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Original Article

Influence of drying method on qualities of Jerusalem artichoke (*Helianthus tuberosus* L.) tuber harvested in Northeastern Thailand

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Abstract

The aim of this study was to determine the effect of two drying methods, greenhouse solar drier and oven drier, on qualities of Jerusalem artichoke (*Helianthus tuberosus* L.) tuber (JAT). The quality characteristics were determined in term of physical and chemical qualities as well as microbial safety in the final samples. The results showed that protein, fat, ash, carbohydrate and total fiber content were not significantly different between solar drying and oven drying ($p>0.05$). However, inulin, total phenolic content (TPC) and antioxidant activity (AOA) in solar dried JAT was significantly ($p\leq0.05$) higher than oven dried sample. Moreover, the color of JAT powder produced by solar displayed brighter than oven drying. Both drying methods were effective to reduce water content in dried products and had the total plate count and total yeast & mold count with the acceptable level.

Keywords: drying, phenolic, fiber, inulin, Jerusalem artichoke

1. Introduction

Jerusalem artichoke (*Helianthus tuberosus* L.) tuber is a plant which originally found in North America. In Thailand, JAT cultivars were developed during the past few decades, especially in the Northeast region of Thailand (Tanjor, Judprasong, Chaito, & Jogloy, 2012). JAT has been introduced for many applications, such as low-calorie food materials, functional food ingredients, animal feed, bioenergy production and biochemical products (Kaur & Gupta, 2002; Li, Li, Wang, Du, & Qin, 2013). Nowadays, JAT has been considered as an excellent source of inulin with high concentration between 14-19 g/100 g, wet basis (w.b.), which was similar to chicory root, the commercial inulin production source (15-20 g/100 g, w.b.) (Van Loo, Coussement, Leenheer, Hoebregs, & Smits, 1995). Moreover, there are many foods that contain a large quantity of inulin, for example garlic, asparagus root, salsify and dandelion root (Kaur & Gupta, 2002). Inulin provides many health benefits as functional dietary fiber, such as reducing lipid metabolism and the risk of gastrointestinal diseases, anti-carcinoma activities, enhancing calcium, magnesium and iron absorption, preventing of diabetes and stimulating immune system (Shoaib *et al.*, 2016). According to Judprasong, Tanjor, Puwastien, and Sungpuag (2011) reported that JAT grown in Thailand showed a potential source of inulin by content of 19.5 g/100 g (w.b.). Due to its diverse functional properties, the interest of inulin for food industry has increased as food ingredient. Thus, it is possible that JAT can be the potential crop replacing commercial inulin source plants like chicory root.

Besides inulin content, JAT contains phenolic compounds that are the main contributor to anti-radical

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scavenging activities (Mattila & Hellstrom, 2007; Petvoka, Ivanov, Denev, & Pavlov, 2014). According to Saikaew, Tangwong-chai, and Sae-Eaw (2010), fresh JAT variety HEL65 with harvesting time of 120 days planted in Khon Kaen University farm, Thailand, consisted of TPC by 42.50 mg/100 g, dry basis (d.b.). While, dried JAT powder harvested during winter season from Zheinjiang, China, reached phenolics level to 426 mg/100 g (d.b.) (Afoakwah *et al.*, 2015).

Drying is an application of heat under a controlled condition to release the moisture in food. Drying obviously affects the nutritious substances, color change and textural quality in dried food (Vega-Gálvez *et al.*, 2009). Dried JAT in form of powder has widely consumed and sold as food supplement in the Thailand market. The dried JAT will be beneficial for food business that has increased the market value of this plant. Moreover, dried JAT can be stored for a number of years with high inulin content. Oven drying is usually applied in drying process as well. It is able to control a homogeneous temperature that ensures the end of product quality. In general, oven drying method has been widely used to dry fresh JAT slices with temperature of 60-70ºC (Inchuen, Porniammongkol, & Duangkhamchan, 2014; Khuenpet, Jittanit, Sirisansaneeyakul, & Srichamnong, 2015). However, this method consumes high energy and high cost of operation. Solar drier is the oldest drying technique related to food preservation. It has been widely used to obtain good quality of dried food with the better market price of the product (Toshniwal & Karale, 2013). However, the limitation of issues with solar drier was only used during day time when adequate amount of solar energy provides (Tiwari, 2016). For industrial production, it is very important to study the chemical and physical change, and food safety in the dried product for making a decision and for commercial production benefits. No comparison on the effect of commercial scale of oven and solar drying technique on quality and safety values of dried JAT have yet been studied.

