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Rheological Properties of Dandelion Root Concentrates by Extraction Solvents

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Abstract This study was performed to provide basic rheological data of dandelion root concentrates in order to predict their processing aptitude and usefulness as functional foods material. The hot water and 70% ethanol extracts of dandelion root were concentrated at 5, 20, and 50 Brix, and their static viscosity, dynamic viscosity, and Arrhenius plots were investigated. Almost all hot water concentrates showed the typical flow properties of a pseudoplastic fluid, but evaluation using the power law model indicated that the 70% ethanol concentrates showed a flow behavior close to a Newtonian fluid. The apparent viscosity of hot water and 70% ethanol concentrates decreased with increasing temperature. Yield stresses of hot water and 70% ethanol concentrates by Herschel-Bulkley model application were in the range of 0.026 - 1.368 Pa and 0.022 - 0.238 Pa, respectively. The effect of temperature and concentration on the apparent viscosity was examined by Arrhenius equation. The activation energies of hot water and 70% ethanol concentrates were in the range of 8.762 - 23.778 $\times 10^3$ J/mol·kg and 3.217-20.384$\times 10^3$ J/mol·kg with increasing concentration, respectively. Storage (G') and loss (G") moduli were generally increased with increasing frequency. For the 70% ethanol concentrates, G" predominated over G' at all applied frequencies and so they showed the typical flow behavior of a low molecular solution. However, for the hot water concentrates, G' predominated over G" at more than 1.9 rad/sec (cross-over point) and so they showed the typical flow behavior of a macromolecular solution.

Keywords: dandelion root concentrates, rheological properties, static viscosity, dynamic viscosity, Arrhenius plotting

Introduction

The dandelion (*Taraxacum*) has been widely used as a remedy in traditional oriental medicine for its choleretic, diuretic, anti-rheumatic, anti-viral, and anti-inflammatory properties (1-2). It has been assumed that the therapeutic components of dandelion are composed of bitter taste substances. The major physiologically active substances of dandelion are sesquiterpene, lactones, taraxacoside, triterpenes, phytosterols, phenolic acid, and flavonoid (3-5).

Dried dandelion leaf and root are sold as a herbal tea and the powdered root is sold in capsule form and as a coffee substitute (6). Several reports have shown that dandelion induces cytotoxicity through TNF-α and IL-1α secretion in Hep G2 cells (7). Further studies have reported the antioxidative activity such as reactive radical and nitric oxide scavenging activity of dandelion (*Taraxacum officinale*) flower extract *in vitro* (8), the changes of hepatic antioxidant enzyme activities and lipid profile in streptozotocin-induced diabetic rats by supplementation of dandelion water extract (9), the growth promotion effect of some bifidobacteria with *Taraxacum officinale* root (10), and the optimum extraction condition for supercritical fluid extraction of dandelion leaves (11). Nevertheless, the basic rheological properties of dandelion root extract and concentrate required to confirm the processing and development of products have not yet been reported.

Recently, there has been increasing demand for dandelion leaf and root as an ingredient in foodstuffs, food additives and functional food materials. The aim of this study was to provide basic data on the rheological properties of dandelion root concentrates in order to predict the processing aptitude and usefulness of dandelion root as a foodstuff ingredient and functional food materials. Therefore, we investigated the static viscosity, dynamic viscosity and Arrhenius plot of dandelion root concentrates by extraction solvent.

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Materials and methods

Materials Fresh dandelion root harvested at Gyeongbuk in 2003 was supplied by Miju-food (Gyeongbuk, Korea). The fresh dandelion roots were washed with tap water and dried at 40±5°C.

Roasting and grinding Two types of sample were prepared. One was only dried dandelion root, while the other was roasted dandelion root. The dried dandelion root was roasted to develop good flavor and desirable organoleptic characteristics by a rotary roaster (Probat Co., Germany) at 210°C for 1 min. The dried and roasted roots were ground to 20-30 mesh in a grinder (IKA M 20, IKA, Germany).

