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Dehydration of Onion: a Review

[1] Y.A.Sargar, [2] S.B.Swami, [3] K.H.Pujari
[1][2] Department of Post Harvest Engineering, Post Graduate institute of Post Harvest Management, Killa-Roha 402 116 Dist Raigad (MS).
[3] (Dr.Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli Dist Ratnagiri 415 712 (MS))

Abstract*- Onion (Allium cepa L.) is considered to be one of the most important crops in all countries. It is the round in shape edible bulb. Red, white and gold onions represent the most common varieties of this species. It is widely used as seasoning in foods. Onion is a strong-flavoured vegetable used in a wide variety of ways, and its characteristic flavour (pungency) or aroma, biological compounds and medicinal uses are mainly due to their high organo-sulphur compounds. Dehydration process removes moisture content of food. The advantage of dehydrated foods is that low moisture content slows down or prevents the growth of microorganisms that causes spoilage reactions and increases its storability. Dried onions are a product of great significance in world trade produced either as flaked, minced, chopped or powdered forms. Various drying methods being used for dehydration of onion such as open air drying, solar drying, convective air drying, fluidized bed drying, vacuum microwave drying, infrared drying, microwave freeze drying and osmotic drying. The commonly used dehydration method is open air sun drying and solar drying demands longer drying time, high temperature and affected by daily fluctuation of weather and thereby making it difficult to maintain the product moisture content and quality properly because of air-borne dirt and dust so other drying methods are good for dehydration and to maintain the quality of product. The color and flavour of dried onions are considered the most important quality attributes affecting the degree of acceptability of the product by the consumer. Hence colour and flavor retention of onion during drying is most important attributes for the onion dehydration.

Key Words: - Onion, seasoning, dehydration, flavour, retention.

I. INTRODUCTION

Onion (Allium cepa L.) is the most commonly used vegetable grown all over the world it ranks third in the world production of major vegetables (Mitra et al. 2012). It is the round edible bulb of botanically included in the Liliaceae family and one of the oldest cultivated vegetable crops. Red, white and gold onions represent the most common varieties of this species. India produces all three varieties of onion viz. red, yellow and white. The production as well as market value of this potential vegetable is increasing day by day. Production of onion in India in the year 2015-2016 is 20.30million tones while in the year 2016-2017 its increased by 21.71 million tones (NHB:HSD, 2017) In Maharashtra in the year 2015-2016 the production of onion was 6million tones.(FAO, 2016) It is commonly used in the world food preparations specially in the tropical countries. Although, it is classified as vegetable, it has special qualities, which add to taste and flavour to food and hence it is mainly used in India for cuisine and culinary preparations. It is widely used in salads, stew and as flavouring in all cooked vegetables. In current times, the onion is an important vegetable that is served as an ingredient in dishes, as toppings on burgers, in seasonings and as chip coatings (Sharma et al., 2005). The importance of onions lies in the flavour that it imparts to several other dishes. The sulfur containing compounds in onion give distinctive flavour and pungency anthocynin in onion give red, purple colour and quercetin and its derevatives give yellow colour the two chemical groups such as flavanoids and alk(en)yl cysteine sulphoxides (ACSO) have perceived benefits to health(Griffiths et al.,2002) Onions are low in calories and are a source of dietary fiber. Bulb onions also provide vitamin C, with one medium onion providing 15 to 20 percent of the daily requirement. Onions have been thought to have certain medicinal and disease prevention powers; In theUnited States, products that contain onion extract are used in the treatment of topical scars, some studies have found their action to be ineffective, while others found that they may act as an anti-inflammatory or bacteriostatic. 3-Mercapto-2-methylpentan-1-ol in onion was found to have an antioxidant potent that inhibits peroxynitrite-induced diseases(Olalusi Ayoola, 2014). Onions are stimulant and mild counter irritant. The lipoproteins in raw onions helps to reduce cholesterol in human, also which helps in blood pressure and controlling coronary heart diseases. Onions are also used in the treatment of anaemia, urinary disorders, bleeding piles and teeth disorders. (Mitra et al., 2011;Anonymus DOA: 03.01.2018) Due to such increasing production of onion, storage of fresh onion is one of the most important stages of the production process, as it is during this stage that significant quantities of the foodstuff may undergo deterioration. As such, preservation is the key in reducing food loss. Onions are generally dried from an initial moisture content of about 86 % (wb) to 7 % (wb) or less for efficient storage and processing. Dehydrated onions in the form of flakes or powder are in extensive demand in several

