Changes of bioactive compounds during storage of dried *Andrographis Paniculata* leaves after drying using different methods

Chayanant Tummanichanont[1], George Srzednicki[2*] and Singhanat Phoungchandang[1]

ABSTRACT: Dried *A. paniculata* leaves from cabinet dryer (CAD) at 45°C, heat pump dryer (HPD) at 30°C and freeze dryer (FD) were used in storage experiment. Total phenolics content (TPC), total antioxidant activities (AOA), andrographolide and neoandrographolide content were found to decrease with increase in storage time and temperature in all samples. The degradation of TPC, AOA, andrographolide and neoandrographolide in dried *A. paniculata* leaves during storage followed the first-order equation with respect to temperature. The results showed an increase in the kinetic constant (k) with the increase of temperature. Half-life correlated with time at which the bioactive compounds were decreased by 50% with respect to time zero. The half-life ($t_{1/2}$) of andrographolide and neoandrographolide of dried *A. paniculata* leaves in different drying methods and stored at 25°C was higher than of those stored at 35°C. The activation energy of major compounds in CAD, HPD and FD dried *A. paniculata* leaves was 5.85, 5.94 and 7.51 kJ/mol, for andrographolide and 6.28, 14.10 and 15.40 kJ/mol, for neoandrographolide, respectively. Dried *A. paniculata* packed in PET/Al/PE foil bags at 25°C preserved most of the bioactive compounds.
Keywords: DPPH, andrographolide, bioactive compounds, drying, shelf-life

Introduction

Andrographis paniculata Nees has been widely used in traditional herbal medicine in China and Southeast Asia. Its Thai name is Fah Talai Jone. Due to the extreme bitter taste of this herb, it is known as 'King of Bitters'. Mostly leaves and roots have been traditionally consumed over centuries for different medicinal purposes. Andrographolide and neoandrographolide, the common diterpenoid lactones, are the major active compounds of *A. paniculata*, and also flavonoids (Koteswara et al., 2004). They have been found to exhibit a large spectrum of biological activities such as anti-inflammatory (Sheeja et al., 2006), antioxidant (Verma and Vinayak, 2008) and antiviral (Lin et al., 2008).

Drying herb is the most important method to extend shelf-life, preserve the quality of herb and minimize handling and storage (George and Cenkowski, 2009). The removal of water from the product to the point where the water activity is sufficiently low ensures that the product is microbiologically and enzymatically stable (Wray and Ramaswamy, 2015).

[1] Department of Food Technology, Khon Kaen University, Muang Khon Kaen 40002, Thailand
[2] Food Science and Technology, School of Chemical Engineering, University of New South Wales, Sydney, 2052, NSW, Australia
* Corresponding author: georgesrz@yahoo.com

The drying methods and storage may result in a considerable reduction of bioactive compounds of food. Storage stability of dried food mostly depends on the storage conditions (temperature, light, humidity and package). The significant decrease in bioactive compounds of dried products could have been caused by decomposition of chemical compounds with antioxidant properties. Likewise, the storage may cause the reduction of polyphenols content. The decrease in total phenolics was mostly due to the fact that the phenolic compounds were oxidized or polymerized during processing and storage (Wang et al., 2000).

Changes of bioactive compounds in different storage temperatures are significant for the quality of dried herbs. Several studies were conducted on the effect of storage on bioactive compounds in *A. paniculata* powder using FD (Puranik et al., 2012). However, there have not been any studies on the degradation of bioactive compounds during storage after drying using different methods. The purpose of this research was to evaluate the storage stability of dried *A. paniculata* dried by CAD, HPD and FD. This included the determination of TPC, AOA, andrographolide and neoandrographolide during 6 months storage at temperature 25°C and 35°C in metallized film pouches.

Materials and Methods

Experimental Procedure

Present experiment was performed in the year 2015 at School of Chemical Engineering, University of New South Wales. *A. paniculata* were obtained from a farm in Queensland State in the north-east of Australia. The most appropriate stage of maturity of *A. paniculata* leaves was selected following Tummanichanont et al. (2017) (110-150 days after seeding or 50% of blooming). *A. paniculata* leaves were harvested on May from the plant stalk and were cleaned in water.

