EFFECT OF INULIN IN JERUSALEM ARTICHOKE (HELIANTHUS TUBEROSUS L.) FLOUR ON THE VISCOELATIC BEHAVIOR OF COOKIE DOUGH AND QUALITY OF COOKIES

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ABSTRACT
The aim of this research was to investigate the effect of inulin in Jerusalem artichoke on developing a gluten-free bakery product. Jerusalem artichoke flour (JF) was used as a substitute for wheat flour to enhance texture, functional and nutritional properties. The cookie dough with JF showed more elastic behavior due to a higher water holding capacity and fat absorption capacity compared with wheat flour and potato flour. The inulin influenced the properties of flour and also contributed to changes in the properties of the dough and cookies. The cookies made from 100 % JF had 42.67 % inulin. As the addition of JF increased, the dough showed a cohesive structure and the cookies did not expand in either diameter or thickness. Hardness of cookie increased with JF increased. The color and antioxidant activities were improved by JF due to the acceleration of Maillard reaction by inulin during baking.

Keywords: Jerusalem artichoke, inulin, viscoelasticity, cookie development

1. INTRODUCTION

Jerusalem artichoke (*Helianthus tuberosus* L.) tuber is a kind of potato. It stores carbohydrates in the form of inulin instead of starch. Inulin is a non-digestible carbohydrate and present in many vegetables, fruits and cereals (Zahn et al. 2010; Bach et al. 2012; Rinaldoni et al. 2012). Previous studies have reported that inulin has anti-obesity and antioxidant activities (Niness 1999, Lee and Kang 2009). In addition, inulin is used for applications in the food industry and has been used in a variety of food products due to its technological and nutritional benefits (Meyer et al. 2011, Rinaldoni et al. 2012). Several studies have examined the feasibility of inulin as replacement for fat or sugar in dairy and bakery products. Appropriate methods to enhance the texture and sensory properties of cookies using inulin have been reported (Zoulias et al. 2002; Meyer et al. 2011; Rodríguez-García et al. 2012). Generally, gluten possesses a structure-forming ability that contributes to the overall appearance and crumb structure of many baked products. Some studies have reported that adding inulin to more than an optimum level resulted in a hard and brittle texture, mainly due to insufficient expansion after baking (Rodríguez-García et al. 2012).

To develop a gluten-free baking product, a replacement with similar physical characteristics in bakery products must be developed. Thus, the rheological properties of dough and the textural properties of baking products are the most important properties in developing a gluten-free baking product. The rheological properties of dough are generally determined by measuring the viscoelasticity using creep recovery, stress relaxation, and small amplitude oscillatory shear test. Many small strain measurements have been conducted to evaluate the effect of ingredients and the processing conditions on the viscoelastic properties of cookie doughs (Bhattacharya 2010; Šeremešić et al. 2013; Pedersen et al. 2014; Raymundo et al. 2014; Filipčev et al. 2015; Sarabhai and Prabhasankar. 2015; Petrović et al. 2015; Mancebo et al. 2016). However, the small deformation test showed a difficulty to find a relationship between the assessed parameters and the dough properties during processing, so that a large deformation tests are required for understanding the dough properties during processing. The stress relaxation test with a large deformation has been used to characterize the viscoelastic properties of dough (Rodríguez-Sandoval et al. 2009; Bhattacharya 2010). Generally, the stress relaxation data can be analyzed by various models such as Maxwell model (Mohsenin 1970) or Peleg model (Peleg and Normand 1983). A nonlinear three-parameter model was also applied to predict the stress relaxation behavior of chickpea dough (Yadav et al. 2006).
Several studies have investigated gluten-free products made with grain flours (Schober et al. 2003; Ellouze-Ghorbel et al. 2010; Gupta et al. 2011; Zucco et al. 2011; Torbica et al. 2012) other than wheat and have shown an improvement in texture, mouthfeel, flavor, and nutrition. Recently, several functional ingredients such as starches or fibers also have been used for the gluten-free cookie development (Šeremešić et al. 2013; Raymundo et al. 2014; Filipčev et al. 2015; Petrović et al. 2015; Mancebo et al. 2016). Overall analysis has indicated that cookies with acceptable physical characteristics and improved nutritional profiles could be produced with partial or complete replacement of wheat flour (Zucco et al. 2011). Rice flour and buckwheat flour were successfully incorporated into gluten-free, cereal-based products, resulting in cookies

with a pleasant flavor and acceptable sensory qualities (Torbica et al. 2012). In addition, wheat bran and whole barley flour could be used for enriching biscuit fiber content without undesirable changes to their textural and sensory properties (Ellouze-Ghorbel et al. 2010, Gupta et al. 2011).

As previous studies have indicated, Jerusalem artichoke flour (JF) could be a useful replacement for the development of a gluten-free bakery product, especially cookies, but the rheological properties of dough and the quality characteristics of cookies with JF should be investigated. The objectives of this study were to characterize the effect of inulin in JF on the structure formation on cookie dough, and the characteristics compared with dough and cookie containing potato flour (PF). Eventually, the physical and nutritional properties of cookies prepared with PF and JF were evaluated.