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parts of the world,for example UK, Japan, Russia, Germany, Netherlands and Spain (Swasdisevi et al., 1999). Drying has been a major means of preserving agricultural food products. It is regarded as one of the oldest methods of food preservation processes available to mankind since prehistoric times, and it represents a very important aspect of food processing. Longer shelf-life, product diversity and substantial volume reduction are the reasons for the popularity of dried agricultural produce, including improvements in product quality, preservation of nutritive values. Dried onions are a product of great significance in world trade produced either as flaked, minced, chopped or powdered forms (Arslan and Ozcan, 2010). Generally, onions are dried for efficient storage and processing but also to reduce bulk handling, facilitate transportation, allow for their use during the off-season. However, the use of dried onions, which have a decreased mass compared to fresh onions, requires that an efficient and effective dehydration method be employed. Drying or dehydration is defined as a process of moisture removal caused by simultaneous heat and mass transfer. Heat transfer from the surrounding environment evaporates the surface moisture of the drying object. The moisture inside the product can be transported to the surface of the product and then evaporated to the surrounding. The advantage of dehydrated foods is that low moisture content slows down or prevents the growth of microorganisms that causes spoilage reactions and increases its storability. Different drying techniques are used such that Open-sun drying,convective drying, microwave drying, infrared drying, vacuum drying, osmotic drying and other combined techniques are common in drying operations and the type and condition of dehydration procedures play a significant role in determining the quality aspects of final product. The color and flavour of dried onions are considered the most important quality attributes affecting the degree of acceptability of the product by the consumer. Hence colour and flavor retention of onion during drying is most important.

Nutritional Composition of onion

Onions are low in calories (50 kcal/100 g) yet add abundant flavor to a wide variety of foods. Onion is known for its nutritional value and for the utility as herbal medicine inour country. It has moderate amounts of protein, fat, fibre and good amounts of calcium, phosphorous and potassium,vitamin C and B6. Apart from onion as such even the stalk is edible. The stalk contains good amount of carotene and iron. Onion has both glucose (reducing sugar) and sucrose(non-reducing sugar). The pungent taste of onion is due to volatile oil Allyl-propyl-disulphide present in it. The nutritional composition of onion bulb, stalk and dehydratd onion is shown in Table.1.

Table1. Nutritional composition of onion

Particulars	Big Onion (1)	Onion stalks (1)	Dehydrated onion (2)
Moisture (g)	86.6	87.6	4.6
Protein (g)	1.2	0.9	10.6
Fat (g)	0.1	0.2	0.8
Minerals (g)	0.4	0.8	3.5
Fibre (g)	0.6	1.6	6.4
Carbohydrate (g)	11.1	8.9	74.1
Energy (K cal)	50.0	41.0	-
Calcium (mg)	46.9	50	300.0
Phosphorus (mg)	50.6	50.0	290.0
Iron (mg)	0.6	7.43	2.0
Carotene (ug)	--	595.0	--
Thiamin (mg)	0.08	--	0.42
Riboflavin (mg)	0.01	0.03	0.06
Niacin (mg)	0.4	0.3	--
Folic acid (Total) (mg)	6.0	--	--
Vitamin C (mg)	11.0	17.0	147.0
Magnesium (mg)	16.0	104.0	--
Sodium (mg)	4.0	2.2	40.0
Potassium (mg)	127.0	109.0	1000.
Copper (mg)	0.18	0.45	--
Manganese (mg)	0.18	0.74	--
Molybdenum (mg)	0.03	2.29	--
Zinc (mg)	0.41	--	--

(Source: NHRDF,2009)

Methodsused in onion dehydration

Sun drying:

The simplest method of onion drying is open air sun drying,the crop is exposed to direct sunlight. Onion slices are distributed uniformly as a thin layer onto the stainless steel trays and dried under direct sunlight at temperatures between 20 and 300 C(Balladin and Headley, 1999).

