Onion dehydration: a review

Jayeeta Mitra · S. L. Shrivastava · P. S. Rao

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Abstract Onion (*Allium cepa*), a very commonly used vegetable, ranks third in the world production of major vegetables. Apart from imparting a delicious taste and flavour due to its pungency in many culinary preparations, it serves several medicinal purposes also. Processing and preservation of onion by suitable means is a major thrust area since a long time. The various kinds of treatments followed for dehydration of onion such as convective air drying, solar drying, fluidized bed drying, vacuum microwave drying, infrared drying and osmotic drying are reviewed here. These techniques are mainly used for preservation and value addition of onion. Several researchers have tried for decades to model the drying kinetics and quality parameters, which are also compiled here briefly.

Keywords Onion · Dehydration · Nutritional value · Mathematical modeling

Nomenclature

a, b	Empirical constants for equation (4.10)
a_w	Water activity of product
A_x	Exchange area (m^2)
C, Y	Optical index
C'	Thiosulphinate concentration ($\mu\text{mol/g}$)
c_1, c_2, c_3, c_4	Model parameter values for equation (4.11)
d_1, d_2, d_3, d_4	Model parameter constants for equation (4.13)
db	Dry basis (g/g solid)
d_p	Dry matter fraction

J. Mitra (✉) · S. L. Shrivastava · P. S. Rao
 Department of Agricultural and Food Engineering,
 Indian Institute of Technology,
 Kharagpur 721302, India
 e-mail: jayeeta12@gmail.com

exp	Exponential
$g_1, g_2, g_3, g_4, g_5, g_6$	Model parameter values for equation (4.12)
H	Absolute humidity (kg/kg dry basis)
K	Reaction rate constant for equation (4.1)
k, c	Reaction rate constant for equation (4.3)
K'	Reaction rate constant for equation (4.8)
L_s	Dry border strip width (m)
M	Moisture content (% dry basis)
$m_1, m_2, m_3, m_4, m_5, m_6$	Model parameter constants for equation (4.14)
R	Universal gas constant (kJ/mol Kelvin)
t	Time
T	The absolute temperature (Kelvin)
V	Air flow velocity (m/s)
V_s	Actual volume of single particle (m^3)
wb	wet basis (g water/g material)
X	Moisture content (g/g solid)
X_x	Amount of water removed per unit mass of dry matter through the walls x

Subscripts

0	Initial states
e	Equilibrium
p	Product
x	Relative to surface x

Greek

α	Water content ratio X/X_0
$\alpha_0, \alpha_1, \alpha_2, \alpha_3$	Empirical constants for equation (4.4)
$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$	Empirical constants for equation (4.6)
$\delta_0, \delta_1, \delta_2, \delta_3, \delta_4$	Empirical constants for equation (4.7)
$\gamma_0, \gamma_1, \gamma_2, \gamma_3$	Empirical constants for equation (4.5)
$\eta_0, \eta_1, \eta_2, \eta_3, \eta_4$	Empirical constants for equation (4.2)

Introduction

Onion (*Allium cepa*) is the most commonly used vegetable 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. Besides adding a delicious taste and flavour, onion serves as a good medicinal compound for cataract, cardiovascular disease and cancer due to its hypocholesterolemic, thrombotic and antioxidant effects as stated by Block (1985), Block et al. (1997), Stavric (1997), Nuutila et al. (2003) and Vidyavati et al. (2010). Several antioxidant compounds, mainly polyphenols such as flavonoids and sulfur-containing compounds, have been described in onion and garlic by the researchers namely Kourounakis and Rekka (1991), Horie et al. (1992), Yamasaki et al. (1994), Prasad et al. (1995), Block et al. (1997), Suh et al. (1999), Banerjee et al. (2002), Nuutila et al. (2003), Gorinstein et al. (2005) and Ly et al. (2005).

At least 175 countries grow onions. According to the latest information available from United Nations Food and Agriculture Organization (FAO 2009), the world production of onion is 64.48 million tons from 3.45 million ha area. Approximately 8% of this global onion production is traded internationally. Productivity of onion is highest in Ireland (58 tons/ha), followed by Korea Republic (57 tons/ha), USA (55.88 tons/ha), Spain (52 tons/ha), Chile (48.50 tons/ha), and Australia (49 tons/ha) while India has a productivity of 13.20 tons/ha (NHRDF 2009). 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. Table 1 shows the yearly increase in area and yield of onion production in India.

