Nutritional composition and drying kinetics of aonla fruits

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Abstract Drying kinetics and effects of drying on nutritional properties of 5 varieties of aonla were investigated using cabinet dryer. Thin shreds of aonla were spread in a layer in dryer and dried at varying temperature of 40, 50 and 60 °C till constant weight attained. Thin layer Newton model was proposed to study drying kinetic of aonla varieties. Degradation in TPC (total phenolic content) and ascorbic acid content were studied at varying temperature. Total phenolic and ascorbic acid content were retained maximum at 50 °C and higher values of R^2 and the lowest value of root mean square error (RMSE), Chi square and mean biased error (MBE) for all varieties indicated that Newton model appropriately described the drying curve of aonla. Among the varieties, variety Banarasi had maximum value of R^2 (0.993) and the lowest values for RMSE (0.039), Chi square (0.018) and MBE (0.001) at 50 °C. Reduction was observed in ascorbic acid, reducing sugar, polyphenol content and pectin content of aonla varieties during drying process. From study, it was observed that drying of aonla at 50 °C was best in terms of higher retention of TPC and ascorbic acid and Newton model was found suitable to explain drying pattern within temperature range under study.

Keywords Drying kinetic · Polyphenol · Ascorbic acid · Newton model

Introduction

Emblica officinalis (aonla), indigenous to tropical India and Southeast Asia, has been introduced world-wide. It has been recognized as an excellent source of antioxidants, being rich in ascorbic acid and other phytochemicals. Being highly perishable in nature (Verma and Gupta 2004), aonla fruit needs processing for increased shelf life and value-addition especially during glut period (Prajapati et al. 2011). Shelf life of aonla varied from 8 to 10 days at ambient condition (Singh et al. 2005) and shelf life of aonla shreds was observed up to 9 months by Singh et al. (2006a, b). Seasonal (November–February) glut affect availability and market price of fruit (Murthy and Joshi 2007) and market price varied from rupees 10–100/Kg depending upon season.

Dehydration is the preferred method to preserve the fruits from the ancient time, which reduces the cost of managing, packaging, storage and transportation. Main aim is the reduction of water to the level (5–9%) at which microbial growth and deterioration reactions are minimized. During the drying process fruits and vegetables undergo physico-chemical and nutritional changes and some quality attributes like colour, flavour and texture can get altered (Di Scala and Crapiste 2008). Earlier sun drying of aonla was practiced. Convenient, economic and time saving drying method with minimum reduction in nutritional content is desired to make the availability of nutritive fruit throughout the year. Nowadays, cabinet dryer that consists of insulated chamber and fan circulate air through the food or material by cross flow is preferred for the low temperature drying along with control of RH.

In drying kinetics, mathematical equations are used to illustrate the characteristic behaviour of a drying process and use of kinetic model is having advantage of cost and

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time saving in production and drying process analysis (Chukwuma and Ozoma 2006; Turner and Mujumdar 1996). The drying kinetics is complex phenomenon, therefore simple representations such as use of thin layer models, mathematical equations are required to predict the drying behaviour and for optimizing the drying parameters (Vadivambal and Jayas 2007; Popa and Petrus 2017; Popa et al. 2014).

Literature availability is limited on drying of various Indian cultivars of aonla. Therefore, work was planned to investigate proper drying temperature range at which nutritional, antioxidants and sensory characteristics of aonla will not be compromised and to predict the drying model suitable for such temperature range. Present investigation was planned to study drying kinetics of aonla fruits and to investigate optimum conditions desirable for retaining maximum total phenolic, ascorbic acid content and other nutrients as well as to observe the effect of dehydration on nutritional quality of aonla powder.

Materials and methods

Selection and dehydration of aonla varieties

Five aonla (*Emblica officinalis*) varieties namely Banarasi, Chakaiya, Desi, Kanchan and NA-7 were procured at ripened stage from Central State Farm, Hisar. Dehydration of aonla fruits was carried out using cabinet drier (Oven 300, NSW 354) at different temperatures. Washing and grading of fruits was done to remove dust and other impurities from the surface after that aonla was grated and drying was done in cabinet dryer at 40, 50, 60 °C and at 30% RH to attain constant moisture content. To study the drying kinetics of aonla varieties, weight of samples was noted at particular interval till constant weight was attained. All analysis was conducted in triplicate. After drying, samples were ground using pestle and mortar and final size reduction was done using mixer grinder.

Drying kinetic

The experimental values for moisture content were converted to moisture ratio. The moisture ratio (MR) of aonla fruit during drying experiments was calculated using equation:

$$MR = (M - M_e) / (M_0 - M_e) \quad (1)$$

where M, M₀, and M_e are moisture content at any drying time, initial and equilibrium moisture content (kg water/kg dry matter), respectively (Nag and Dash 2016).