Solar drying

A solar tunnel dryer is essentially an enclosed structure which traps the short wavelength solar radiation and stores the long wavelength thermal radiation to create a favorable micro-climate for higher productivity. A greenhouse heating system is used to increase the thermal energy storage inside the greenhouse during the day or to transfer excess heat from inside the greenhouse to the heat storage area (Priyanka, and Rathinakumari, 2015). A comparison of drying in various solar dryers with that in mechanical and open air sun drying indicated that the drying rate was fastest in mechanical cabinet dryer followed by those in 11 matrix bed air heater, rock type air heater (both solar dryers) and open air drying.. The suitability of various solar dryers for drying the sliced white onions and the influence of sulphitation on colour retention by the dried onion flakes (Powar et al.1988).

Convective or Hot air drying

Hot-air drying is the most commonly employed commercial technique for drying vegetables and fruits, but the hot-air drying process remains largely an art (Mazza and

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LeMaguer, 1980). The air temperatures generally considered for drying onions range between 50 and 80°C. The equilibrium moisture content of onion at 50°C temperature and more than 20% relative humidity is higher than 8% wb (Kiranoudis et al., 1993) that is why the relative humidity of the drying air is maintained below 20% for all levels of drying air temperature(Lewicki, 1998). Onions are uniformly sliced to the required thickness, and the onion slices are dried in a thin layer at 50, 60 and 70°C air tempera¬ture and at a constant airflow velocity of 1.5 m/s. Slices of raw onion samples were uniformly spread in each trays and kept in dryer. The drying continued till the final moisture content of about 0.07 g water per g dry matter was reached in the dried product. However, the major disadvantage associated with hot-air drying is the long drying time even at temperatures near 600C, resulting in the degradation of sliced onion quality. Extensive research was carried out on onion drying by conventional hot-air methods (Sarsavadia et al., 1999).

Water removal using high tem¬peratures and long drying times may cause seri¬ous decreases in nutritive and sensorial values, damaging mainly the flavour, colour and nutrients of dried products (Lenart 1996; Lin et al., 1998).

Microwave Drying The use of microwaves in the drying of products has become widespread because it minimizes the decline in quality and provides rapid and, effective heat distribution in the material as well. Furthermore, high quality product is obtained via microwave drying in addition to the decline in drying period and energy conservation during drying. Microwave drying creates an effective moisture transfer, leading to a water vapour pressure gradient between thesurface and internal part of the material, the advantage of microwave drying is shortening of drying time, a homogenous energy distribution on the material and, formation of suitable dry product characteristics due to the increase in temperature in the centre of the material (Ozkan et. al, 2005). Drying trials were carried out by Sorour and Mesery (2014) at three microwave generation power levels: 300, 500, and 700 W. The onion slices(100 g) selected from uniform and healthy plants. Three drying trials were conducted at each power level. The values obtained from these trials were averaged and the drying parameters determined. The rotating glass plate was removed from the oven every 30 s during the drying period and moisture loss determined by weighing the plate using a digital balance with 0.01 g precision

Infrared Radiation Drying

When IR irradiation is used to heat or to dry moist vegetables or fruits, the radiation impinges on the exposed vegetable or fruit surfaces and penetrates, and the energy of radiation is converted into heat (Ginzburg 1969). The depth of penetration depends on the composition and structure of the vegetables and fruits and on the wavelengths of the IR irradiation. When a food is exposed to the irradiation, the food is heated intensely, and the temperature gradient throughout the food is reduced within a short period. Further, by the application of intermittent IR irradiation, where in the periods of heating are followed by cooling, the intense displacement of moisture from the core toward the surface can be achieved. (Kumar et. al, 2005 The infrared dryer was run empty for approximately 0.5 h to equilibrate the instrument relative to pre-set experimental drying conditions before each trial. Approximately 100 g of onion slices were uniformly spread on a tray and placed inside the dryer. The drying experiments were conducted at infrared radiation intensity levels of 3000,4000 and 5000 W/m2 and a constant drying air temperature of 35oC and constant air velocity of 0.5 m/s(Sharma and others, 2005).The mass of the onion was measured using a digital electronic balance (±0.01 g) at intervals of 15 min during the drying experiment..

Osmotic dehydration.