Drying Methods

Drying experiments were conducted using following drying methods: cabinet dryer (CAD), heat pump dryer (HPD) and freeze dryer (FD). Convective hot air drying of *A. paniculata* leaves was conducted in a CAD in thin layer (UNSW, School of Chemical Engineering workshop, Sydney, Australia). The drying process was performed at 45°C with constant air velocity of 0.5 m/s. The final moisture content of dried leaves was found to be 6.91% d.b.

Drying of leaves in a HPD (Greenhalgh Refrigeration Pty. Ltd., Caloundra, Qld, Australia) was performed at 30°C for 13 hours with the air velocity of 0.5 m/s. The relative humidity in the HPD was maintained constant at 20%. The drying process was carried on until the sample weight was achieved. The final moisture content of dried leaves was 6.16% d.b.

Freeze drying (FD) (Leybold-Heraeus, Cologne, Germany. Model: Lyovac GT2) was carried out in two stages. Primary drying was performed at -20°C for 24 hours. Secondary drying stage was conducted at -70°C for 24 hours at 15 Pa. The final moisture content of dried leaves was about 3.14% d.b. Dried *A. paniculata* leaves were vacuum packed in a laminated metallized film laminate (PET/Al/PE).

Storage Conditions

The dried *A. paniculata* leaves were vacuum-packed using a Henkovac vacuum packaging machine (Henkovac,'s-Hertogenbosch, the Netherlands) in PET/Al/PE foil bags with high barrier capability. The preserved products were stored for 6 months at two different temperatures: 25°C and 35°C. They were kept in temperature controlled environment

chambers (Hotpack, Philadelphia, PA, USA). Samples were analyzed in triplicate after 0, 2, 4, and 6 months for total phenolics content (TPC), antioxidant activity (DPPH), ferric reducing antioxidant power (FRAP), andrographolide and neoandrographolide. Storage at 35°C was considered as an accelerated storage temperature.

Chemical Analysis

Sample Preparation

The polyphenol content was determined in extracts produced from the fresh and dried *A. paniculata* leaves according to the method of Singh et al. (2011) with some modifications. A fresh sample or dried leaves (2 g or 1 g) was extracted with 50 milliliter (mL) of methanol and refluxed for 4 h. The methanol extract was subsequently filtered through a 0.45 µm Millipore filter under vacuum and finally made up to 5 mL volume with methanol prior to chemical analysis.

Total Phenolics Content (TPC)

The microplate total phenolics method was based on the 96-well microplate Folin-Ciocalteu method given by Muller et al. (2010) with some modifications. The methanolic extract of sample 20 microliters (µL) was mixed with 100 µL of 1:10 diluted Folin-Ciocalteu reagent and shaken for 60 s in a flat-bottom 96-well microplate. The mixture was left for 240 s and then 80 µL of sodium carbonate solution (0.75%) were added. After 2 hours at room temperature, the absorbance was measured at 765 nm using a SpectroMax® M2 multidetection microplate reader (Molecular Devices, Sunyvale, California, USA). Gallic acid dilutions (10 – 500 µM) were used as standard for calibration.

DPPH Radical Scavenging Activity

The microplate DPPH methodology was based on 96-well microplate assay described by Herald et al. (2012) with some modifications. A total of 20 µL of the diluted sample was added to 180 µL of 2, 2-diphenyl-l-picrylhydrazyl (DPPH) solution in methanol-water (80:20, v/v) and shaken for 60 s in a 96-well microplate. After 1 hour in the dark at room temperature, the absorbance was measured at 517 nm in the SpectroMax® M2 multidetection microplate reader. The antioxidant activity was expressed as percent inhibition which was calculated as $[(A_o-A_e)/A_o]/100$ (A_o = absorbance of DPPH; A_e = absorbance of DPPH with extract).

Ferric Reducing Antioxidant Power (FRAP) Assay

The FRAP assay was carried out according to the procedure of Wojdylo et al. (2007) with slight modifications. The FRAP reagent consisted of a 300 mM acetate buffer (pH 3.6), 10 mM 2,4,6-tripyridyl-s-triazine (TPTZ) in 40 mM hydrochloric acid and 20 mM ferric chloride in a ratio of 10:1:1. An aliquot 150 µL of the reagent was mixed with 20 µL of diluted sample in a 96-well microplate, which was incubated for 8 min at room temperature. The absorbance was measured at 595 nm. Ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$) and Milli Q water were used as positive and negative controls, respectively. The absorbance was compared with standard aqueous ferrous ion solutions (60-1000 µM) and FRAP was expressed as the amount of ferrous ion produced by the reduction of ferric ion. The antioxidant activity was reported as µmol Fe(II) equivalent/g d.b.