For the selection of best drying temperature for aonla varieties, drying curves were fitted to well known Newton

model of thin layer drying models. Three parameters: coefficient of determination (R²), reduced Chi square (χ²) and root mean square error (RMSE) using Eq. (2–4) were estimated and used for the evaluation of the goodness of fit. Statistical analyses were carried out using SPSS 16 software.

$$R^2 = 1 - \frac{\sum_{i=1}^n (MR_{pre_i} - MR_{exp_i})^2}{\sum_{i=1}^n (MR_{pre_mean} - MR_{exp_i})^2} \quad (2)$$

$$\chi^2 = \frac{\sum_{i=1}^n (MR_{exp_i} - MR_{pre_i})^2}{N - n} \quad (3)$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^n (MR_{pre_i} - MR_{exp_i})^2 \right]^{1/2} \quad (4)$$

In the above Equations MR_{pre_i} is the *i*th predicted moisture ratio, MR_{exp_i} is the *i*th experimental moisture ratio, N is number of observations and n is number of constants. The criteria for the selection for goodness of fitness, was based on the maximum values for R² and lower values for Chi square and RMSE (Demir et al. 2004). The established model was validated by plotting MR against time for the experimental and predicted values obtained from model for each experimental run.

Chemical analysis of powder of different aonla varieties

Total soluble solid (TSS) were measured using portable hand-held refractometer (Atago), pH by digital pH meter, fat content by solvent extractor (VELP Scientifica SER 148, Italy). Aonla powder (5 g) was taken in pre-weighed thimbles and petroleum ether was used for the extraction. Extraction was completed in 2 h. The residue of fat extract was used for the determination of crude fibre using fiberaplu (FES6 Pelican equipments India). Carbohydrate content (%) was calculated by difference method [100 – (%moisture – %ash – %fat – %protein – %fiber)]. Some other essential attributes like titratable acidity, ascorbic acid and total polyphenol content were determined by AOAC (2005) method. Diluted aonla extract was titrated against 0.1 N sodium hydroxide using phenolphthalein indicator. Titratable acidity was reported as citric acid (%). Aonla powder was extracted using meta-phosphoric acid and titrated rapidly with indo-phenol dye. Similarly standard ascorbic acid solution and meta-phosphoric acid (blank) solution titrated against the indo-phenol dye. Total polyphenol extraction was done with distilled water in boiling water bath. The extract (1 ml) was taken in test tube and to this 0.5 ml of Follin Ciocalteau reagent was added, after 3 min 1 ml of saturated sodium carbonate solution was added and volume was made 10 ml with distilled water. Absorbance was taken at 760 nm after 30 min. Standard

curve was prepared using the graded concentration (20–100 ppm) of the gallic acid standard and with reference to the standard curve, concentration of total polyphenols was determined as gallic acid equivalent. Protein content was calculated by multiplying 6.25 to total nitrogen content (micro kjeldhal). Total sugar, reducing sugar and non reducing content were measured using methods of Yemm and Will's (1954) and Hodge and Hofrieter (1962), respectively. Extraction of total sugar was carried out using 80% ethanol. Sample extract (0.1 ml) was taken in triplicate in each test tube and anthrone reagent (10 ml) was pipetted in empty test tubes placed in ice-cold water bath. Then early dilutions were added to anthrone reagent and test tubes were placed in boiling water bath for 10 min for colour development. After cooling, absorbance was noted at 625 nm. Standard curve was prepared using the graded concentration of glucose solution (25–250 ppm) (Parveen and Khatkar 2015). Starch content of the samples was determined by using method (AOAC 2005). Pectin content was estimated in the form of calcium pectate using method described by Ranganna (1986). Pectin was extracted using 0.05 N hydrochloric acid and 1 N sodium hydroxide, was added to the extract for neutralisation. After overnight storage, 50 ml of 1 N acetic acid and 25 ml of 1 N calcium chloride were added. Solution was filtered through the dry and pre-weighed Whatman filter paper no.4. After washing, precipitates were dried overnight at 100 °C in hot air oven and reported as (%) calcium pectate (Parveen and Khatkar 2015). Mineral content and heavy metal estimation was done using atomic absorption spectrophotometer (GBC 932 plus, Advance Scientific, Australia). Sodium, potassium, zinc, calcium, iron and heavy metals such as lead, mercury were estimated using wet ashing method (Parveen and Khatkar 2015).