Osmotic dehydration is the most reported pre-treatment used prior to air-drying (Mundada et al., 2010). It removes water from the fruit or vegetable up to a certain level, which is still high for food preservation so that this process must be followed by another process in order to lower even more the fruit water content. It is a useful technique that involves the immersion of the fruit in a hypertonic aqueous solution leading to the loss of water through the cell wall membranes of the fruit and subsequent flow along the inter-cellular space before diffusing into the solution (Sereno et al., 2001). As a partial dehydration process, osmosis may be regarded as a simultaneous water and solute diffusion operation, wherein the sample incurs a gain of solids and a simultaneous loss of moisture (McMinn and Magee, 1999). The shelf life quality of the final product is better than without such treat¬ment due to the increase in sugar/acid ratio, the im¬provement in texture and the stability of the colour pigment during storage (Lombard et al., 2008). The onion slices were partially dehydrated using osmotic drying technique. The slices were placed in different containers holding 10, 15 and 20°Brix of NaCl solution at ambient temperature (30°C) for 1 h; and stirring of the solution was done at regular intervals of 15 min¬utes. Solution to sample ratio was kept as 2.5:1 in each experiment. After a period of 1 h, slices were removed quickly and blotted gently using a tissue paper to remove the surface moisture.

Fluidized bed drying

Several researchers have studied fluidized bed drying of onion for making onion flakes, slices and powder(Gelder1962; Yamamoto and Stephenson 1968).Mazza and LeMaguer(1980) dehydrated the yellow globe type onions with 1.5 mm slice thickness at drying air

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temperatures of 40, 50 and 65°C with air flow rates of 5.5,8.1 and 10.3 m3/min in a vibro fluidizer and discussed the possible diffusion mechanism. The Swasdisevi et al. (1999) conducted fluidized bed drying of chopped spring onion and found air temperature and specific air velocity as major parameters affecting thedrying characteristics. Experimental results showed that at air temperature of 32°C and relative humidity of 62%, theminimum fluidization velocities were approximately 1.36, 1.20, 0.95 and 0.62 m/s at initial moisture contents of 95,71, 56 and 5% w.b., respectively.

Microwave–freeze drying.

In general, vacuum freeze-drying is one of the best methods of moisture removal with final products of highest quality compared with the other methods. The dehydration is based on the sublimation (frozen water or ice converts directly to vapour) of food products. It can minimise losses of flavour and aroma compounds owing to low temperature and low absolute pressure and consequently giving highly porous structure, no substantial shrinkage, keeping primary shape of products and minimal reduction in volume. Microwave-vacuum drying is also rapid, more uniform and energy efficient compared with other dryingtechniques which recently have been investigated as a potential method for obtaining high-quality dried food products. This method combines the advantages of both microwave and vacuum drying. The low temperature and fast mass transfer combined with rapid energy transfer generates very rapid, low-temperature drying which leads to higher quality parameters in food products. The potential and practical capability of microwaves for dehydrating the frozen food products, namely onion slices, in order to combine the advantages of both microwave-vacuum drying and freezing which is called microwave–freeze drying. Moreover, the quality characteristics (microstructure, colour, dehydration ratio, volume) of onion slices were compared with those dehydrated by several common methods(Abbasi and Azari, 2008).

Vaccum drying

To counter the undesirable effects of these drying methods and to improve quality as well as nutritional value, a potentially useful technique called vacuum drying is attempted. It allows effective removal of moisture under low pressure (Jaya and Das, 2003). Vacuum enhances the mass transfer because of an increased vapour pressure gradient between the inside and outside of the sample to dry and maintain a low temperature level essential for thermo labile products (Péré and Rodier, 2002). Consequently, vacuum drying provides higher drying rate compared to conventional methods, lower drying temperature and an oxygen deficient processing environment (Wu et al., 2007).

The dryer was provided with anarrangement for circulating hot water into the header plates through pipelines to maintain the desired drying temperature. Stainless steel trays were used for placing the onion slices in a single layer for drying. A watering vacuum pump was used to create the desired vacuum of 710±5mm Hg inside the drying chamber. There was a thermostat type temperature controller attached to the system. The dryer was also equipped with a vacuum gauge and indicators for showing the temperatures of product as well as vapour. The dryer was set at the desired drying temperature of 50, 60 or 70 ◦C by circulating hot water through the header plates. Onion slices of a particular thickness were placed in separate stainless steel trays in single layers. Initial weights of trays and the samples were noted. Trays were placed onto the header plate in the drying chamber after steady state condition was achieved. Door of the vacuum dryer was securely tightened and a vacuum corresponding to 50±5mm Hg absolute was maintained. Initially the onion sample trays were taken out for weighing at 15 min intervals up to 90 min and thereafter at every 30 min interval till a constant weight was achieved. Vacuum was broken and restored before and after the weight measurement and each process took less than 1min. Drying was continued till a constant weight was attained at three consecutive intervals The pressure of 50±5mm Hg absolute, maintained inside the vacuum dryer chamber corresponded to a saturation temperature of 37.18 ◦C(Mitra et al., 2011).

