parameters

Table 4.21 Organoleptic evaluation of dehydrated garlic

Storage Period (Days)	Organoleptic parameters				Mean
	Colour	**Flavor**	**Texture**	**Overall acceptability**	
0	70	70	70	60	67.5
30	70	70	69	50	64.8

60	60	60	70	60	62.5
90	60	60	70	50	60.0
120	60	50	69	60	59.8

*Average of ten replications

4.7.3 Garlic powder

The garlic cloves/slices were dried in mechanical tray dryer at optimized process parameters (60ºC and 1.5 m/s air velocity) and dehydrated cloves were ground, sieved, packed in the plastic pouches and stored for 4 months at ambient conditions for sensory quality evaluation after every 30 days interval. The results have been given in Table 4.22-4.23.

It is very well clear from Table 4.22 that with duration of storage flavour strength decreased for all the samples. The maximum value of flavor strength was obtained as 0.30 and it reduced to 0.16 after four months of storage. The flavour strength was found to be 0.30, 0.24, 0.19, 0.18 and 0.16 at storage periods of 0, 30, 60, 90 and 120 days, respectively.

Table 4.22 Effect of storage period on the flavor strength of garlic powder

S. No.	**Storage period (days)**				
	0	**30**	**60**	**90**	**120**
1	0.30	0.24	0.20	0.18	0.17
2	0.29	0.25	0.19	0.19	0.17
3	0.31	0.23	0.19	0.19	0.16
Mean ± S.D.	**0.30 ± 0.007**	**0.24 ± 0.0**	**0.19 ± 0.0**	**0.18 ± 0.014**	**0.16 ± 0.014**

The dried garlic flakes were also tasted organoleptically for colour, flavor, texture and overall acceptability and score awarded by the judges has been shown in Table 4.23. It can be seen from the Table 4.23 that no significant variation has been found in all the organoleptic parameters up to 60 days of storage. After 90 days of storage colour (40), flavor (50), texture (50) and overall acceptability (50) was decreased to an unacceptable level.

Table 4.23 Organoleptic parameters of garlic powder

Storage period (Days)	Organoleptic parameters				Mean
	Colour	Flavour	Texture	Overall acceptability	
0	60	80	70	80	72
30	50	70	70	80	67
60	50	70	60	70	62
90	50	60	60	60	57
120	40	50	50	50	52

*Average of ten replications

4.8 Technology Package for Garlic Processing

The production of garlic products can be mechanized with adoption of appropriate technology *viz*., garlic grader, garlic bulb breaker, clove peeler, mechanical dryer, wet and dry pulverizer, and packaging machine etc. The developed garlic products *viz*., garlic paste, dehydrated flakes and slices and powder can be stored up to 3-4 months without deterioration in the flavor strength and colour value as per findings. The process package for production of garlic paste and powder is given below.

4.8.1 Technology packages for garlic paste

Suitable technology package is suggested for the production of garlic paste at cottage industry level. The different unit operations involved in the manufacturing of garlic paste are grading, clove separation, peeling, wet grinding, packaging and storage. The clove separation and peeling can be performed using garlic bulb breaker and the developed clove peeler. For grinding purpose low temperature grinder can produce best quality product. To improve the shelf life of the garlic paste suitable packaging machine shall be used (Fig. 4.22).

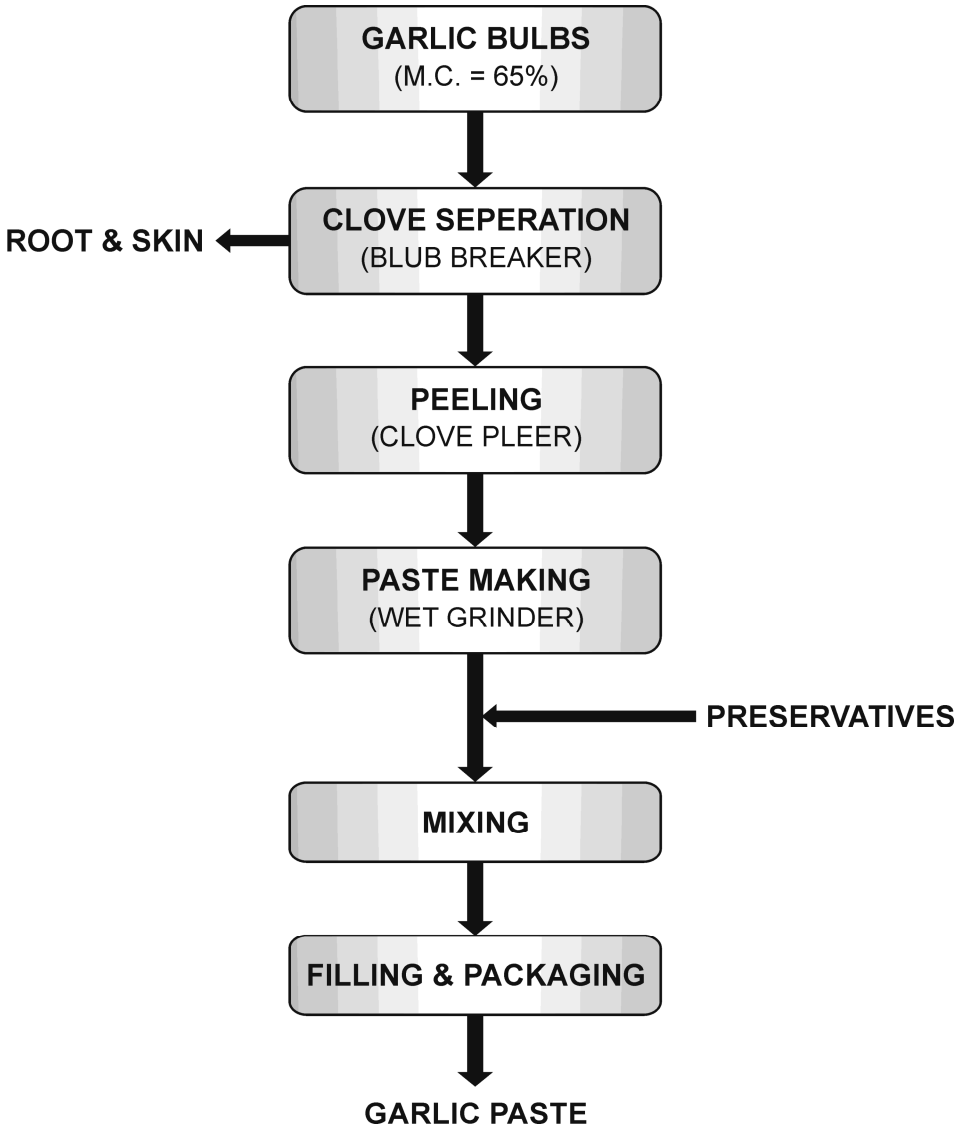


Fig. 4.22 Process package for production of garlic paste

4.8. 2 Technology packages for garlic powder and flake

Dehydrated garlic flakes and powder can be produced at industrial level using following unit operations and machines. The cloves separations can be performed using garlic bulb breaker. The peeling of garlic cloves can be done using clove peeler. The dehydration of cloves and flakes can be done using mechanical dryer. The size reduction operation can be done using low temperature grinder or pulverizer. The powder thus produced shall be packed using appropriate packaging machine for improving the shelf life of the final product. (Fig. 4.23)