Results and discussion

Drying kinetic of aonla fruits using drying model

Fruits of aonla varieties viz. Banarasi, Chakaiya, Desi, NA-7 and Kanchan were dried at temperature 40, 50 and 60 °C to study the drying kinetics. Drying process was continued till the constant weight was achieved and drying time of aonla varieties varied from 8 to 12 h under different temperature conditions. Moisture ratio was calculated as function of time by SPSS 16 software and XLSTAT, 2015, and non-linear regression analysis was carried out on experimental data using Newton model of thin layer drying. Table 1 showed the results of non-linear regression analysis.

Drying curves of various aonla varieties dried at particular temperature condition are presented in Fig. 1 MR

(Moisture ratio) of the sample was fitted to Newton equation Mujumdar (1987).

$$MR = (M - M_e)/(M_0 - M_e) = \exp(-kt)$$

MR is the moisture ratio, M, M_0 , and M_e are moisture content at any drying time, initial and equilibrium moisture content (kg water/kg dry matter), respectively.

Values of constant (k) and R^2 , Chi square and RMSE, MBE were calculated by plotting exponential trendline for each experimental data of moisture ratio against time. Criteria for selection of best temperature condition for aonla drying was based on taking into account the highest average values of R^2 and the lowest average values RMSE, Chi square and MBE. The statistical analysis values including drying constants and their equation at different temperature condition along with the criteria used to evaluate best fit model is given in Table 1. The best temperature condition for drying aonla varieties was 50 °C (Table 1). Among the varieties, Banarasi variety showed the maximum value of R^2 (0.993) and the lowest values for RMSE (0.039), Chi square (0.018) and MBE (0.001) at 50 °C (Table 1) compared to the values at 60 and 40 °C of R^2 (0.974), R^2 (0.988), RMSE (0.077), Chi square (0.047) and MBE (0.006) RMSE (0.052), Chi square (0.033) and MBE (0.003) respectively while the variety NA-7 showed minimum value of R^2 and higher values of RMSE, Chi square and MBE at all the temperature conditions (Table 1).

Figure 1 showed the variation of experimental moisture ratio with drying time for aonla varieties at 40, 50 and 60 °C temperature. As depicted in Fig. 1 with increase in drying temperature, a decrease was noted in drying time and rate of drying was not constant for all aonla varieties. Good agreement was observed between predicted and experimental variable which indicated that Newton model could be used to calculate the drying of aonla between drying temperature 40–60 °C. Drying constant (k) showed an increase with increase in temperature (Table 1), that might be due to rise in driving force of heat and mass transfers with temperature (Methakhup et al. 2005). Similar trend in the value of k was observed by Hashim et al. (2014) in the study of pumpkin drying kinetic. The value of constant k was in accordance with data reported by Methakhup et al. (2005). Relationship of drying temperature and drying rate can be explained using equation $k = Ae^{(-E/RT)}$ (Arrhenius equation). Plot of $\ln MR$ against time also explained the same. Rate of drying also depend on availability of free water (Guine et al. 2007). At first stage of drying, a sharp decline was observed in free water while at later stage availability of water was reduced and process became slow.

Table 1 Newton model statistical data at different temperatures for aonla varieties

Variety	Temperature (°C)	Constant	Equation	Drying time (h)	R ²	X ²	RMSE	MBE
Banarasi	40	k = 0.269	MR = exp (− 0.269t)	8	0.988	0.033	0.052	0.003
	50	k = 0.319	MR = exp (− 0.319t)	12	0.993	0.018	0.039	0.001
	60	k = 0.430	MR = exp (− 0.430t)	12	0.974	0.047	0.077	0.006
Chakaiya	40	k = 0.242	MR = exp (− 0.242t)	13	0.989	0.031	0.049	0.002
	50	k = 0.279	MR = exp (− 0.279t)	10	0.991	0.021	0.043	0.002
	60	k = 0.415	MR = exp (− 0.415t)	9	0.976	0.044	0.070	0.005
NA-7	40	k = 0.275	MR = exp (− 0.275t)	11	0.977	0.059	0.073	0.005
	50	k = 0.306	MR = exp (− 0.306t)	9	0.984	0.034	0.062	0.004
	60	k = 0.456	MR = exp (− 0.456t)	7	0.968	0.051	0.086	0.007
Desi	40	k = 0.253	MR = exp (− 0.253t)	12	0.983	0.047	0.063	0.004
	50	k = 0.295	MR = exp (− 0.295t)	11	0.983	0.043	0.062	0.004
	60	k = 0.318	MR = exp (− 0.318t)	9	0.982	0.032	0.060	0.004
Kanchan	40	k = 0.261	MR = exp (− 0.261t)	12	0.981	0.054	0.067	0.004
	50	k = 0.277	MR = exp (− 0.277t)	10	0.991	0.021	0.043	0.002
	60	k = 0.415	MR = exp (− 0.415t)	8	0.977	0.041	0.072	0.005