2. MATERIALS AND METHODS

2.1. Materials

All ingredients used in cookie production (i.e., wheat flour (WF), unsalted butter, sugar, common salt, sodium bicarbonate and potato (*Solanum tuberosum* L.) flour (PF) were supplied from a local market in Chuncheon, Korea. Jerusalem artichoke (*Helianthus tuberosus* L.) flour (JF) was purchased from the Sangol farm (Hoengseong-gun, Korea). JF and PF with particle sizes below 100 μm were used for making cookies.

2.2. Chemical composition analysis

The chemical characteristics of ash in WF, PF, and JF, were determined according to AOAC (2000) methods. The moisture content was measured with a moisture analyzer (MB45, Ohaus, New Jersey, USA).

Water Holding and Fat Absorption Capacity

The water holding capacity (WHC) was determined using the methods described by Chen et al. (1988) and Tang (2007) with some modifications. The fat absorption capacity (FAC) was measured according to the method of Lin et al. (1974). The WHC and FAC are expressed as g of water and fat per gram of the sample on a dry basis (Tang 2007). Triplicate samples were analyzed for each treatment.

2.3. Preparation of Dough and Cookies

The control cookies were formulated with 220 g WF, 75 g sugar, 75 g salt-free butter, 50 g egg, 2 g sodium bicarbonate, and 0.5 g common salt. The dough was shaped into cylindrical discs with 5 cm diameters and 0.5 cm thicknesses, then baked at 180 °C for 10 min. After cooling for 1 h, the cookies were packed and used for the evaluation of various chemical, textural characteristics. All controls were made with WF only.

2.4. Dough Rheology Measurement

2.4.1. Stress Relaxation test

The level of PF and JF in the dough samples for stress relaxation test was adjusted to 50 % and 100 % flour in dough. Stress relaxation tests were conducted with a texture analyzer (CT3, Brookfield, Raynham, Massachusetts, USA). Dough samples (50 mm in diameter and 40 mm thickness) were prepared with a cylindrical cutter. The sample was compressed by 10 % for the small deformation and 60 % for the large deformation with a cylinder probe (TA25/1000) of 50 mm diameter. The crosshead speed was 3mm/s. This constant compressive strain was applied to the sample for 100 s.

For analyzing the data from the small deformation test, Maxwell model. The generalized Maxwell model with 2 elements was applied.

$$E(t) = E_1 \exp(-t/\lambda_1) + E_2 \exp(-t/\lambda_2) + E_e \quad (1)$$

where E is the spring modulus (s), λ is relaxation time of the Maxwell body and Ee is the lone spring modulus. The viscosity of element i (number of element) can be calculated according to following equation:

$$\eta_i = E_i \lambda_i \quad (2)$$

Peleg model (Peleg and Normand 1983) and a three-parameter nonlinear model (Yadav et al. 2006) were applied to analyze the stress relaxation data from the large deformation (60 %). In the Peleg model (Eqn. 3), the stress relaxation data was described as the stress normalized.

$$(\sigma_0 t)/(\sigma_0 - \sigma(t)) = k_1 + k_2 t \quad (3)$$

The three-parameter nonlinear model (Eqn. 4) proposed by Yadav et al. (2006) was also used to predict the force decay during relaxation.

$$\mathrm{F(t)} = A\exp(-\alpha \mathrm{t}) + F_e \quad (4)$$

where F_e is the residual force at equilibrium, A is equivalent to initial force (F_0) when t is zero. When t is large, $F(t) \rightarrow F_e$. α represents the rate of exponential decay (Yadav et al. 2006, Bhattacharya 2010). The curve fitting tool in Matlab® (The MathWorks, Inc., Natick, Massachusetts, USA) was used for analyzing all the models.

The goodness-of-fit the theoretical models were assessed by calculating and comparting the root mean square error (RMSE) values of the models using Eqn. 5:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_1^n [\text{Experimental value - Model value}]^2}{\text{Degree of freedom}}} \quad (5)$$

2.4.2. Dynamic Oscillatory Measurement

Dynamic oscillatory measurement was conducted with a dynamic rheometer (Discovery HR-3, TA instruments, New Castle, USA). The level of PF and JF in the dough samples for the rheological measurements were adjusted at 25% and 50%, respectively. The dough sample was loaded between the plates and the gap was adjusted to 3 mm. The measurement system consisting of parallel plate geometry (40 mm diameter). Frequency sweeps test was performed from 1 to 10 Hz at a strain 0.02 % to determine the storage modulus (G'), loss modulus (G'') and loss tangent (tan δ) as a function of frequency. The strain level was selected from the linear viscoelastic region (approximately 0.05%) after the stress sweep test (data are not shown). All measurements were conducted at 25 °C. All tests were triplicated.

2.5. Scanning Electron Microscopy (SEM)
The structures of the flour, dough and cookie samples were analyzed by variable pressure field emission scanning electron microscopy (VP-FESEM). The surface of flour, dough and cookies were observed under a SUPRA55V VP-FESEM (SUPRA55V, Carl Zeiss, Jena, Germany) at the Korean Basic Science Institute, Chuncheon. The samples of dough and flours (particle sizes below 100 μm) were dried at room temperature for 24 h and cookies were ground without drying.

