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Inulin extraction from Jerusalem artichoke (*Helianthus tuberosus* L.) tuber powder and its application to yoghurt snack

Khuenpet, K.[1*], Truong, N. D. P.[2] and Polpued, R.[1]

[1]Department of Food Science and Technology, Faculty of Science and Technology, Thammasat University, 99 Phahonyothin Road, Klong Luang, Pathum Thani 12121, Thailand; [2] Faculty of Food Science and Technology, Nong Lam University, Linh Trung Ward, Thu Duc District, Ho Chi Minh City, Vietnam.

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Abstract A ratio of Jerusalem artichoke tuber powder (JATP) and water at 1:20 (w/w), the concentrated Jerusalem artichoke extract contained the highest inulin content of 33.14 mg/ml and 2.06 mg/ml of reducing sugar. For yoghurt mixture formulation, the concentrated JA extract was used as an ingredient. Yoghurt was mixed with sugar, concentrated JA extract and juice, namely tomato juice 20% (T), lemon juice 20% (L), passion fruit juice 20% (P), the combination of T 10% with L 10% (TL), T 10% with P 10% (TP) or L 10% with P 10% (LP). The sensorial evaluation demonstrated that the treatment added with P 20% got significantly higher scores than other treatments ($p<0.05$), which were between 7.03 to 7.93 in aspects of color, flavor, sweetness, sourness and overall acceptability indicating that the panelists like sample very much. The sugar in P-JA yoghurt mixture formula was substituted by four sweeteners including maltitol, xylitol, prebiotic syrup and JA syrup. It appeared that the sugar substitution with JA syrup in P-JA yoghurt mixture caused insignificantly different in flavor, sweetness, sourness and overall acceptability from control (sugar). Yoghurt fortified with concentrated JA inulin, PJ and JA syrup was foamed and dried by foam-mat drying technique. The addition of 35% foaming agent solution (2% methocel and 1.5% carboxymelthyl cellulose) produced stable foam. The obtained foam was squeezed into circle shape and dried at 70^{o}C for 2 h to form JA inulin yoghurt snack. The moisture content, a_w and pH of dried snack were 5.73%wb, 0.39 and 4.24 respectively. JA yoghurt snack contained inulin 129.78 mg/g and reducing sugar 146.44 mg/g.

Keywords: Foam-mat drying, Inulin, Jerusalem artichoke, Juice, Yoghurt snack

Introduction

Jerusalem artichoke (*Helianthus tuberosus* L.) is a native plant of North America including tropical climates in Thailand (Ruttanaprasert *et al*., 2013; Ruttanaprasert *et al*., 2014; Puangbut *et al*., 2012). Jerusalem artichoke (JA) is tuberous plant accumulates high levels of inulin (16–20% of fresh weight) and

* **Corresponding Author:** Khuenpet, K.; **Email:** krittiya23@tu.ac.th

fructooligosaccharides (FOS) which is widely used as an ingredient in the development of functional food and beverage products (Rubel *et al*., 2018). Inulin is a natural soluble dietary fiber, consisting of a fructan of linear chain constituted by fructose molecules linked by β (2→1) bonds which have length from 2 to 60 units (Iraporda *et al*., 2019). Human digestion system cannot absorb or digest inulin in the small intestine, but inulin can be decomposed by beneficial bacteria in the colon (Yu *et al*., 2018). Commercially, inulin is mainly produced from chicory and dahlia; however, Jerusalem artichoke is also considered as a good source of inulin for industrial production (Iraporda *et al*., 2019). Generally, Jerusalem artichoke tuber (JAT) can be used as a main dish or additive in various manu (Koczoń *et al*., 2019). Hot water extraction is a popular method for isolating inulin from JAT because of its water solubility property especially in hot water (Termrittikul *et al*., 2018).

Snack is a small portion of food, mainly eaten between meals. Consumption of snack food is always considered as poor diet because it contains high sodium, fat and sugar. Besides, calories from snack food could cause overweight and obesity. Modern lifestyles and social awareness of consumption are constantly growing which result in the increase of demand from consumers for quick meals and snacks that are good nutrition sources (Izzo and Niness, 2001). In addition, the traditional method for snack food production is frying. This process also has a negative effect on human health. Huang and Zhang (2012) reported that drying become an important method for the food production worldwide because they are accepted as healthy for human consumption. Therefore, drying method could be the common and suitable method for producing healthy snack.