Therefore, the objectives of this study was to investigate the effect of two commercial drier, oven and greenhouse solar drier, on the chemical compositions as functional ingredients, physical and microbiological properties of dried JAT powder.

2. Materials and Methods

2.1 Chemicals and reagents

Megazyme total dietary fiber assay kit and Megazyme fructan HK assay kit were purchased from Megazyme International Ireland Ltd, Wicklow, Ireland. A 1,1-diphenyl-2-picrylhydrazyl (DPPH), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 2,2'-azino-bis-3-ethylbenzothiazoline-6-solfonic acid diammonium salt (ABTS) and gallic acid were purchased from Sigma-aldrich. Folin-ciocalteu reagent was purchased from Merck.

2.2 Sample preparation

JAT of Kaentawan#1 variety was planted at the Agronomic Research Farm, Khon Kaen University, Thailand, and harvested about 18 weeks after planting. All tubers were washed by tap water to eliminate soil and then sliced to approximately 2 mm thick. The sliced JAT was immediately immersed in 0.5% w/v citric acid solution for 30 min and drained the solution out. Two drying methods were used including, oven and solar drier. For oven drying, the industrial single door oven drier (Pasture Limited Partnership, Bangkok, Thailand) with overall dimension (m) by 0.9×0.8×1.5 was used. The samples were dried for 10 hrs under air temperature at 65 ℃ with the air velocity of 3 m/s. In term of commercial solar drying, the greenhouse solar drier was operated at Siam AgBio Co., Ltd., Khon Kaen Province, Thailand. The overall dimension of drier was (3×10.5×2.5) m and the roof structure was made form polycarbonate sheets. The three axial flow fans were installed in the wall. The drying experiment was started from 10.30 am to 4.40 pm under temperature of 40-55 ℃ for 2-3 days. The dried samples from both drying processes were collected when the moisture content was lower than 8±1% (w.b.). Then, dried JAT chips were grounded to be fine powder using a blade grinder. JAT powder was stored in aluminum foil bags and kept under 4±0.5 ℃ for further quality analysis.

2.3 Proximate analysis

Proximates were analyzed following the Association of Official Analytical Chemists (AOAC, 2012) method. Moisture was analyzed using a drying method at 100±2 ℃ until the weight constant. Total protein was determined using Kjeldahl method (981.10) with 6.25 as a factor for converting nitrogen to protein. Fat content was determined by soxhlet extraction using petroleum ether as a solvent (945.16). Ash was analyzed by burning all organic matter at 550±5 ℃ (945.46).

2.4 Inulin

The inulin was analyzed using Megazyme kit (Megazyme International Ireland Ltd., Wicklow, Ireland) that incorporated the key components of AOAC (999.03). The result was expressed as g of inulin per 100 g sample (d.b.).

2.5 Soluble and insoluble dietary fiber analysis

Soluble and insoluble dietary fiber were analyzed using the rapid integrated total dietary fiber assay by Megazyme test kit (Megazyme International Ireland Ltd., Wicklow, Ireland) following the key components of AOAC (985.29). The total dietary fiber was calculated by accumulation between soluble and insoluble dietary fiber. The result was expressed as g of fiber per 100 g sample (d.b.).

2.6 AOA and TPC analysis

The extraction process was following the method described by Mattila & Hellstrom (2007) with some modification. A 0.30 g of JAT powder was added to 7 ml of 10% acetic acid in methanol (3:17, v/v). The mixture was extracted for 30 min using ultrasonic bath and was filtered by Whatman filter paper No.1 after centrifuging at 3000 rpm for 5 min by centrifuge (Z-200A, HERMLE, Wehingen, Germany). The residue was re-extracted by some addition of the same solvent and the same procedure as described above. The extracted solution was measured for AOA and TPC.