2.6. Measurement of Inulin Content
The method used to measure the level of inulin in cookies was appropriately modified based on the spectrophotometric method (Lingyun et al. 2007, Saengkanuk et al. 2011). For the analysis of inulin, all cookie samples were made without sugar. Each sample was pounded and 5.56 g of the sample was extracted with 50 mL of water by sonication for 20 min at 68 °C. The extracted liquid was centrifuged at 4000 g for 20 min to remove suspended particles. The supernatant was diluted before determination. The inulin contents in cookies were calculated using the following equation:

$$\text{Inulin} = k(F_{tot} - F_f) \qquad (6)$$

where k is a correction factor for the glucose portion of the inulin and for the water loss during hydrolysis, F_{tot} is the total fructose content, F_f is the free fructose content. In this study, the k value was 0.995 (Saengkanuk et al. 2011).

2.7. Spread Ratio of Cookies
To measure the physical characteristics of cookies, round-shaped cookies with 5 cm diameters and 0.5 cm thickness were made and baked at 180 °C for 10 min. Cookies were analyzed for diameter (D), thickness (T) and spread ratio (D/T) (Rajiv et al. 2011). The mean of six values is presented.

2.8. Color Measurement
The color of cookie surface was measured using a CIELAB colorimeter system (CM-600d, KONIKA MINOLTA, Tokyo, Japan) for L*, a* and b*, respectively. The mean of 12 values and the standard deviation values were used for further analysis.

2.9. Hardness of Cookies
The hardness of cookies (5 cm diameter and 0.5 cm thickness) made with WF, PF and JF was measured using a texture analyzer (CT3-50 kg, Brookfield, Massachusetts, USA). The measuring devices and conditions were: a load cell of 50 kg, a 6 mm diameter stainless steel cylindrical probe (TA41), the travel distance 5 mm, and the trigger force at 50 g.

2.10. Ferric Reducing Antioxidant Power (FRAP) Activity
According to the method of Benzie and Stranin (1996), samples were prepared using the same method as for measuring the total phenolic compounds. FRAP was measured using a spectrophotometer at 595 nm.

2.11. 1,1-Diphenyl-2-picryl-hydrazyl (DPPH) Scavenging Activity
The DPPH radical scavenging activity of the flours and cookies were measured according to the method of Brand-Williams et al. (1995). The absorbance of the mixture was read at 490 nm (Wootton-Beard et al. 2011) using a spectrophotometer. The DPPH radical scavenging activity was calculated as follows:

$$\begin{aligned}&\text{DPPH scavenging activity (\%)}\\&= \{1 - (\text{Absample} - \text{Abblank})\} \times 100\end{aligned} \qquad (7)$$

where Ab_{sample} is the absorbance of the mixture, and Ab_{blank} is the absorbance of the mixture without a sample.

2.12. Statistical Analysis
All experiments were conducted three times, and mean values are given as results. The significant differences between treatments were evaluated by a one-way ANOVA using MS-Excel 2013.

3. RESULTS

3.1. Physico-chemical Characteristics of Flours
The results of the evaluated physico-chemical characteristics of wheat flour (WF), potato flour (PF), and Jerusalem artichoke flour (JF) are shown in Table 1. The average moisture content of WF was the highest followed by JF and PF. The crude ash content of JF was significantly different from the other flours ($p < 0.05$). The water holding capacity (WHC) and fat absorption capacity (FAC) of JF showed a significantly higher than those of WF and PF ($p < 0.05$).

Table 1: Physico-Chemical Characteristics of Flours

Characteristics	Wheat flour	Potato flour	Jerusalem artichoke flour
Moisture (%)	13.1±0.3^{a}	6.4±0.2^{b}	10.8±0.3^{c}
Crude ash	2.0±0.0^{a}	2.1±0.1^{a}	2.5±0.0^{b}
Water-holding capacity	0.5±0.0^{a}	2.7±0.0^{b}	3.7±0.2^{c}

(g water/g dry weight)			
Fat absorption capacity (g fat/g dry weight)	0.6±0.0^{a}	0.7±0.0^{b}	1.1±0.0^{c}

$^{*a–c}$ Means followed by different superscripts within a raw were significantly different at $p < 0.05$.

3.2. Dough Rheological Analysis

3.2.1. Stress Relaxation-Small Deformation

The generalized Maxwell (GM) model (Eqn. 1) were applied to characterize the stress relaxation behavior of doughs at a small deformation 10 %. The calculated constants for models are presented in Table 2. All of the stress relaxation data at small deformation were suitably fitted with both of models (r^2>0.99). The RMSE values of GM model for cookie doughs ranged 34.1 to 220.6.

In the generalized Maxwell model, the dough of 100 % JF had a larger elastic modulus (E_1, E_2 and E_e) and viscosity (η_1 and η_2) than other doughs. The relaxation time (λ_1 and λ_2) also showed a higher value on the dough with JF.