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 in our 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 proximate composition and energy values of raw and dehydrated onion are shown in Table 2.

Onions contain significant amount of a flavonoid called quercetin. Although quercetin is available in tea and apples, earlier research proved that absorption of quercetin from onions is twice that from tea and more than three times that from apples (Singh 2005). Onions are stimulant and mild counter irritant. Crushed raw onion can be applied on the forehead to get relief from headaches. Red small onions can be used as an expectorant. Eating raw onions help to reduce cholesterol levels because they increase levels of high-density lipoproteins. It is advisable to include raw onions in the salads daily. It helps in controlling coronary heart disease, thrombosis, and blood pressure. This use of onion is controversial. There are conflicting reports about this property. Onion can cause migraine in some people and flatulence. Eating raw onion can also lead to bad breath. Sulphur compounds present in onion will help to prevent the growth of cancer cells. Onions are also used in the treatment of anaemia, urinary disorders, bleeding piles and teeth disorders. Anti tumor and anti cancer effect, platelet-anti-aggregating agent, anti-hypercholesterolemia, anti-ulcer and anti-gastric cancer agent activity of onion are also found by several researchers (Table 3).

Dehydrated onion

Processed and value added products are gaining importance in the worldwide markets. According to Singh et al. (2006) onion has 6% share in the overall production of vegetables in India and about 93% of the total export of fresh vegetables from India. Onion is mainly exported in the form of dehydrated onion, canned onion and onion pickle. Free water is removed from the vegetables during the drying process so that microorganisms do not survive and reproduce. Simultaneously, the solids such as sugar and organic acids are concentrated thereby exerting osmotic pressure to further inhibit the microorganisms. Drying process involves the application of heat to vaporize water and removal of moist air from the dryer.

Dehydrated onions are considered as a potential product in world trade and India is the second largest producer of dehydrated onions in the world. There is a large demand of dehydrated onion in the European countries only (Srinivasa

Table 1 Yearwise production status, area and yield of onion in India

Year	Area (m ha)	Production (mt)	Yield (tons/ha)
2001–2002	0.45	4.83	10.69
2002–2003	0.42	4.21	9.91
2003–2004	0.50	5.92	11.78
2004–2005	0.55	6.43	11.72
2005–2006	0.66	8.68	13.12
2006–2007	0.62	8.18	13.20

(Source: FAO 2009)

Table 2 Proximate composition and energy values of raw and dehydrated onion (per 100 g of onion)

Particulars	Big onion	Small onion	Onion stalks	Dehydrated onion
Moisture, g	86.6	84.3	87.6	4.6
Protein, g	1.2	1.8	0.9	10.6
Fat, g	0.1	0.1	0.2	0.8
Minerals, g	0.4	0.6	0.8	3.5
Fibre, g	0.6	0.6	1.6	6.4
Carbohydrate, g	11.1	12.6	8.9	74.1
Energy, K cal	50.0	59.0	41.0	–
Calcium, mg	46.9	40.0	50.0	300.0
Phosphorus, mg	50.0	60.0	50.0	290.0
Iron, mg	0.6	1.2	7.43	2.0
Carotene, µg	–	15.0	595.0	–
Thiamin, mg	0.08	0.08	–	0.42
Riboflavin, mg	0.01	0.02	0.03	0.06
Niacin, mg	0.4	0.5	0.3	–
Folic acid, mg	6.0	–	–	–
Vitamin C, mg	11.0	2.0	17.0	147.0
Magnesium, mg	16.0	–	104.0	–
Sodium, mg	4.0	–	2.2	40.0
Potassium, mg	127.0	–	109.0	1000.0
Copper, mg	0.18	–	0.45	–
Manganese, mg	0.18	–	0.74	–
Molybdenum, mg	0.03	–	2.29	–
Zinc, mg	0.41	–	–	–

(Source: Onion crop details, NHRDF 2009)

Murthy and Subramanyam 1999). Hyma Jyothi (2003) found a positive and significant growth rate in onion export which is of 6.27% per annum.