There are many drying methods for producing snack food such as extrusion, drum drying and freeze drying, etc. The foam mat drying process is a simple and inexpensive process. This drying technique can be used for heat sensitive because of its rapid drying rate and enhanced product quality (Ekpong *et al*., 2016). Liquid foods are converted in to a stable foam and then spreaded on a tray with thin porous sheet before drying by hot air. The foam mat drying process requires a foaming agent for producing stable foam by decreasing surface tension between the liquid and the gaseous phases (Benković *et al*., 2019). The advantages of this drying method are low cost, easy to operate and lower drying temperature (approximately 50-80 ^{o}C) (Febriant *et al.*, 2012). The dried finish product obtained from the foam mat drying method is better than that of the drum drying and spray drying method because of its honeycomb structure and better rehydration properties (Rajkumar *et al*., 2007). The reasons for adopting foam-mat drying for production of snack compared to other drying methods are less drying time, less power requirement and less production cost.

Thus, the foam mat drying process was proposed in this study. The objectives were to investigate the optimum solvent ratio for the inulin extraction from Jerusalem artichoke tuber powder (JATP) and to examine the influence of inulin extract on the yoghurt snack quality.

Materials and Methods

Jerusalem artichoke tuber powder (JATP) and Jerusalem artichoke syrup (JA syrup) were obtained from Fermentation Technology Reserch Center, Faculty of Agro-Industry, Kasetsart University, Thailand. Yoghurt, sugar, and prebiotic syrup were purchased from local supermarkets nearby Thammasat Universtiy, Phatumtani. Sweeteners (maltitol, xylitol) were supplied from Chemipan Corporation Co., Ltd., Bangkok, Thailand.

The experiment was done at laboratory at Thammasat University, Pathum Thani, Thailand. Inulin extraction from JATP**:** Inulin extraction condition of Khuenpet *et al.* (2017) was applied with some modifications. Inulin was extracted from the JATP using hot water 85^{o}C for 30 min with various ratios of JATP : water at 1:10, 1:20 and 1:30 (w/w). Then, the extract was cooled down under ambient condition and then the sediment was separated using filter cloths. The JAT inulin extract was evaporated to 19 ^{o}Brix concentration by boiling on a hot plate with stirring. The concentrated inulin extract samples were then stored at 4^{o}C before use and analysis.

JA-Yoghurt mixtures formulation

Fruit juice selection: Jerusalem artichoke tuber has a nutty, potato-like flavor (Bach *et al*., 2012; Wang and Cantwell, 2014). Therefore, the application of Jerusalem artichoke inulin extract as functional ingredient in yoghurt mixture was studied. Sour taste fruit juices were selected to reduce off-flavor and taste of JA inulin extract in yoghurt mixture samples. Three types of fruit juices, namely tomato juice (T), lemon juice (L) and passion fruit juice (P) were added to yoghurt mixture formulas. The amounts of concentrated JA inulin extract, sugar and yoghurt were fixed at 5, 5 and 70% respectively. Therefore, 20% of fruit juice was used in the formula for either single juice (T, L and P) or combination of two types of juices (TL, TP and LP). There were six formulas of fruit juice-JA yoghurt mixtures. The sensorial qualities of all samples were evaluated in facets of color, flavor, sweetness, sourness and overall acceptabitity applying the acceptance tests (the 9-point hedonic scale). One formula of fruit juice-JA yoghurt mixture that get the most preferable sensorial score were selected and applied in the further experiment.

Sugar substitution: The selected formula of fruit juice-JA yoghurt mixture was prepared, and the sugar in fruit juice- JA yoghurt mixture was substituted by four types of sweeteners including maltitol, xylitol, prebiotic syrup and Jerusalem artichoke syrup (JA syrup). The formula of a sugar-substituted mixture that obtained the most preferable sensorial scores (flavour, sweetness, sourness and overall acceptabitiy) were chosen and applied in the next experiment.

Foaming agent addition: The appropriate mixture formula was prepared and mixed with foaming agent. 2% methocel and 1.5% carboxymelthyl cellulose were used for the preparation of foaming agent solution. The mixture was foamed by using a food mixer machine (Spar mixer, 800-B, Taiwan) with a wire whip at low speed for 5 minutes. Then each proportion of foaming agent solutions was added to the mixture (35, 40, 45 and 50%). The machine was speed up to high speed and whipped for 15 minutes for foam whipping. The foam properties, including foam density, overrun and liquid drainage were determined.

