**POST-HARVEST TECHNOLOGY AND VALUE ADDITION OF GARLIC**

**VD Mudgal1, Bogala Madhu2\*, PS Champawat3**

1Former Dean, College of Dairy and Food Science Technology, MPUAT, Udaipur, Rajasthan.

2Assistant Professor and Head, Department of Agricultural Engineering, Siddharth institute of Engineering and Technology, Puttur

3Professor (Retd.,), Department of Processing and Food Engineering, CTAE,

\*Corresponding Author Email ID: madhucae10@gmail.com

**Abstract**

The primary aim of this review paper is to provide a simplified knowledge in the field of post-harvest management and value addition of the garlic for quality product development. Many operations *i.e* curing, drying, sorting and grading, packaging, storage of garlic bulbs are being performed between the cultivation of garlic in the field and reaching the quality bulbs to the consumers. Conventional production and processing of garlic implicate a number of hygienic problems which can pose tremendous risks for farmers, producers and consumers by adversely affecting the quality and storage life. There is a need for the adoption of innovative technologies for the separation, peeling, drying and grinding of garlic cloves in the process of product development. This contribution summarizes the major problems associated with conventional post-harvest practices and provides a review of alternative technologies developed so far as the demand for garlic has grown at an increasing rate owing to its classification as a functional or health food that enhances nutrition and health along with imparting taste.

*Keywords:* Garlic, Post-harvest technology, Storage, Drying, Value addition.

**1. Introduction**

Spices and herbs have been popular throughout the world since **ancient times** for various reasons such as flavoring and preserving foods, medicinal and cosmetic purposes (Purseglove *et al*., 1981; Srinivasan, 2005; Subbulakshmi and Naik, 2002). Garlic (*Aliium sativum* L.) is one of the earliest known food flavouring and seasoning plants, which have succeeded in infusing itself with the culinary tradition of many civilizations all over the world. It started its journey in central Asia, domesticated during Neolithic times, spread to the Middle East and northern Africa in 3000 BC, which quickly enabled it to reach Europe. By offering its unique nutritional and medicinal benefits, this plant has been quickly identified a one of the most precious gift of our nature. Improved varieties of the crop are grown widely throughout the world in many different soils under a variety of climatic conditions. In view of its importance in food and medicine, garlic has enjoyed an unprecedented attention amongst the scientific activities worldwide.

The total global production quantity of garlic in the year 2016 was 265.76 lakh tons and the harvested area to generate the above-mentioned production quantity was 14.68 lakh hectares of land. China was the global leader in the quantity of garlic produced with a production of 211.97 lakh tons, which represented approximately 80 per cent, share of the global market. The other producers are India and Republic of Korea followed by Bangladesh, Egypt and others (APEDA, 2016). India is the second largest producer of garlic with a total production of about 16.93 lakh tons and cultivation area of 3.2 lakh hectares during 2016-17. Rajasthan, Madhya Pradesh, Uttar Pradesh, Gujarat, Punjab, Assam, West Bengal, Maharashtra, Odisha, and Haryana are the main states where garlic is grown commercially. Rajasthan, Madhya Pradesh, and Uttar Pradesh produce 78 per cent of country's garlic. Himachal Pradesh, Karnataka, Chhattisgarh, Nagaland, Bihar, and Tamil Nadu also produce a sizeable quantity of garlic in cooler regions of the states. (<http://nhrdf.org>).

**2. Composition and Nutritional Value**

The high nutritional value and multiple uses in culinary preparations have made garlic an important spice crop in popularity and value. Table 2.1 gives the proximate composition and nutritive value of garlic (USDA, 2019). The chemical composition of the garlic includes enzymes, protein, vitamins (B1, B2, B6, C), flavonoids, minerals (Ca, Cu, Fe, Mn, P, K) antioxidants and thiosulfinates. Garlic is mostly used in preparation of pickles, food processing, pharmaceutical and medicinal usage, ayurvedic formulations etc. The consumption of garlic reduces the risk of cardiovascular disease and cancer (Arnault *et al.,* 2005). Garlic is considered as the main source of allicin which appears to be effective against E. coli, Staphylococcus aureus, *Clostridium perfringens and Salmonella* spp. (Yu and Wu, 1989).

**Table 2.1: Proximate composition and nutritive value of garlic bulb**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Constituents** | **per 100 g** | **Constituents** | **per 100 g** | **Constituents** | **per 100 g** |
| Water | 58.58 g | Potassium, K | 401 mg | Vitamin C | 31.2 mg |
| Energy | 149 Kcal | Calcium, Ca | 181 mg | Vitamin B6 | 1.235 mg |
| Carbohydrates | 33.06 g | Phosphorus, P | 153 mg | Niacin | 0.7 mg |
| Protein | 6.36 g | Magnesium, Mg | 25 mg | Pantothenic | 0.596 mg |
| Fibre | 2.1 g | Sodium, Na | 17 mg | Thiamin | 0.2 mg |
| Ash | 1.5 g | Iron, Fe | 1.7 mg | Vitamin E | 0.08 mg |
| Total lipid (fat) | 0.5 g | Manganese, Mn | 1.672 mg |  |  |
| Sugar | 1 g | Zinc, Zn | 1.16 mg |  |  |
|  |  | Copper, Cu | 0.299 mg |  |  |

**3. Post-harvest processing of garlic**

Post-harvest processing of garlic includes the unit operations like curing, drying, grading, sorting, packaging, storage and transportation.The time of harvesting, initial microbial load, mechanical damage, method of curing and drying, relative humidity, temperature, air ventilation and method of packing during storage are the important factors which affect the shelf life and the spice flavor level of garlic. Enhancement of the shelf life of garlic requires microbial activity inhibition, decrease in metabolism and oxidation. The late harvesting of garlic is to be avoided as it leads to re-sprouting of cloves. Mechanical damage to the outer cloves of bulbs during harvesting leads to decay during storage. By imparting practical training to the farmers and entrepreneurs for proper application and use available scientific knowledge of post-harvest practices, a huge amount of losses occurring before reaching to the consumer can be eliminated.

**3.1. Harvesting and Curing of Garlic Bulbs**

Maturity indices help in deciding the harvest time of the crop and to ensure that the crop is ready to be sold in the market, possessing desirable eatable qualities. It should be kept in mind during selecting the harvest maturity that the harvested commodity has its peak acceptable quality and maximum contents of active ingredients (Thompson, 1996; Pruthi, 1994). Garlic is harvested for the specialty markets in several stages of development but most garlic is harvested when the bulbs are well grown.