2.6.1 DPPH assay

The DPPH free radical-scavenging method was determined according to the method described by Leong & Shui (2002) with some modifications. The 0.1 mM solution of DPPH in methanol was freshly prepared. A 100 µL of sample extract was mixed with 4.0 mL of DPPH solution and incubated for 30 min at room temperature in the dark condition before analysis at 571 nm by spectrophotometer (Shimadzu UV-1800, Japan). Trolox was used as antioxidant standard. AOA was expressed as mg trolox equivalent per 100 g sample based on dry basis (mg trolox/100 g, d.b.).

2.6.2 ABTS assay

The ABTS radical scavenging assay was based on a method described by Stratil, Klejdus, & Kuban (2006) with some modifications. The stock solution of $ABTS^{\bullet+}$ radical cation was made by reacting 7 mM of ABTS with 4.95 mM of potassium persulphate at the ratio 1:1 (v/v) for 12 h at room temperature in the dark condition. An $ABTS^{\bullet+}$ working solution was diluted with distillated water for the absorbance values at 1.0 AU at 734 nm using spectrophotometer. A 40 µL sample extract was mixed with 3 mL of $ABTS^{\bullet+}$ working solution and then incubated for 10 min at room temperature in the dark before measurement. AOA was expressed as mg trolox equivalent per 100 g sample based on dry basis (mg trolox/100 g, d.b.).

2.6.3 TPC

TPC was determined following the method of Dewanto, Wu, Adom, & Liu (2002). The reaction mixture was contained of 125 µL of extract sample and 250 µL of Folin-Ciocalteu reagent followed by the addition of 3 mL distilled water in a test tube. The mixture was mixed well and incubated for 6 min before added to 2.5 mL of 7% sodium carbonate solution. The mixture was allowed to stand for 90 min at room temperature before measuring at 760 nm. TPC was expressed as mg gallic acid equivalent per 100 g based on dry basis (mg gallic acid/100 g, d.b.).

2.7 Color analysis

The parameter of L*, a*, b*, Chroma (C*) and hue angle (h°) were described the color of the sample using colorimeter (MiniScan XE Plus, HunterLab, Virginia, USA). L* is a value to represent the brightness from black (0) to white (100). The parameter a* shows redness (green (-) to red (+)), b* shows yellowness (blue (-) to yellow (+)). C* and h° are described the intensity and dominant wavelength of color, respectively.

2.8 Microbial analysis

In this research, microbial analysis was described with total plate count and yeast & mold count following the method of the US Food and Drug Administration Bacteriological Analytical Manual (2005). The result was reported in colony form unit per gram sample (CFU/g).

2.9 Statistical analysis

The comparison of all samples was carried out as a randomized complete design. One-way analysis of variance was used to analyze the data. The Duncan Multiple Range Test (DMRT) was conducted to evaluate mean differences with significant effect at $p \leq 0.05$. All statistical analyses were carried out using IBM SPSS Statistic version 19.0 software (SPSS Inc., USA).

3. Results and Discussions

3.1 Proximate compositions

Both fresh and dried JAT were analyzed and have the proximate compositions shown in Table 1 and Table 2, respectively. The major components in fresh tuber were 75.46% moisture and 21.33% carbohydrate, while the minor compositions were protein (2.36%), fat (0.09%) and ash (0.78%). Similar results were reported by Judprasong, Archeepsudcharit, Chantapiriyapoon, Tanaviyutpakdee, and Temviriyanukul (2018), used fresh JAT that was collected from four major growing areas in Thailand, Nakhon Pathom, Khonkaen, Nakhon Ratchasima, and Phetchabun Province, during April to May 2014 contained 78.0% moisture content, 18.6% carbohydrate, 2.3% protein, 0.1% fat, and 1.0% ash (w.b.).

Drying is the application of heat under a controlled environment to remove moisture from food. However, the effectiveness of drying depends not only on moisture reduction but also lowering operation cost while remains good quality of dried food. After drying by solar and oven drier, both dried JAT samples presented moisture content by 6.57 and 4.40%, respectively (Table 2), with water activity (A_w) by 0.33 and 0.24, respectively (data not shown). To meet the Thai community product standard (TCPS) of dried fruit and

Table 1. Proximate compositions of fresh Jerusalem artichoke tuber.