3.2.2. Stress Relaxation-Large Deformation

Stress relaxation data at a large deformation (60 %) were analyzed by Peleg model (Eqn. 3) and nonlinear three parameter (NT) model (Eqn. 4). The k_1 and k_2 values were calculated from the Peleg model and the A, α and F_e were determined from the NT model (Table 3). The dough samples were suitably fitted with the Peleg model (r^2>0.99), but the NT model was fitted with r^2 ranging from 0.79 to 0.88. The RMSE values of Peleg model and NT model for cookie doughs ranged 10.4 to 17.6 and 0.6-3.9, respectively. In the Peleg model, the constants (i.e., k_1 and k_2) of the control sample were significantly lower than those of other samples. Meanwhile, the doughs of 100 % PF and 100 % JF did not show any significant differences on the k_1 value. In the NT model, the addition PF and JF significantly affected the model parameters, except α value. A value (equivalent to initial force) and F_e significantly increased as the amount of PF and JF increased.

Table 2: Constants calculated for Maxwell Model for describing Stress Relaxation of Doughs

	CON	PF50	PF 100	JF50	JF 100
E_1	31.1 ±1.2^{a}	27.8 ±1.4^{b}	29.6 ±0.4^{c}	43.7 ±3.0^{d}	41.5 ±0.4^{d}
E_2	130.1 ±2.1^{a}	119.7 ±3.1^{b}	140.4 ±1.3^{c}	159.6 ±12.2^{d}	150.6 ±9.2^{d}
λ_1	18.7 ±0.0^{a}	16.3 ±0.7^{b}	12.4 ±0.3^{c}	18.2 ±0.2^{a}	20.9 ±2.5^{a}
λ_2	0.6 ±0.0^{ab}	0.6 ±0.0^{a}	0.5 ±0.0^{b}	0.6 ±0.0^{ac}	0.7 ±0.1^{d}
E_e	11.8 ±1.2^{a}	21.0 ±0.2^{b}	30.8 ±1.7^{c}	42.4 ±4.0^{d}	67.4 ±4.6^{e}
η_1	581.5 ±24.6^{a}	454.5 ±40.6^{b}	366.8 ±3.3^{c}	788.7 ±44.9^{d}	867.5 ±111.1^{d}
η_2	74.3 ±2.6^{a}	67.3 ±2.3^{b}	72.1 ±1.1^{a}	97.3 ±6.6^{d}	105.2 ±16.8^{d}
RSME	34.1	51.4	63.1	71.2	220.6

$^{*a–e}$ Means followed by different superscripts within a raw were significantly different at p <0.05.

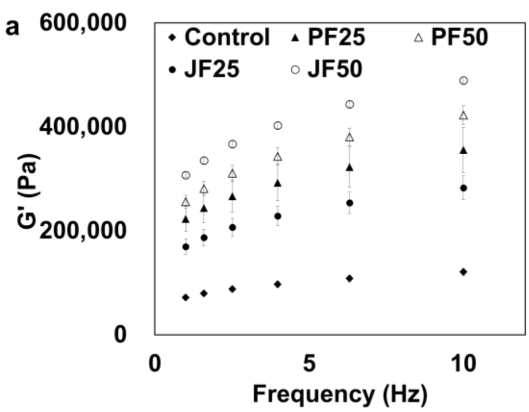
Table 3: Parameters calculated from the Peleg Model (PM) and the Nonlinear Three Parameters model (NT)

		CON	PF50	PF 100	JF50	JF 100
PM	k_1	1.1± 0.1^{a}	1.3± 0.1^{b}	2.0± 0.3^{c}	1.5± 0.0^{d}	2.0± 0.1^{c}
	k_2	1.1± 0.0^{a}	1.1± 0.0^{b}	1.2± 0.0^{c}	1.1± 0.0^{d}	1.2± 0.0^{e}
	RMSE	10.4	10.4	16.1	13.0	17.6
NT	A (N)	8.3± 0.8^{a}	14.2± 0.1^{b}	39.7± 2.9^{c}	26.2± 3.1^{d}	52.7± 5.2^{e}
	α (s^{-1})	0.3± 0.0^{a}	0.2± 0.0^{b}	0.2± 0.0^{c}	0.2± 0.0^{b}	0.2± 0.0^{c}
	F_e (N)	2.4± 0.3^{a}	6.0± 0.3^{b}	19.5± 0.8^{c}	10.8± 1.1^{d}	39.6± 3.1^{e}
	RMSE	0.6	1.0	2.5	1.9	3.9

*a–e Means followed by different superscripts within a raw were significantly different at p <0.05.

3.2.3. Dynamic Oscillatory Measurement

The mechanical spectra from the frequency sweep test on cookie doughs were shown in Fig. 1. The control dough had lower elastic modulus (G') and viscous modulus (G") than other doughs. As the amount of PF and JF in dough increased, elastic (G') and viscous (G") moduli increased significantly. The dough with 50 % JF showed the highest G' and G" values. The tan δ (G"/G') of dough with 50 % PF is higher than other doughs, but there was no difference in tan δ between dough samples at 0 Hz, significantly, except dough with 25 % JF.