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 parts of the world, for example UK, Japan, Russia, Germany, Netherlands and Spain (Sarsavadia et al. 1999).

Onion varieties suitable for dehydration

Jones and Mann (1963) and Saimbhi et al. (1970) reported some essential characteristics that should be present in onion cultivar suitable prior to drying. White coloured flesh with total solid content 15–20% and having high pungency is strongly recommended for drying. Insoluble solid should be high whereas, ratio of reducing to non-reducing sugar should be low to lessen discolouration and browning during drying. Resistance to diseases, moulds and insects both in

Table 3 Medicinal value of onion

Effect	Reference
Antimicrobial	Whitmore and Naidu (2000)
Antiasthmatic	Dorsch and Wagner (1991)
Anti tumor and anti cancer effect	Block (1994)
	Kamel and Saleh (2000)
	Miron et al. (2003)
Platelet- antiaggregating agent	Mochizuki and Nakazawa (1995)
Anti hypercholesterolemia	Lanzotti (2006)
Anti ulcer and anti gastric cancer agent	Elsom et al. (2000)
	Canizares et al. (2004)

the field and during storage increases the acceptability of an onion cultivar for processing.

Poor keeping cultivars have low dry matter content and high rate of water loss, low refractive index and are generally less pungent (Van Kampen 1970). The acceptable Indian onion varieties for dehydration among white flesh onions are 'Bombay White', 'No-36-1-3-4', 'Udaipur-102', 'S-74', 'Pb-48', 'L-131', 'L-124', 'L-106', 'Pusa White Round', 'Pusa White Flat', 'N-257-9-1' etc. and the red onion varieties are 'Ropali', 'Rangda', 'Udaipur-101', 'Pusa Red', 'VL-1', 'Punjab Red', 'Sel-102-1', 'Arka Niketan', 'N-2-4-1', 'Agrifound Light Red', 'Agrifound Dark Red', Arka Kalia, 'N-53' etc. Several researchers have evaluated the suitability of onion varieties for dehydration purpose as mentioned in the Table 4.

Dehydration practices for onion

Dehydration of food is aimed at producing a concentrated product, which when adequately packaged has a long shelf life, after which the food can be simply reconstituted without substantial loss of flavour, taste, colour and aroma. Several types of dryers and drying methods, each better

suitable for a particular situation are commercially used to remove moisture from a wide variety of food products including fruits and vegetables. Factors, on which the selection of a particular dryer or drying method depends, include the form of raw material and its properties, desired physical form and characteristics of the product, necessary operating conditions and operating costs. The most commonly adopted drying practices for onion are sun drying or solar drying, convective air drying, green house drying and infrared drying.

Solar drying

Moyis (1986) described the construction and performance of a natural convection solar dryer for drying the fruits and onion and found that from 342 m² area, 500 kg of material can be dried in 3–5 days with a peak air temperature of 63°C and an air flow rate of 79 m³/min. Powar et al. (1988) tested 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. A comparison of drying in various solar dryers with that in mechanical and open air drying indicated that the drying rate was fastest in mechanical cabinet dryer followed by those in matrix bed