RMSE Root mean square error, MBE mean bias error, exp exponential, MR moisture ratio, t time

Effect of drying on total phenolic and ascorbic acid content of aonla

Effect of drying temperature on total phenolic and ascorbic acid content in aonla varieties is presented in Table 2. Significant ($p < 0.05$) affect was noted in TPC and ascorbic acid content among aonla varieties after subjecting to drying at varying temperature conditions (Table 2). Phytochemicals in aonla are mainly phenolic in nature and ascorbic acid with polyphenol are credited for their antioxidant activity and other health benefits. Ascorbic acid is heat labile in nature and therefore an important attribute in assessing the effect of drying in aonla. Ascorbic acid content of aonla showed significant reduction on drying. Among the varieties, Chakaiya variety was affected most significantly at varying drying temperature followed by variety Banarasi, NA-7, Desi and Kanchan. Sample dried at 40 °C had the lowest value of ascorbic acid varied from 0.92 to 1.06 g/100 g among the varieties that might be due to long drying time taken for drying while at 50 °C maximum retention of ascorbic acid was observed (1.19–1.26 g/100 g). Value of ascorbic acid for sample dried at 60 °C ranged from 0.99 to 1.15 g/100 g among the varieties that might be due to adverse effect of high temperature on ascorbic acid content. Results showed that higher heating temperature and longer drying time had an adverse effect on ascorbic acid content. Similarly, reduction in ascorbic acid content during drying of aonla using vacuum and low-pressure superheated steam drying was noted by Methakhup et al. (2005). Famurewa and Olumofin (2015) reported significant decrease in ascorbic acid

content in okra dried in cabinet dryer at varying temperature (40, 50 and 60 °C).

Similar trend was observed in total phenolic content among the varieties dried at varying temperature conditions. Results of analysis showed that aonla samples dried at 40 °C had the minimum values of TPC (17.65–23.98%) while the highest value was observed in sample dried at 50 °C (21.59–28.86%). TPC in sample dried at 60 °C varied from 19.67 to 25.56% among the aonla varieties. Lower value of TPC in sample dried at 40 °C might be due longer drying time while reduction at 60 °C might be due to high temperature exposure. Similarly, López et al. (2010) reported decline in TPC in blueberries during drying at varying temperature (50, 60, 70 and 80 °C). Decrease was observed in TPC in murtilla fruit on hot air drying at 65 °C in the study by Alfaro et al. (2014).

Chemical analysis of dehydrated aonla powder

Dehydrated aonla was ground to fine powder. Final drying time varied from 9 to 12 h for different varieties. Yield of the aonla powder showed the varietal difference. Average yield of aonla powder of different varieties at 50 °C varied from 14.66 to 17.80%, Banarasi showed maximum yield (17.80%), followed by Kanchan (16.79%), Chakaiya (16.76), Desi (16.07%) and NA-7 had minimum yield (14.66%). Yield of the powder varied due to the variation in the genetic makeup and moisture content of the varieties. Colour of dehydrated aonla powder was light brown. Observed data of chemical analysis of dehydrated aonla powder on dry weight basis is presented in Table 3.

Fig. 1 Experimental moisture ratio of aonla varieties during drying at different temperature. **a** Banarasi, **b** Chakaiya, **c** Desi, **d** NA-7 and **e** Kanchan

Moisture content of dehydrated aonla powder ranged from 8.56 to 8.97% (Table 3). Maximum ash content was found in Desi, followed by Chakaiya and Kanchan had minimum ash content (Table 3). Protein of dehydrated aonla powder ranged from 2.13 to 3.21% on dry weight basis, Banarasi showed the highest value and Chakaiya had lowest value. Like protein content, fibre and fat content showed the significant ($p < 0.05$) varietal difference (Table 3). Results for fat content of the powder were similar to the reported data by Mishra et al. (2009). Acidity of the dehydrated aonla powder varied from 10.43 to 11.54%. Desi had the maximum value followed by Chakaiya and Banarasi had

the lowest value. No significant variation was observed in pH and TSS (Table 4). Study by Singh et al. (2006a, b) supported observed data while deviation was observed from data reported by Pragati and Dhawan (2003); Pareek and Kaushik (2012). Deviation might be due to the difference in drying technique. Observed data of ascorbic acid content ranged from 1.19 to 1.26 g/100 g in aonla powders. Variety Desi was observed to have maximum value followed by Banarasi and Kanchan was having the least value. Results were in accordance with data reported by Pragati et al. (2003); Murthy and Joshi (2007); Pareek and Kaushik (2012). Total phenolic content in aonla powder showed the