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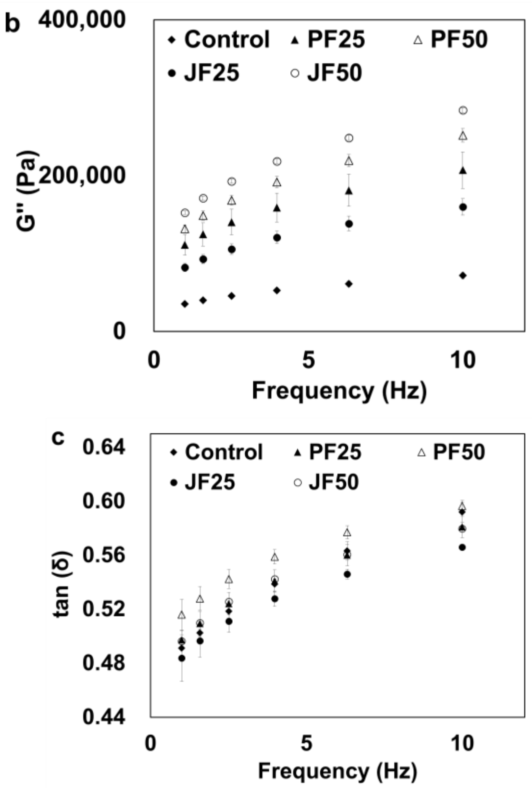

Figure 1: Mechanical Spectra of Dough Containing Different Flours

3.3. Microstructure of Flour, Dough and Cookie

Structural differences between WF, PF, and JF were clearly shown in Fig. 2. WF showed the starch granules with round shape. PF showed the smooth surface. Many small granules were observed in JF. The micrographs of dough and cookies with WF, PF, and JF are presented in Fig. 3. The dough with JF 50 % (Fig. 3c) showed a more cohesive structure than the control (Fig. 3a) and dough with PF 50 % (Fig. 3b). The surfaces of cookie with JF showed the deeper fractures (Fig. 3f).

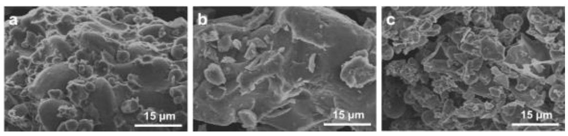

Figure 2: Scanning Elelctron Micrographs of Flours a) WF b) PF c) JF (Magnification: 2,000).

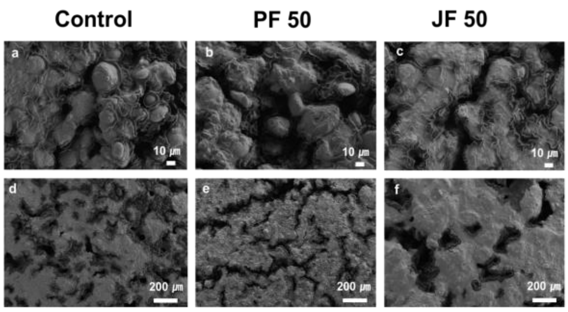

Figure 3: Scanning Electron Micrographs of Surface of Dough (a-c), Surface Fractures of Cookies (d-f). Dough at magnification of 1,500, surface of fractures of cookies at magnification of 200.

3.4. Determination of Inulin Content in Cookies

The inulin content of cookies made with different amounts of JF was measured and calculated using Eqn. (6) (Table 4). The amount of inulin in the control sample was close to 0 %, and as the proportion of JF increased, the amount of inulin in the cookies increased. The inulin content in the cookies made from 100 % JF was 42.7 (±1.7) %.

Table 4: Inulin Content of Cookies

	Content of sugar (dry wt. %)		
	Total fructose (F_{tot})	Free fructose (F_f)	Inulin
CON	$0.0±0.8^a$	$0.3±0.0^a$	$-0.3±0.8^a$
PF50	$3.5±0.8^b$	$0.4±0.0^b$	$3.1±0.7^b$
JF50	$27.8±1.6^d$	$0.4±0.0^d$	$27.3±1.6^d$
JF100	$43.1±1.7^e$	$0.3±0.0^e$	$42.7±1.7^e$

$^{*a–e}$ Means followed by different superscripts within a column were significantly different at $p < 0.05$.

3.5. Spread Ratio of Cookies

The spread ratios were measured by the ratio of the thickness to the diameter of cookies with 100 % WF, 50 and 100 % PF and JF (Table 5). The spread ratio of cookies with 50 % PF was not significantly different from that of the cookies with 100 % JF ($p < 0.05$). Cookies with PF and JF did not expand in either diameter or thickness. However, the spread ratio of cookies with only WF was lower because they expanded in both diameter and thickness.