Preparation of dandelion root concentrates by extraction solvent Dried and roasted dandelion roots (750 g) were refluxed with 20 volumes (v/w) of distilled water (100°C) and 70% ethanol (80°C) for 3hr. The extraction was repeated three times. The extract solution was centrifuged at 10,000×g for 30 min. A portion of the supernatant was filtered by filter paper (Whatman No. 2) and concentrated at 5, 20 (dried and roasted) and 50 Brix with a vacuum evaporator at 40°C.

Measurement of rheological parameters The static viscosity and dynamic viscosity were measured with a controlled-stress rheometer (Carri-Med CSL 100, TA Instruments, New Castle, DE, USA) at 5, 25, and 45°C using a cone-plate system (2°, 4 cm diameter, zero gap 500 μm). In order to describe the variation in the rheological properties of dandelion root concentrates under static viscosity, the data were fitted to the well-known power-law (Eq. 1) (12) and Herschel-Bulkley (Eq. 2) (13) models.

$$\tau = K \cdot \dot{\gamma}^n \quad (1)$$

$$\tau = C + K \cdot \dot{\gamma}^n \quad (2)$$

τ : shear stress (Pa)
$\dot{\gamma}$: shear rate (1/s)
K : consistency index (Pa·s^n)
n : flow behavior index (dimensionless)
C : yield stress (Pa)

The effects of concentration and temperature on the apparent viscosity of dandelion root concentrates were analyzed by Arrhenius equations 3 and 4 (14, 15), respectively.

$$\eta_{app} = \eta_{\infty} \cdot \exp(B \cdot A) \quad (3)$$

$$\eta_{app} = \eta_{\infty} \cdot \exp(E_a/(RT)) \quad (4)$$

η_{app} : apparent viscosity (Pa·s)
η_{∞} : infinite apparent viscosity (Pa·s)
B : concentration dependency constant (dimensionless)
A : concentration (Brix)
E_a : activation energy for flow (J/mol·kg)
R : gas constant (J/K·mol·kg)
T : absolute temperature (K)

Dynamic viscosity was measured over the range of 0.1-10 Hz. The linear viscoelastic region was determined for each sample from stress sweeps at 5 Hz. Carri-Med data analysis software (version DATA V1.2.2.) was used to obtain the experimental data, storage modulus (G') and loss modulus (G"). The reported results are the average of the experiments conducted in triplicate.

Results and Discussion

Approximate composition of raw dandelion root The moisture content of raw dandelion was 88.2% (16). The composition of the dried dandelion root was 11.80% crude protein, 1.73% crude fat, 4.82% crude ash and 73.92% carbohydrate (17).

Static viscosity properties The shear stresses of hot-water and 70% ethanol concentrates at 25°C were measured by the change of the shear rate from 0 to 1500 1/s (Fig. 1). Figure 1 shows that the flow behavior of dandelion root concentrates at 25°C showed a similar tendency to that at 5 and 45°C. The shear stress of hot-water concentrate at 50 Brix increased non-linearly with increasing shear rate, but that of 70% ethanol concentrate