Parameters	Amount (g/100 g, wet basis)
Moisture	75.46 ± 0.52
Carbohydrate	21.33 ± 0.06
Protein	2.36 ± 0.11
Fat	0.09 ± 0.02
Ash	0.78 ± 0.10

Table 2. Proximate compositions of solar and over dried Jerusalem artichoke tuber powder.

Parameters	Amount (g/100 g, wet basis)	
	Solar drier	Oven drier
Moisture*	6.57^{a} ± 0.34	4.40^{b} ± 0.23
Carbohydrate	82.06^{a} ± 1.44	83.38^{a} ± 0.28
Protein	6.76^{a} ± 0.61	7.26^{a} ± 0.45
Fat	0.31^{a} ± 0.18	0.28^{a} ± 0.03
Ash	4.30^{a} ± 0.28	4.48^{a} ± 0.02

^{a,b}: values within each row with the different letter are significantly different ($p \leq 0.05$). *: g/100g based on dry basis

vegetable (TCPS No.136, 2015), the moisture and A_w level in dried food must be lower than 12% and 0.6, respectively. The reduction of moisture content and A_w can prolong storage time of dried product because low-moisture foods can inhibit the growth of microorganisms and can reduce moisture-mediated degradation and chemical and enzyme reactions (Jayaraman & Das Gupta, 1995). This indicated that both drying processes successfully decreased the moisture content and A_w of JAT. Similar result was obtained by Khuenpet *et al.* (2015), JAT dried by tray drying at 65 °C had moisture content by 5.7-6.8% (w.b.). However, high moisture content of dried JAT chips has the effect on the final quality of dried powder including, agglomeration and stickiness problem during storage (Khuenpet, Jittanit, Sirisansaneeyakul, & Srichamnong, 2016). There were not significantly different of carbohydrate, protein, fat and ash content between both dried samples, by the value in the range between 82.06-83.38%, 6.76-7.26%, 0.28-0.31% and 4.30-4.48%, respectively. The similar concentration of carbohydrate (84.79%) and ash (3.58%) were reported by Khuenpet *et al.* (2016) who studied in dried powder of JAT variety JA102 obtained from Kasetsart University, Thailand.

3.2 Inulin and fiber composition

Inulin is classified as soluble fiber with a polymerization degree of 2 to about 60 monomers of fructose. Inulin provides many health benefits such as functional as dietary fiber, reduction in risk of gastrointestinal diseases and bifidogenic effect and stimulation of immune system (Shoaib *et al.*, 2016). The result appeared that inulin content in fresh JAT was 10.09 g/100 g, (d.b) (or 2.48 g/100 g, w.b.) which was lower than the result reported by Gupta & Kaur (1997) (15-20 g/100 g, w.b.). However, inulin content in JAT depend on many factors, such as plant variety, storage conditions, climate and growing conditions, and harvesting maturity (Khuenpet *et al.*, 2015). With regarding to effect of drying method, inulin content in solar dried sample was significantly ($p \leq 0.05$) higher than oven dried sample. From the previous study, the inulin could be converted into reducing sugar via hydrolysis occurring during drying temperature around 35-85 °C (Li *et al.*, 2015), additionally, fructo-oligosaccharide (low molecular weight inulin) was also formed by hydrolysis of inulin (Gupta, Kaur, & Kaur, 2003). However, the study reported by Li *et al.* (2015) noted that inulin could be hydrolyzed to sugars under low drying temperature (35-55 °C) due to the existing of a common enzyme in JAT (inulinase), but this enzyme is deactivated at the temperature higher than 60 °C. Moreover, they mentioned that drying temperature higher than 65 °C apparently impacted on the inulin loss more than lower temperature. According to Gupta, Kaur, and Kaur (2003), chicory root dried by oven drying with temperature 80-90 °C had lower inulin concentration compared with sun dried sample with temperature 30-35 °C. Thus, in our present study, inulin content of dried JAT would be expected to be lower at high drying temperature of oven drier.