Comparison between drying methods Drying on two convective dryers vertical convective and horizontal convective was studied by (Mesery and Mwithiga 2012) in that the rate of moisture removal increased with increase of drying air temperature and air velocity in both dryers. Within the experimental range of this work, varying the drying air temperature had a greater effect on the drying process than varying the air velocity. In general, the reduction of moisture ratio with time was higher for the samples dried under the HC dryer when compared to those dried in the VC dryer for the same setting of air temperature and velocity.The horizontal dryer was found to be more efficient in drying onion slices when compared to vertical dryer and it also had a higher rehydration ratio. The process of freeze drying of fresh onion samples has a positive effect on the levels of total flavonols and anthocyanins, facilitating their extraction between 25 and 32%.A good alternative would be freeze-drying to obtain onion powder for cooking, which will be reasonably stable for half-a-year (Mesery and Mwithiga 2012) has prepared two dryers gas fired hot air dryer and electrically heated hot air dryer they observed that Increasing the air temperature resulted in an increase in the drying rate of onion slices, and this was true both in the gas dryer and the electric dryers. When the air velocity was increased while holding the air temperature constant, it

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resulted in a decrease in the drying duration for both the gas and electric dryer.The specific energy consumption of the gas heated dryer was lower than that of the electrically heated dryer. The thermal efficiency of the gas dryer was higher than that of the dryer that used an electrical heater. Also, the onion slices dried in both dryer, and for all drying conditions within the range of this study, and were of good quality in terms of rehydration ratio and visual appearance. Drying behaviour of onion slices in tray dryer was investigated in that increase in dry¬ing air temperature decreased drying time. Pre-treated onion slices have shorter drying time than the untreated samples(Revaskar, 2014)

The study on microwave and infrared drying of onion shows following results in table no. 2

Table 2 Color and Browning Change of Onion Slices after Drying

Drying Methods	Total Color Change (δE)	Browning Index (BI)
Microwave Drying		
200 W	19.13	16.61
300 W	20.86	13.53
400 W	19.99	19.99
Infrared Drying		
3000 W/m2	23.93	19.95
4000 W/m2	24.08	20.57
5000 W/m2	25.05	21.94

A comparison of microwave and infrared drying times indicate that irrespective of the power or radiation intensity applied, microwaving is an effective method of shortening the time required for drying to the desired moisture content without charring the samples. Moreover, microwave drying had less influence on the color and rehydration ratio of the finished product than infrared drying(Sorour and Mesery, 2014)

Table 3. Analysis of the vitamins C and D content in dried onion samples.

Samples	Vitamin C	Vitamin D
Raw red	6.43b ± 0.01	0.12± 0.001
Raw white	6.51	0.11 ± 0.01
Red 50°C	6.25 ± 0.10	0.024± 0.003
Red 60°C	6.18± 0.004	0.021 ± 0.001
Red 70°C	6.12 ± 0.02	0.016± 0.001
White 50°C	6.36 ± 0.010	0.04 ± 0.001
White 60°C	6.18 ± 0.13	0.03± 0.001
White 70°C	6.24 ± 0.01	0.029 ± 0.001

An increase in drying air temperature had a negative effect on quality for both vitamin C and vitamin D which is a thermo-sensitive compound; this was likely due to the elevated processing temperature and period of exposure. Dried red and white onion at an air temperature of 50˚C had the highest vitamin C retention after drying.The quantity of thiolsulphinate decreased with an increase in drying time and temperature. Thiolsulphinate loss increased with a decrease in moisture content to a certain level(Ayoola Olalusi, 2014) Drying process conditions exhibited a significant effect on the drying characteristics and on the quality of dried onion slices during a combination IR irradiation and hot-air drying process. Drying of thin (2 mm) slices of onion at 600C with a convective flow of 2 m/s and a moderate air temperature of 400C retained greater pungency and color. The combined IR irradiation and hot-air drying of onion slices resulted in a rapid drying process and improved the quality of the onion slices dried with IR irradiation or hot air alone (Kumar et. al 2005) Practical applicability of combined microwave freeze drying in decreasing processing time and costs, the quality properties of slices produced by this novel method were also completely comparable and competitive with commercial freeze drier with over 96% saving on processing time and enormous amount on energy and capital investments.