Andrographolide and Neoandrographolide

The high performance liquid chromatography (HPLC) instrumentation was a Shimadzu HPLS system (Tokyo, Japan), equipped with a DGU-20A5 degasser, a LC-20AD liquid Chromatograph solvent delivery unit, a SIL-20A HT auto sampler, a SPD-M20A diode array detector and

a CBM-20Acommunications bus module. The analytical column used was a Phenomenex Luna C_{18} (2) (250x4.6 µm, i.d., 5µm) with a C_{18} guard column (Phenomenex, Sydney, Australia). The mobile phase consisting of methanol (HPLC grade, Merck) and water in the proportion (55:45 v/v) was used. The solvent flow rate was 1.0 mL/min. and the column temperature was set at 25°C. The UV detector was monitored at 223 nm (Patarapanich et al., 2007). Andrographiolide and neoandrographolide were identified by comparing their HPLC retention times with those of standards (Sigma-Aldrich (M) Sdn. Bhd, Selangor, Malaysia). The compounds were quantified by comparison with the retention time of the standard. All analyses were performed in triplicate and the mean results were calculated as mg/100 g d. b.

Stability Study and Shelf-life prediction

The degradation kinetics of chemical compounds of dried *A. paniculata* leaves during storage were modeled using zero order (Eq. 1) and first order (Eq. 2) degradation reaction kinetics (Stamp and Labuza, 1983).

$$C = C_0 \pm kt \qquad (1)$$

$$C = C_0 \exp(\pm k_1 t) \qquad (2)$$

Where

C is the concentration of the quality parameter after time t; C_0 is the initial concentration of the quality parameter; t is the storage time (month); k_0 is the zero-order kinetics constant (mg/month) and k_1 is the first-order kinetics constant ($month^{-1}$). Where (+) and (-) indicated formation and degradation of quality parameter respectively.

Half-life value ($t_{1/2}$), the time needed for 50% degradation for chemical compounds of the zero and first order degradation reaction (Labuza and Schmidl, 1985) were calculated using the equations given below

$$\text{Zero-order:} \quad t_{1/2} = \frac{-0.5C_0}{k} \qquad (3)$$

$$\text{First-order:} \quad t_{1/2} = \frac{-\ln 0.5}{k} \qquad (4)$$

Where

k is rate constant (month-1)

Activation energy (Ea) is the minimum energy necessary to cause a chemical reaction to occur. Activation energy was calculated according to the Arrhenius equation:

$$\ln \frac{k_2}{k_1} = \frac{E_a(T_2 - T_1)}{RT_1T_2} \qquad (5)$$

Where

E_a is the activation energy (J/mol); R is ideal gas constant (8.3145 J/mol K) and T is temperature (K) (Labuza, 1984).

Statistical Analysis

Kinetic modeling for the characteristic degradation was evaluated using linear and non-linear regression analysis by SPSS 23.0 for Windows (SPSS, Inc., Chicago, IL, USA). The quality of fit of the kinetic degradation equations was evaluated using the coefficient of determination (R^2), standard error of estimate (SEE) and root mean square error (RMSE) (Sarsavadia et al., 1999).

The effect of time and storage temperature on polyphenol contents were evaluated by 4x2 split-plot experiments. Main plot unit was the storage time (0, 2, 4, and 6 months), the sub-plot treatment factor was the storage temperature (25 and 35°C). Three replications were used to determine each parameter. SPSS 23.0 for Windows was used to perform the analysis of variance (ANOVA). Duncan's multiple range test was used to determine the significant differences between treatments at a 95% confidence interval.

Results and Discussion

Total Phenolics and Antioxidant Activities

Quantitative evaluation of total phenolics in methanolic extract of the different dried *A. paniculata* leaves were estimated by the method of Folin-Ciocalteu and total antioxidant activities in terms of DPPH and FRAP assays.