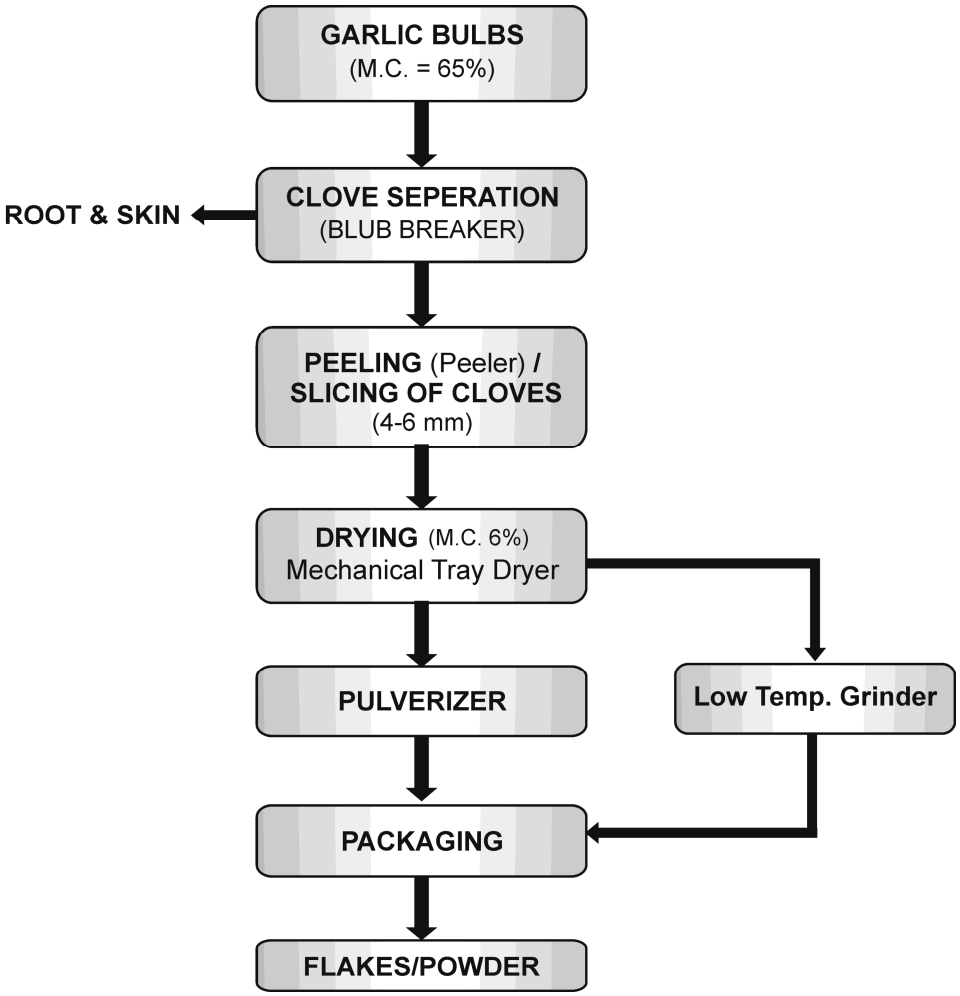


Fig. 4.23 Process package for production of dehydrated flakes/garlic powder

4.9 Techno-Economic Feasibility of Developed Process Technology

Feasibility studies aim to objectively and rationally uncover the strengths and weaknesses of an existing business or proposed venture, opportunities and threats present in the environment, the resources required to carry through, and ultimately the prospects for success. In its simplest terms, the two criteria to judge feasibility are cost required and value to be attained.

Cost of production per unit is an important indicator of efficiency of garlic paste and powder production. The cost estimation for processing of 40,000 kg garlic paste and powder has been carried out and presented in Table 4.24 and 4.25. The production cost of garlic paste and powder was estimated at Rs 38.15 and 141.16/kg. The low production cost of the garlic products and high return can mobilize the rural people to establish the garlic processing unit at production catchment.

Table 4.24 Cost estimation for production of garlic paste

Fixed cost		
S.No	Fixed cost	Rs/ year
(i)	Rent of land and building (20,000 x 12)	2,40,000
(ii)	Plant and machinery	1,00,000
(iii)	Pre operative expenses	10,000
(iv)	Interest on fixed asset (@ 10% P.A)	10,000
	Total	3,60,000
Variable cost		
(a)	Supervision/ Accountant (10,000/ M x12)	1,20,000
(b)	Semi-skilled and unskilled labourer	2,40,000
	(5 x 4000/ M x 12)	
(ii)	Raw material (40,000 Kg) @ 10 Rs/ kg	4,00,000
(iii)	Packaging and preservatives charges	50,000
(iv)	Electricity Power and water	2,50,000
(v)	Miscellaneous	
	Total	10,60,000
Interest on working capital @ 10% per annum		1,06,000
Total cost= Fixed cost + Variable cost = 3, 60,000 + 11, 66,000=15,26,000		

Paste production yearly= 40,000 kg

Production cost of paste (Rs/ kg) = total cost in Rs.÷ paste production in kg

=15,26,000 ÷ 40,000

= **Rs. 38.15 /kg**

Assumption

Yearly production of garlic paste is assumed 40 tons and average purchasing price is taken as 10 Rs/ kg for above calculations

Table 4.25 Cost estimation for production of garlic powder

Fixed cost		
S.No	Fixed cost	Rs/ year
(i)	Rent yearly	2,40,000
(ii)	Plant and machinery	4,00,000
(iii)	Pre operative expenses	10,000
(iv)	Interest on fixed asset	40,000
	Total	6,60,000
Variable cost		
(a)	Supervision/ Actt	1,20,000
(b)	Semi-skilled and unskilled labourer	1,20,000
(ii)	Raw material	4,00,000
(iii)	Packaging and preservatives charges	50,000
(iv)	Power and water	2,50,000
(v)	Miscellaneous	
	Total	9,40,000
	Interest on working capital @ 10% per annum	94,000
Total cost = Fixed cost + Variable cost = 6, 60,000 + 9, 40,000 + 94,000=16, 94,000		

Cost per unit weight (12,000 kg powder) = 16, 94,000/ 12,000 = 141.16 Rs./ kg

Assumption

Yearly production of garlic powder is assumed 12 tones and average purchasing price is taken as 10 Rs. / kg for above calculations

CHAPTER V

SUMMARY AND CONCLUSIONS

Garlic (*Allium sativum* L.) has been used as a food, a condiment, and for medicinal purposes for over many centuries. Garlic is still probably nature's most powerful medicinal plant to us today. It is recognized to have remarkable preventive and curative abilitities. Garlic is mainly used aromatic spices and pickles as it has digestive, carminative and anti-rheumatic properties. It is being used in ayurvedic formulation since a long for curing lungs, healing intestinal ulcer and checking muscular pain & giddiness. The alliin is found within the mesophyl cells and also in the garlic clove around the phloem in the cells around the vascular bundles an enzyme called alliinase is present. When garlic cloves are crushed, the combination of these two produces allicin and other thiosulphonates. The largest concentration of alliin is actually found in garlic that is why garlic is considered the main source of allicin. The allicin appears to be effective against *E. coli*., *Staphylococcus aureus*, *Clostridium perfringens* and *Salmonella* spp.