Table 2 Ascorbic acid and total polyphenol contents of powder of different aonla varieties

Variety	Temperature (°C)	Drying time (h)	Ascorbic acid (g/100 g)	Total polyphenol content (%)
Banarasi	40	12	1.04 ± 0.03 ^d	18.67 ± 0.34 ^c
	50	12	1.23 ± 0.17 ^{fg}	21.59 ± 1.42 ^g
	60	8	1.02 ± 0.09 ^{cd}	20.15 ± 0.25 ^e
Chakaiya	40	13	0.92 ± 0.07 ^a	20.34 ± 0.03 ^f
	50	10	1.21 ± 0.98 ^f	24.34 ± 1.26 ¹
	60	9	1.05 ± 0.04 ^d	22.67 ± 0.78 ^j
NA-7	40	11	0.99 ± 0.10 ^{bc}	17.89 ± 0.12 ^b
	50	9	1.19 ± 0.42 ^{ef}	22.33 ± 1.00 ⁱ
	60	7	1.04 ± 0.03 ^d	19.67 ± 0.09 ^d
Desi	40	12	1.06 ± 0.12 ^d	23.98 ± 0.45 ^k
	50	11	1.26 ± 0.42 ^g	28.86 ± 0.41 ⁿ
	60	9	1.15 ± 0.04 ^e	25.56 ± 0.23 ^m
Kanchan	40	12	0.97 ± 0.12 ^b	17.65 ± 0.09 ^a
	50	10	1.19 ± 0.38 ^{ef}	21.89 ± 0.51 ^h
	60	8	0.99 ± 0.14 ^{bc}	20.13 ± 0.37 ^e

^aThe values are mean ± SD of determinations made in triplicates. Mean values followed by different letters within a same column differ significantly ($p < 0.05$)

Table 3 Proximate analysis of powder of different aonla varieties

Varieties	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fibre (%)	Carbohydrate (%)
Banarasi	8.56 ± 0.01 ^a	2.57 ± 0.02 ^{ab}	3.21 ± 0.01 ^d	0.56 ± 0.01 ^b	6.48 ± 0.03 ^a	78.62 ± 0.01 ^d
Chakaiya	8.85 ± 0.02 ^{bc}	2.66 ± 0.05 ^b	2.13 ± 0.01 ^a	0.59 ± 0.01 ^c	10.87 ± 0.12 ^b	74.90 ± 0.02 ^c
Desi	8.97 ± 0.02 ^c	3.13 ± 0.08 ^c	2.18 ± 0.02 ^a	0.66 ± 0.01 ^d	21.54 ± 0.06 ^c	63.52 ± 0.02 ^a
Kanchan	8.58 ± 0.01 ^a	2.26 ± 0.01 ^a	2.70 ± 0.01 ^b	0.40 ± 0.01 ^a	16.84 ± 0.08 ^d	69.22 ± 0.01 ^b
NA-7	8.78 ± 0.06 ^a	2.57 ± 0.00 ^{ab}	3.02 ± 0.01 ^c	0.40 ± 0.01 ^a	16.13 ± 0.06 ^c	69.10 ± 0.06 ^b

^aThe values are mean ± SD of determinations made in triplicates. Mean values followed by different letters within a same column differ significantly ($p < 0.05$)

^bCarbohydrate content was calculated by difference

^cAll the data except moisture is reported on dry wt. basis

significant ($p < 0.05$) varietal difference that ranged from 21.59 to 28.86% (Table 4). Similarly significant difference was exhibited in total sugar and reducing sugar content. Chakaiya was observed to have the highest sugar content followed by NA-7 while variety Desi had the lowest value.

Pectin content of the dehydrated aonla powder varied from 3.03 to 12.21% (Table 4), Desi showed the maximum value and Kanchan had the lowest value. Results of the study were similar to data reported by Pareek and Kaushik (2012). In contrary to this, deviation was observed from data reported by Pragati et al. (2003); Singh et al. (2006a, b) that might be due to the differences in drying techniques and conditions. Singh et al. (2006a, b) dried aonla in batch type solar tunnel dryer. Starch content of aonla powder among the varieties varied from 12.52 to 26.72% on dry weight basis. Maximum value was observed

in variety Chakaiya followed by Desi and Banarasi showed the minimum value.