Garlic varieties be different significantly in their inherent period of dormancy, either as measured by the stage to sprout in storage or after planting in the field. The period of maturity of cloves at harvest has a significant influence on dormancy. Garlic is harvested when the tops turn brownish or yellowish, show symptoms of drying up and bend over. Bulbs harvested after neck fall have been reported to take less time for drying and curing and to have a marked reduction in storage rot. On the other hand, if bulbs are harvested before the neck fall, will take more time for proper drying and curing and also, they will be more susceptible to storage disease (Dhall and Ahuja, 2013). The bulbs begin maturing in 4-5 months following planting, depending on the season and soil.

Curing is one of the furthermost vital post-harvest management practices that is required for long-term storage of onion with minimum losses. Curing can be done naturally on the field or artificially by using hot air. The term “curing” is preferred because the removal of moisture is only from the outer scale, rather than from throughout the bulb. (Kalyani *et al.,* 2017). Curing of garlic bulbs helps in the development of skin color, enhancement of storage life and decay reduction and healing the skins wounded during harvesting (Petropoulos *et al.,* 2016, Thompson *et al.,* 1972). Traditionally curing is performed by covering the bulbs along with their tops in the field until foliage turns yellow. For about a week at 35 °C temperature and 3.2 m/s airflow velocity for 14 hours has been by recommended NHRDF to minimize the storage losses (<http://nhrdf.org>).  Houses with a provision of fans and heaters for redistributing temperature and relative humidity are reported to serve as Modern curing systems. Bulbs harvested after neck fall have been reported to take less time for curing and to have marked reduction in storage rot (Dhall and Ahuja, 2013).

**3.2. Cleaning, Grading and Sorting of Garlic Bulbs**

Cleaning involves of trimming the leaves and roots and removing the dirty outer bindings. While trimming the tops one must be cautious that skin caring the distinct cloves should not to be damaged and adequate stem on hard necks be left to make cracking easy. The power operated garlic and onion bulb cutter can be used for top cutting of garlic bulbs. It is reported to work satisfactorily with the output capacity of 35 kg/h. The average stem length left after top cutting of garlic bulbs is claimed to be 2.5 cm (https://www.garlicfarm.ca/storing-garlic.html).

Exterior cloves of bulbs are certainly spoiled during mechanical harvest and these damaged areas discolour and deterioration during storage. Hence, separation of damaged or infested garlic bulbs preceding to storage is the basic prerequisite of appropriate storage of superior quality garlic for the fresh market. Size grading is done after sorting. Value addition by grading is an established fact in any commodity and garlic is no exception to this process for better returns. It is very considerably essential for attainment the better value and to reduce losses on account of driage and decay. For local markets, bulbs are graded based on sphere-shaped diameter as small (10-20 mm), medium (15-25 mm) and big (20-30 mm). The hard work of human labour involved for sorting of garlic bulbs can be decreased by utilization of hand operated as well as mechanical garlic bulb graders (Dhall and Ahuja, 2013).

**3.3. Packaging of Garlic Bulbs**

The packaging material used for handling and transportation of garlic bulbs can be classified into the following three groups *i.e*. flexible sacks, fibreboard boxes and bamboo/ plastic baskets.

1. Flexible sacks: The garlic bulbs are packed in open mesh jute bags and nylon-netted bags of 40/60 kg capacity for domestic market whereas 8, 25 and 50 kg sizes are recommended as per grading and packing rules.
2. Fibreboard boxes: These boxes are lightweight, easy to handle, come in various sizes, and come in different colours, which can make produce that is more attractive to consumers. Holes on the surface (top and sides) of the box should be made to allow necessary aeriation for the produce and resist generation of heat, which can cause rapid product deterioration. For export purposes, perforated 10 ply corrugated fiber board boxes of 18 and 25 kg size are recommended for packaging of garlic bulbs.
3. Bamboo/plastic baskets:Plasticbaskets are generally make with polypropylene, or polyethylene polyvinyl chloride. These plastic boxes are durable and can last for many years.

**3.4. Storage of Garlic Bulbs**

Garlic bulbs eventually become soft, spongy and shrivelled due to water loss in about one month when stored at ambient temperature. Proper storage is essential for augmenting steady and continuous supply to domestic as well as overseas marketing because of increasing demand for quality garlic products. The main pre- and post-harvest factors that affect storage of garlic are very well described by Petropoulos *et al.,* 2017. They reported that genotype, irrigation, fertilizer and chemical agents used and harvest stage are main pre-harvest factors and bulb handling, curing, storage conditions and treatments during processing are main post-harvest factors. The influence of different storage conditions and parameters on quality characteristics of garlic have been analysed and reported by Vazquez-Barrios *et al.,* 2006 and [Pellegrini](https://www.researchgate.net/profile/C_Pellegrini2) *et al.,* 2000. Sprouting is a major problem of garlic storage. Pre-harvest application and use of growth regulator, maleic hydrazide (MH) can check sprouting (Dhall and Ahuja, 2013). An integrated approach right from selection of varieties, balanced nutrition, time schedule of application of nitrogenous fertilizers, balanced use of irrigation water and field and shade curing of bulbs help in reducing storages losses in garlic.

**3.4.1 Storage practices**

The farmers as per their requirements and availability of materials developed traditional storage structures for the storage of the garlic bulbs. Structures constructed with wooden bantams are used for bulk storage of garlic bulbs. The sidewalls are made of bamboo and plastered with clay and cow dung paste. These structures usually temporary type and the storage losses in these structures are reported to be very high.

Tripathi and Lawande (2006) studied the effect of the cold store in the storage of onion and garlic. The results showed that the cold storage of onion and garlic minimizes the storage losses up to 5 to 10 per cent. Treatment with gamma irradiation and cold storage are helpful in decreasing vast storage losses and reducing the price variations. The cold storage chain may be profitable near metropolitan markets and non-onion and garlic growing areas.

Onion and garlic can be stored in for 6-9 months by maintaining 0-2 °C and 65-70 per cent relative humidity. The storage losses are absolutely nil in cold storage. However, post-cold storage is a major constraint in cold storing of garlic. When taken out of the cold store bulbs start sprouting immediately due to vernalization. Sprouting is 100 per cent for one week and sprouted onions or garlic do-not fetch a good market price. The cost of cold storage is very high and individual farmers cannot afford. Further, lower capacity cold storages are not economically viable. Traders or corporate cooperatives also can create cold storage facilities in strategic growing areas (Lawande, 2018; Tripathi and Lawande, 2006; Tripathi *et al.,* 2009).

Tripathi *et al.* (2009) also studied the effect of the storage environment and packing material on storage losses in garlic. Well-cured garlic was stored in four storage structures and packing materials i.e. stakes, hessian cloth bags. The results revealed that the physiological weight loss was less in traditional storage structure and bottom ventilated structures with wooden bantam or mud plastered walls while it was higher in bottom-ventilated structures with chain links on sides. The infection of soft rot was higher in traditional storage structure than other structures. The colour change of garlic bulbs in the bottom ventilated storage structure was less frequent as compared to the traditional non-ventilated storage structure. In conclusion, garlic storage in circular heaps without cutting leaves in bottom ventilated storage structures was best method to reduce the losses.