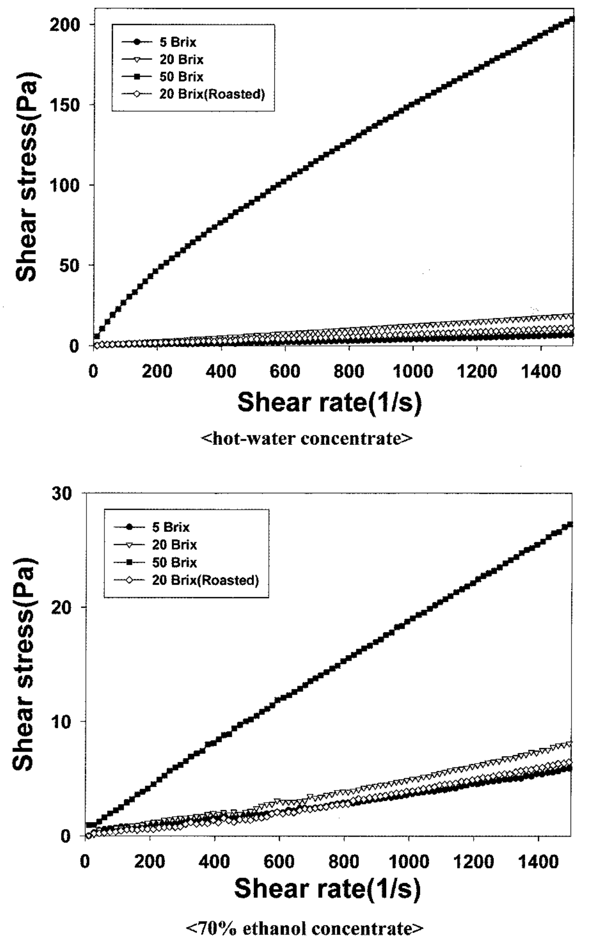

Fig. 1. Shear stress vs. shear rate plot of dandelion root concentrates by extraction solvents at 25°C.

at 50 Brix increased linearly. The shear stresses of hot-water and 70 % ethanol concentrates increased with increasing soluble solid content. On the other hand, the shear stresses of roasted hot-water and 70% ethanol concentrates at 20 Brix increased linearly with increasing shear rate.

Table 1 shows the application of power law and Herschel-Bulkley models to the rheological parameters of hot-water and 70% ethanol concentrates of dandelion root. Almost all hot water concentrates showed the typical flow properties of a pseudoplastic fluid (n = 0.733 - 1.043), but evaluation using the power law model indicated that the flow behaviors of 70% ethanol concentrates were close to a Newtonian fluid (n = 0.826 - 1.046). The consistency index (K) decreased with increasing temperature at constant concentration but it increased with increasing concentration at constant temperature. The flow properties of dandelion root concentrates were similar to those observed in common commercial fluid foods. Yield stresses of hot water and 70% ethanol concentrates by Herschel-Bulkley model evaluation were in the range of 0.026 - 1.368 Pa and 0.022 - 0.238 Pa, respectively.

In the case of roasted dandelion root concentrates, the flow behaviors of all hot water and 70% ethanol concentrates were close to those of a Newtonian fluid (n = 1.001-

Table 1. Rheological parameters of dandelion root concentrates by extraction solvents

Extraction solvents	Conc. (Brix)	Temp. (°C)	Power law model			Herschel-Bulkley model			
			n (-)	K (Pa·s^n)	R^{2} [1)]	n (-)	K (Pa·s^n)	C (Pa)	R^{2} [1)]
Hot water	5	5	0.965	0.006	0.96	1.159	0.002	0.036	0.95
		25	1.043	0.003	0.93	1.259	0.001	0.026	0.99
		45	1.026	0.003	0.97	1.298	0.000	0.033	0.98
	20	5	0.850	0.096	0.96	0.931	0.019	0.445	0.95
		25	0.872	0.077	0.98	1.037	0.016	0.418	0.99
		45	0.877	0.013	0.98	1.029	0.003	0.346	0.99
	50	5	0.733	2.105	0.99	0.741	2.042	1.368	0.99
		25	0.745	1.022	0.99	0.745	0.872	1.072	0.99
		45	0.790	0.431	0.99	0.802	0.670	0.500	0.99
	20 (roasted)	5	1.001	0.013	0.99	1.005	0.013	0.351	0.99
		25	1.018	0.013	0.99	1.048	0.010	0.306	0.99
		45	1.021	0.009	0.97	1.070	0.005	0.048	0.99
Ethanol, 70%	5	5	1.023	0.002	0.96	1.165	0.001	0.034	0.94
		25	1.029	0.002	0.98	1.222	0.001	0.022	0.98
		45	1.046	0.002	0.96	1.344	0.001	0.003	0.98
	20	5	0.946	0.007	0.98	1.076	0.005	0.040	0.98
		25	0.996	0.005	0.97	1.141	0.001	0.049	0.98
		45	1.005	0.005	0.92	1.181	0.001	0.024	0.99
	50	5	0.826	0.087	0.99	0.942	0.013	0.173	0.99
		25	0.832	0.059	0.99	0.949	0.012	0.238	0.99
		45	0.881	0.025	0.99	0.977	0.014	0.231	0.99
	20 (roasted)	5	1.017	0.004	0.94	1.084	0.004	0.115	0.98
		25	1.055	0.004	0.98	1.198	0.004	0.049	0.98
		45	1.175	0.002	0.98	1.213	0.003	0.047	0.98