Mineral profile of dehydrated aonla powder

Minerals are important part of diet and are required for metabolic reactions, nerve impulses transmission, rigid bone formation and for regulating balance of water and salt (Dini et al. 2008). As depicted in Table 5 mineral profile of the dehydrated aonla powder showed significant varietal difference ($p < 0.05$) among the varieties. Maximum iron content was noted in the Chakaiya variety followed by NA-7, Kanchan, Desi and Banarasi (Table 5). Variety Desi was observed to have maximum calcium content while potassium content was found to be the minimum. Variety Chakaiya had the highest zinc, iron content among the

Table 4 Nutritional composition of powder of different aonla varieties

Varieties	Acidity (%)	pH	TSS °Brix	Ascorbic acid (g/100 g)	Polyphenols (%)	Total sugar (%)	Reducing sugar (%)	Non-reducing sugar (%)	Pectin (%)	Starch (%)
Banarasi	10.45 ± 0.01 ^a	2.94 ± 0.00 ^b	16.93 ± 0.00 ^{ab}	1.23 ± 0.17 ^d	21.59 ± 1.42 ^a	30.09 ± 0.10 ^c	15.46 ± 0.10 ^c	14.63 ± 0.09 ^b	2.21 ± 0.13 ^a	12.52 ± 0.05 ^a
Chakaiya	10.43 ± 0.63 ^a	2.99 ± 0.06 ^c	18.91 ± 0.01 ^a	1.21 ± 1.98 ^c	24.34 ± 1.26 ^b	36.41 ± 1.06 ^e	20.10 ± 0.62 ^e	16.31 ± 0.57 ^c	2.85 ± 0.11 ^b	26.72 ± 0.12 ^d
Desi	11.54 ± 0.66 ^c	2.80 ± 0.00 ^a	15.94 ± 0.00 ^b	1.26 ± 1.42 ^e	28.86 ± 1.41 ^c	28.38 ± 0.30 ^a	13.89 ± 0.17 ^a	14.49 ± 0.26 ^b	11.21 ± 0.05 ^c	16.55 ± 0.02 ^c
Kanchan	10.81 ± 0.03 ^b	2.89 ± 0.00 ^b	16.92 ± 0.00 ^{ab}	1.19 ± 0.58 ^a	21.89 ± 0.51 ^a	29.37 ± 0.34 ^b	16.62 ± 0.24 ^d	12.75 ± 0.42 ^a	2.03 ± 0.05 ^a	12.73 ± 0.02 ^a
NA-7	10.53 ± 0.04 ^a	2.91 ± 0.00 ^b	17.91 ± 0.00 ^a	1.19 ± 1.42 ^b	22.33 ± 1.00 ^a	33.50 ± 0.58 ^d	14.891 ± 0.10 ^b	18.61 ± 0.34 ^d	1.97 ± 0.06 ^a	15.37 ± 0.02 ^b

^aThe values are mean ± SD of determinations made in triplicates. Mean values followed by different letters within a same column differ significantly ($p < 0.05$)

^b All the data except the value for pH and TSS are reported on dry wt. basis

varieties. Kanchan variety showed the highest sodium and potassium content among the varieties. In aonla powder material heavy metal, lead and mercury were not detected. Observed data showed the deviation from the reported data by Mishra et al. (2009) due to variation in drying technique and environmental conditions. The powder of Chakaiya variety was prepared by different techniques like freeze drying, sun drying, spray drying, hot air drying and vacuum drying by Mishra et al. (2009).

Effect of dehydration on nutritional profile of aonla

In dehydration process due to the moisture loss dry matter increased as reported in literature. Ash, minerals and protein content of different varieties were not affected by drying procedure. Total sugar content in aonla powder increased during dehydration, it might be due the conversion of starch or other polysaccharide materials into sugar or simpler form (Goodenough and Atkin 1981; Patter 1985). Reducing sugar content decreased during drying process. Reason might be the conversion of hexose sugar into unsaturated and others reactive forms 2-furaldehyde and 5-hydroxymethyl-2-furaldehyde (Damodaran et al. 2007).