The consumption of garlic reduces the risk of cardiovascular disease and cancer (Arnault *et al.*, 2005). The protective mechanism of the garlic against cancer andcardiovascular diseases has been well established. Garlic is considered the main source of allicin which appears to be effective against *E. coli, Staphylococcus aureus, Clostridium perfringens* and *Salmonella* spp. (Yu and Wu, 1989). It has been proved that garlic has different applications as antimicrobial, antitumor, antithrombotic, hypolipidaemic, antiarthritic and hypoglycemic agent (Abdel-Salam *et al*., 2008). The garlic bulbs are valued for their flavor and have wide applications in food industries (Mishra *et al*., 2011; Puranik *et al*., 2011and Dewi *et al.,* 2011).

The most important part of garlic plant is the compound bulb. Each bulb is made of 6-26 cloves and is wrapped in white papery sheath. Some varieties have a radish or purplish sheath. Garlic processing involves various unit operations such as curing, cleaning, grading, storage, bulb breaking, clove separation, peeling, dehydration, size reduction, packing and product (flakes, powder, paste, pickle, oil pills etc.) formation etc.

The separation of garlic cloves requires special care and skill due to its typical physical characteristics and presence of essential volatile oils in the epidermal cells. Conventionally, separation of garlic cloves is performed manually by rubbing the bulb between palms, against jute bags or by beating with wooden stick. A prototype for garlic clove separation has been reported to be developed (Mudgal, 2009; Mudgal and Sahay, 2009). Peeling of cloves is the unit operation through which papery outer skin is removed to facilitate further processing. Typical shape of cloves makes the peeling to be very tedious and time-consuming operation. The peeling of garlic cloves requires special care and skill because of the typical physical characteristics and presence of essential volatile oils in the epidermal cells imparting garlic its characteristic aroma. Conventionally, peeling is performed by rubbing the cloves against jute bags on a hard surface. Typical size and shape of cloves makes the peeling to be very tedious and time-consuming operation. Peeling efficiency of the garlic peelers was also found to be affected with variety and moisture present.

Keeping the product fresh is the best way to maintain its nutritional value, but most storage techniques require low temperatures, which are difficult to maintain throughout the distribution chain. On the other hand, drying is a suitable alternative for post harvest management especially in countries like India where low temperature distribution and handling facilities are poorly established. 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. Fluidized bed drying technique is a very convenient method of drying for heat sensitive food materials as it prevents them from overheating. Drying of vegetables in a fluidized bed dryer produces dry vegetable pieces of excellent quality in a much shorter time than in continuous belt dryers which are generally used for drying (Bobic *et al.* 2002).

Freeze dehydration typically results in biological products with a porous crust and of superior rehydration capability whereas hot air drying results in a dense product with an impermeable crust. The nutrients are lost during different processing conditions while freeze drying in which the nutrient loss are minimized has the advantage over other methods and also it retains the flavour, sensory quality, wholesomeness and original structure of product. This is an improved method of preparing stable water-soluble product from aroma and flavour bearing materials

(Kylink, 1990).

The dehydration with little induced degradation of nutritional properties while having higher retention of flavour/essential oils can be the valued technology for garlic preservation. Availability of raw garlic at cheaper prices during lean season offers a very attractive opportunity for entrepreneur in the field of garlic processing. The garlic paste, dehydrated flakes and powder being a good value added product can fetch good foreign exchange by exporting quality garlic products. Growth in popularity of convenient foods has stimulated increasing demand for high quality dehydrated garlic products like garlic flakes, garlic oil and garlic powder. Considering the increasing demand for garlic products in domestic and export market, an attempt has been made for a study on post harvest processing of garlic with the following specific objectives:

1. To study the existing mechanical methods of garlic processing for further improvement,
2. To study the process parameters of garlic processing,
3. To optimize the process parameters of garlic processing,
4. To develop a technology package for garlic processing and
5. To evaluate techno-economic feasibility.

Yamuna Safed variety of garlic was selected for conducting all experimental trials. The physical characteristics of garlic bulb and cloves *viz.*, moisture content (%), bulk density (kg/m^3), bulb diameter (mm), length and thickness of garlic clove (mm), number of cloves per garlic bulb were evaluated. It was found that the number of cloves in a garlic bulb varied from 16-52 cloves/bulb. The weight of garlic bulbs and cloves were found to vary from 22.40 to 52.22 g and 0.8 g to 1.32 g, respectively. The diameter of garlic bulb of the variety in use was found to vary from 32 mm to 38 mm. The clove length ranged from 1.92 cm to 3.78 cm. The thickness of garlic clove ranged from 5.25 to 9.23 mm. The average thickness was recorded as 7.07 mm. Sphericity of garlic clove was ranged from 0.38 - 0.48. The mean value of sphericity of garlic bulb was calculated as 0.42. Average bulk density was observed to be 332.2 kg/m^3.

A survey was conducted to study and analyze the existing methods of garlic

processing in the major garlic producing districts of Rajasthan. The survey results revealed that most of the on farm practices are performed with traditional methods. The garlic bulb breaker was the only prototype found to be used for separation of cloves for purpose seed or further processing. The performance evaluation studies of garlic bulb breaker were performed with test sample of 5 kg healthy garlic bulbs of *Yamuna Safed* variety. The capacity of the existing garlic bulb breaker was found to vary between 720 and 780 kg/h. Clove separation efficiency of the same prototype was estimated in the range of 92.80- 93.37%. It has been observed that the existing garlic bulb breaker works with output capacity of 750 kg/h with 93 per cent clove separation efficiency with 0.5-2 per cent crushing losses.

The performance of existing garlic clove peeler was found unsatisfactory. The peeling per cent was observed to be very low and there was crushing/ bruising of garlic cloves.

The pre-treatments *viz.*, hydrothermal(blanching the garlic cloves for 2, 6 and 10 minutes in boiling water), thermal (heating at three temperature levels (50, 60 and 70ºC) for the time of 10, 20 and 30 min)and chemical(soaking in 0.1 per cent $NaHCO_3$ solution and keeping at ambient temperature for 10 min; application of 2% mustard oil and conditioning for 10 min at ambient temperature) treatment were applied to the garlic cloves to facilitate the peeling operation. The peeling time in thermal tratment (12.10 min for 30 min heating at 70°C)was observed as minimum as compared to the other treatments *i.e.* chemical treatment, hydrothermal treatment and control treatment. Hence, combination of both 70 ^{o}C air temperature and 30 min thermal treatment in air oven was finally selected for peeling of garlic cloves for further investigations. The average manual peeling time for 100 g of untreated cloves was found to be 28.7 min.

A garlic clove peeler was developed in which peeling of clove is performed with the assistance of compressed air. The height of peeling chamber (400 mm) was kept 50 mm higher than the maximum bouncing height (350 mm) to safe guard of garlic clove carried away along with the skin at husk outlet. Bed depth (60 mm) was selected in such a way that all the material (garlic cloves) come in contact of swirling air and gets peeled. Preliminary trials on clove peeling were conducted to optimise the process parameters on the basis of maximum peeling recovery and peeling efficiency

with minimum damage of cloves. The optimized attributes *viz.* diameter of peeling chamber (130 mm), air jet pressure (10 kg/cm^2) and air jet position (60 mm) were taken to develop batch type clove peeler for peeling of 500 g garlic cloves with the assistance of compressed air.