Foam mat drying process: After the prepared mixtures were whipped, the foam samples were extruded manually on straining cloth, and directly forwarded to drying process in a tray dryer under controlled condition of 60^{o}C for 2 hours. After drying, the JA yoghurt snacks were removed from the tray and then kept in the plastic bag at room temperature for analysis.

Quality determination

Chemical quality**:** Chemical quality was determined including total soluble solid content (^{o}brix), moisture content, water activity (a_w), and pH. Total soluble solid contents were measured by a refractometer (ATAGO, MASTER-2M, Japan). Moisture contents of JA inulin extract and all dried JA yoghurt products were determined applying the method of Willits (1951). Water activity values were probed by a water activity meter (AQUA LAB, CX2, USA) while the pH values were measured using a pH meter (Sartorius, PB-20, Germany) following the method adapted from Ekpong *et al*. (2016).

Total sugar, reducing sugar and inulin content: Total sugar contents were determined by the Phenolsulphuric acid method described by Dubois *et al*. (1956). The reducing sugar contents of inulin extract and final formula of JA yoghurt snack were measured by the 3,5-Dinitrosalicylic acid (DNS) method described by Miller (1959). The inulin contents were calculated by the difference between total sugar and reducing sugars.

Sensory evaluation**:** The consumer panel comprised with 30 untrained panelists using 9-point hedonic scale (where 9 = like extremely and 1 = dislike extremely).

Foam density: The density of foam was determined by dividing the mass of the foam by its volume (Falade and Okocha, 2012). The foam was weighted in the 30 ml bottle of known weight. The excess foam on the body of bottle was wiped off. Foam density was calculated by following equation:

$$\text{Foam density (g/ml)} = \frac{\text{Weight of foam (g)}}{\text{Volume of foam (ml)}}$$

Overrun: Overrun was determined according to method of Rajkumar *et al*. (2007). The mixture before whipping and foam after whipping were weighted in the known weight container. Overrun of samples were calculated following equation:

$$\text{Overrun (\%)} = \frac{\text{weight of mixture before whipping (g) - weight of foam after whipping (g)}}{\text{weight of foam after whipping (g)}} \times 100$$

Liquid drainage: Foam stability or liquid drainage was determined applying the method of Boonyawattana (2005). The foam was placed in the funnel and allowed to drain into 25 ml graduated cylinder. The drainage volume was recorded after 2 hours.

Statistical analysis

Completely randomized design (CRD) was used in the experiment for quality determination and the experiment for sensory evaluation was set up as Randomized Completely Block Design (RCBD). Data were analyzed using analysis of variance (ANOVA). Duncan test was applied to determine the difference between mean values at significant level of $p<0.05$. Values of quality attributes were evaluated from three replications and presented as mean $\pm$ standard deviations.

Results

JA inulin extraction

Result showed the values of total soluble solid (TSS), moisture content and evaporation time of inulin extraction at different water ratios that appeared initial TSS of JA inulin extracted samples were ranged between 5.00-9.07 ^{o}Brix (Table 1). Then, all extracted samples were concentrated to approximately 19 ^{o}Brix. The maximum evaporation time was 122.67 minutes in case of 1:30 ratio sample. Moisture contents of all extracted samples were ranged between

82.15-83.96% wet basis. All extracted samples were analyzed for total sugar, reducing sugar and inulin contents as shown in Table 2. It was found that total sugar, reducing sugar and inulin content of 1:20 ratio sample were higher than its counterparts while the minimum values were found at 1:10 ratio sample.