**3.4.1. Irradiation for long-term preservation of garlic**

**The FDA approved sterilization of spices with ionizing radiation in the year 1983. Snyder and Poland (1995) reported that the radiation dose of 0.05 to 0.15 KGy to the garlic bulbs inhibits sprouting. Several workers have attempted irradiation of garlic with gamma rays for controlling sprouting and recommended the Irradiation with 2-6 Krad of cobalt 60 gamma rays for controlling sprouting in storage. Use of gamma irradiation with controlled** atmosphere condition i.e. only less than 0.5 per cent of oxygen or combined with 5-10 per cent carbon dioxide and the spray of maleic hydrazide **before harvesting was reported as a viable measure to control sprouting and increase in shelf life.** Perez *et al.* (2007) studied the influence of gamma rays in garlic bulbs and revealed that a 60 Gy dose aggravated a significant decrease in contents of fatty acid and lipids with a simultaneous decrease in the occurrence of sprouting. Application of irradiation practices has been also extensively studied mostly by considering their capacity to expand the shelf life of garlic (Pellegrino *et al.,* 2000; Perez *et al.,* 2007; Thomas, 1999; Dhall and Ahuja, 2013). Irradiation process also used to reduce or avoid the microbial infection during the period of storage, along with to substitute use of chemical fungicides for the duration of the post-harvesting period (Thomas, 1999). Gamma radiation doses of 10 Gy considerably decreased the sprouting in garlic and stopped the process of mitosis (Pellegrino *et al.,* 2000).

Croci and Curzio (1983) studied the influence of gamma-irradiation (0.03 kGy of Co–60) during storage (6–32 °C; 58–86 R.H.) garlic and reported that the process did not adversely affect the acceptability of the product after 300 days of storage. Curzio *et al*. (1986) observed that the garlic bulbs irradiated with 30 Gy and stored and found appropriate for enhancing shelf life during critical periods. Croci *et al*., 1990 and Ceci *et al*., 1991 studied the gamma rays in the storage behaviour of early garlic with a dose of 50 Gy of Co-60 at 30 days after harvest and the results show that both the raw/fresh market for this early cultivar and the garlic processing industry would profit from the radio inhibition process.

Directorate of Onion and Garlic Research (DOGR) recommended that the garlic bulbs treated with irradiation ranging from 2 to 6 Krad of cobalt 60 gamma rays minimize the sprouting during storage (<http://www.dogr.res.in>). Treatment with UV light for about 0.5 h further decreases the loss up to 8 per cent of bulbs stored in cold stores for 5 months (http://www. nhrdf.com). Irradiation doses higher than 10 Kr decreases the content of diallyl disulphide which provides garlic flavour (Dhall and Ahuja, 2013). Applying 0.1 per cent carbendazim before harvesting and using a clean and dry place for storing and handling the bulbs also greatly decrease the post-harvest losses, especially decay loss (<http://nhrdf.org/en-us/pPostHarvestTech_G>). Application of nitrogen can increase the physiological weight loss and use of potassium and phosphorus decreases the weight loss of garlic during storage. (http://www. nhrdf.com). Unfortunately, irradiation facilities are very limited and every farmer cannot reach them. Traders can avail such facilities (Lawande, 2018; Tripathi and Lawande, 2006; Tripathi *et al.,* 2009).

**3.4.2. Storage conditions**

Storage temperature and relative humidity are the two main parameters, which can influence the shelf life of the garlic bulbs. Various researchers were studied the effect of temperature and relative humidity on the storage losses and enhancing the shelf life of the garlic bulbs Takagi, 1990; Miedema, 1994; Cantwell and Suslow, 2002; Cantwell, 2004 and Volk *et al.*, 2004). The effect of temperature and relative humidity on storage losses and shelf life enhancement of garlic bulbs are presented in Table 2 (Madhu *et al*., 2019).

**Table 2: Effect of temperature and relative humidity on storage losses and shelf life enhancement of garlic bulbs**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Temp. (°C)** | **Relative humidity (per cent)** | **Storage duration** | **Remarks** | **Reference** |
| -1 to 0 | 60-70 | 9 months | Storage losses were less with the provision of good airflow to prevent any moisture accumulation | <http://www.cargohandbook.com/index.php/Garlic> |
| 0 | 65-70 | 12 months | Garlic bulbs can be stored at 0 °C with minimum losses | Dhall and Ahuja, 2013 |
| 0-2 | 65-70 | 6-9 months | The cold storage of garlic minimizes the storage losses up to 5 to 10 per cent. | Lawande, 2018 |
| 1-5 | 75 | 10 months | Storage losses were 12.5 per cent at temperature ranging from 1-5 °C with 75 per cent relative humidity as compared to 42.4 per cent losses in garlic stored at ambient temperature | (http://www. nhrdf.com) |
| 5-18 | 60-70 |  | Sprouting of garlic bulbs occurs due to the rapid end of the dormancy of bulbs | Cantwell, 2004; Cantwell and Suslow, 2002; Dhall and Ahuja, 2013 |
| 10 | 65-70 |  | Ideal storage of garlic bulb for seed | Cantwell and Suslow, 2002 |
| 10-20 | 60-70 |  | Sprouting was initiated | Miedema, 1994 |
| 13-18 | 40 to 60 |  | Pest, fungi and pathogens are less active at these ranges of temperature and relative humidity | <https://www.gourmetgarlicgardens.com> |
| 20-30 |  | 1-2 months | During ambient temperature storage garlic bulbs lose their stiffness or firmness, turn into elastic (spongy) and change in colour because of the water loss | <http://www.cargohandbook.com/index.php/Garlic> |
| 28-30 | 65-70 | 6-8 months | High moisture and shrinkage losses found at higher temperature | Dhall and Ahuja, 2013 |

**3.4.3 Storage pest and diseases**

Mites sometimes found damaging the cloves during storage. The fumigation of bulbs with methyl bromide (35 g/m3) after harvest and before storage can control the mites.

Garlic may be treated with sprout inhibitors (*i.e.*, maleic hydrazide) prior to harvest or be irradiated after harvest to control sprout development and lengthen the storage period. The chemical is to be sprayed when the tops are green and before the neck fall. The recommended concentration is 1500 to 3000 ppm. It gives good effect if sprayed when the temperature is mild and during the cooler part of the day. The appropriate treatments and storage techniques to be applied to harvested garlic in order to reduce damage and fungal infestation as suggested by PCARRD (2004) includes hot water treatment and use of dried lagundi leaves (*Vitex negundo*) during storage. Moreover, hot water treatment is done by dipping the bulbs in boiling water for 10 seconds then sun-drying them for 2-4 hours followed by air drying for 24 hours. The lagundi leaves are, likewise, sun-dried for 2-3 days until leaves could be crushed manually. Crushed lagundi leaves are mixed with the bulbs or those stored in boxes at 1:20 ratio, or 1 part of lagundi in every 20 parts of garlic bulbs.