As a rule, throughout storage, the content of bioactive compounds included in food are decreasing. However, the quality of changes in antioxidant capacity is slightly different for dried products compared with fresh products, and it relates to the type of product and the storage conditions.

In the course of CAD (**Table 1**), a decrease of 50.92% and 56.32% was observed for total phenolics after 6 months of storage at 25 and 35°C, likewise 14.7% and 15.56% was observed for DPPH and 19.96% and 23.77% for FRAP after 6 months of storage period. During the storage of heat pump dried products, after the time of 2 months'time a decline of antioxidant capacity was observed. At the end of storage (6 months) at 25 and 35°C, a decrease of 53.09%, 15.8% and 19.30% in total phenolics, DPPH and FRAP was observed in dried *A. paniculata* leaves stored at 25°C. Similarly, a decrease of 63.09%, 16.65% and 22.54% in total phenolics, DPPH and FRAP was observed in dried *A. paniculata* leaves stored at 35°C. Finally, both total phenolics and antioxidant activity (DPPH and FRAP) in the stored product obtained using FD decreased significantly. Losses of 48.27%, 14.54% and 18.46%, respectively, were observed. A similar trend was observed at 35°C, where levels of total phenolics and antioxidant activity (DPPH and FRAP) decreased by 53.72%, 16.05% and 21.06%, respectively. It was observed that the maximum decrease in total phenolics and antioxidant activity occurred at 35°C.

The decrease in the total phenolic content and antioxidant activity of materials during storage has been reported by several authors such as Puranik et al. (2012) who carried out a detailed study on total phenolics and percentage radical scavenging activity of freeze dried *A. paniculata* leaves during storage at subzero temperature for a period of two months. With the increase of storage time, the total phenolics as well as percentage radical scavenging activity have decreased.

Moreover, Nowacka et al. (2014) assessed changes of radical scavenging activity during the storage of the dried apple and they reported that after 3 months of storage, the radical scavenging activity of microwave – convective dried samples was reduced significantly at temperature of 4°C, 25°C, and 40°C. Meanwhile, the radical scavenging activity and polyphenols content of infrared-convective dried apple were decreased only to a small extent.

The significant decrease in total phenolics and antioxidant activity of dried products could have been caused by decomposition of chemical compounds with antioxidant properties. Likewise, the storage caused the reduction of polyphenols content. The decrease in total phenolics was mostly due to the fact that the phenolic compounds were oxidized or polymerized during processing and storage (Wang et al., 2000).

Andrographolide and Neoandrographolide

Figure 1 shows the chromatograms of standard andrographolide and neoandrographolide. The levels of andrographolide and neoandrographolide in the CAD-dried *A. paniculata* leaves were ranged from 9.81 – 22.93 mg/100 g d.b. and 2.95 – 5.67 mg/100 g d.b., respectively in all the samples studied at 25°C and 35°C (**Table 1**). Conversely, andrographolide content has decreased by 53.99% and 57.22% and neoandrographolide

was obtained to be reduced at 46.74% and 47.97% at 25 and 35°C, respectively.

Figure 2 shows the chromatograms of dried leaves by HPD. HPD and FD dehydrated *A. paniculata* leaves showed smaller losses of andrographolide and neoandrographolide compared with CAD dried ones. However, a statistically significant decrease of andrographolide and neoandrographolide was observed in the samples from both HPD and FD. There was a 54.79 and 48.66% observed decrease in the andrographolide content in HPD and FD dehydrated sample and stored at 25°C, respectively. Meanwhile, at 35°C the andrographolide decreased by 56.30 and 50.27%. Likewise, at 25°C the neoandrographolide content of the HPD and FD dehydrated leaves decreased by 37.40 and 38.34% and 46.33 and 43.11% at 35°C, respectively.

The most considerable loss of andrographolide and neoandrogrpholide contents was noticed in the sample stored at the higher temperature (35°C). Pholphana et al. (2004) studied the changes in storage of andrographolide and neoandrographolide of *A. paniculata* obtained from different supplier in Thailand during storage. The content of andrographolide and neoandrographolide in all samples were decreased during the storage. In addition, Lomlim et al. (2003) investigated the stability of clean andrographolide (crystal and amorphous forms) at 70°C for three months and discovered that crystalline andrographolide was greatly stable over a term of 3 months while its amorphous form was deteriorated quickly during 2 months of storage under the same conditions.