Reduction was observed in phenolic content of different aonla varieties that might be due to activity of enzyme polyphenoloxidase on polyphenol present in aonla and their conversion into other forms or products. Significant reduction has occurred in the ascorbic acid content (Parveen and Khatkar 2015) during drying process. Phenolic content of variety Desi, Banarasi, Kanchan, Chakaiya and NA-7 was reduced from 31.80, 25.77, 25.33, 28.81 and 26.94% to 28.86% 21.59, 21.89, 24.35 and 22.33% respectively. Reduction in the ascorbic acid content varied from 38.5 to 69% among the varieties. Ascorbic acid might be lost due to oxidation during grating, thermal destruction during process of drying. Data in the literature by Sethi (1986); Singh et al. (2006b) supports the observed value for reduction of ascorbic acid, reducing sugar, polyphenol content and pectin during drying process. Fat content showed increase in values after drying. It might be due to less affect of heating temperature on cell wall structure of aonla fruit peel and might be due to conversion of simple compound into complex structure. Fiber, starch, acidity decreased after drying process. Decrease in acidity content might be due to conversion of acids into sugars or some other products (Prajapati et al. 2011) and pH content increase as acidity was reduced during drying. Reduction in starch content might further be due to the conversion of starch into sugar because of partial hydrolysis and that might have caused browning in the final dehydrated product.

Table 5 Mineral profile of the aonla powders of different varieties

Varieties	Iron (mg/100 g)	Zinc (ppm)	Sodium (ppm)	Potassium (mg/100 g)	Calcium (mg/100 g)	Lead (ppm)	Mercury (ppm)
Banarasi	1.83 ± 2.64 ^a	39.52 ± 1.00 ^a	50.49 ± 1.00 ^a	56.81 ± 5.70 ^b	18.61 ± 3.05 ^a	n.d.	n.d.
Chakaiya	3.19 ± 1.73 ^c	64.249 ± 3.78 ^c	65.83 ± 1.52 ^d	60.67 ± 2.00 ^c	25.65 ± 11.05 ^c	n.d.	n.d.
Desi	2.02 ± 2.00 ^b	47.35 ± 1.00 ^b	55.71 ± 0.58 ^b	42.69 ± 1.00 ^a	29.54 ± 2.88 ^c	n.d.	n.d.
Kanchan	2.60 ± 5.77 ^c	48.84 ± 1.53 ^c	69.46 ± 2.00 ^c	63.68 ± 3.45 ^c	25.74 ± 3.21 ^d	n.d.	n.d.
NA-7	2.79 ± 3.05 ^d	51.76 ± 1.53 ^d	58.95 ± 1.52 ^c	62.08 ± 2.00 ^d	22.331 ± 3.78 ^b	n.d.	n.d.

^aThe values are mean ± SD of determinations made in triplicates. Mean values followed by different letters within a same column differ significantly ($p < 0.05$)

^bAll the data reported on dry wt. basis

n.d. not detected

Conclusion

Drying behavior of aonla varieties was studied by applying thin layer Newton model. The study concluded that thin layer model successfully predicted the drying kinetic of aonla varieties and drying of aonla fruits at 50 °C was found the best in terms of TPC and ascorbic retention among the different temperature conditions. Newton model showed the maximum value of R^2 and minimum value of RMSE, Chi square and MBE and also there is a good agreement between model prediction and experiments at varying temperature. The results of present study suggest that proposed model can be applied successfully to optimize drying conditions, in order to retain higher quality attributes in dried aonla in terms of nutritional characteristics.