**4. Processing and Value Addition**

The main objective of processing of spices is to generate the value-added products with best quality and sensory characteristics like flavour and aroma. Further, the value addition through packaging, storage and other post-harvest technologies will be helpful in extensively growing the export basket of garlic and its value added products. Processing of garlic bulbs comprises several unit operations like curing, cleaning and grading, storage, bulb breaking, clove separation and peeling, dehydration, size reduction, packing and product development.

**4.1. Garlic Clove Separation**

Bulb breaking is the main unit operation in which cloves are separated from bulbs to enable further processing. The separation of cloves involves special care and skill due to its typical physical characteristics and presence of essential volatile oils in the epidermal cells (Mudgal *et al*., 2009; Champawat, 2013). Traditionally, garlic clove separation was done manually by rubbing the bulb in between the palms, by beating with a wooden stick or against jute bags. These procedures are time consuming and very tedious (Mudgal *et al.,* 1998).

A prototype for separating garlic cloves using a hollow rotary cylindrical beater of 200 mm diameter and 500 mm length with a capacity of 125 kg/h was developed by Mudgal *et al.*, 1998. Theskin and roots were separated during the breaking of garlic bulbs remained with the cloves in this process and consume considerable time and energy for cleaning and separating skin and roots from the cloves. Mudgal (2009) developed efficient and economical clove separator with a provision of removing husk and roots from separated single cloves. The capacity, clove separation efficiency and bulb breaking efficiency were reported as 750 kg/h, 91.7 per cent and 97.9 per cent respectively. The developed machine was reported economically feasible for bulb breaking and clove separation with the operating cost of Rs.0.05/kg as against Rs.2.25/kg for manual operation for clove separation. Return-on-investment was calculated to be 411 per cent, with a payback period of ninety days (Mudgal and Sahay, 2009).

**4.2. Garlic Clove Peeling**

Garlic peeling is the most critical and key unit operations prior to any subsequent handling activity. This unit operation needs special attention and ability because of the typical physical properties and presence of essential volatile oils in the epidermal cells imparting garlic its characteristic aroma. As soon as the clove is crushed the natural compound of allicin losses its beneficial properties within hours because it begins to react with other components of garlic. Conventionally, peeling is done by rubbing the cloves against jute bags on a hard surface. This method is very tedious with much more chances of surface injuries to the cloves. The development of garlic clove peeling prototypes based on abrasive action has been reported by Mudgal *et al.,* 1998.

The abrasion-based gadgets for garlic peeling were observed to perform well initially but found infeasible in due course of time as sticky material of crushed cloves adhered to the lining material, imparting smoothness to the abrasive surfaces. It adversely affects the performance and renders it quite inefficient within a short span (Anonymous, 2005). The studies on garlic clove peeling were conducted at AICRP on PHET, MPUAT, Udaipur and reported to develop continuous garlic clove peeling gadget working on the principle of whirling action of compressed air (Anonymous, 2005).

Shanmugam *et al.* (2015) reported to design and fabricate automatic garlic peeler in which box containing garlic cloves is vibrated rapidly by reciprocating connecting rods. The garlic inside the box hits top and bottom side of the box to remove the skin. They reported that the efficient garlic peeling can be attained by reciprocating rapidly in the vertical direction. A fully automated garlic peeling machine of 200 kg/h capacity with peeling effectiveness of 90 per cent has been claimed to develop by Nagarajan (2006).

The design and development of semi-automatic garlic clove peeler of 400 g capacity and 97 per cent peeling efficiency with peeling time of 70 s has been published and popularized by Mudgal and Champawat (2011). A power operated garlic peeling prototype of 27 kg/h throughput capacity with the peeling efficiency, peel separation, and unpeeled garlic, damage and yield of peeled garlic were 86.6, 15, 86.29, 4.7 and 9.15 per cent respectively have been reported to be developed and evaluated by Manjunatha *et al.*, 2014.

The development of continuous garlic clove peeler has been reported by Anon, 2017. Integrating automatic electronic control system for opening and closing timings of feeding and outlet section in the prototype developed earlier by Mudgal and Champawat, 2011. The developed garlic clove peeler was observed to work satisfactorily with 86.45 per cent average peeling efficiency and output capacity of 15 kg/h. It can be used for small scale/cottage industry for garlic processing which is the need of Indian socio-economic conditions.

**4.3. Drying of Garlic Cloves**

Drying is an appropriate method for reducing the post-harvest losses particularly in nations like India due to the lack of handling facilities (Pragati and Preeti, 2014). Drying prevents deterioration of the harvested garlic from pests and microbial contaminants producing aflatoxins to enhance shelf life and allows storage in a stable condition. Conventional air drying is one of the most frequently used operation for garlic dehydration (Puranik *et al.,* 2012). Major factors associated with the spoilage of garlic powder are improper drying and handling, chemical reactions due to the presence of moisture during storage. Garlic powder is one of the products of garlic that can be stored for long periods without much attention towards spoilage microorganisms (Kiezbukowska *et al.,* 2015). The quality of the powder deteriorates during storage as the type of packages and storage condition do not match. There is also degradation of colour, flavour and other parameters limiting the shelf life and use (Pruthi, 1994; Sacilik and Unal, 2005; Fernando *et al.,* 2008; Rasouli *et al.,* 2011).

As most of the spices and herbs required the temperature of drying up to 65 °C which can be easily obtained in the solar tunnel dryers even in winter season, therefore, they can be considered as low cost techno-economically feasible improved alternative to dry garlic cloves as well as bulbs. The convective, freeze, vacuum, microwave, osmotic drying methods or a combination (hybrid drying) of two of these methods as mechanical means for dehydration of food products. Table 2.3 gives the various drying methods used for drying and their effects on quality characteristics of the cloves.