Dietary fiber is considered as the functional substances from JAT. Total dietary fiber in fresh JAT from this result was 2.65 g/100 g, d.b. After drying, total dietary fibers, soluble and insoluble fiber in both dried samples were higher than the fresh JAT (Table 3). This result might be due to the thermal treatments which caused the formation of fiber-protein complexes that are resistant to heating and as quantified as fiber (Caprez, Arrigoni, Amado, & Neucom, 1986). However, different drying methods significantly ($p \leq 0.05$) affected soluble fiber content, while, total dietary fiber and insoluble fiber was not different ($p > 0.05$). The JAT powder from oven drying had higher content of soluble fiber than that of solar. According to Gupta, Kaur, & Kaur (2003), fructo-oligosccharides referred to soluble fiber were formed during higher drying temperature because of inulin hydrolysis. Thus, this reason might be supported the higher level of soluble fiber in oven dried JAT.

Table 3. Inulin and dietary fiber content in fresh and solar and oven dried Jerusalem artichoke tuber powder.

Parameters*	Fresh tuber	Dried powder	
		Solar drier	Oven drier
Inulin	$10.09^{c} \pm 0.17$	$46.85^{a} \pm 1.85$	$42.58^{b} \pm 1.61$
Total dietary fiber	$2.65^{b} \pm 0.37$	$23.59^{a} \pm 1.29$	$26.57^{a} \pm 1.50$
Insoluble fiber	$0.54^{b} \pm 0.10$	$19.17^{a} \pm 1.29$	$18.10^{a} \pm 1.18$
Soluble fiber	$2.11^{c} \pm 0.28$	$4.37^{b} \pm 0.35$	$8.47^{a} \pm 0.30$

[a,b,c]: values within each row with different letter are significantly different ($p \leq 0.05$). *: g/100g based on dry basis

3.3 TPC

Phenolics are secondary plant metabolites located primarily within plant cell. These compounds are considered as the major contributor to antioxidant capacity in food. TPC in fresh and dried JAT is shown in Table 4. It was found that solar dried JAT sample gave higher TPC than oven dried sample. Similar observation was supported by Arslan, Özcan, and Mengeş (2010), TPC in dried peppermint leaves by sun dry (20-30 °C, 13 hrs) was higher than sample dried by oven dry (50 °C, 12 hrs). Our observation was also supported by Chan *et al.* (2009), who found that sun dry (35 °C, 27 hs) process produced TPC higher than oven dry (50 °C, 5 hrs) in ginger powder. Thus, our result could be explained that high temperature produced by oven dry might affect the loss of phenolic compound in sample. The TPC in both dried samples was in the range between 437.49-949.73 mg gallic acid/100g (d.b.), which was similar to dried JAT powder reported by Inchuen *et al.* (2014) (335-644 mg gallic acid/100 g, d.b.). However, both drying methods caused the increasing of TPC when compared to fresh sample. Drying may affect the acceleration of bound phenolic compounds releasing from the breakdown of cellular constituents into simpler phenolic compounds (Arslan, Özcan, & Mengeş, 2010). Similar finding in peeled JAT was also reported by Inchuen *et al.* (2014), who found that shade drying enhanced TPC higher than the fresh sample.

3.4 AOA

Two different assays, ABTS and DPPH assay, were used to measure AOA. The ABTS and DPPH assay is based on electron transfer and involves reduction of color (Floegel, Kim, Chung, Koo, & Chun, 2011). There were significant

Table 4. Total phenolic content and antioxidant activities in fresh and solar and oven dried Jerusalem artichoke tuber powder.