References

- Alfaro S, Mutis A, Quiroz A, Seguel I, Scheuermann E (2014) Effects of drying techniques on murtilla fruit polyphenols and antioxidant activity. *J Food Res* 3(5):73–82
- AOAC (2005) Official methods of analysis, 18th edn. Association of Official Analytical Chemists, Washington
- Chukwuma P, Ozoma RT (2006) Tropical plant perishables, handling, storage and processing of food commodity series. Silicon Valley Publishers, Enugu 2, pp 93–94
- Damodaran S, Parkin KL, Fennema OR (2007) Fennema's food chemistry, 4th edn. CRC Press, Boca Raton
- Demir V, Gunhan T, Yagcioglu AK, Degirmencioglu A (2004) Mathematical modeling and the determination of some quality parameters of air-dried bay leaves. *Biosys Eng* 88:325–335
- Di Scala KC, Crapiste GH (2008) Drying kinetics and quality changes during drying of red pepper. *LWT- Food Sci Technol* 41(5):789–795
- Dini I, Tenore GC, Dini A (2008) Chemical composition, nutritional value and antioxidant properties of *Allium caepa* L. Var. tropeana (red onion) seeds. *Food Chem* 107:613–621
- Famurewa JAV, Olumofin KM (2015) Drying kinetic and influence on the chemical characteristics of dehydrated okra (*Abelmoschus esculentus*) using cabinet dryer. *Eur J Eng Technol* 3(2):7–19
- Goodenough PW, Atkin PK (1981) Quality in stored and processed vegetables and fruits. Academic Press, London
- Guine RPF, Ferreira DMS, Barroca MJ, Goncalves FM (2007) Study of the drying kinetics of solar-dried pears. *Biosyst Eng* 98:422–429
- Hashim N, Daniel O, Rahaman E (2014) A preliminary study: kinetic model of drying process of Pumpkins (*Cucurbita moschata*) in a convective hot air drying. *Agric Agric Sci Proc* 2:345–352
- Hodge JE, Hofreiter BT (1962) Determination of reducing sugars and carbohydrates. In: *Methods in carbohydrate chemistry*, vol 1. Academic Press, London, pp 380–394
- López J, Uribe E, Vega-Gálvez A, Miranda M, Vergara J, Gonzalez E, Di Scala K (2010) Effect of air temperature on drying kinetics, vitamin C, antioxidant activity, total phenolic content, non-enzymatic browning and firmness of blueberries variety O'Neil. *Food Bioprocess Technol* 3:772–777
- Methakhup S, Chiewchan N, Devahastin S (2005) Effect of drying methods and conditions on drying kinetics and quality of Indian gooseberry flake. *LWT-Food Sci Technol* 38:579–587
- Mishra P, Srivastava V, Verma D, Chauhan OP, Rai GK (2009) Physico-chemical properties of Chakiya variety of Amla (*Emblica officinalis*) and effect of different dehydration methods on quality of powder. *Afr J Food Sci* 3:303–306
- Mujumdar AS (1987) Handbook of industrial drying. Marcel Dekker, New York
- Murthy ZVP, Joshi D (2007) Fluidized bed drying of Aonla (*Emblica officinalis*). *Drying Technol* 25:883–889
- Nag S, Dash KK (2016) Mathematical modeling of thin layer drying kinetics and moisture diffusivity study of elephant apple. *Int Food Res J* 23:2594–2600
- Pareek S, Kaushik RA (2012) Effect of drying methods on quality of Indian gooseberry (*Emblica officinalis* Gaertn.) powder during storage. *J Sci Res* 71:727–732
- Parveen K, Khatkar BS (2015) Physico-chemical properties and nutritional composition of aonla (*Emblica officinalis*) varieties. *Int Food Res J* 22:2358–2363
- Patter HE (1985) Evaluation of quality of fruits and vegetables. AVI Publishing Co Inc., Westport
- Popa C, Petrus M (2017) Heavy metals impact at plants using photoacoustic spectroscopy technology with tunable CO2 laser in the quantification of gaseous molecules. *Microchem J* 134:390–399. <https://doi.org/10.1016/j.microc.2017.07.006>
- Popa C, Dumitras DC, Patachia M, Banita S (2014) Testing fruits quality by photoacoustic spectroscopy assay. *Laser Phys.* <https://doi.org/10.1088/1054-660X/24/10/105702>

- Pragati DS, Dhawan SS (2003) Effect of drying methods on nutritional composition of dehydrated aonla fruit (*Emblica officinalis* Gaertn.) during storage. *Plant Food Hum Nutr* 58:1–9
- Prajapati VK, Nema PK, Rathore SS (2011) Effect of pretreatment and drying methods on quality of value-added dried aonla (*Emblica officinalis* Gaertn) shreds. *J Food Sci Tech* 48(1):45–52
- Ranganna (1986) Hand book of analysis and quality control for fruit and vegetable products. Tata McGraw-Hill Publishing Co., Pvt. Ltd., New Delhi, pp 40–43
- Sethi V (1986) Effect of blanching on drying of aonla. *Indian Food Packer* 40(4):7–10
- Singh BP, Pandey G, Sarolia DK, Pandey MK, Pathak RK (2005) Shelf-life evaluation of aonla cultivars. *Indian J Hort* 62:137–140
- Singh PL, Ganesan S, Singh S (2006a) Drying study of amla (*Emblica officinalis* Gaertn.) in a solar tunnel dryer. *Indian Food Packer* 60:47–51
- Singh R, Dashora LK, Upadhyay B (2006b) Effect of pre-drying treatments and drying methods on physico-nutritional quality of dehydrated aonla shreds. *Indian Food Packer* 60:57–63
- Turner I, Mujumdar AS (1996) Mathematical modeling and numerical techniques in drying technology. Marcel Dekker, New York
- Vadivambal R, Jayas DS (2007) Changes in quality of microwave-treated agricultural products—a review. *Biosyst Eng* 98:1–16
- Verma RC, Gupta A (2004) Effect of pre-treatments on quality of solar-dried amla. *J Food Eng* 65:397–402
- Yemm EW, Willis AJ (1954) The estimation of carbohydrates in plant extracts by anthrone. *Biochem J* 57(3):508–514