Table 4 Comparison of mean colour parameters of onion slices dried by various methods

Drying method	L*	a*	b*
Commercial freeze drier	87.97	-0.7	19.88
Microwave-vacuum–freeze drier	79.68	-1.5	23.14
Microwave-vacuum drier	63.04	0.3	26.06
Microwave drier without vacuum	55.96	7.11	28.57

Microwave oven drying with low output power (210 W) could retain phenolics of the product better than sun and oven drying. The changes in the concentrations of minerals were dependent on the method and the drying temperature. By oven drying at 700C, the mineral content of dried sample became higher than that of other dried samples. It is also noted that the large drying period for which the product is exposed to the atmospheric oxygen has an adverse effect on some quality aspects like reduction in ascorbic acid, etc. (Sarsavadia, 2007). Microwave drying yield the highest Deff values which were approximately 50 fold higher than that of sun and oven (500C) drying(Arslan and Ozcan, 2010) In this study, convective, vacuum, and microwave drying behaviors of onion slices with and without a pretreatment were studied. Drying rates and diffusion coefficients of samples increased with temperature or power level and decreased with slice thickness. Brine solution had a negative effect on convective drying time but adversely, had a positive effect on both vacuum and microwave drying times. ctivation energies of pre-treated samples were lower than slices contained no salt solution under vacuum and microwave drying conditions and all samples dried by three methods (Seufer et. al, 2016) Increasein the drying temperature and decrease in the slice thickness caused a decrease in drying time significantly in vaccum drying (Mitra et.al,2010).

II. CONCLUSIONS

Open sun drying and solar drying are increases the drying time than other methods, they are also affect the product quality, most common method followed for drying convective hot air drying. Different changes in convective drying such vertical and horizontal dryer and gas fired and electrical supplied dryer is also influence the drying of onion. Microwave drying is best method for the highest retention of colour, flavour and, vitamins and thiosulphur contents. Review of different dehydration techniques of onion reveals that several analytical and numerical methods are available for analyzing the drying behaviour as well as quality parameters. Combination of two or more drying methods or multimode drying techniques can also be adopted for drying of onion. Most of the modeling of drying kinetics has been done for hot air drying method. These models can be tested for other drying methods also.

REFERENCES

1. Abbasi S, Azari S (2009) Novel microwave–freeze drying of onionslices. Int J Food Sci Technol 44:974–979.
2. Balladin, Derrick A., and Oliver Headley. "Evaluation of solar dried thyme (Thymus vulgaris Linne) herbs." Renewable Energy 17.4 (1999): 523-531.
3. D.G. Praveen kumar H. Umesh hebbar D. Sukumar and M.N. Ramesh (2005) Infrared and hot-air drying of onions Journal of Food Processing and Preservation 29 132–150.
4. Derya Arslan, Mehmet Musa Özcan (2010) Study the effect of sun, oven and microwave drying on quality of onion slices Food Science and Technology 43 1121-1127
5. FAO (2009) Food and Agricultural Organization, Area and production data. www.fao.org. Access date 01 Dec 2009
6.
7. Gareth Griffiths, Laurence Trueman, Timothy Crowther, Brian Thomas and Brian Smith (2002) Onions—A Global Benefit to Health Published online in Wiley InterScience16, 603–615
8. Gelder AV (1962) Fluidized bed process for dehydration of onion, garlic and the like. US Patent 3063848
9. Ginzburg, A. S. (1969). Application of infra-red radiation in food processing (No. 664.0288 G5).
10. Hany S. EL-Mesery and Gikuru Mwithiga (2012) The drying of onion slices in two types of hot-air convective dryers , African Journal of Agricultural Research Vol. 7(30), pp. 4284-4296,
11. Hussain sorour and Hany el-mesery (2014) Effect of microwave and infrared radiation on drying of onion slices 2, (5), 119-130
12. Jaya, S. and Das, H., (2003) A vacuum drying model for mango pulp. Drying Technology, 21(7): 1215–1234.
13. Jayeeta Mitra, S. L. Shrivastava and P. S. Rao (2012) Onion dehydration: a review J Food Sci Technol 49(3):267–277
14. Kiranoudis C.T, Maroulis Z.B, Tsami E, Marinos-Kouris D (1992) Drying kinetics of onion and green pepper. Drying Technol 10(4):995–1011
15. Kumar D.G.P, Hebbar H.U, Ramesh M.N (2006). Suitability of thin layer models for infrared-hot air-drying of onion slices. Leben smittel Wissens chaft Technol. 39:700-705.
16. Lenart A., (1996) Osmo-convective drying of fruits and vegetables: technology and application. Drying Technol¬ogy, 14: 391–413.
17. Lewicki PP (1998) Effect of pre drying, drying and rehydration on plant tissue properties, a review. Int J Food Prop 1:1–22
18. Lin T.M., Durance D.T., Scaman C.H., (1998) Characteri¬zation of vacuum microwave, air and freeze dried carrot slices. Food Research International, 31: 111–117.