Table 4 Reported varietal studies for onion dehydration

Examined varieties	Parameter studied	Recommended varieties	Reference
Seven onion varieties	Quality of dehydrated product	Bombay White	Saimbhi et al. (1970)
Sixteen cultivars of white onion grown at IARI	Quality of dehydrated product	Cultivar no-36-1-3-4	Sethi et al. (1973)
Six white onion varieties namely 'Udaipur 102', 'Pusa White Round', 'N-257-9-1', 'Pusa White Fat', 'S-48' and 'Bombay White', one light red variety of onion, 'VL-1', and seven red varieties of onions viz., 'N-2-4-1', 'Pusa Red', 'S-11', 'Udaipur-101', 'S-14', 'Sel-102-1' and 'N-53'	Losses during storage of fresh onions, suitability of dehydration and extent of pungency during dehydration and subsequent storage	white variety Udaipur-102' and red variety 'Udaipur-101'	Singh and Kumar (1984)
Four commercial varieties of red onion, viz. 'Mahua', 'Ropali', 'Nasik' and 'Rangda'	Varietal characteristics, storage and drying behavior, dehydration ratio, insoluble solid, flavor content, colour	Ropali' variety	Maini et al. (1984)
Five varieties of white onion viz. 'Pusa White', 'White Globe', 'Pb-48', 'VL-1' and 'S-74' and two red onions namely 'Punjab selection' and 'N-53'	Organoleptic quality of the dehydrated onion, flesh colour, pungency, total solid	'S-74'	Kalra et al. (1986)
'Pusa White round', 'Pusa white flat', 'Pb-48' and 'N-257-9-1' among white types; 'Pusa Red', 'Agrifound Light Red', 'Arka Niketan', 'N-2-4-1' in light red types; and 'Agrifound Dark Red', 'Arka Kalia' and 'N-53' in dark red types	Quality of dehydrated product	'Pusa White' round and 'Pb-48'	Pandey (1989)
Ten onion varieties	Shrinkage ratio, dehydration ratio, coefficient of rehydration, pyruvic acid content, colour, ascorbic acid, reducing sugar and sensory evaluation.	'VL-1'	Sharma and Nath (1991)

air heater, rock type air heater (both solar dryers) and open air drying.

A solar dryer with a heater arrangement was made by Bennamoun and Belhamri (2003) and tested on onion due to its swift deterioration property. They concluded that surface of the collector, the air temperature and the product characteristics had profound effect on drying and developed empirical equations to explain drying kinetics. Jain (2005) performed an even shape packed bed green house drying of onion and developed a transient analytical model to compute the air temperatures and various functional components of the drying systems for a day of the month of May for the climatic condition of Delhi (India). The parametric study involved the effect of length and breadth of greenhouse and mass flow rate of air on the temperatures of crop. The drying rate and hourly reduction in moisture content in the crop trays were studied by the thin layer drying equation and observed that crop moisture content and drying rate decreases with the drying time of the day.

Convective air drying

At a commercial level the convective drying of onion is used mainly now-a-days. Gupta and Gowda (1976) found that three stage drying of onion flakes had better effect on organoleptic characteristics of onion compared to one constant drying temperature of 50°C. However this convective drying method has some adverse effect on the finished product. Conventionally air dried products tend to be difficult to rehydrate satisfactorily due to structural changes in the product and of indifferent quality due to excessive thermal damage as stated by Holdsworth (1986).

Munde et al. (1988) dried onion slices of 4 mm thickness at 50, 60, 70, 80, 90 and 100°C temperatures upto 30, 40, 50 and 60% cut off moisture levels; the remaining moisture was removed at control temperature of 50°C. They recommended that the onion flakes could be dehydrated in two stage; in the first stage by employing 90°C temperature removing moisture upto 50% and in the second stage employing 50°C temperature removing the remaining moisture. It was further recommended that four stage drying process - drying at 90°C upto 50% moisture level, at 80°C from 50 to 40% moisture, at 70°C from 40 to 30% moisture and then drying at 50°C could be employed to save 25% of drying time as compared to that otherwise needed for two stage drying.

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) reported that

convective drying usually extends over long period and causes many undesirable changes in the material.

A laboratory scale thin layer dryer was developed for dehydration of fresh onion by Akbari et al. (2001). They examined the effect of process parameters such as drying air temperature, air velocity and slice thickness on the drying time, sensory quality, rehydration characteristics and bacterial counts using Central Composite Rotatable Design. They recommended that 76°C temperature with 27 m/min velocity of air is sufficient to get good quality dehydrated 3 mm thick slices in a minimum drying period of 58 min. Akbari and Patel (2006) also reported similar findings.

At a commercial level the convective drying of onion is used mainly. Drying of onion at different temperatures of 50, 60, 70 and 75°C and air velocities of 0.6, 1.0, 1.2 and 1.5 m/s was studied by Kaymak-Ertekin and Gedik (2005). They also studied the quality attributes in terms of non-enzymatic browning and thiosulphinate concentration, during storage at different temperatures of 20, 30 and 45°C and different water activities of 0.332, 0.432 and 0.570. Non-enzymatic browning as measured by the optical index increased proportionately with time and temperature during drying, whereas it increased with a decrease in moisture content upto a certain level. The maximum browning rate occurred in the moisture content range of 2–3 (% db). The drying air velocity did not affect the browning and thiosulphinate content of the dried product significantly.