Kinetic Analysis of Bioactive Compounds

As a rule, throughout storage the content of bioactive compounds included in food is decreasing. However, the kinetics of changes of antioxidant capacity are slightly different in dried products in comparison with fresh products, and it relates to the type of product and the storage conditions. The degradation of antioxidant activity and total phenolics during storage followed the first-order equation with respect to temperature and showed a high coefficient of determination (R^2) and low SEE and RMSE. This result is indicated by the increase in the kinetic constant (k) with the increase of temperature. The first-order kinetic model is generally used to study the kinetics of changes in chemical compounds. Similar results were reported by Nayak et al. (2011) for total phenolics in potato and Jaiswal et al. (2012) for antioxidant activity in cabbage, and Yilmaz and Karadeniz (2014) for L-ascorbic acid in quince nectar.

The kinetics of degradation of major compounds in *A. paniculata* leaves (andrographolide and neoandrographolide) during storage were investigated. The first-order kinetics equation was the best fit for the major compounds with the highest R^2 value (Table 2). These results show that the rate of the degradation is exactly proportional to the concentration of the compounds and agreed well with the prior studies. Verbeyst et al. (2011) investigated the thermal degradation of anthocyanin in raspberries that was fitted to the first-order reaction model. Moreover, the kinetics degradation of anthocyanin in black carrot juice concentrate during storage at -23, 5 and 20°C was fitted to the first-order reaction model (Türkyilmaz and Özkan, 2012).

Further to the degradation rate, the half-life time ($t_{1/2}$) was calculated by the Arrhenius equation for the bioactive compounds in samples subjected to different drying temperatures. Half-life corresponds to the time at which the bioactive compounds are decreased by 50% with respect to time zero (Desobry et al., 1997). It was found that the $t_{1/2}$ values of total phenolics of CAD, HPD and FD leaves at 25°C were 159.9, 163.8, and 194.4 days, respectively. This is higher than the $t_{1/2}$ values of 130.8, 133.2, and 146.4 days of the samples stored at the higher temperature of 35°C.

This trend is similar to that of $t_{1/2}$ values of antioxidant activity (DPPH and FRAP). Therefore, it could be summarized that the half-life ($t_{1/2}$) time of total phenolics and antioxidant activity (measured as DPPH and FRAP) of *A. paniculata* leaves dried in different drying methods and stored at 25°C is higher than that of samples stored at 35°C.

The $t_{1/2}$ values obtained for the andrographolide content of CAD, HPD and FD leaves at 25°C were 150.6, 153 and 179.4 days, respectively, whereas the $t_{1/2}$ values at 35°C were 139.5, 141.6 and 162.6 days, respectively. Also the $t_{1/2}$ values obtained for the neoandrographolide content of CAD, HPD and FD at 25°C were 198, 233.7 and 244.5 days, respectively, and the $t_{1/2}$ values at 35°C were 182.4, 194.4 and 199.8 days, respectively.

Activation energy (E_a) may also be defined as the minimum energy required to starting a chemical reaction. Activation energy (E_a) of total phenolic of cabinet, heat pump and freeze dried *A. paniculata* leaves calculated for the temperature at 25 and 35°C were 15.37, 15.70 and 21.60 kJ/mol, respectively. Furthermore, the activation energy of major compounds in CAD, HPD and FD dried *A. paniculata* leaves were 5.85, 5.94 and 7.51 kJ/mol, respectively, for andrographolide content and 6.28, 14.10 and 15.40 kJ/mol, respectively, for neoandrographolide. The results of this work were agreed with Potisate et al. (2015) who reported that the activation energy of total flavonoids in dried *Moringa oleifera* leaves was 14.07 kJ/mol stored in PP and 13.08 kJ/mol in PET/Al/PE.