Samples	Antioxidant activities[1]		Total phenolic content[2]
	ABTS	DPPH	
Fresh	764.73^{a} ± 36.02	3,005.55^{a} ± 177.83	281.40^{c} ± 16.06
Dried powders			
Solar drier	864.82^{a} ± 170.22	2,712.88^{a} ± 356.95	949.73^{a} ± 122.73
Oven drier	409.59^{b} ± 23.75	314.15^{b} ± 11.07	437.49^{b} ± 9.58

^{a,b,c}, values within each column with the different letter are significantly different ($p \leq 0.05$).
[1]: Antioxidant activities were expressed as mg Trolox/100g sample based on dry basis.
[2]: Total phenolic content was expressed as mg gallic acid/100g sample based on dry basis.

differences in AOA between solar and oven dried sample (Table 4). Solar drying showed an efficient drying method on the preservation of AOA. Similar result was observed by Arslan and Özcan (2011), AOA measured by ABTS and DPPH assay of red-bell pepper dried by sun dry (30 °C) was higher than oven dry (50 °C). The AOA by both assays correlated with TPC which could be indicated that higher concentration of TPC in solar dried sample contributed to higher AOA. Phenolics are molecules bearing active hydroxyl groups that effectively donate hydrogen atoms or electrons to free radicals (Lü, Lin, Yao, & Chen, 2010). Moreover, drying at high temperatures lead to poor quality of the final product, for example the formation of Maillard and enzymatic reactions, and also the destruction of the heat-sensitive antioxidant compounds (Arslan & Özcan, 2011).

3.5 Color

Color is one of the most important criteria affecting the consumer preference and product quality. The less color shade of dried JAT powder usually is the most preferred color. Dried JAT powders were determined for color parameters (L*, a*, b*, C* and h° value). The result showed that the color values as L*, a*, b*, C* and h° were significantly affected by drying ($p \leq 0.05$) (Figure 1). The L* and b* of JAT powder produced by oven dry (65 °C) was lower than dried sample by solar dry (40-55 °C), whereas, a* of oven dried sample was higher. That could be indicated that oven dried JAT powder showed more dark-brown color, while solar dried JAT was more light yellow. Additionally, both dried JAT showed h° value between 79.58-83.26 which represents a color in the slightly reddish-yellow region, however, oven dried sample had lower h° and higher in C* value than solar dried, which could be indicated that oven dried JAT showed more intense of reddish-yellow color. This result might be caused by the formation of browning pigment of the non-enzymatic process (Maillard reaction) which was accelerated by high drying temperature (Doymaz, 2017). Thus, drying by solar drier was suitable method for desirable color of JAT. This reason agreed with Doymaz (2018), the increasing of redness in oven dried JAT was higher at high drying temperature (60-80 °C).

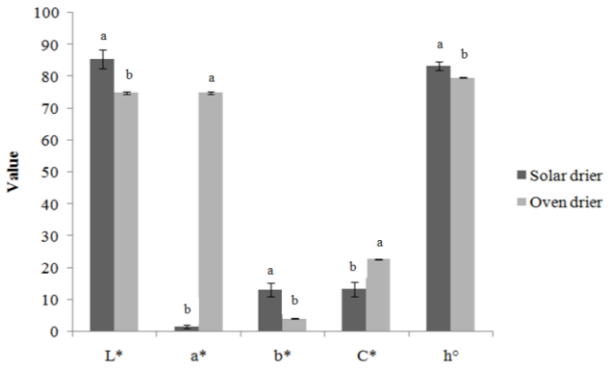

Figure 1. Color attributes of solar and oven dried Jerusalem artichoke tuber powder. Different letters on each bar indicate significant different ($p \leq 0.05$) between drying methods.

3.6 Total plate count and yeast & mold count

Microbiological analysis of dried JAT powder in both drying methods, showed with total plate count and yeast & mold count, were less than 10 cfu/g (Table 5), this level is considered as an acceptable level referred to TCPS (No.136, 2015). The main purpose of drying in the food product is to remove water to a level which deterioration reactions and microbial spoilage were minimized. In this study, the application of both drying methods might inhibit mold and pathogenic microorganism.

4. Conclusions

It was concluded that both solar and oven drying methods did not affect proximate compositions as well as microbial safety in dried JAT powder. However, the solar dried JAT powder had better quality in term of AOA, TPC, inulin content and color. With respect to operating cost, solar

Table 5. Microbiological value in solar and oven dried Jerusalem artichoke tuber powder.

Microbiological parameter *	Drying methods	
	Solar drier	Oven drier
Total plate count	<10	<10
Yeast and mold	<10	<10

*Colony form unit per gram)cfu/g(

drying should be considered as a suitable method for production of dried JAT powder applied for industry.

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