A batch type garlic clove peeler (500 g capacity) consisting four main components *viz*. feed hopper, peeling chamber, air jet positions and husk discharge outlet was fabricated with optimized parameters. Provision of opening and closing of hopper was made by providing a movable check of MS plate at the bottom of the hopper, so that pressure inside the peeling chamber can be maintained during peeling operation. Galvanised iron pipe of 10 mm diameter was inserted and positioned at a height of 60 mm from the bottom of the peeling chamber to flow the air from the compressor. A hopper was provided at the upper portion of the peeling chamber for feeding separated garlic cloves. A circular mild steel plate was hinged at the bottom of the peeling chamber with a provision of clamping the bolt on the other side. Rubber ring gasket was provided under the chamber wall to prevent the air leakage.

The maximum peeling efficiency (97.6 %) was observed with peeling time of 70 s. With increase in the peeling time after 70 s the peeling recovery and peeling efficiency were observed to decrease because of abrasive damage to the skin of peeled cloves. With 60 s of peeling time, the peeling efficiency was recorded to be 90.4 %. No damage to the surface of peeled garlic was noticed for peeling time of 60 s though 9.4 % cloves remained unpeeled. Therefore, 70 s peeling time was found most suitable for peeling garlic cloves with 97.6 % peeling efficiency.

The information collected on garlic drying revealed that this unit operation is not carried out by the farmers. However, the processors and industrialist are using different drying methods namely solar drying, mechanical drying, fluidized bed drying and freeze drying. The processor emphasized on mechanical drying and exporters emphasized on freeze drying.

Sun drying took nearly 50 h of exposure in drying of unpeeled garlic cloves whereas only 40 hours were required for peeled samples to reach the same moisture level in the range of 7.46 to 7.80 % (db) from initial moisture content of 198.5 % (db)**.** It can be seen that 20 % time could be saved for drying of peeled cloves with comparison to unpeeled samples of peeling. The effect of drying time on variation in moisture content reduced from 198.5 % (d.b.) to 7.82 % (d.b.) in 50 hrs in unpeeled garlic cloves while peeled garlic cloves 198.51 % (d.b.) to 7.46 % (d.b.) in 40 hrs.

About 33 h were required for solar drying of unpeeled garlic cloves (up to moisture content of 7.9 %) whereas only 28.5 h were required for peeled samples to

reach the 7.5 per cent moisture level from initial moisture content of 198.5 % (db). The drying rate of garlic cloves for solar cabinet dryer was found to be higher at initial stage and it decreased with reduction in moisture content. The drying rate was found to be higher in solar drying than that of open sun drying.

The convective drying behaviour of dehydrated garlic cloves at drying air temperature of 40, 50 and 60°C and velocities of 1.0, 1.5 and 2.0 m/s were studied. A wide variation in drying time from 570 to 1200 min for the range of drying air temperatures and air velocities was observed during study. Drying time in general decreased with increase in drying air temperature as well as increase in drying air velocity but the effect of air temperature was more pronounced as compared to air velocity. It was also observed that drying rate increased with increase in drying air temperature. This resulted into substantial decrease in drying time and no constant rate period was found during convective drying of dehydrated garlic cloves and entire drying took place in falling rate period. Moisture diffusivities were calculated and found to vary in the range of 3.03×10^{-10} m²/s to 8.64×10^{-10} m²/s. during convective drying of garlic cloves.

The garlic slices were also dehydrated in fluidized bed dryer at air temperature of 40, 50 and 60°C with air velocity of 3.0m/s. 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 similar to tray drying process. The drying time for garlic slices dried at 40, 50 and 60ºC was found to be 306, 274 and 180 min for air velocity of 3.0 m/s. It was found that complete drying took place in falling rate period and constant rate period of drying is completely missing similar to tray drying process.

The 4 mm garlic slices were also dried in freeze dryer at freezing temperature of - 40°C. About 48 h of drying time was recorded to reduce the initial moisture content of 198.50 per cent to 7.8 per cent in freeze dryer.

The L value and flavour strength of fresh garlic was recorded to be 72.64 and 0.66, respectively. The L value was observed to be 52.32, 58.72, around64.79, 66.42 and 68.23 for the samples dried in open sun, solar, convective, fluidized bed and

freeze drying method, respectively. L-value reduced when drying air temperature was increased from 40 to 60°C due to the exposure of product to high temperature for long duration which could have darkened the surface of the dried product. The flavour strength found to be 0.17, 0.19, 0.30, around 0.27 and 0.41 for the open sun, solar, convective, fluidized bed and freeze drying method, respectively. The flavour strength was observed to decrease with increase in drying temperature in case of convective tray drying for all drying air velocities. The water activity of garlic cloves and slices dehydrated in different drying methods varied between 0.25 and 0.29.

The garlic paste prepared from fresh cloves; dehydrated garlic cloves, slices and ground powder dried in convective tray dryer (at 60 ºC temperature and drying air velocity of 1.5 m/s) were taken for the shelf life study. The effect of storage period on the flavour strength and organoleptic parameters of garlic paste, dried garlic cloves, slices (flakes) and powder were studied up to 120 days. For paste, the flavour strength was found to be 0.65, 0.49, 0.46, 0.45 and 0.44 at interval of 0, 30, 60, 90 and 120 days, respectively. The colour, flavour and overall acceptability of the garlic paste, dehydrated cloves and powder was found to be satisfactory up to the storage period of 90, 120 and 90 days, respectively.

The recommended process flow chart for

1. Garlic flakes /powder

   Garlic bulb ⟶ Clove separation ⟶ Peeling/Slicing ⟶ Drying ⟶ Pulverizing ⟶ Packaging ⟶ Storage

2. Garlic paste

   Garlic bulb ⟶ Clove separation ⟶Peeling ⟶ Wet grinding ⟶ Addition of preservatives ⟶ mixing ⟶ Packaging ⟶ Storage

For analysis of cost of garlic paste and powder production the relevant costs were categorized into fixed and variable costs, To work out the per kg cost of garlic paste and powder production, it is necessary to compute average net cost per kg garlic paste and powder. The annual powder production was assumed 12,000 kg and paste 40,000 kg. The total cost of production of garlic paste and powder was found to be Rs 38.15 per kg and 141.16 per kg, respectively.

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Appendix: A-1

Survey questionnaire for existing garlic processing practices

Respondents = 60

S.No.	Parameters	Score (%)	
		Manual	Mechanical
1.	Curing, drying and storage of garlic bulbs	95(Traditional methods)	5 (Improved methods)
2.	Grading methods of garlic	97	3
	Processing garlic	91(Consumed as raw)	9(Processed)
3.	Clove separation	90	10
4.	Peeling	99	1
5.	Drying of cloves (Open sun drying/solar drying/mechanical drying)	95(Solar drying)	5(Mechanical drying)
6.	Processed Product storage	70 (HDPE, LDPE polyethylene)	30 (Bottling and jar)

APPENDIX A-2

Specifications of tray dryer

S.No.	Particulars	Details
1.	Model	12 TD
2.	Make	Lab line, Gujarat
3.	Outer dimensions (mm)	1450 x 650 x 950
4.	Drying chamber (mm)	1320 x 500 x 860
5.	No. of trays (metal)	2 (Stainless steel)
6.	Tray size (mm)	340 x 270 x 38
7.	Loading density (kg / m^2)	1.089
	No. of heaters	4
8.	(i) Energy	2.5 kWh
	(ii) Temperature range	up to 92°C
	(iii) Control	Thermostatic
9.	No. of fans	One
10.	Motor	One, 1-phase, 230 V, 50 Hz, 0.375 kW (0.5 HP)
11.	Rating controls	On – off (thermostatic)

APPENDIX A-3

Specifications of Hunter lab colorimeter

S.No.	Particulars	Details
1.	Manufacturer's Name	Hunter Associates Laboratory, Inc.
2.	Product Name	Colour flex
3.	Model	CFLX-DIEF, CLFX-45
4.	Illumination and viewing	
	(i) Source	Dual beam Xenon flash lamp
	(ii) Source UV	Nominal match to D65
	(iii) Integrating Sphere	63.5 mm diameter, high efficiency, white coating
5.	Port diameters/view diameters	
	(i) 45/0 model	31.8 mm/25.4 mm
	(ii) Diffuse/8°	14.9 mm/8.0 mm

APPENDIX A-4

Numerical scoring test for rehydrated sample

Sensory evaluation form used for various sensory attributes of dried and rehydrated garlic samples.