19. Mazza G, Lemaguer M (1980a) Dehydration of onion: some theoretical and practical considerations. J Food Technol 15:181–194

20. McMinn, W. A. M., & Magee, T. R. A. (1999). Principles, methods and applications of the convective drying of foodstuffs. Food and Bioproducts Processing, 77(3), 175-193.

21. Mitra J, Shivastava SL Srinivasa RP (2012). Vacuum Dehydration kinetics of onion slices, Food Bioprod. Process. 89:1-9.

22. Mitra, J., Shrivastava, S. L., & Rao,P.S. (2011).. Onion dehydration: a review J Food Sci Technol 49(3):267–277.

23. Mota CL, Luciano C, Dias A, Barroca MJ, Guine RPF (2010)Convective drying of onion: kinetics and nutritional evaluation. Food Bioprod Process 88:115–123

24. Mundada, M., Hathan, B. S., & Maske, S. (2010). Convective dehydration kinetics of osmotically pretreated pomegranate arils. Biosystems engineering, 107(4), 307-316.

25. Olalusi, A. (2014) Hot Air Drying and Quality of Red and White Varieties of Onion (Allium cepa).Journal of Agricultural Chemistry and Environment, 3, 13-19.

26. Pere, C., and Rodier, E. (2002). Microwave vacuum drying of porous media: experimental study and qualitative considerations of internal transfers. Chemical Engineering and Processing: Process Intensification, 41(5), 427-436.

27. Powar V N, Singh N I, Dev D K, Kulkarni D N, Ingle U M (1988) Solar drying of white onion flakes. Indian Food Packer 42(1):15–28

28. Priyanka, U. Rathinakumari, A. Design and development of tunnel type Solar dryer for dehydration of onion And amla, Department of agricultural engineering University of agricultural sciences, Bengaluru-560 0652015

29. Revaskar VA, Pisalkar PS, Pathare PB, Sharma GP. Dehydration kinetics of onion slices in osmotic and air convective drying process. Research in Agricultural Engineering2014, 60, 92-99.

30. Sarsavadia PN, Sawhney RL, Pangavhane DR, Singh SP (1999) Drying behaviour of brined onion slices. J Food Eng 40:219–226

31. Sereno A.M., Moreira R., Martinez E., 2001. Mass transfer coefficients during osmotic dehydration of apple in single and combined aqueous solutions of sugar and salt. Journal of Food Engineering, 47: 43–49.

32. Seufer E.O, Sezer S, Demir H. Thin layermathematical modeling of convective, vacuum and microwave drying of intact and brined onion slices. J Food Process Preserv.2017;00: e13239.

33. Sharma GP, Verma RC, Pathare P (2005) Mathematical modeling of infrared radiation thin layer drying of onion slices. J Food Eng71:282–286

34. Swasdisevi T, Soponronnarit S, Prachayawarakorn S, PhetdasadaW (1999) Drying of chopped spring onion using fluidization technique. Dry Tehnol 17(6):1191–1199

35. Wang J (2002). A single-layer model for far-infrared radiation drying of onion slices. Drying Technol. 20(10):1941-1953

36. Wu, L., Orikasa, T., Ogawa, Y. and Tagawa, A., 2007, Vacuumdrying characteristics of egg plants. Journal of FoodEngineering, 83: 422–429

37. Yamamoto JS, Stephenson RM (1968) Free-flowing onion, garlic orhorseradish. US Patent 3378380