Table 1. The total soluble solid (TSS), moisture content, and time of evaporation of JA inulin extraction at different ratios

JATP: Water Ratio	Initial TSS (^{o}Brix)	Concentrated TSS ^{ns} (^{o}Brix)	Evaporation time (min)	Moisture content (% wb)
1: 10	$9.07^{a1/} \pm 1.01$	19.30 ± 0.14	$61.33^{c} \pm 1.53$	$83.96^{a} \pm 0.13$
1: 20	$6.00^{b} \pm 0.00$	19.27 ± 0.13	$92.67^{b} \pm 2.52$	$82.15^{c} \pm 0.23$
1: 30	$5.00^{b} \pm 0.00$	19.34 ± 0.15	$122.67^{a} \pm 2.52$	$83.18^{d} \pm 0.44$

1/: Different letters in the same column indicates that values are significantly different ($p < 0.05$)
NS: no significant difference ($p \geq 0.05$)

Table 2. The amount of total sugar, reducing sugar and inulin content in JA inulin extract

JATP : Water Ratio	Total sugar content (mg/ml)	Reducing sugar content (mg/ml)	Inulin content (mg/ml)
1:10	$20.46^{b1/} \pm 1.24$	$1.74^{c} \pm 0.01$	$18.71^{b} \pm 1.19$
1:20	$35.19^{a} \pm 0.39$	$2.06^{b} \pm 0.01$	$33.14^{a} \pm 0.39$
1:30	$33.69^{a} \pm 0.35$	$2.24^{a} \pm 0.01$	$31.44^{a} \pm 0.35$

1/: Different letters in the same column indicates that values are significantly different ($p < 0.05$).

Formulation of fruit juice-JA yoghurt mixture

The result of sensory evaluation of yoghurt samples blended with different fruit juice additions found that the yoghurt mixed with 20% passion fruit juice (P) formula had higher scores in terms of color, flavor, sweetness, sourness an overall acceptability than other formulas (Table 3). The sourness of fruit juice such as lemon juice had influenced to the overall acceptability. It was noticed that the overall acceptability scores decreased when lemon juice was added to mixtures probably due to its sourness. The result revealed that the panelists disliked formula L very much in aspect of sourness and dislike slightly in sourness characteristics of formula TL and LP.

Table 3. Sensory evaluation values of yoghurt with various fruit juice addition

Formula	Color	Flavor	Sweetness	Sourness	Overall acceptability
T	6.50$^{bc1/}$±1.17	5.37^{c}±1.43	5.53^{c}±1.10	5.17^{c}±1.34	5.23^{c}±1.25
L	6.77^{abc}±1.48	3.93^{d}±1.84	2.57^{e}±1.50	2.73^{e}±1.36	3.27^{e}±1.60
P	7.03^{ab}±1.59	7.80^{a}±1.10	7.60^{a}±1.37	7.77^{a}±1.19	7.93^{a}±0.98
TL	6.37^{bc}±1.54	4.77^{c}±1.41	3.97^{d}±1.77	4.13^{d}±1.46	4.23^{d}±1.50
TP	6.10^{c}±1.52	6.57^{b}±1.25	6.60^{b}±1.07	6.53^{b}±1.01	6.67^{b}±0.84
LP	7.27^{a}±1.62	5.07^{c}±1.37	3.77^{d}±1.22	4.17^{d}±1.11	4.43^{d}±1.22

1/: Different letters in the same column indicates that values are significantly different ($p< 0.05$).
T = 20% tomato juice, L = 20% lemon juice, P = 20% passion fruit juice, TL = 10% tomato juice + 10% lemon juice, TP = 10% tomato juice + 10% passion fruit juice and LP = 10% lemon juice + 10% passion fruit juice.

The results indicated that P-JA yoghurt mixture with prebiotic syrup got the lower scores in sweetness than other formulas. On the other hand, P-JA yoghurt mixture samples added maltitol and JA syrup had significantly higher scores in flavor, sweetness, sourness and overall acceptability than xylitol and prebiotic syrup formulas. The overall acceptability scores of P-JA yoghurt mixture mixed with maltitol and JA syrup were not significantly different in overall acceptability scores. However the sensorial scores of P-JA yoghurt mixture with JA syrup had higher score than maltitol substitution. A mean linking score of overall acceptability was 7.70, which demonstrated that the panelists like moderately P-JA yoghurt mixture sample.

Table 4. Sensory evaluation values of P-JA yoghurt mixture samples substitued with various sweeteners

Formula	Flavor	Sweetness	Sourness	Overall acceptability
Sucrose (control)	6.57$^{ab1/}$±1.25	6.27^{b}±1.46	6.40^{bc}±1.52	6.33^{b}±1.37
Maltitol	7.13^{a}±0.90	7.10^{a}±1.32	7.10^{a}±1.21	7.30^{a}±1.26
Xylitol	6.13^{bc}±0.90	6.27^{b}±1.17	6.23^{cd}±0.94	6.20^{b}±0.89
Prebiotic syrup	5.80^{c}±1.42	5.20^{c}±1.73	5.70^{d}±1.49	5.53^{c}±1.33
JA syrup	7.03^{a}±1.09	7.33^{a}±1.21	7.27^{a}±1.31	7.70^{a}±1.02

1/: Different letters in the same column indicates that values are significantly different ($p< 0.05$).