Mota et al. (2010) have recently studied drying kinetics and nutritional evaluation for convective drying of onion at three different temperatures ranging from 30 to 70°C. They estimated the effect of drying temperature on the chemical composition of onion (Table 5). Their research revealed that while sugars, acidity and Vitamin C were significantly affected by temperature, other parameters viz., fat, ash, crude protein and crude fibre were not at all influenced by temperature.

Fluidized bed drying

Several researchers have studied fluidized bed drying of onion for making onion flakes, slices and powder (Gelder 1962; Yamamoto and Stephenson 1968). Problems such as scorching or the agglomeration of onion slices during tray, tunnel or conveyor belt drying were resolved during fluidized bed dehydration techniques as reported by Gummery (1977), in which contact between onion pieces was kept to a minimum.

Mazza and LeMaguer (1980a) dehydrated the yellow globe type onions with 1.5 mm slice thickness at drying air 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. Mazza and LeMaguer (1980b) showed that percent retention of flavour such as

Table 5 Chemical composition of onion, fresh and dried under various temperatures

	Fresh	Dried at 30°C	Dried at 40°C	Dried at 50°C	Dried at 70°C
Moisture (% wet basis)	91.2±0.54	21.5±0.04	13.3±0.88	17.5±0.50	16.0±0.41
Ash (g/100 g dry solid)	3.4±0.06	3.4±0.38	5.3±0.35	4.6±0.84	4.2±0.50
Total sugars (g/100 g dry solid)	56.0±0.80	43.4±1.22	40.3±2.60	33.3±3.03	22.4±1.45
Fat (g/100 g dry solid)	0.56±0.03	0.24±0.08	0.41±0.02	0.27±0.06	0.34±0.08
Crude Protein (g/100 g dry solid)	0.56±0.10	1.01±0.09	0.10±0.01	0.29±0.07	0.36±0.05
Crude Fibre (g/100 g dry solid)	5.60±0.63	4.3 ±0.07	6.1±0.89	4.87±0.12	4.8±0.31
Acidity (ml/100 g dry solid)	36.71±2.90	21.0±1.20	20.8±1.36	19.4±1.41	15.8±1.38
Vitamin C (mg/100 g dry solid)	1889±69	137.0±11	136.0±12	134.0±10	89.0±2

(Source: Mota et al. 2010)

1-propanethiol, methyl propyl disulphide, di-propyl disulphide and 1-propanol was almost linearly related to moisture content. The final retention of volatiles increased with increase in dehydration temperature. High temperature led to a more rapid formation of the dry layer and lowered the diffusion of the flavour compound at the evaporating surface.

Swasdisevi et al. (1999) conducted fluidized bed drying of chopped spring onion and found air temperature and specific air velocity as major parameters affecting the drying characteristics. Experimental results showed that at air temperature of 32°C and relative humidity of 62%, the minimum 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. They recommended Page's model to predict the experimental data accurately. The air-product temperature should be kept lower than 53°C to maintain the acceptable green color of the dried product.

Microwave and freeze drying

Kamoi et al. (1981) investigated microwave drying of onion with a hot air pretreatment and compared the products with traditionally dried ones. The colour of microwave and freeze dried onions was similar to that of air dried onions at 80 and 60°C, respectively. However, rehydration was better in case of freeze drying. Higher level of shrinkage was observed in case of microwave dried samples.

Abbasi and Azari (2009) studied the rehydration ratio, colour (L^* , a^* and b^*) and micro-structure of white onion slices of various thicknesses dried using commercial freeze dryer at an absolute pressure of 0.005 mbar and 45°C; in a microwave-vacuum drier at absolute pressure down to 300 mbar under various microwave powers of 120 to 1,200 W and microwave-vacuum-freeze drier at -20°C for 2 h. They found that microwave-vacuum-freeze drier is practically a rapid, simple, efficient, economic and novel dehydration technique which can be used for dehydration

of foodstuffs. This novel method was also found superior over commercial freeze drier with over 96% saving in processing time coupled with considerable saving in energy and capital investments.