Table 5: Spread Ratio of Cookies

	Cookie diameter (cm)	Cookie thickness (cm)	Diameter(D) /Thickness(T)
CON	$5.3±0.1^a$	$1.1±0.1^a$	$5.0±0.5^a$
PF50	$5.2±0.1^b$	$1.0±0.1^b$	$5.1±0.6^b$
PF100	$5.0±0.0^c$	$0.8±0.1^c$	$6.1±0.6^c$
JF50	$5.0±0.0^d$	$0.7±0.0^d$	$6.7±0.4^d$
JF100	$5.0±0.1^{cd}$	$0.9±0.1^e$	$5.4±0.4^b$

$^{*a–e}$ Means followed by different superscripts within a column ere significantly different at $p < 0.05$.

3.6. Color Properties

The color on the surface of cookies was measured (Table 6). The images of cookie containing PF and JF are shown in Fig. 4. The lightness value (L*) of cookies prepared with PF and JF decreased compared to the control cookie. As the amount of PF and JF increased, the a* and b* values increased. The a* and b* values showed higher values on the surface of the cookie with 100 % JF. All the color values did not show any significant differences between cookie with 100 % PF and 50 % JF.

Table 6: Color of Cookies made from Potato Flour (PF) and Jerusalem artichoke Flour (JF)

	L^*	a^*	b^*
CON	84.4±1.4^a	1.8±0.6^a	27.1±0.9^a
PF50	73.2±3.2^b	6.8±2.0^b	32.3±2.1^b
PF100	63.0±1.1^c	13.2±0.7^c	38.9±0.4^c
JF50	63.1±4.0^c	13.6±1.5^c	38.8±0.5^c
JF100	57.7±3.2^d	15.1±0.9^d	39.1±1.0^c

*a–d Means followed by different superscripts within a column were significantly different at p <0.05.

Figure 4: Cookies made from Wheat Flour (WF), Potato Flour (PF) and Jerusalem artichoke Flour (JF).

3.7. Texture Property of Cookies

The effect of the addition of JF on the hardness of cookie was measured (Table 7). As the amount of JF increased, the hardness of the cookie was increased. Between cookies with PF had no significant difference (p<0.05).

3.8. Nutritional Properties of Flours and Cookies

Antioxidant activities in flours and cookies are shown in Table 7, respectively. DPPH radical scavenging activity and FRAP activity were used to evaluate the antioxidant activities of samples. Both DPPH and FRAP in samples with JF were significantly higher than for other flours. The antioxidant activities of cookies were lower than those of flours because other mixed ingredients, such as egg, butter, and sugar, have low antioxidant levels. The cookies with JF showed higher antioxidant activities than those with PF.

Table 7: Hardness of Cookies and Antioxidant Activities of Flour and Cookies

		Hardness (g)	DPPH radical scavenging activity (%)	FRAP activity (O.D. 595 nm)
Flour	WF	-	20.8 ± 1.7^a	0.1 ± 0.0^a
	PF	-	52.9 ± 2.2^b	0.1 ± 0.0^b
	JF	-	58.1 ± 1.3^c	0.1 ± 0.0^c
Cookie	CON	6204.2 ± 970.7^a	13.3 ± 2.4^d	0.1 ± 0.0^a
	PF50	3072.5 ± 348.1^b	35.9 ± 0.8^e	0.1 ± 0.0^b
	PF100	3338.3 ± 265.2^b	-	-
	JF50	7720.0 ± 330.0^c	51.1 ± 1.9^b	0.1 ± 0.0^d
	JF100	13574.2 ± 495.6^d	55.4 ± 1.7^c	0.1 ± 0.0^c

*a–d Means followed by different superscripts within a column were significantly different at p <0.05.

4. DISCUSSION

4.1. Flour Properties

The crude ash content of JF was higher than other flours because the major component of JF is inulin, a non-digestible carbohydrate (Rinaldoni et al. 2012). The WHC and FAC of flours are highly related to the compositions of flours. According to Raymundo et al. (2014), the amount of water-uptake increased as the level of fibers in flour increased. Generally, a large number of hydroxyl groups existing in the fiber structure allows more water interactions through hydrogen bonding (Ellouze-Ghorbel et al. 2010). In addition, the binding of oils depends on the surface availability of hydrophobic amino acids and other non-polar side chains of dietary fiber components (Benítez et al. 2013). This demonstrates that JF might be a good natural ingredient for cookies due to its high content of inulin (Zahn et al. 2010, Aravind et al. 2012).

4.2. Effect of JF on the Rheological Behavior of Dough

The rheological behaviors of dough samples were interpreted using the viscoelastic models. In the stress relaxation test at small deformation, the constants estimated from the generalized Maxwell model showed that elasticity and the viscosity of doughs were significantly different from the amount of PF and JF in doughs. The relaxation time (λ_1 and λ_2) of dough indicating the flexibility of dough is the useful parameter to determine how well the dough are applied to the processing. At a higher value of the relaxation time, the dough requires more time to reach to a new equilibrium status and it would be an inappropriate for dough handlings such as flattering and sheeting with a fast processing time (Bhattacharya 2010). The first term of the relaxation time (λ_1) showed no significant difference from that of the control dough. This implies that the addition of JF could be appropriate for the dough processing with slight modification of processing time.