Foaming agent concentration selection

The foam properties of P-JA yoghurt mixture sample with JA syrup at different levels of foaming agent addition resulted that the higher content of foaming agent solution (2% methocel and 1.5% carboxyl methtl cellulose) foam density and liquid drainage values (Table 5). Moreover, the foam overrun increased with the increasing amount of foaming agent. The foam density reduced from 0.39 g/ml to 0.30 g/ml while the foam overrun increased from 169.42 % to 257.88 % when adding the foaming agent solution. The use of a foaming agent solution at 50% provided stable foam with lower density, liquid drainage and higher in overrun.

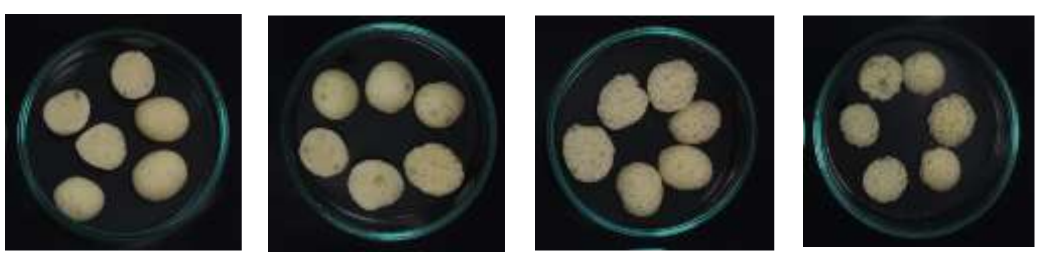
Table 5. Foaming characteristics of P-JA yoghurt mixture sample with JA syrup whipped with different proportions of foaming agent solution

Amount of foaming agent solution (%)	Density (g/ml)	Overrun (%)	Liquid Drainage (g/min)
35	$0.39^{a1/} \pm 0.002$	$169.42^{d} \pm 2.30^{d}$	$0.0050^{d} \pm 0.00^{d}$
40	$0.37^{b} \pm 0.004$	$182.12^{c} \pm 2.28^{c}$	$0.0048^{c} \pm 0.00^{c}$
45	$0.31^{c} \pm 0.002$	$243.33^{b} \pm 1.63^{b}$	$0.0045^{b} \pm 0.00^{b}$
50	$0.30^{d} \pm 0.003$	$257.88^{a} \pm 3.15^{a}$	$0.0042^{a} \pm 0.00^{a}$

1/: Different letters in the same column indicates that values are significantly different ($p < 0.05$).

The whipped foam of P-JA yoghurt mixture using JA syrup as sweetener was dried at 60°C for 2 hours. The photographs of dried JA yoghurt snacks are shown in Figure 1. It demonstrated the porous structure of JA yoghurt snack products. The addition of foaming agent 35% resulted in the small porous distribution inside the foam dried product whereas the larger size of porosity occurred when the increasing amount of foaming agent solutions were applied.

It was found that the dried JA yoghurt snack had low moisture content (5.73 ± 0.08%wb) and water activity (0.39 ± 0.02). The pH of snack was 4.24 ± 0.00. Total sugar content, reducing sugar content and inulin content of dried JA yoghurt snack were 276.22 ± 1.68, 146.44 ± 6.47 and 129.78 ± 5.86 mg/g respectively.



(a) (b) (c) (d)

Figure 1. Dried JA yoghurt snacks whipped from various amounts of foaming agent solution at 35% (a), 40% (b), 45% (c) and 50% (d)

Discussion

JA inulin extraction

The increase of water ratio from 1:10 to 1:30 resulted in the lower initial TSS. The explanation is that amount of JATP was diluted with the increased ratio of water. In agreement with the study of Termrittikul *et al*. (2018), inulin extraction with lower proportion of water showed a higher concentration of solution. The sample with high ratio of water showed long time requirement to adjust TSS of JA inulin extract to final target concentration (approximately 19^{o}Brix). Evaporation is usaully apply to increase the solids concentration by removing amount of water (Heldman and singh, 1981). Thus, higher amount of water in the sample caused the longer time for evaporation.