**Table 2.3: Various drying methods used for drying of garlic cloves**

|  |  |  |  |
| --- | --- | --- | --- |
| **Method of Drying** | **Drying parameters** | **Findings** | **Reference** |
| **Convective drying** | Temperature: 60, 70, 80 and 90 ºC, Multistage dehydration | 2-stage and 3-stage dehydration save about 16 per cent of drying time as compared with single stage drying at 60ºC | Dash and Bhatnagar, 1994 |
| Temperature: 50, 60, 70, 80 and 90 ºC, Air velocities: 0.5, 0.75 and 1 m/s, slice thickness: 2, 3 and 4 mm | Reported that an optimum drying temperature of 70 ºC was obtained for drying 2 mm garlic slice | Madamba, 1996 |
| Temperature: 2.5, 45 and 65 ºC | The effective diffusivity increased with temperature, ranging from 1.54 to 3.45 10−10 m2/s in the wet zone and from 0.34 to 0.58 10−10 m2/s in the dry zone. | **Pezzutti and Crapiste,** 1997 |
| Temperature: 40, 50, 60 and 70 ºC, Air velocities: 1 and 2 m/s | 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 an increase in air temperature and velocity. | Sharma *et al.,* 2003 |
| Temperature: 60 ºC, Clove slice thickness: 3 mm, Pre-treatment: 0.1 per cent sodium meta bisulphate, Air velocity: 9 m/s | Drying air temperature and slice thickness significantly affected color, rehydration ratio and final moisture content and also reported that air velocity affected rehydration ratio while no effect was observed for concentration of sodium meta bisulphite. | Dhingra and Paul, 2005 |
| Temperatures: 40, 50 and 60 °C, Slice thicknesses: 3 and 5 mm | Effective diffusivity was found in between 195 and 335 μm2 s−1 and activation energy was found as 23·48 kJ mol−1. Rehydration capacity was found in the range between 2·37 and 2·84. | **Sacilik****and Unal,** 2005 |
| Temperature, 20, 37 and 50 °C, Relative humidity, 30, 50, 70 and 90 per cent | The lightness, redness and yellowness were found to be dependent on relative humidity and temperature. The reduction in the lightness and increase in the redness with time can suitably be described by a first-order kinetics model. For yellowness, it rises to a maximum value, after which it declines, and such characteristics of the yellowness-time curve can be represented by first-order reactions in series. Colour difference was maximum for garlic which was isothermally heated at a relative humidity of 70 per cent. | Prachayawarakorn *et al.,* 2004 |
| Temperature, 50, 60 and 70 °C, Air velocities: 0.7 and 1.7m/s | Shrinkage of garlic clove was found at high temperature. The loss of volatile oil loss was higher at high-temperature drying. | Prachayawarakorn *et al.,* 2006 |
| Pre-treatment: citric acid (CA), potassium metabisulphite (KMS), and ethylenediamine Tetraacetic acid (EDTA), Temperature: 45, 50 and 55 °C | Results reported that the hot air drying of garlic slices is effective but reduced the quality. | [Abano *et al.,* 2011](http://scialert.net/fulltext/?doi=ajft.2012.311.319&org=10#896933_ja) |
| Temperature range: 55–75 °C, Relative humidity: 20 per cent, Air velocity: 0.2 m/s | The effective moisture diffusivity was found to in between 2.221 ×10-10 and 4.214 ×10-10 m2s1. The activation energy was also found to be 30.582 kJ mol-1. | Demiray and Tulek, 2014 |
| **Fluidized bed drying** | |  |  |  |  | | --- | --- | --- | --- | | |  |  |  | | --- | --- | --- | | |  |  | | --- | --- | | |  | | --- | |  | | | |   Temperature: 40, 50 and 60 °C, Air velocity: 2.5, 3.0 and 3.5 m/s. | Drying temperature had significant effect on drying time, whereas air velocity had non-significant effect at 5 per cent level. The effective moisture diffusivity was in the range of 1.02 x 10-9 to 1.40 x 10-9 m2/s. The activation energy for garlic slices ranged between 12.16 and 12.81 kJ/mol | Shoba *et al.,* 2012. |
| Air temperatures: 50, 60, 70 and 80 °C | |  |  |  |  | | --- | --- | --- | --- | | |  |  |  | | --- | --- | --- | | |  |  | | --- | --- | | |  | | --- | |  | | | |   Semi fluidized bed convective drying with temperature 50 to 60 °C was suitable to produce dried garlic. Activation energy was found between 51.32 and 60.58 kJ/mol and the specific energy consumption (SEC) was placed in the range of 0.316 × 10 6 and 0.979 × 10 6 kJ/kg. | Amiri *et al.,* 2012 |
| Combined drying (fluidized + microwave) , Pre-treatments: 0.1 per cent to 0.5 per cent KMS, Temperature: 55 °C to 75 °C, Microwave power level: 810 W - 1350 W. | The decreasing moisture content trend with the drying time irrespective of the drying air temperature, KMS concentration and microwave power level was found. | Grewal *et al.,* 2016 |
| **Vacuum drying** | 100 per cent power level for 7 min, followed by 50 per cent power level for 8 min, and finally 18 per cent power level for 20 min), then hot-air (45 C) drying to about 5 per cent moisture | Flavor or pungency, color, texture and rehydration ratio, the quality of garlic slices dried by the combination of microwave-vacuum drying and air drying was close to that of freeze-dried product and much better than that dehydrated by conventional hot-air drying. | Cui *et al.,* 2003 |
| Heat surface temperatures: (T, 48 – 78 ˚C), air pressure: (30 – 330 mbar), drying time: 3 – 11 h | Optimal conditions for all response variables were heat surface temperature of 78 °C, air pressure of 30 mbar and drying time of 11 h, while generated model predicted obtaining of dried garlic with following physical properties: moisture content 8.73 per cent, water activity 0.326, total colour change 11.95 and shear force 598.32 ×10-2 N | Anitha *et al.,* 2016 |
| **Microwave drying** | Temperatures: 40 °C, 50 °C, 60 °C and 70 °C, velocities: 1.0 and 2.0 m/s, microwave power: 40 W (continuous) | Combined microwave–hot air drying resulted in a reduction in the drying time to an extent of 80–90 per cent in comparison to conventional hot air drying and a superior quality final product. | Sharma and Prasad, 2001 |
| Microwave power: 10–40 W, air temperature: 40–70 °C, air velocity: 1–2 m/s. | Effective moisture diffusivity increases with decrease in moisture content and increase in both drying air temperature and microwave power at a given air velocity. With increase in air velocity, diffusivity values were lower for the similar drying conditions resulting into slower drying of the product. | Sharma and Prasad, 2004 |
| Air temperatures: 40, 50, 60 and 70 °C, air velocities: 1.0 and 2.0 m/s and microwave power levels: 10, 20, 30 and 40 W | The microwave power of 40 W, air temperature of 70 °C and air velocity of 1.0 m/s gave a good quality dehydrated garlic cloves and involved low specific energy consumption in the drying process | Sharma and Prasad, 2006 |
| **Infrared drying** | Air temperature: 45, 55, 65, and 75 °C, air velocity: 0.25, 0.75, 1.25 m/s, radiation intensity: 0.075, 0.15 and 0.225 W cm-2 | Drying rate, thermal efficiency, rehydration ratio, flavour strength and the colour difference were higher for the combined heating mode in comparison with the convection mode. Drying time and specific energy consumption for the combined mode were lower than the convection mode | Abdelmotaleb *et al.,* 2009 |
| Temperatures: 50,60,70, 80 °C, powers: 675 to 2,025 W | Thiosulfinates showed no significant changes versus moisture content during the whole drying period at 50, 60 and 70°C, while a notable degradation of thiosulfinates was observed at 80C. Total phenolic compounds in garlic slices all rapidly decreased versus moisture content initially at all investigated drying conditions. Whereas the total phenolic compounds in dried garlic slices significantly enhanced with drying temperature from 50 to 80 °C at 1,575 W. Antioxidant activity increased during infrared drying, which was contradictory with the changes of total phenolic compounds and thiosulfinates. | Zhou *et al.,* 2017 |
| **Freeze drying** | vacuum chamber pressure of 0.1-1.0 torr, -10 ºC | Drying rate of 0.5- 1.25 cm thick samples in a vacuum chamber pressure of 0.4 torr was faster than that at 0.1 or 0.2 torr of the vacuum chamber. | Lee *et al.,* 1989 |
| Temperature: -5, -15, and -25 ºC | They reported that dried at -5ºC showed significantly lower open pore porosity compared with the samples dried at -15 and -25ºC respectively. | Sablani *et al.,* 2007 |
| Temperature: -40ºC  Vacuum: 0.01 bar | Freeze dried garlic clove slices were highly accepted than convective dried cloves and found very les loss of colour, volatile compounds in freeze dried sample | Neetu, 2014 |