The results from the stress relaxation test at large deformation were in accordance with those at small deformation. In the Peleg model, a high k_1 value shows a noticeable elastic behavior. The k_2 value indicates the degree of solidity and it varies from 1, for an ideal liquid, to infinity, for an ideal elastic solid where the stress does not relax at all (Peleg and Normand 1983, Fu et al. 2014). Thus, the dough with JF had more elastic characters than other doughs. In the NT model, the A value indicates the force at the beginning of relaxation test. Hence, the high A value requires a high resistive force which may not be a desirable condition for dough processing. Since the A values of dough with JF were higher than those of others, the processing ability such as flattering or sheeting of the dough with

JF was lower. The exponential decay (α) indicates the rate of decaying from the initial force to the residual force. The α values became lower as the amount of PF and JF in dough increased. Based on the model parameters, addition of JF appears to be less workable than the control.

The viscoelastic properties of dough have been studied using Maxwell or the Peleg model based on the stress relaxation data. Rodríguez-Sandoval et al. (2009) characterized the stress relaxation behavior of cassava dough with a model included two Maxwell elements with a residual spring in parallel and Peleg model. The dough properties were compared by the cooking time and methods, and the storage temperature. Bhattacharya (2010) also used both models to explain viscoelastic behavior of moth bean flour dough. The author performed the stress relaxation tests at low and large deformation and the 4 elements Maxwell model was chosen based on the r^2 value. In this study, Peleg model was less suitable to describe the rheological behavior of doughs affected by different moisture contents. The NT model proposed by Yadav et al. (2006) suitably described the effect of the moisture content in dough within 27 to 39 % on the rheological properties of dough. Bhattacharya (2010) also used the NT model to interpret the handling characteristics of moth bean flour dough with varied moisture contents in the range of 28 to 34 % and 40 to 46 %. The NT model was more suitable to describe the rheological behavior of doughs with high level of moisture content (Yadav et al. 2006, Bhattacharya 2010). The NT model parameters were sensitive particularly at low moisture content (25%) and higher strain level (75%). In our study, most of models suitably described the rheological behavior of doughs, but the NT model was not appropriate (r^2=0.79-0.88) than other models. This may because our dough samples had a low level of moisture content (below 17 %).

Addition of JF into the cookie dough significantly influenced the dynamic rheological properties of the dough. According to the mechanical spectra, G' was higher than G" (tan δ<1) in the applied frequency range indicating solid elastic like behavior for all dough samples (Šeremešić et al. 2013; Sarabhai and Prabhasankar 2015). Both PF and JF increased the elastic properties, but adding JF more increased the elastic characters of dough. The inulin in JF might enhance to form network structures on cookie dough and increased the elasticity of dough. It implies that addition of JF may have a limitation to add in the dough although JF gives many benefits to the products. Recent studies on dough proposed the JF as a replacement of wheat flour because it influenced significantly the thermo-mechanical properties of dough. Addition of JF influenced positively the rheological properties of dough, bringing about its strengthening in concentration up to 10% of total amount of flour (Gedrovica and Karklina 2011).

The inulin in JF dramatically increased the water absorption properties of the cookie dough. High water absorption properties increased the elastic behavior of dough (Petrović et al. 2015). This is in agreement with the high G' values observed from the dough with JF. Similarly, Raymundo et al. (2014) reported that the G' values of biscuit dough increased by adding the Psyllium flour as fiber abundant ingredient. The higher fiber content of Psyllium flour related to increasing G' values of the dough because of its strong water absorption ability, the possibility of establishment of interactions between other ingredients. Moreover, the structure of flour granules affects the dough characteristics. As shown in Fig. 3, the small granules aggregated in the dough with JF dough showed more complex structures which gives more possibility to interact with other ingredients. According to Schiedt et al. (2013), the interaction between starch and proteins in the dough increases the elastic nature of the dough. The small granules of JF observed in the microscopic image provides a visual evidence that the elastic behavior of the dough increased with the addition of JF.

Consequently, low deformation experiments can generate data to understand the behavior of dough and the aspects of structural features and large strain non-linear deformation data are suitable for practical aspects of cookie dough handling (Bhattacharya 2010).

4.3. Effect of JF on the Physical Properties of Cookie

A high content of inulin in cookies made from JF implies that the physical properties, such as structure, color, and texture, of dough and cookies with JF. Many studies have showed that the physical properties of cookies with inulin were very different from those of cookies with WF only. Inulin has been used as a replacement for sugar or fat in bakery products (Zoulias et al. 2002, Zahn et al. 2010). According to previous studies, the addition of inulin to baked goods plays an important role in the overall appearance and crumb structure of baked products by replacing wheat, sugar, and fat. In our study, the inulin in JF influenced the cookie hardness by forming a firm structure. Several studies on the effect of inulin on the physical and sensory properties of baked products have shown that those baked products that included inulin had hard and brittle characteristics (Zoulias et al. 2002; Zahn et al. 2010; Morris and Morris 2012). This is because the baked product, with a low concentration of gluten, was not able to expand properly after baking (Rodríguez-García et al. 2012). Other researchers have observed that inulin or fiber-based fat replacers increased crumb firmness (hardness) in muffins (Zahn et al. 2010).