Name: ---------- Date: ----------

Instruction: You are requested to assess the given sample and evaluate organoleptic quality parameters *viz.*, colour, flavor, taste, appearance and overall acceptability on the basis of grade scores given below:

Quality grade description	Score
Excellent	80-100
Good	60-79
Fair	40-59
Poor	20-39
Very poor	0-19

Code No.	Colour	Flavour	Taste	Appearance	Overall acceptability
1					
2					
3					
4					
5					

Signature

APPENDIX A-5

Specification of Freeze dryer

Dimensions	: 1100 X 850 X 650 mm
Weight	: 200 kg
Number of Shelves	: 2 active + 1 compensating
Shelf dimensions	: 350 X 275 X 70 mm
Total usable shelf area	: 0.2 m^2
Condenser	
Chamber Diameter	: 200 mm
Max. Ice Capacity	: 5 kg
Temperature	: 55 C ±5 °C @ 20 °C ambient
Cooling system	
Method	: direct fluid, single expansion
Minimum Temperature	: -47°C
Refrigerant	: CFC free
Compressor	: 0.75 hp
Shelf heating system	
Method	: Direct electrical heat input
Maximum temperature	: 60°C
Type	: Cartridge type heater
Heat Load	: 300 Watts, 50 V
Temperature	
Control	: 1 °C
Uniformity	: 1 °C
Measurement	: 3 temp. probes (2 for product, 1 for fluid)
Door Seal Lubricant	: Silicon Grease
Electrical power requirement	: 220-240 V, 50 Hz, 1 phase
Maximum Current	: 10 amps
Refrigeration	
Compressor	: 0.75 hp hermetic unit
Refrigerant	: CFC free
Heat extraction rate	: 200 kcal h^{-1} @ -35 °C @ 20 °C ambient
Instrumentation	: Rock type

Fridge	: Green ON/OFF
Pump	: Green ON/OFF
Defrost	: Red ON/OFF

Gauges

Vacuum	: Digital pirani
Temperature	: Thermocouple

Vacuum pump

Type	: DD 12 rotary type
Oil	: Molecular distilled
Oil quantity	: 1.0 Lit max.
Pump exhaust	: EMF filter

APPENDIX B-1

Drying data in open sun for unpeeled and peeled garlic clove

Ambient air conditions

Temperature : 35°C

Relative humidity : 56-58%

Garlic cloves characteristics

Initial moisture content (db) :198.51%

Initial weight : 1000 g

S. No.	Unpeeled clove		Peeled clove	
	Drying time (h)	Moisture Content (% db)	Drying time (h)	Moisture Content (% db)
1	0.0	198.50	0.0	198.51
2	1.0	185.07	2.0	179.01
3	2.0	171.83	4.0	162.00
4	3.0	159.34	6.0	141.10
5	4.0	149.32	8.0	125.00
6	5.0	143.38	10.0	105.00
7	6.0	138.88	12.0	92.00
8	7.0	136.34	14.0	80.80
9	8.0	128.22	16.0	70.00
10	9.0	123.62	18.0	65.00
11	10.0	122.32	20.0	56.00
12	11.0	118.73	22.0	48.00
13	12.0	115.15	24.0	35.00
14	13.0	111.12	26.0	33.00
15	14.0	110.19	28.0	24.00
16	15.0	106.09	30.0	20.00
17	16.0	102.05	32.0	16.00
18	17.0	98.30	34.0	13.00
19	18.0	94.49	36.0	11.00
20	19.0	91.30	38.0	8.50
21	20.0	86.50	40.0	7.46

22	**21.0**	**81.90**	**--**	**--**
23	**22.0**	**76.50**	**--**	**--**
24	**23.0**	**71.10**	**--**	**--**
25	**24.0**	**66.90**	**--**	**--**
26	**25.0**	**62.50**	**--**	**--**
27	**26.0**	**58.00**	**--**	**--**
28	**27.0**	**54.10**	**--**	**--**
29	**28.0**	**51.90**	**--**	**--**
30	**29.0**	**48.30**	**--**	**--**
31	**30.0**	**45.10**	**--**	**--**
32	**31.0**	**42.50**	**--**	**--**
33	**32.0**	**39.41**	**--**	**--**
34	**33.0**	**36.71**	**--**	**--**
35	**34.0**	**33.20**	**--**	**--**
36	**35.0**	**30.50**	**--**	**--**
37	**36.0**	**28.90**	**--**	**--**
38	**37.0**	**26.20**	**--**	**--**
39	**38.0**	**23.70**	**--**	**--**
40	**39.0**	**21.50**	**--**	**--**
41	**40.0**	**19.50**	**--**	**--**
42	**41.0**	**17.90**	**--**	**--**
43	**42.0**	**15.10**	**--**	**--**
44	**43.0**	**13.50**	**--**	**--**
45	**44.0**	**12.00**	**--**	**--**
46	**45.0**	**11.00**	**--**	**--**
47	**46.0**	**10.00**	**--**	**--**
48	**47.0**	**9.74**	**--**	**--**
49	**48.0**	**8.62**	**--**	**--**
50	**49.0**	**7.82**	**--**	**--**

APPENDIX B-2

Solar drying data for unpeeled and peeled garlic clove

Ambient air conditions

Temperature	35°C
Relative humidity	56-58%

Garlic cloves characteristics

Initial moisture content (db)	198.51%
Initial weight	1000g

S.No.	Drying hour	Unpeeled clove Moisture Content % db	Peeled clove Moisture Content % db
1	0.0	198.50	198.50
2	1.5	179.01	175.10
3	3.0	162.00	158.00
4	4.5	141.10	134.80
5	6.0	125.00	115.00
6	7.5	105.00	101.00
7	9.0	92.00	96.00
8	10.5	80.00	82.90
9	12.0	70.50	71.80
10	13.5	65.10	65.12
11	15.0	60.00	52.17
12	16.5	52.00	45.15
13	18.0	41.00	38.21
14	19.5	37.00	31.42
15	21.0	32.00	25.25
16	22.5	28.00	17.46
17	24.0	24.00	14.10
18	25.5	22.00	9.59
19	27.0	18.00	8.03
20	28.5	13.00	7.50
21	30.0	11.00	--
22	31.5	9.60	--
23	33.0	7.90	--