Infra red drying

The drying of welsh onion by far infra red radiation under vacuum condition was investigated by Mongpraneet et al. (2002). The radiation intensity level influenced dramatically the drying rate and the product qualities. They found 70 W power level was the most suitable for good product quality. The radiation also had significant effects on chlorophyll content. The long time in drying and high temperature may have contributed to a decrease in rehydration properties.

Gabel et al. (2004) compared onion dehydration using a catalytic flameless gas fired infrared (CFGIR) drier and forced air convection (FAC) drier. CFGIR drying exhibited greater drying rates at 70°C than conventional drying in case of thin layer onion dehydration and induced less colour change also. Air circulation inside the CFGIR did not affect the drying rates.

An infra red radiation thin layer drying was tested for onion slices at infra red power levels of 300, 400 and 500 W, air temperatures of 35, 40 and 45°C and air velocities of 1.0, 1.25 and 1.5 m/s by Sharma et al. (2005). The drying occurred in the falling rate drying period. Drying rate was proportional with infra red power at a given air temperature and velocity and thus reduced the drying time. They found the Page model more suitable for modeling the drying behaviour of onion slices accurately.

Effective moisture diffusivity of 6 mm thick onion slices was examined by Pathare and Sharma (2006) under infrared convective drying condition. They observed that the values of effective moisture diffusivity of onion slices increased with radiation intensity for the same value of drying air temperature and air velocity. Average effective moisture diffusivity decreased at all air temperatures and applied

radiation intensities with increase in air velocity. It was indicated that decrease in activation energy caused an increase in drying rate. Higher drying rates were observed for higher radiation intensity and inlet air temperature. Infrared intensity was found dominant for moisture removal.

Vacuum drying

Onion slices were dried in a single layer of thickness varying from 1 to 5 mm in the temperature range of 50–70°C in a laboratory scale vacuum dryer. The effect of pretreatment, drying temperature and slice thickness on the drying kinetics of onion slices was studied using different thin layer models (Mitra et al. 2011). The moisture diffusivity values were found ranging from $1.32\text{E}-10$ to $1.09\text{E}-09$ m^2/s for untreated and $1.32\text{E}-10$ to $1.09\text{E}-01$ m^2/s for treated onion slices. Effective moisture diffusivity showed increasing trend with increase in temperature and thickness.

Freeze drying

Hamed and Foda (1966) studied freeze drying of onion slices. Onion slices of 4 to 6 mm thickness were rapidly frozen to -30°C for 7–8 h at 6.1 mm Hg pressure. The colour, flavour, nutrient content and rehydration were found better than traditionally dried product. Popov et al. (1976) described a commercial process for freeze drying of onions. In this process best quality onions were subjected to preliminary freezing to -20°C while the amount of water evaporated at the sub zero temperature amounted to 85%.

Hot air drying of onion slices to 50% of their initial weight at 100°C followed by freeze drying occupied only about half the volume of conventionally freeze dried products but possessed similar rehydration properties except having a deeper colour as examined by Andreotti et al. (1981) and thus suitable for packaging, storage and transport. Freeze drying is recognized by Somogyi and Luh (1986) to be the most superior method among all the dehydration procedures for many fruits and vegetables. Only drawback which hinders its large commercial use is its high operating cost compared to other dehydration methods. Freeman and Whenham (2006) found that freeze-dried onion retained more of the characteristic flavour components of fresh onion, as judged by sensory tests, than hot air drying and other normally practised post-harvest processes for onion.

Osmotic dehydration

Osmotic dehydration of onion slices is gaining importance now-a-days as an emerging drying technique. Osmotic drying is carried out in order to remove the moisture prior to mechanical drying. Three salt concentration levels of 5, 12.5, and 20% and three temperature

levels of 28, 43 and 58°C were taken by Sutar and Gupta (2007) to analyse the weight loss and solid gain of onion slices. The sample to solution ratio of 1:5, agitation of 100 shakes per min, sample thickness of 4 mm and 0.2% potassium metabisulphite mixed with osmotic solution were used for the study. They concluded that the two parameter models developed by Azuara et al. (1992) can describe the mass transfer kinetics in the osmotic dehydration process of onion slices at any time satisfactorily when other conditions of osmosis are kept constant. They also observed the effect of solution concentration and solution temperature on moisture loss and solid gain. It was derived that equilibrium moisture loss and solid gain are related to solution concentration and solution temperature logarithmically. Osmotic dehydration at 20% salt concentration at 28°C solution temperature for 1 h was found optimum for further drying of onion slices.