The high WHC and FAC of JF, mainly due to the inulin in JF, highly influenced the micro structure of dough samples. The structure differences caused by inulin have been applied in the formation of new structures to replace fat or sugar in baked products (Zoulias et al. 2002, Zahn et al. 2010). As the gluten content decreased, the structure became cohesive, and eventually, some part of structure became cracked (Fig. 3f). Rosell et al. (2009) studied the structure of inulin and found that inulin is composed of granular particles with numerous

aggregates with modular shapes. Our results demonstrated that the addition of JF changed the internal structure of cookies to more compact (Fig. 3) and consequently the surface of cookies became more fractured (Fig. 4).
The spread ratios indicate the spread ability of dough during baking. It might be due to the changes in the use of free water in the cookie dough. Generally, adding an ingredient having higher water retention properties into wheat dough results in aggregates with increased competitive capacity for the limited free water present in cookie dough. Rapid partitioning of free water to these hydrophilic sites, occurring during dough mixing, results in a decreased solution of sugar, increased concentration of the solution and greater internal dough viscosity (Hooda and Jood 2005, Rajiv et al. 2011). Such partitioning of free water due to an ingredient having a high WHC would limit gluten and starch hydration during mixing and baking, resulting in a less developed structure. Thus, adding JF or PF, which have higher WHC, holds more free water than dough made with only WF, consequently lowering the spread ability of cookie dough during baking. A similar behavior was found in the sponge cake process, where the height of a sponge cake with inulin was lower than one without inulin (Rodríguez-García et al. 2012). Moreover, the amount of free water in the dough was reduced by adding JF, so that it caused an insufficient hydration of proteins and their conversion into a suitiably developed gluten network. Thus, the protein matrix interacted with the starch granules may not be changed during cooking (Raymundo et al. 2014).

4.4. Effect of JF on the Cookie Characteristics by Marillard reaction

The formation of color and flavor in the crust of all bakery products during baking is the result of the Maillard reaction of caramelization. The Maillard reaction involves condensation of amino groups and reducing sugars that result in the formation of intermediate chemical compounds that ultimately polymerize to form brown pigments (Isleroglu et al. 2012).
The level of inulin in cookies with JF might accelerate the chemical reactions involved in the surface color of cookies. The surface color of cookies is an important quality associated with flavor, texture, and appearance characteristics that are important to consumers and is often used as an indicator of baking completion. During baking, the fructan chains of inulin in JF were degraded, leading to the formation of new low-molecular weight products on the crusty surface, and eventually, the Maillard reaction of the crust of baked goods could be accelerated (Poinot et al. 2010). Similar results have been reported by Sharma and Gujral (2014) where a slight increase in non-enzymatic browning upon baking was observed as the proportion of barley flour increased. In our study, the changes in color and degree of browning showed a positive influence from the addition of JF and demonstrated that JF can be used to improve the consumer acceptance of flavor and color.
The high antioxidant activities in samples with JF might be associated with a higher degree Maillard reaction due to the inulin. Many previous studies have had similar results. Bressa et al. (1996) reported that antioxidant activities in butter cookies could be increased by producing a brown compound using the Maillard reaction. According to Zeng et al. (2011), as heating time increased, DPPH radical scavenging increased because of the Maillard reaction with fructose in psicose-lysine and fructose-lysine model systems. Vhangani and Wyk (2013) also showed that the antioxidant activity associated with the Maillard reaction in the fructose-lysine model based on DPPH radical scavenging activity was increased with an increase in the reaction temperature and time. The antioxidant activities of cookies with JF were higher than those of the control cookies with only WF due to inulin in JF and to the degree of the Maillard reaction during baking. These results demonstrated that the addition of JF could enhance the nutritional characters of cookies.

5. CONCLUSIONS

Jerusalem artichoke flour (JF) presented better physico-chemical characteristics, adequate texture properties of dough and cookies and improved nutritional properties in compared with potato flour (PF). Notably, the inulin content in the cookies made from 100 % JF was 42.7 (±1.7) %. Increasing the amount of JF in the dough enhanced the elastic properties of cookie dough. The inulin in JF mainly contributed to change the internal structures, and the structural changes due to the inulin were reflected in the stress relaxation and dynamic oscillatory data. The increase of water holding capacity and fat absorption capacity associated with the inulin in JF directly related to the rheological properties of dough. The cookies with JF showed the highest values of hardness. This might be due to the firm structure in the baked products associated with the inulin in JF. The internal structure, illustrated by the micrographs, showed the cohesive structure of dough and cookies with JF. JF also affects the appearance of the product and chemical changes. The cookies with JF had a suitable surface color. The Maillard reaction due to inulin content caused changes in the surface color of cookies. In addition, the antioxidant activities of cookies with JF were higher than those of the controls (with only WF) due to the inulin in JF being highly related to the degree of Maillard reaction during baking. Such comprehensive research can be used to develop cookies with JF for improved consumer acceptance of texture, flavor and color.

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