APPENDIX C-1
Data on convective drying of garlic cloves

Ambient air conditions

Temperature - 32°C Relative humidity- 56-58%

Drying air conditions

Temperature - 40 °C Air velocity - 1 m/s

Garlic cloves characteristics

Initial moisture content (db) - 198.50% Initial weight- 100.00 g

S. No.	Time , min	M. C. (db), %	M.C. (wb), %	Drying rate, g w/ g dm-min	MR	ln(MR)
1	0	198.51	66.50	-	1.000	0
2	15	184.63	64.87	0.00925	0.928	-0.075
3	30	174.62	63.59	0.00667	0.876	-0.133
4	45	165.08	62.28	0.00636	0.826	-0.191
5	60	155.96	60.93	0.00608	0.778	-0.251
6	90	139.15	58.19	0.00560	0.691	-0.370
7	120	124.44	55.45	0.00490	0.614	-0.488
8	150	111.84	52.79	0.00420	0.548	-0.601
9	180	100.22	50.06	0.00387	0.488	-0.718
10	210	89.53	47.24	0.00356	0.432	-0.839
11	240	79.15	44.18	0.00346	0.378	-0.973
12	300	69.39	40.96	0.00163	0.327	-1.117
13	360	60.30	37.62	0.00151	0.280	-1.274
14	420	51.59	34.03	0.00145	0.234	-1.451
15	480	43.68	30.40	0.00132	0.193	-1.644
16	570	36.27	26.61	0.00082	0.155	-1.867
17	660	29.41	22.72	0.00076	0.119	-2.130
18	750	23.10	18.77	0.00070	0.086	-2.453
19	840	17.48	14.88	0.00062	0.057	-2.870
20	930	13.53	11.91	0.00044	0.036	-3.322
21	1020	10.19	9.25	0.00037	0.019	-3.979
22	1110	7.53	7.01	0.00030	0.005	-5.327
23	1200	7.28	6.79	0.00003	0.004	-5.636

APPENDIX C-2

Data on convective drying of garlic cloves

Ambient air conditions

Temperature - 32°C Relative humidity- 56-58%

Drying air conditions

Temperature - 50 ^{o}C Air velocity - 1 m/s

Garlic cloves characteristics

Initial moisture content (db) - 198.50% Initial weight- 100.00 g

S. No.	Time , min	M. C. (db), %	M.C. (wb), %	Drying rate, g w/ g dm-min	MR	ln(MR)
1	0	198.51	66.50	-	1.000	0
2	15	182.59	64.61	0.0106	0.917	-0.087
3	30	170.48	63.03	0.0081	0.854	-0.158
4	45	159.09	61.40	0.0076	0.795	-0.230
5	60	148.54	59.77	0.0070	0.740	-0.302
6	90	129.69	56.46	0.0063	0.641	-0.444
7	120	113.40	53.14	0.0054	0.557	-0.586
8	150	99.49	49.87	0.0046	0.484	-0.726
9	180	87.01	46.53	0.0042	0.419	-0.870
10	210	75.60	43.05	0.0038	0.360	-1.023
11	240	64.76	39.31	0.0036	0.303	-1.194
12	300	54.49	35.27	0.0017	0.250	-1.388
13	360	45.18	31.12	0.0016	0.201	-1.604
14	420	36.62	26.80	0.0014	0.156	-1.855
15	480	28.89	22.41	0.0013	0.116	-2.153
16	570	21.63	17.78	0.0008	0.078	-2.547
17	660	17.26	14.72	0.0005	0.056	-2.891
18	750	13.39	11.81	0.0004	0.035	-3.341
19	840	9.89	9.00	0.0004	0.017	-4.066
20	930	7.26	6.77	0.0003	0.003	-5.673

APPENDIX C-3
Data on convective drying of garlic cloves

Ambient air conditions
Temperature - 32°C Relative humidity- 56-58%

Drying air conditions
Temperature - 60 °C Air velocity - 1 m/s

Garlic cloves characteristics
Initial moisture content (db) - 198.50% Initial weight- 100.00 g

S. No.	Time , min	M. C. (db), %	M.C. (wb), %	Drying rate, g w/ g dm-min	MR	ln(MR)
1	0	198.51	66.50	-	1.000	0.000
2	15	180.95	64.41	0.01256	0.908	-0.096
3	30	167.11	62.56	0.01008	0.836	-0.179
4	45	154.19	60.66	0.00947	0.769	-0.263
5	60	142.48	58.76	0.00866	0.708	-0.345
6	90	122.04	54.96	0.00767	0.602	-0.508
7	120	104.49	51.10	0.00671	0.510	-0.673
8	150	89.47	47.22	0.00586	0.432	-0.840
9	180	76.25	43.26	0.00526	0.363	-1.014
10	210	64.20	39.10	0.00487	0.300	-1.204
11	240	52.95	34.62	0.00399	0.242	-1.421
12	300	42.20	29.68	0.00160	0.186	-1.685
13	360	32.62	24.60	0.00132	0.136	-1.998
14	420	24.16	19.46	0.00082	0.091	-2.392
15	480	16.50	14.16	0.00051	0.052	-2.965
16	570	10.32	9.35	0.00021	0.019	-3.944
17	660	7.10	6.63	0.00005	0.003	-5.943
18	750	6.93	6.48	0.01256	0.002	-6.380

APPENDIX C-4
Data on convective drying of garlic cloves

Ambient air conditions

Temperature - 32°C Relative humidity- 56-58%

Drying air conditions

Temperature - 40 ^{o}C Air velocity – 1.5 m/s

Garlic cloves characteristics

Initial moisture content (db) - 198.50% Initial weight- 100.00 g

S. No.	Time , min	M. C. (db), %	M.C. (wb), %	Drying rate, g w/g dm-min	MR	ln(MR)
1	0	198.51	66.50	-	1.000	0
2	15	183.80	64.76	0.0098	0.923	-0.080
3	30	172.95	63.36	0.0072	0.867	-0.143
4	45	162.57	61.92	0.0069	0.813	-0.207
5	60	152.63	60.42	0.0066	0.761	-0.273
6	90	134.15	57.29	0.0062	0.665	-0.409
7	120	117.77	54.08	0.0055	0.579	-0.546
8	150	103.50	50.86	0.0048	0.505	-0.683
9	180	90.21	47.43	0.0044	0.436	-0.831
10	210	77.85	43.77	0.0041	0.371	-0.991
11	240	65.80	39.69	0.0040	0.309	-1.176
12	300	54.37	35.22	0.0019	0.249	-1.391
13	360	43.62	30.37	0.0018	0.193	-1.646
14	420	34.47	25.64	0.0015	0.145	-1.929
15	480	26.75	21.10	0.0013	0.105	-2.254
16	570	20.14	16.76	0.0007	0.071	-2.652
17	660	14.64	12.77	0.0006	0.042	-3.173
18	750	10.75	9.70	0.0004	0.022	-3.835
19	840	7.46	6.94	0.0004	0.004	-5.407
20	930	7.05	6.58	0.0001	0.002	-6.060