Mathematical modeling in dehydration

Mathematical modeling of dehydration process is an inevitable part of design, development and optimization of a dryer according to Brook and Bakker-Arkema (1978), Bertin and Blazquez (1986), Vagenas and Marinou-Kouris (1991). It mainly involves elaborative study of drying kinetics, which describes the mechanisms and the influence that certain process variables exert on moisture transfer (Perry 1985; Mulet et al. 1989; Sereno and Medeiros 1990; Tong and Lund 1990; Gekas and Lamberg 1991). Empirical models help to understand the trend of experimental/process variables both dependent and independent.

Saravacos and Charm (1962) as well as Mazza and Lemaguer (1980a) have developed theoretical models of onion drying for heated ambient air conditions. Kiranoudis et al. (1992) examined the drying kinetics of onion slices in a trough dryer by introducing one parameter empirical power law mass transfer model, where the characteristic parameter namely drying constant was a function of process variables

$$-dM/dt = K \times (M - M_e) \quad (1)$$

where,

$$K = \eta_0 . L^{\eta_1} T^{\eta_2} . M^{\eta_3} . v^{\eta_4} \quad (2)$$

The model was tested with the data produced in an experimental trough dryer, using direct regression analysis. The parameters of the model considered were found to be greatly affected by sample characteristic dimension and temperature. While analyzing the drying characteristics of shredded onion they have obtained high characteristic dimension and air velocities as compared to the values usually practiced in commercial onion drying.

Sarsavadia et al. (1999) studied thin layer drying behaviour of brined onion slices in a batch type dryer at four levels of drying air temperature in the range of 50–80°C, four levels of air flow velocity ranging from 0.25 to 1.00 m/s and three levels of air relative humidity in the range of 10–20%. It was seen that drying rate of sliced onions increased with increase in the temperature and air velocity, whereas it decreases with increase in absolute humidity of the drying air. The influence of temperature on the drying rate was more pronounced as compared to the influence of air flow velocity and absolute humidity. It was noticed that constant rate drying period was not visible in the drying of sliced onions. This establishes the diffusion phenomena as the main physical mechanism governing moisture transfer in sliced onion, supporting the view of Mazza and Lemaguer (1980a) and Rapusas and Driscoll (1995a). Upon integrating eq. (1), they found

$$\frac{M - M_e}{M_0 - M_e} = c \exp(-kt) \quad (3)$$

They tried both Arrhenius and power models to express drying rate constant and found that Arrhenius-type model was more suitable for predicting drying rate constant. Both the constants can be presented in the following form.

Arrhenius-type of equation:

$$k = \alpha_0 V^{\alpha_1} H^{\alpha_2} \exp\left(\frac{-\alpha_3}{T}\right) \quad (4)$$

$$c = \gamma_0 V^{\gamma_1} H^{\gamma_2} \exp\left(\frac{-\gamma_3}{T}\right) \quad (5)$$

Power model:

$$K = \beta_0 \cdot V^{\beta_1} H^{\beta_2} \cdot T^{\beta_3} \quad (6)$$

$$c = \delta_0 \cdot V^{\delta_1} H^{\delta_2} \cdot T^{\delta_3} \quad (7)$$

Quality of the finished product is influenced by several operations during drying. For instance non-enzymatic browning produces undesirable flavour, loss of colour and lowers the nutritive value also (Aguilera et al. 1975; Labuza and Saltmarch 1981; Troller 1989). Rate of browning reaction depends on moisture content or water activity and temperature of the food (Saguy and Karel 1980; Labuza and Saltmarch 1981). Samaniego-Esguerra et al. (1991) studied browning in commercially dehydrated onion flakes at ambient to near ambient temperatures (20–40°C) and concluded that the change in colour of the onion flakes was due to a non-enzymatic browning mechanism which can be explained by a zero-order reaction. Rapusas and Driscoll (1995b) found out that the non-enzymatic browning in

onion slices during isothermal heating is a zero-order kinetic reaction.