According to the results, total sugar, reducing sugar and inulin contents in 1:10 ratio sample was lower than those of 1:20 and 1:30. Similar to a study of Gaafar *et al*. (2010), higher proportion of water resulting in the increase of extractable inulin. Termrittikul *et al.* (2018) reported that the increase of solvent proportion enhanced inulin extraction yield. However, 1:30 ratio sample required long time to concentrate JA inulin extract. It is disadvantage for industrial-scale because of the increase in energy use and cost management. Therefore, 1:20 is the suitable and effective ratio of JATP and water for JA inulin extraction.

JA-Yoghurt mixtures formulation

The highest sensorial scores in the terms of flavor, sweetness, sourness and overall acceptance were observed in the mixed yoghurt with 20% passion fruit juice (P) formula. The explanation is that passion fruit contains volatile compounds, especially ester, that provide fruity, floral, and sweet aromas characteristic (Mamede *et al*., 2017). Thus, the unique flavor of passion fruit probably had a positive effect on customer satisfaction and could overwhelm the natural flavor and taste of concentrated JA inulin extract. In contrast, the mixed yoghurt with 20% lemon juice (L) had the lowest score in the terms of sweetness, sourness and overall acceptability. The sensory acceptance scores may relate to the taste of fruit juice. The pH value of 20% lemon juice (L) formula was lower than other formulas, thus excess of sourness affects consumer liking. Furthermore, passion fruit juice yoghurt (P-JA yoghurt mixture) was developed by substitution of sugar with sweeteners to produce a healthy yoghurt snack. It appeared that sugar substitution with JA syrup in P-JA yoghurt mixture leaded to the higher sensorial scores of flavour, sweetness, sourness and overall acceptability scores than those of control (sucrose) and other sweeteners. The average overall acceptability scores of sugar substitution with JA syrup were 7.70, which almost located at the terms “like very much”.

Foaming agent addition

For foam-mat drying, 2% methocel and 1.5% carboxyl methylcellulose were used as foaming agent solution to produce stable foam. Methocel is used as a foaming agent that reduced the interfacial tension and assisted the foam formation (Sangamithra *et al*., 2014). Carboxyl methylcellulose (CMC) is used as a foam stabilizer that enhanced the stability of foam and acted as a viscosity modifier (Sangamithra *et al*., 2014). The combination of methocel and CMC can produce the stable foam by trapping more air bubbles in the foam during the whipping process. Moreover, the hydrophobic groups facilitated the absorption at the interface and the partially unfolding molecules accumulated at the liquid-air interface. The stability of foam resulted from the association of partially unfolding molecule to form the stabilizing film around the bubbles (Mine, 1995; Mounir, 2017). These effects of foaming agents had positive effect to JA-yoghurt mixture foam characteristics. The foam density and liquid drainage decreased significantly with the increasing concentration of the foaming agent, while overrun increased. The explanation is that foaming agent encouraged the formation of strong film and stabilized the interfacial film (Karim and Wai, 1999). In this study, the foam density of JA-yoghurt mixture is in the range of 0.2-0.6 g/ml that is suitable for foam mat drying (Mounir, 2017) because the structure would not collapse during the drying process.

The increase of foaming agents concentrate also resulted in the porous structure in dried JA-yoghurt snack products as shown in Figure 1. Pores were created through moisture movement during the drying process resulting in the porosity structure (Mounir, 2017). It can be seen that dried JA-yoghurt snack product with higher amount of foaming agent solution produced more open pores. In agreement with the report of Ekpong *et al*. (2016), the increase of foaming agent concentrate resulted in the greater stability of foam with more open pores. However, open and large pores may influence consumer acceptance in the term of appearance. Thus, foaming agents with 35% concentration produced stable foam with better appearance.

JA-yoghurt snack had low moisture content, water activity, and pH providing long shlelf life of product as well as safe from microbilogical growth. In addition, this study demonstrated that JA inulin extracted from Jerusalem artichoke tuber powder can be applied in food product development to produce healthy snack, which contains inulin of 129.78 mg/g.

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