APPENDIX C-5

Data on convective drying of garlic cloves

Ambient air conditions

Temperature - 32°C Relative humidity- 56-58%

Drying air conditions

Temperature - 50 ^{o}C Air velocity – 1.5 m/s

Garlic cloves characteristics

Initial moisture content (db) - 198.50% Initial weight- 100.00 g

S. No.	Time , min	M. C. (db), %	M.C. (wb), %	Drying rate, g w/ g dm-min	MR	ln(MR)
1	0	198.51	66.50	-	1.000	0.000
2	15	181.72	64.50	0.0112	0.912	-0.092
3	30	168.72	62.79	0.0087	0.845	-0.169
4	45	156.43	61.00	0.0082	0.781	-0.248
5	60	144.96	59.18	0.0076	0.721	-0.327
6	90	124.22	55.40	0.0069	0.613	-0.490
7	120	105.99	51.45	0.0061	0.518	-0.658
8	150	90.09	47.39	0.0053	0.435	-0.832
9	180	75.59	43.05	0.0048	0.360	-1.023
10	210	62.15	38.33	0.0045	0.289	-1.240
11	240	50.20	33.42	0.0040	0.227	-1.482
12	300	39.42	28.28	0.0018	0.171	-1.766
13	360	29.52	22.79	0.0017	0.119	-2.125
14	420	20.82	17.24	0.0014	0.074	-2.602
15	480	14.27	12.49	0.0011	0.040	-3.220
16	570	9.65	8.80	0.0005	0.016	-4.142
17	660	6.96	6.50	0.0003	0.002	-6.286

APPENDIX C-6

Data on convective drying of garlic cloves

Ambient air conditions

Temperature - 32°C Relative humidity- 56-58%

Drying air conditions

Temperature - 60 ^{o}C Air velocity – 1.5 m/s

Garlic cloves characteristics

Initial moisture content (db) - 198.50% Initial weight- 100.00 g

S. No.	Time , min	M. C. (db), %	M.C. (wb), %	Drying rate, g w/ g dm-min	MR	ln(MR)
1	0	198.51	66.50	-	1.000	0
2	15	179.66	64.24	0.0126	0.902	-0.103
3	30	164.53	62.20	0.0101	0.823	-0.195
4	45	150.34	60.05	0.0095	0.749	-0.289
5	60	137.34	57.87	0.0087	0.681	-0.384
6	90	114.32	53.34	0.0077	0.561	-0.577
7	120	94.20	48.51	0.0067	0.456	-0.784
8	150	76.62	43.38	0.0059	0.365	-1.008
9	180	60.82	37.82	0.0053	0.283	-1.264
10	210	46.21	31.60	0.0049	0.206	-1.578
11	240	34.24	25.51	0.0040	0.144	-1.938
12	300	24.63	19.76	0.0016	0.094	-2.365
13	360	16.68	14.30	0.0013	0.053	-2.946
14	420	11.73	10.50	0.0008	0.027	-3.622
15	480	8.69	7.99	0.0005	0.011	-4.522
16	570	6.81	6.37	0.0002	0.001	-6.837

APPENDIX C-7

Data on convective drying of garlic cloves

Ambient air conditions

Temperature - 32°C Relative humidity- 56-58%

Drying air conditions

Temperature - 40 °C Air velocity - 2 m/s

Garlic cloves characteristics

Initial moisture content (db) - 198.50% Initial weight- 100.00 g

S. No.	Time , min	M. C. (db), %	M.C. (wb), %	Drying rate, g w/ g dm-min	MR	ln(MR)
1	0	198.51	66.50	-	1.000	0.000
2	15	183.80	64.76	0.0098	0.923	-0.080
3	30	172.95	63.36	0.0072	0.867	-0.143
4	45	162.57	61.92	0.0069	0.813	-0.207
5	60	152.63	60.42	0.0066	0.761	-0.273
6	90	134.15	57.29	0.0062	0.665	-0.409
7	120	117.77	54.08	0.0055	0.579	-0.546
8	150	103.50	50.86	0.0048	0.505	-0.683
9	180	90.21	47.43	0.0044	0.436	-0.831
10	210	77.85	43.77	0.0041	0.371	-0.991
11	240	65.80	39.69	0.0040	0.309	-1.176
12	300	54.37	35.22	0.0019	0.249	-1.391
13	360	43.62	30.37	0.0018	0.193	-1.646
14	420	34.47	25.64	0.0015	0.145	-1.929
15	480	26.75	21.10	0.0013	0.105	-2.254
16	570	20.14	16.76	0.0007	0.071	-2.652
17	660	14.64	12.77	0.0006	0.042	-3.173
18	750	10.75	9.70	0.0004	0.022	-3.835
19	840	7.46	6.94	0.0004	0.004	-5.407
20	930	7.05	6.58	0.0001	0.002	-6.060

APPENDIX C-8
Data on convective drying of garlic cloves

Ambient air conditions

Temperature - 32°C Relative humidity- 56-58%

Drying air conditions

Temperature - 50 °C Air velocity - 2 m/s

Garlic cloves characteristics

Initial moisture content (db) - 198.50% Initial weight- 100.00 g

S. No.	Time , min	M. C. (db), %	M.C. (wb), %	Drying rate, g w/ g dm-min	MR	ln(MR)
1	0	198.51	66.50	-	1.000	0
2	15	181.72	64.50	0.0112	0.912	-0.092
3	30	168.72	62.79	0.0087	0.845	-0.169
4	45	156.43	61.00	0.0082	0.781	-0.248
5	60	144.96	59.18	0.0076	0.721	-0.327
6	90	124.22	55.40	0.0069	0.613	-0.490
7	120	105.99	51.45	0.0061	0.518	-0.658
8	150	90.09	47.39	0.0053	0.435	-0.832
9	180	75.59	43.05	0.0048	0.360	-1.023
10	210	62.15	38.33	0.0045	0.289	-1.240
11	240	50.20	33.42	0.0040	0.227	-1.482
12	300	39.42	28.28	0.0018	0.171	-1.766
13	360	29.52	22.79	0.0017	0.119	-2.125
14	420	20.82	17.24	0.0014	0.074	-2.602
15	480	14.27	12.49	0.0011	0.040	-3.220
16	570	9.65	8.80	0.0005	0.016	-4.142
17	660	6.96	6.50	0.0003	0.002	-6.286

APPENDIX C-9
Data on convective drying of garlic cloves

Ambient air conditions
Temperature - 32°C Relative humidity- 56-58%

Drying air conditions
Temperature - 60 ^{o}C Air velocity - 2 m/s

Garlic cloves characteristics
Initial moisture content (db) - 198.50% Initial weight- 100.00 g

S. No.	Time , min	M. C. (db), %	M.C. (wb), %	Drying rate, g w/ g dm-min	MR	ln(MR)
1	0	198.51	66.50	-	1.000	0.000
2	15	179.66	64.24	0.0126	0.902	-0.103
3	30	164.53	62.20	0.0101	0.823	-0.195
4	45	150.34	60.05	0.0095	0.749	-0.289
5	60	137.34	57.87	0.0087	0.681	-0.384
6	90	114.32	53.34	0.0077	0.561	-0.577
7	120	94.20	48.51	0.0067	0.456	-0.784
8	150	76.62	43.38	0.0059	0.365	-1.008
9	180	60.82	37.82	0.0053	0.283	-1.264
10	210	46.21	31.60	0.0049	0.206	-1.578
11	240	34.24	25.51	0.0040	0.144	-1.938
12	300	24.63	19.76	0.0016	0.094	-2.365
13	360	16.68	14.30	0.0013	0.053	-2.946
14	420	11.73	10.50	0.0008	0.027	-3.622
15	480	8.69	7.99	0.0005	0.011	-4.522
16	570	6.81	6.37	0.0002	0.001	-6.837

APPENDIX D-1

Data on fluidized bed drying of garlic slices

Ambient air conditions

Temperature	32°C
Relative humidity	56-58%

Drying air conditions

Temperature	40 ^{o}C
Air velocity	3 m/s

Garlic slices characteristics

Initial moisture content (db)	198.50%
Initial weight	50 g
Thickness of sample	4 mm