$$Y = Y_0 + K't \quad (8)$$

They further incorporated Arrhenius relationship in the zero-order reaction model, which led to a generalized kinetic model of onion browning as a function of time, water activity and temperature of the product. The maximum browning occurred in the water activity range of 0.60–0.70.

$$Y = Y_0 + (-0.41 + 10.95a_w - 9.65a_w^2) \exp[-15088(1/T - 1/333.05)]t \quad (9)$$

Elustondo et al. (1996) developed a simple model for calculating drying time of onion pieces, as a function of the piece size and initial drying rate for constant air conditions. They also studied the influence of particle size and shape on the final quality of the product.

$$A_x(t) = \frac{V_s(t)}{L_s} = \frac{V_{s0}[1 - X_x(t)d_p](1 + X_0)[a\alpha(t)X_0 + b]}{L_s[\alpha(t)X_0 + 1]} \quad (10)$$

Kaymak-Ertekin and Gedik (2005) reported that non-enzymatic browning was found to follow a zero-order reaction (Fig. 1) rate while thiosulphinates loss followed a second order reaction (Fig. 2) during drying and storage. According to them the temperature dependency of the reaction rate followed the Arrhenius relationship. The activation energy values obtained for browning at different moisture contents were lower than those reported by other authors for browning in dried vegetables (Mizrahi et al. 1970; Saguy and Karel 1980; Rapusas and Driscoll 1995b).

Fig. 1 Non-enzymatic browning in onion slices during drying at various temperatures and air velocity 1.2 m/s (Source: Kaymak-Ertekin and Gedik 2005)

Fig. 2 Thiosulphinate loss in onion slices during drying at various temperatures and air velocity 1.2 m/s (Source: Kaymak-Ertekin and Gedik 2005)

While the activation energy values for browning during storage were higher than those during drying, the activation energy values obtained for thiosulphinate loss were in the same range during both drying and storage and were within the acceptable range for flavour and enzymatic reactions in food (Thijssen 1979; Saguy and Karel 1980). Kinetic models were developed which described the quality losses in onions during drying and storage as a function of temperature, moisture content and water activity. The generalized model to predict non-enzymatic browning in onion during drying was as follows:

$$C = C_0 + c_3 \times X^{c_4} \times \exp\left(-\frac{(c_1 + c_2 \times X)}{R.T}\right) \times t \quad (11)$$

Thiosulphinate loss in onion slices during drying was modeled as:

$$\frac{1}{C} = \frac{1}{C_0} + \exp\left[\left(g_4 + g_5 X + g_6 X^2\right) - \left(\frac{g_1 + g_2 X + g_3 X^2}{R.T}\right)\right] \times t \quad (12)$$

Overall mathematical model for browning reaction in onion during storage was obtained as:

$$C = C_0 + d_3 \times a_w^{d_4} \times \exp\left(-\frac{d_1 + d_2 \times a_w}{R.T}\right) \times t \quad (13)$$

The model given for describing the thiosulphinate content in onion slices during storage is as follows:

$$\frac{1}{C} = \frac{1}{C_0} + \exp\left[\left(m_4 + m_5 \times a_w + m_6 \times a_w^2\right) - \left(\frac{m_1 + m_2 \times a_w + m_3 \times a_w^2}{R.T}\right)\right] \times t \quad (14)$$

Moreno et al. (2006) studied the effect of the Maillard reaction evaluation on the overall antioxidant activity (AA) of stored dehydrated onion and garlic. They reported that a substantial increase of AA was observed in dehydrated onion samples in agreement with a major Maillard reaction evolution. A positive correlation between colour and antioxidant properties was observed during storage of dehydrated onion at 50°C.

Conclusion

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. However, there are some other methods of drying such as vacuum drying, dehumidified air drying etc. which can be explored in order to assess the effect of different operating parameters on quality of onion as it contains several essential nutrients and has enormous medicinal value as well. 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. Moreover, there is a scope for establishing proper correlation between drying conditions and energy consumption. Further research can be done to recommend suitable method of drying and to optimize the requisite conditions for drying of onion.

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