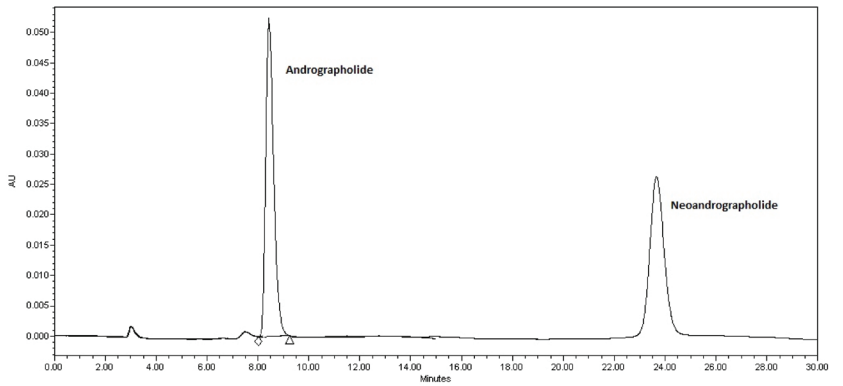

Figure 1 Chromatograms of andrographolide and neoandrographolide standards

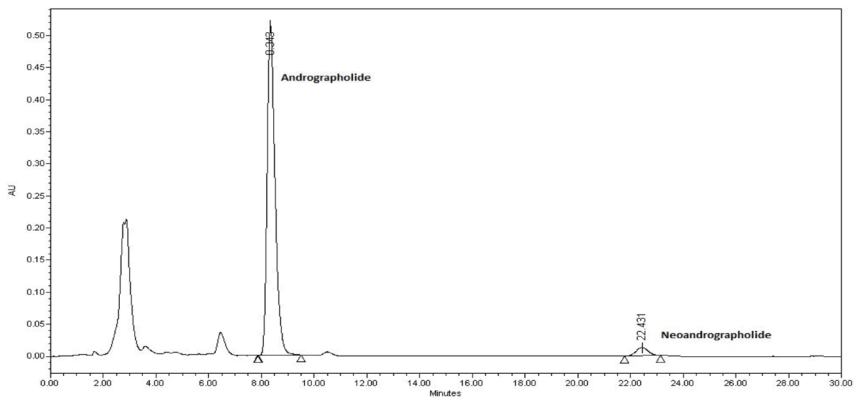

Figure 2 Chromatograms of HPD dehydrated *A. paniculata* leaves

Table 1 Effect of storage time, storage temperature and dryers on TPC, DPPH, FRAP, andrographolide and neoandrographolide

Dryer	Temperature (°C)	Time (months)	Total phenolics (mg GAE/g d.b.)	DPPH (%inhibition)	FRAP (μmol Fe(II)/g d.b.)	Andrographolide (mg/100g d.b.)	Neoandrographolide (mg/100g d.b.)
Cabinet	Control		7.60±0.10^{g}	47.42±0.34^{c}	44.13±0.61^{k}	22.93±1.63f^{g}	5.67±0.04^{m}
	25	2	5.26±0.01^{o}	38.22±0.10^{j}	38.86±0.06^{m}	16.73±0.03^{j}	4.68±0.04^{o}
		4	4.20±0.05^{q}	34.25±0.27^{o}	37.07±0.04^{n}	12.52±0.22^{l}	3.73±0.01^{q}
		6	3.73±0.01^{r}	32.72±0.18^{q}	35.32±0.20^{o}	10.55±0.45^{m}	3.02±0.02^{s}
	35	2	4.87±0.02^{p}	36.70±0.13^{l}	37.01±0.03^{n}	15.61±0.07^{k}	4.25±0.04^{p}
		4	3.68±0.01^{r}	33.49±0.10^{p}	35.45±0.05^{o}	12.30±0.05^{l}	3.48±0.01^{r}
		6	3.32±0.02^{s}	31.86±0.24^{r}	33.64±0.02^{p}	9.81±0.01^{n}	2.95±0.02^{t}
HPD	control		11.49±0.06^{b}	51.95±0.74^{b}	54.67±0.47^{b}	34.42±0.26^{b}	9.39±0.12^{c}
	25	2	8.68±0.05^{e}	41.49±0.12^{e}	50.81±0.04^{e}	24.26±0.02^{e}	7.12±0.01^{i}
		4	6.90±0.02^{i}	38.84±0.14^{i}	46.81±0.03^{h}	19.88±0.11^{h}	6.26±0.02^{k}
		6	5.39±0.03^{n}	36.15±0.02^{m}	44.12±0.10^{k}	15.56±0.08^{k}	5.63±0.01^{m}
	35	2	7.65±0.03^{g}	40.62±0.01^{f}	48.76±0.10^{f}	23.13±0.04^{f}	6.62±0.01^{j}
		4	5.66±0.03^{m}	37.16±0.07^{k}	44.50±0.04^{j}	18.43±0.18^{i}	5.94±0.02^{l}
		6	4.25±0.04^{q}	35.30±0.04^{n}	42.35±0.04^{l}	15.04±0.01^{k}	5.04±0.01^{n}
FD	control		13.03±0.02^{a}	52.71±0.24^{a}	58.17±0.51^{a}	36.50±0.17^{a}	12.78±0.03^{a}
	25	2	10.55±0.01^{c}	42.10±0.04^{d}	53.85±0.08^{c}	26.41±0.15^{c}	9.57±0.02^{b}
		4	8.27±0.02^{f}	39.33±0.18^{h}	50.49±0.03^{e}	22.30±0.08^{g}	8.39±0.01^{e}
		6	6.74±0.04^{j}	38.17±0.13^{j}	47.43±0.12^{g}	18.74±0.01^{i}	8.00±0.02^{f}
	35	2	8.87±0.06^{d}	41.79±0.06^{de}	51.94±0.10^{d}	25.46±0.03^{d}	8.51±0.01^{d}
		4	7.41±0.02^{h}	37.47±0.31^{k}	46.49±0.03^{h}	20.41±0.22^{h}	7.72±0.02^{g}
		6	6.03±0.02^{l}	36.66±0.06^{l}	45.92±0.01^{i}	18.15±0.02^{j}	7.27±0.03^{h}