S. No	Time	MC %(db)	Drying rate, g w/ g dm-min	MR	ln(MR)
1	0	198.50	-	1.000	0
2	4	190.00	0.019	0.524	-0.646
3	8	183.30	0.019	0.501	-0.691
4	12	175.60	0.019	0.483	-0.727
5	16	168.00	0.019	0.463	-0.771
6	20	163.10	0.012	0.442	-0.816
7	24	155.30	0.020	0.429	-0.846
8	28	146.50	0.022	0.408	-0.896
9	32	141.10	0.014	0.385	-0.955
10	40	129.80	0.014	0.370	-0.994
11	48	121.90	0.010	0.340	-1.079
12	56	113.50	0.011	0.319	-1.143
13	64	105.70	0.009	0.296	-1.216
14	72	100.20	0.007	0.275	-1.289
15	84	93.37	0.006	0.261	-1.344
16	96	84.03	0.008	0.242	-1.417

17	**108**	**76.17**	**0.007**	**0.217**	**-1.526**
18	**120**	**68.30**	**0.007**	**0.196**	**-1.628**
19	**132**	**57.99**	**0.009**	**0.175**	**-1.742**
20	**148**	**49.14**	**0.005**	**0.148**	**-1.913**
21	**164**	**41.28**	**0.005**	**0.124**	**-2.088**
22	**180**	**34.89**	**0.004**	**0.103**	**-2.274**
23	**196**	**28.50**	**0.004**	**0.086**	**-2.456**
24	**212**	**22.60**	**0.004**	**0.069**	**-2.679**
25	**228**	**18.18**	**0.003**	**0.053**	**-2.941**
26	**242**	**14.74**	**0.002**	**0.041**	**-3.195**
27	**258**	**11.30**	**0.002**	**0.032**	**-3.449**
28	**274**	**8.85**	**0.002**	**0.023**	**-3.792**
29	**290**	**7.86**	**0.001**	**0.016**	**-4.137**
30	**306**	**6.88**	**0.001**	**0.013**	**-4.317**

APPENDIX D-2

Data on fluidized bed drying of garlic slices

Ambient air conditions

Temperature	32°C
Relative humidity	56-58%

Drying air conditions

Temperature	50 ^{o}C
Air velocity	3 m/s

Garlic slices characteristics

Initial moisture content (db)	198.50%
Initial weight	50 g
Thickness of sample	4 mm

S. No	Time	MC %(db)	Drying rate, g w/ g dm-min	MR	ln(MR)
1	0	198.50	-	1	0
2	4	188.00	0.024	0.523	-0.649
3	8	181.30	0.019	0.495	-0.704
4	12	174.90	0.016	0.477	-0.741
5	16	163.10	0.030	0.460	-0.777
6	20	153.30	0.025	0.428	-0.848
7	24	144.50	0.022	0.402	-0.911
8	28	136.10	0.021	0.378	-0.972
9	32	129.80	0.017	0.356	-1.033
10	40	120.20	0.012	0.339	-1.081
11	48	111.50	0.011	0.314	-1.160
12	56	101.70	0.013	0.290	-1.237
13	64	93.37	0.010	0.264	-1.332
14	72	85.03	0.010	0.242	-1.420
15	84	76.17	0.008	0.220	-1.516
16	96	66.30	0.008	0.196	-1.630

17	**108**	**56.99**	**0.008**	**0.169**	**-1.775**
18	**120**	**49.14**	**0.007**	**0.145**	**-1.934**
19	**132**	**41.28**	**0.007**	**0.124**	**-2.091**
20	**148**	**34.89**	**0.004**	**0.103**	**-2.277**
21	**164**	**28.50**	**0.004**	**0.086**	**-2.459**
22	**180**	**22.60**	**0.004**	**0.068**	**-2.681**
23	**196**	**18.18**	**0.003**	**0.053**	**-2.943**
24	**212**	**14.74**	**0.002**	**0.041**	**-3.197**
25	**228**	**11.30**	**0.002**	**0.032**	**-3.452**
26	**242**	**8.60**	**0.002**	**0.023**	**-3.794**
27	**258**	**7.69**	**0.001**	**0.015**	**-4.181**
28	**274**	**6.58**	**0.001**	**0.013**	**-4.354**

APPENDIX D-3
Data on fluidized bed drying of garlic slices

Ambient air conditions

Temperature	32°C
Relative humidity	56-58%

Drying air conditions

Temperature	60 ^{o}C
Air velocity	3 m/s

Garlic slices characteristics

Initial moisture content (db)	198.50%
Initial weight	50 g
Thickness of sample	4 mm

S. No	Time	MC %(db)	Drying rate, g w/ g dm-min	MR	ln(MR)
1	0	198.5	-	1.000	0
2	4	182.30	0.037	0.523	-0.648
3	8	168.10	0.039	0.479	-0.735
4	12	154.80	0.033	0.442	-0.818
5	16	142.00	0.032	0.406	-0.901
6	20	131.00	0.028	0.372	-0.989
7	24	121.00	0.025	0.342	-1.072
8	28	115.00	0.015	0.316	-1.153
9	32	107.00	0.021	0.300	-1.205
10	40	96.00	0.013	0.278	-1.279
11	48	81.61	0.018	0.249	-1.391
12	56	68.45	0.017	0.210	-1.559
13	64	58.50	0.012	0.175	-1.742
14	72	51.99	0.008	0.149	-1.906

15	**84**	**44.23**	**0.007**	**0.131**	**-2.031**
16	**96**	**34.40**	**0.008**	**0.110**	**-2.203**
17	**108**	**25.06**	**0.008**	**0.084**	**-2.474**
18	**120**	**19.66**	**0.005**	**0.059**	**-2.826**
19	**132**	**14.74**	**0.004**	**0.045**	**-3.105**
20	**148**	**10.32**	**0.003**	**0.032**	**-3.452**
21	**164**	**8.88**	**0.001**	**0.020**	**-3.918**
22	**180**	**7.05**	**0.001**	**0.016**	**-4.133**

Appendix E

Colour value and flavor strength of garlic clove and slice in different drying methods

S. No.	Drying methods	Temperature (°C)	Color value (L value)	Flavor strength (%)	Water activity (a_W)	Rehydration ratio
1.	Open sun drying (cloves)	---	52.32	0.17	0.28	2.37
2.	Solar drying (cloves)	---	58.72	0.19	0.27	2.33
3.	Mechanical tray drying Air velocity 1.0 m/s (cloves)	40	64.12	0.36	0.27	2.40
		50	64.95	0.34	0.28	2.21
		60	65.47	0.32	0.27	2.18
4.	Mechanical tray drying Air velocity 1.5 m/s	40	64.97	0.36	0.26	2.40
		50	64.79	0.34	0.28	2.20
		60	63.94	0.30	0.27	2.19
5.	Mechanical tray drying Air velocity 2.0 m/s (cloves)	40	64.86	0.34	0.25	2.49
		50	63.78	0.33	0.28	2.22
		60	62.71	0.29	0.29	2.19
6.	Fluidized bed drying Air velocity 3.0 m/s (slices)	40	66.57	0.26	0.26	2.39
		50	66.42	0.24	0.27	2.28
		60	66.24	0.21	0.29	2.10
7.	Freeze drying (slices)	- 40	68.23	0.41	0.27	2.38
8.	Fresh garlic (Control)	---	72.64	0.66	---	---