[1)]correlation coefficient.

1.175) by power law model evaluation. Namely, the macromolecular substances in dandelion root were thermally degraded to low molecular materials by roasting treatment at high temperature. Hence, the viscosity of roasted dandelion root concentrate was lower than that of dried dandelion root concentrate of the same 20 Brix. The rheological properties of roasted dandelion root concentrates indicated that the flow property at 20 Brix did not show a similar tendency to that measured for dried dandelion root hot water and 70% ethanol concentrates at 20 Brix.

The much higher K and C values observed in the hot-water concentrates probably arose from the higher amount of viscous macromolecules (starch, pectin, and protein, etc.) extracted from dandelion roots, according to the results of Yoo *et al.* (18) and Lee *et al.* (19). Therefore, it seems that the rheological properties of dandelion root concentrates are influenced by the composition and content of macromolecules in the dandelion extracts prepared by extraction solvents.

Effect of temperature on apparent viscosity The effect of temperature on the apparent viscosity of hot-water and 70% ethanol concentrates was described by the plot of ln η_{app} vs. 1/T in Fig. 2. Table 2 shows the values of η_∞ and E_a in the Arrhenius equation, $\eta_{app} = \eta_\infty \cdot \exp(E_a/RT)$. The activation energies of hot water and 70% ethanol concentrates were in the range of $8.762 - 23.778\times10^3$ J/mol·kg and $3.217 - 20.384\times10^3$ J/mol·kg with increasing concentration, respectively. However, the η_∞ values of hot water and 70% ethanol concentrates were in the range of $1.220 - 0.162\times10^{-4}$ Pa·s and $9.350 - 0.049\times10^{-4}$ Pa·s with increasing concentration, respectively. For the hot-water concentrate, this result was due to the decreased interacting attraction between macromolecules, which have a strong attraction with each other, as their structure becomes loosened with increasing temperature. This result agreed with the study results of mustard suspensions (20) and the rheological properties of ginseng extract (21). This similarity in results probably resulted from the high dependence of molecular binding, and of solvent and solute binding, on high concentration.