Different superscripts in the same column indicate a significant difference ($P \leq 0.05$).

GAE= gallic acid equivalent, Fe(II)E= ferrous ion equivalent, d.b.= dry basis

Table 2 Estimated parameter values for andrographolide and neoandrographolide degradation kinetics equation fitted by Zero- and first-order equations.

	Dryer	Temperature	Zero-order					First-order				
			C_0 (mg)	k_0 (mg/month)	R^2	SEE (mg)	RMSE (mg)	C_0 (mg)	k_1 ($month^{-1}$)	R^2	SEE (mg)	RMSE (mg)
Andrographolide	Cabinet	25°C	21.88	-2.067	0.950	1.2183	1.0551	22.62	0.138	0.989	0.5694	0.4931
		35°C	21.56	-2.133	0.935	1.4563	1.2612	22.41	0.149	0.982	0.7631	0.6610
	Heat pump	25°C	32.67	-3.048	0.948	1.8399	1.5934	33.73	0.136	0.984	1.0074	0.8724
		35°C	32.18	-3.142	0.921	2.3777	2.0591	33.49	0.147	0.974	1.3672	1.1840
	Freeze	25°C	34.60	-2.869	0.931	2.0100	1.7406	35.54	0.116	0.971	1.3033	1.1287
		35°C	34.15	-3.005	0.901	2.5659	2.2222	35.36	0.128	0.957	1.6929	1.4661
Neoandrographolide	Cabinet	25°C	5.61	-0.446	0.995	0.0852	0.0738	5.70	0.105	0.999	0.0410	0.0351
		35°C	5.43	-0.448	0.951	0.2620	0.2268	5.57	0.114	0.985	0.1473	0.1275
	Heat pump	25°C	8.92	-0.606	0.908	0.4983	0.4315	9.10	0.089	0.947	0.3800	0.3287
		35°C	8.80	-0.686	0.891	0.6176	0.5349	9.04	0.107	0.937	0.4715	0.4084
	Freeze	25°C	12.02	-0.780	0.856	0.8271	0.7163	12.27	0.085	0.903	0.6765	0.5859
		35°C	11.67	-0.866	0.783	1.1760	1.0184	12.05	0.104	0.849	0.9810	0.8500

Conclusions

Total phenolics, antioxidant activity (DPPH and FRAP), andrographolide and neoandrographolide of dried *A. paniculata* leaves were decreased significantly after storage at all temperatures. The results indicated that the bioactive compounds were largely dependent on the drying methods and on the storage conditions. Kinetics of degradation of major compounds show that the first-order kinetic model fitted best the storage conditions of *A. paniculata*.

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