**4.4 Grinding of Garlic Cloves**

Spices are ground at one stage or the other before consumption though whole spices are also used in culinary practices to a certain extent. Generally, spices are ground either for direct use or making value-added products, such as, ground spices, mixes, oleoresins, and spice oil extracts which have vast industrial applications. Spice volatile oils are used in food, cosmetics, perfumery and personal hygiene products like toothpaste, mouth paste and aerosols besides a variety of pharmaceutical formulations (Anon, 2001a).

The application of cryogenic technology for grinding of spices has been scientifically proved to be a suitable technique with negligible loss of volatile content and improved color of oil and grinding operation of seeds (Saxena *et al.,* 2013).

Pre-cooling of raw spice and maintenance of low temperature within the mill reduce the losses of volatile oils to retain most of the flavor strength. (Pruthi, 1980; Singh and Goswami, 1999a). Pesek *et al.* (1985) studied on the ambient and cryogenic grinding and reported that although the total oil content under the two conditions of grinding was not significantly different, the individual oil components which are responsible for the flavor drastically differed. Pesek and Wilson (1986) studied the effect of cryogenic and ambient grinding on the color of spice to determine its influence on spice quality. A Hunter lab color difference meter and sensory analyses were used to determine if cryogenically milled spices were comparable to ambiently milled spices. Cryogenically milled spices are lighter in color than ambiently milled spices and untrained panelists were able to detect the differences.

Wolf and Pahl (1990) studied the effect of grinding temperature and rotor speed on the volatile oil content of caraway seed. Loss of aroma drastically reduced by cooling the grinding material. The reason for the loss of aroma was that by the grinding process the mass transfer increased because the vapor pressure increased due to the increase of temperature as well as higher gas-solid velocity at higher circumferential velocity.

Murthy *et al.* (1995) studied the effect of four different product temperatures *viz;* high temperature (62 ºC), ambient temperature (50 ºC), chilled water cooled (30 ºC) and liquid nitrogen cooled (-20 ºC), on the retention of volatile oil of black pepper using a kitchen grinder. The volatile oil content of the product indicated that chilled water and liquid nitrogen conditions retained almost same quantity of volatiles (3.56 ml/100g and 3.60 ml/100g respectively) and a quantitative gain of 36 per cent in the retention of volatile oil was found in case of cryogenic grinding as compared to ambient grinding.

Singh *et al*. (1999) found that the fat content of spices poses problems of temperature rise and sieve clogging during grinding. Due to this temperature rise, spices lose a significant fraction of their volatile oil or flavoring components. The tests conducted on the grinding of cumin seed revealed that it could be successfully ground below the temperature of -70 ºC. Above this temperature, sieve clogging took place. They reported that the increase in grinding temperature from-160ºC to -70ºC resulted in a significant increase in particle size of the product and specific energy consumption in grinding. A variation in volatile oil content was obtained in the range of 3.30±3.26 ml/100 g with increasing temperature from -160 to -70 ºC.

Murthy and Bhattacharya (2008) found that the loss of volatile oil in the case of ambient grinding was about 50 per cent as compared to cryogenic grinding. The loss of monoterpenes was high in ambient grinding, as there was a loss of volatile oil in terms of every monoterpene compounds. The cryogenic grinding technique was superior to ambient grinding in terms of monoterpenes retention in the powder. Sensory assessment of the ground samples indicated that cryogenically ground samples were distinctly high in top notes which represented freshness, and marginally high in basic notes also. A pilot plant model pin mill was employed for cryogenic grinding of black pepper at different feed rates and product temperatures. The optimum cryogenic conditions for maximum volatile oil content and a reasonable quantity of monoterpenes were 47 to 57kg/h of feed rate, and -20 to -15ºC of product temperature.

Balasubramanian *et al.* (2012) studies on cryogenics and its application with reference to spice grinding and told that cryogenics is the study of very low temperature and its application on different materials including biological products. Cryogenic freezing finds a pivotal application in food, that is, spices and condiments. Although there is a wide range of cryogens to produce the desired low temperature, generally liquid nitrogen (LN₂) is used in food grinding. The application of low temperature shows a promising pathway to produce a higher quality end product with higher flavor and volatile oil retention. In low temperature grinders, cryogens subject the raw material up to or lower than glass transition temperature before it is ground, thus eliminating much of the material and quality hassles of traditional grinding.

During the normal grinding process grinding temperature rises up to 95ºC which is responsible for a loss of volatile content and change in product color. Continuous operation is also not possible in a normal grinding process due to the melting of fat and sticking of powder on the grinding surface. The application of cryogenic technology for grinding of spices has been scientifically proved to be a suitable technique with negligible loss of volatile content and improved color of oil and grinding (Saxena *et al.,* 2013). A comparative study had shown that ambient grinding needs more power and specific energy than cryogenic grinding (Barnwal *et al.,* 2015).

Liu *et al.* (2013) studied to compare the effects of cryogenic grinding and hammer milling on the flavor attributes of black, white, and green pepper. Cryogenic grinding resulted in minimal damage to the color, flavor, and sensory attributes of the spices. Cryogenic grinding was also better than hammer milling at preserving the main potent aroma constituents, but the concentrations of the main aroma constituents were dramatically reduced after storing the samples at 4ºC for 6 months. Overall, cryogenic grinding was superior to hammer milling for preserving the sensory properties and flavor attributes of pepper without significantly affecting its quality.