Effect of concentration on apparent viscosity The

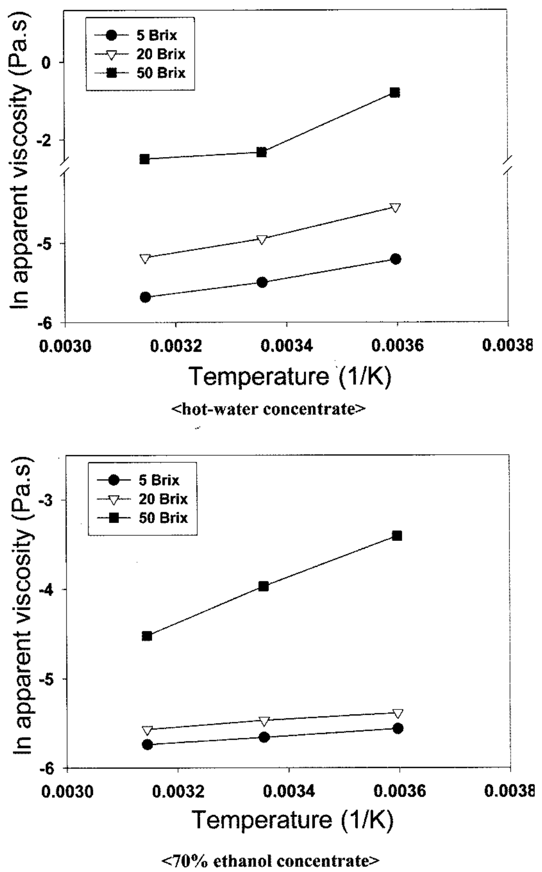

Fig. 2. Effect of temperature on apparent viscosity of dandelion root concentrates by extraction solvents at 1000 1/s.

effect of concentration on the apparent viscosity of the concentrates was described by the plot of ln η_{app} vs. concentrations at 1000 1/s shear rate, as shown in Fig. 3. The η_∞ value tended to decrease overall as temperature increased from 5 to 45°C. The effects at all temperatures and concentrations were described by the Arrhenius equation, $\eta_{app} = \eta_\infty \cdot \exp(B \cdot A)$, and are shown in Table 3. The B values of hot-water and 70% ethanol concentrates were in the range of 0.1067 - 0.0884 and 0.0504 - 0.0282 with increasing temperature, respectively. On the other hand, the η_∞ values of hot water and 70% ethanol concentrates were in the range of 0.002204 - 0.001574 Pa·s and 0.002366 - 0.002529 Pa·s with increasing temperature, respectively.

Dynamic viscosity properties Most macromolecular solutions exhibit a rheological response which demonstrates both solid-like and liquid-like characteristics (viscoelastic materials). The measurement of the viscoelastic behavior of macromolecular solutions is important in understanding and predicting the texture, the flow properties during processing, the shelf-life determination and the other quality attributes of macromolecule-based products (22).

Figure 4 shows the changes in storage (G') and loss (G") moduli as a function of frequency (ω) for hot water and 70% ethanol concentrates of 50 Brix at 25°C. The result at 25°C showed a similar tendency to the results measured at 5 and 45°C. Storage (G') and loss (G") moduli were generally increased with increasing frequency. For the 70% ethanol concentrates, G" predominated over G' at all applied frequencies and so they showed the typical flow

Table 2. Effect of temperature on apparent viscosity of dandelion root concentrates by extraction solvents at 1000 1/s

Extraction solvents	Conc. (Brix)	Temp. (K)	η_{app} (Pa·s)	E_a ($\times 10^3$ J/mol·kg)	η_∞ ($\times 10^{-4}$Pa·s)	r[1)]
Hot water		278	0.005482			
	5	298	0.004094	8.762	1.220	0.99
		318	0.003642			
		278	0.010563			
	20	298	0.007106	11.639	0.673	0.99
		318	0.005620			
		278	0.551507			
	50	298	0.175117	23.778	0.162	0.85
		318	0.154392			
Ethanol, 70%		278	0.003840			
	5	298	0.003486	3.217	9.530	0.99
		318	0.003223			
		278	0.004658			
	20	298	0.004218	3.350	10.803	0.99
		318	0.003816			
		278	0.033071			
	50	298	0.018670	20.384	0.049	0.99
		318	0.010890			

[1)]correlation coefficient.

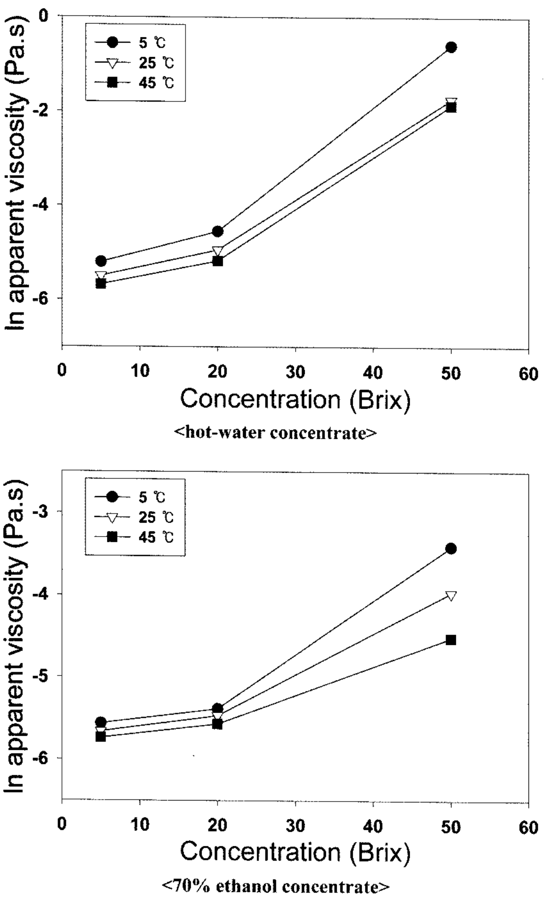

Fig. 3. Effect of concentration on apparent viscosity of dandelion root concentrates by extraction solvents at 1000 1/s.

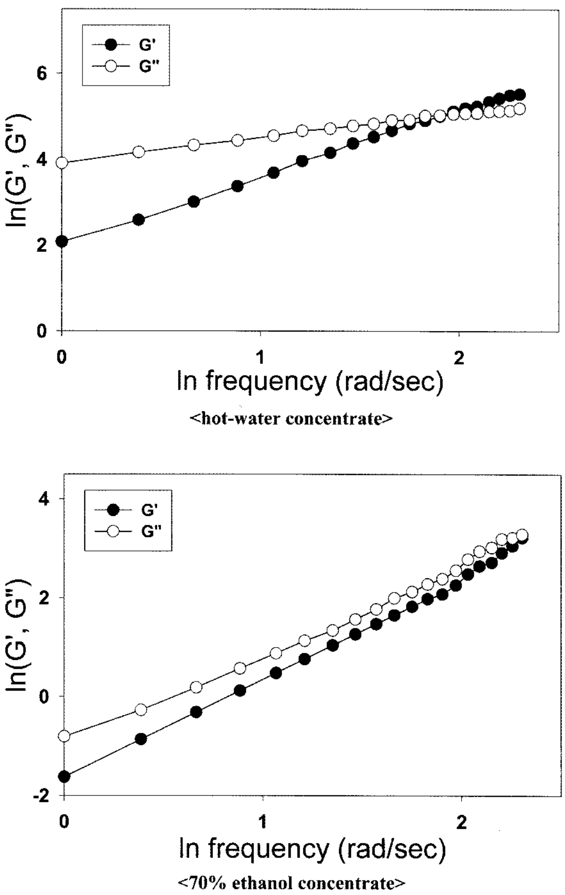

Fig. 4. Ln (G', G") vs. ln frequency (rad/sec) plot of dandelion root concentrates of 50 Brix by extraction solvents at 25°C.

Table 3. Values of η_∞ and B of the dandelion root concentrates by extraction solvents at 1000 1/s

Extraction solvents	Temp. (°C)	Conc. (Brix)	B	η_∞ (Pa·s)	r[1)]
	5	5-50	0.1067	0.002204	0.96
Hot water	25	5-50	0.0868	0.001964	0.96
	45	5-50	0.0884	0.001574	0.96
	5	5-50	0.0504	0.002366	0.93
Ethanol, 70%	25	5-50	0.0393	0.002442	0.95
	45	5-50	0.0282	0.002529	0.96

1) correlation coefficient.

behavior of a low molecular solution. However, for the hot water concentrates, G' predominated over G" at more than 1.9 rad/sec (cross-over point) and so they showed the typical flow behavior of a macromolecular solution.

This result agreed with the study results on the dynamic viscosity of ginseng extract (21). In general, at low frequencies, the flow behavior is controlled by the translational motion of the macromolecules, and G" is usually higher than G'. At higher frequencies, however, the increase of G' value is due to macromolecular distortion and it is close to or higher than that of G".

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