**5. Product Development**

The most of garlic is consumed as such in developing nations and a few efforts are made to produce dehydrated garlic or garlic powder. Moisture loss due to respiration, transpiration and microbiological spoilage are the major causes, which limit shelf life during storage of garlic bulb. High losses during storage have generated an interest in the development of garlic products such as granulates, powder, flakes, paste and oil and oleoresins. Availability of garlic bulbs at low prices in several developing countries offers a very attractive opportunity for an entrepreneur to produce garlic products at competitive prices, mostly in view of cheaper labour available in these nations.

**5.1. Dehydrated garlic granules/powder**

The traditional practice of preparation of powder from garlic 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 (Mudgal *et al*., 1998). Garlic granules are prepared from chopped garlic Colour ranges from cream to golden brown depending in the raw bulbs used.

Pruthi *et al.* (1974) patented improvements in the manufacturing process of garlic powder. Physical, chemical and organoleptic characteristics of sun, hot air, freeze and spray dried powders were investigated by Kim and Nam (1980). They observed that PE (enzymatically produced pyruvate) contents of dried immediately after longitudinal slicing and dried immediately after latitudinal slicing samples were higher than those of left 2 hours before drying after longitudinal slicing and left 2 hours before drying after latitudinal slicing samples.

Physical, chemical and organoleptic characteristics of garlic powder prepared with various drying methods viz., sun drying, hot air drying, freeze-drying and spray drying were studied by Kim *et al.,* 1980**.** Rahman *et al.* (2005) studied the anti-microbial activity of the garlic powder produced by different methods. Li *et al.,* 2007 and Li and Xu, 2007 prepared garlic powder by using a vacuum and combined microwave-vacuum drying and reported that this process can provide high allicin with the quality as good as the powder prepared by using freeze-drying. Marian and Usha, 2016 studied the chemical and shelf life of the dry garlic powder and they reported that that the garlic powder was rich in vitamin C and there were no significant changes were found in physical, chemical and mechanical characteristics during storage. Park *et al.,* 2008 and Park *et al.,* 2018 used the high hydrostatic pressure treatment for manufacturing of garlic powder with improved microbial safety and antioxidant activity and reported that the high hydrostatic pressure treatment at 600 MPa for 5 minutes can help to prepare garlic powder with improved flavour, microbial safety and nutrition. The allinase activity and composition of the garlic powder prepared with less than 60 °C can be identical to those of fresh garlic (Tarak *et al*., 2013).

The improved process standardized by Champawat (2013) for development of dehydrated garlic slices/powder is elaborated hereunder.

1. Sorting: The cleaned and graded healthy garlic bulbs should be taken for producing the dehydrated garlic slices/ powder. Mechanical garlic bulb grader is recommended for grading garlic bulbs on basis of size and diameter.
2. Bulb breaking and clove separation: In this process, the garlic bulbs are broken and separated into single cloves. Garlic bulb breaker described in the earlier section shall be used for separating garlic cloves.
3. Pre-treatment: The separated cloves should be pre-treated by heating at 55 °C for 30 minutes in a solar or mechanical tray dryer. Thermal treatment to cloves facilitates the efficient peeling of cloves. The clove peeler reported in the earlier section can be very well used for this purpose.
4. Slicing: of cloves can be performed manually using a stainless knife or mechanically by using chopper or slicer generally used in fruits and vegetable processing. (optional)
5. Drying: Whole/sliced cloves are to be dried at low temperatures. Considering the quality of the dehydrated product in terms of retention of color and flavor dehydrated product the drying temperature should not exceed 55ºC.
6. Dehydrated garlic cloves/slices are ready as drying is over (mc « 7 per cent).
7. Milling: Garlic powder is obtained by pulverizing the dried garlic clove/ slices. Grinding at low temperature using the low temperature/cryogenic grinder is recommended for a quality product.
8. Packaging: The prepared garlic flakes or ground powder is finally packed using MAP or vacuum packaging for storage or marketing.

**5.2. Garlic Paste**

Garlic paste, a viscous product prepared by crushing the garlic cloves, is a substitute of fresh garlic which can be used in homes, restaurants, hotels, food complex institutes and institutional caterings etc. Various researchers were studied the effect of pre-treatments and storage parameters on quality characteristics of the garlic paste (Ahmed *et al.,* 2001; Ahmed and Shivhare, 2001: Carbonell-Barrachina *et al.,* 2003; Constenla and Lozano, 2005: Casado *et al.,* 2012; Algadi *et al.,* 2014; Mutasim *et al.,* 2016). The flavor strength of fresh garlic paste was observed as 0.55-0.67 and retained up to 0.36-0.46 in 2 months of storage. Maximum losses occur during the processing and packaging at the initial stage (Mudgal *et al.,* 1998). Kubota and Miyamuki (1992) demonstrated that it is possible to use a paste of fresh garlic instead of supernatant of CaCN2 suspension or ‘Merit' solution to promote bud break in five grape cultivars.

Ahmed *et al.*, 2001 prepared the garlic paste with a total solids and pH value of 33 per cent and 4.1 with addition of 10 per cent sodium chloride (w/w) and citric acid. The paste was analysed periodically for colour and microbiological counts. The sults reported that paste contained 33 per cent total solids, 9.6 per cent sodium chloride and 0.35 per cent titratable acidity while pH and water activity values were 4.1 and 0.86, respectively. The Hunter color L\*, a\* and b\* values of the paste were 58.26, -9.54 and 20.96, respectively. The product was found to be safe microbiologically while stored at 25 °C for a period of at least 6 months. Ahmed and Shivhare (2001) studied the effects of storage temperatures and packaging materials on color kinetics and rheological behaviour of garlic puree and reported that both temperature and storage duration had an effect (P≤ 0.05) on the total color and rheological behaviour garlic paste.

Carbonell-Barrachina *et al.,* 2003 investigated the effect of preservatives (citric acid, sodium bisulphate), antioxidant additives and sanitary steps on the quality characteristic of the garlic paste and results reported that the combination of antioxidant additives and sanitary steps and a pH of 4.0 gives the paste with the best sensory and chemical properties at room temperature (20 ± 2 °C) storage.

Prati *et al.*, 2014 reported that the processing of garlic into paste reduced loss of allicin content as compared to the fried garlic samples. The allicin contnt loss of garlic paste was found upto 22 per cent after the storage of 180 days where as in the fried garlic samples the allicin content loss was reached upto 99 per cent. The garlic paste preserved more bioactive compounds as compared to fried samples during storage.

Mutasim and Elgasim, 2016 investigated the effect of preservatives and storage temperatures on the physical, chemical and sensory characterises of the garlic paste prepared from various varieties. Results reported that the garlic paste stored at 40 °C increased the chemical composition except for ash content whereas storage at 25 °C increases the sensory characterises of the garlic paste and recommended that the blending preservatives (ascorbic and citric acid) and storage at 25 °C or less an enhance the shelf life up to ix months with less changes in sensory characteristics.

The paste making process involves clove separation, cleaning and grading, peeling of cloves, paste making, mixing of preservative to improve the shelf life and finally packaging, storage and marketing of the garlic paste. Simple process for making garlic paste has been standardized by Mudgal and Champawat, 2013.

First three steps are same as mentioned in for development of dehydrated garlic slices/powder and rest given hereunder:

1. Grinding: Garlic paste is obtained by wet grinding of the peeled garlic cloves. Low temperature using the low temperature/cryogenic grinder is recommended for quality production.
2. Mixing: Citric acid (0.05 per cent) and salt (1.5 per cent) should be added as a preservative to improve the shelf life of the garlic paste.

**5.3. Spice Oils and Oleoresins**

The characteristic odor and flavor of herbs and spices is due to the presence of a complex mixture of chemical compounds. Some of these components, known as ‘essential oils', are volatile and may be separated by steam distillation. The chemical composition of other components, known as ‘oleoresins' makes them too ‘heavy' to steam distill and these are extracted by solvents (commonly alcohol (ethanol) or other solvents such as hexane). The production of oleoresins is more complex than essential oils because of the requirement to use solvents and solvent recovery equipment.

**5.3.1 Garlic oil**

Garlic contains 0.1-0.36 per cent of volatile oil which is generally considered to be responsible for most of the pharmacological properties of garlic (Dharshini and Anchana, 2017). Garlic oil is extracted by a process of steam distillation of the garlic cloves using solvents such as n-hexane or petroleum ether. It contains a variety of sulphide such as dially disulphide and dilly trisulphide. Garlic oil behaves as a nutraceutical compound, with numerous applications in food and pharmaceutical industries such as the flavoring of some cuisine such as salads, and sauces; can reduce blood pressure, prevent cancer and cardiovascular diseases through reducing serum LDL cholesterol and triglyceride (Carson, 1987; Andreatta *et al*., 2005). In addition, there are many reports on the antioxidant antimicrobial, anticancer and antithrombotic properties of garlic oil, which could be used to prevent nausea, diarrhea, ease coughs, and treatment in conditions such as malaria and cholera (Carson, 1987; Nagpurkar et al., 2000; Turner, 2004).

Many publications have discussed the chemical composition of garlic oil using different techniques of extraction and identification (Leopold, et al., 1992). Fresh garlic consists of the diallyl (57 per cent), allyl methyl (37 per cent) and dimethyl (6 per cent) mono to hexa sulphides. A typical commercial preparation of garlic oil contains 26 per cent diallyl disulphide (DADS), 19 per cent diallyl trisulphide (DATS), 15 per cent allyl methyl trisulphide, 13 per cent allyl methyl disulphide, 8 per cent diallyl tetrasulphide, 6 per cent allyl methyl tetrasulphide, 4 per cent penta sulphide, 3 per cent dimethyl trisulphide and 1 per cent hexa sulphide (Banerjee et al., 2003). Garlic and garlic extracts can be used for food preparations and nutraceuticals (Carson, 1987).

Ali and Mohsen (2014) reported that the specific gravity (0.894 g/cm3) was independent of the extraction method, while the viscosity was changed and more viscosity was obtained by SCF-Co2. The chemical properties i.e. acid value, free fatty acids, saponification value and iodine value of garlic oil extracted by SCF-CO2 were 2.5, 1.27, 1.8 and14.5, respectively. It was observed that the yield of garlic oil was influenced by the extraction method and was approximately 5.5, 6 and 7 per cent for steam distillation, solvent methods and SCF-CO2, respectively. The specific gravity was obtained as 0.894 g/cm3 and independent to the extraction method, while the viscosity was changed and more viscosity was obtained by SCF-CO2. The results showed that the SCF-CO2 had minor quality and nutritional loss on the GO, and could be applied for special purposes such as encapsulation of garlic oil (Ali and Mohsen 2014).

**5.3.2 Garlic oleoresin**

Garlic oleoresin is obtained by the solvent extraction of the crushed bulb of the garlic and it is brown thick paste with a characteristic odor. It can soluble in alcohol and water and it has characteristic taste and flavor of garlic. The major constituents of garlic oleoresin are volatile oil, propyl, alliin and allicin. Volatile oil content of garlic oleoresin is not less than 3 per cent (v/w) (3.12 per cent), Residual solvent is Less than 25 ppm. The shelf life of garlic oleoresin 18 months from the date of manufacture when stored below 25 °C in closed containers away from direct light and not under humid conditions. The oleoresin of garlic is a valuable flavoring agent. It is also used in perfumery and as an insect repellent.

Jo *et al*., 1990 investigated the possibility of processing garlic into garlic oleoresin and storage stability. Optimum components for garlic oleoresin consisted of 1.0 per cent garlic essential oil, 10.5 per cent garlic extract, 10.0 per cent poly sorbate, 0.01 per cent KM-72, 18.0 per cent lecithin, 0.05 per cent TBHQ, 0.15 per cent of phosphoric acid solution and 60.0 per cent water. Judging from thiosulfinate and pyruvate content, and sensory evaluation, quality damage of garlic oleoresin hardly occurred at 5 °C but occurred considerable level at 25 °C during storage for 60 days.

Kim *et al*., 1998 studied the preparation and storage conditions of oleoresin from the root portion of peeled garlic. They found that extraction with ethanol and methanol showed a high solid yield of 27-37 per cent at the temperature range of 30-50 °C. Two hours of extraction were found to be economic because of no significant increase in further extraction. They further reported that storage of the oleoresin under the anaerobic condition such as vacuum or nitrogen resulted in less changes in pH, total acidity, color and thiosulfinate content than those changes under aerobic condition. Addition of ascorbic acid and cysteine into oleoresin retained the garlic flavor, effectively. Kim *et al*., 2006 optimized the extraction conditions of oleoresin from garlic and investigated its physicochemical changes during storage at 4 and 25 °C.

**6. Conclusion**

A comprehensive literature review of post-harvest processing, product development and valorisation of garlic was made. The review gives an overview of the major unit operations after harvesting and value addition of garlic. The post-harvest losses of garlic can be greatly reduced by the promotion and encouragement for eco-friendly effective storage technologies to overcome the storage losses is aimed to accomplish the need of ever-growing population. Mechanization of the unit operations like bulb breaking, clove separation, peeling of cloves and optimization of process parameters for the development of garlic like paste, powder, flakes, granules, oils and oleoresins are need of hour to maximum utilization of produced garlic and income generation to the farmers. Hence, there is a scope of integrating traditional knowledge with modern scientific knowledge for developing appropriate technologies which will be highly beneficial to the people living in the rural areas especially in the agriculture sector.

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