Assessment of Functional Food Dioscorea Japonica Paste As A Thickened Liquid For Elderly With Dysphagia

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Research Article

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Assessment of functional food *Dioscorea japonica* paste as a thickened liquid for elderly with dysphagia

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Abstract

Background: In the elderly, reduced mastication and swallowing functions result in malnutrition and deterioration in the quality of life. As individuals age in the society, the novel concept of dysphagia diet is essential in order to prevent lifestyle and chronic diseases and maintain nutrition intake. Recently, we reported that *Dioscorea japonica*, a wild yam, has preventive effects on chronic inflammation via the inhibition of proinflammatory lipid mediator synthesis. The paste of *Dioscorea japonica* showed conformable physical properties as a thickened liquid for patients with dysphagia in rheological analysis. In the present study, we focused on the unique physical properties of *Dioscorea japonica* paste and evaluated its stability and usefulness as a thickened liquid compared with commercially available thickened liquids.

Methods: The paste prepared using a uniformly freeze-dried *Dioscorea japonica* powder could suitably modify the viscosity by altering the blending amount. Viscosities of the *Dioscorea japonica* paste, xanthan gum, and commercially available thickened liquids were measured using a cone and plate viscometer after 1 min by employing the following setting: temperature of 20°C and shear rate of 50 s^{-1}. The effect of changes in temperature and pH, and addition of NaCl and α-amylase, on viscosity was compared among the thickened liquids.

Results: Compared with the other commercially available agents, the *Dioscorea japonica* paste was stable in terms of viscosity on the addition of NaCl, and no change was observed on the addition of α-amylase as similar as the others. Although the *Dioscorea japonica* paste was relatively stable in terms of viscosity with change in pH, it was slightly unstable with change in temperature.

Conclusion: The findings of this study indicate that the *Dioscorea japonica* paste is useful as a novel type of thickened liquid for patients with dysphagia.

Key words: Dysphagia diet, *Dioscorea japonica* paste, Thickened liquids, Viscosity, Food functionality

Background

With Japan on its way to becoming a super-aged society, patients with dysphagia are also increasing [1–3]. Dysphagia will result in not only impaired quality of life and malnutrition but also severe diseases such as aspiration pneumonia [4,5]. To maintain a healthy body and activities of daily living in the elderly, receiving oral nutrition from high quality food is essential. In patients with impaired swallowing function, consumption of texture-modified food and thickened liquids is preferable [6]; therefore, commercial thickening and gelling agents are commonly used. Today, xanthan gum-based thickened liquids [7,8] are mainly used to prepare foods that vary in texture and for patients with dysphagia for ease of swallowing. Selecting an appropriate thickened liquid to achieve desirable rheological properties based on the swallowing function of individuals and avoid the risk of aspiration is crucial [8,9]. However, thickened liquids with unsuitable viscosity are occasionally used in hospitals and welfare facilities. In Japan, a standard framework for classifying dysphagia diets is in place, and the Japanese Society of Dysphagia Rehabilitation developed the Japanese Dysphagia Diet 2013 (JDD2013) [10]. JDD2013 classifies thickened liquids according to drinking properties, visual properties, and viscosity values as follows: Level 1, Mildly thick; Level 2, Moderately thick; Level 3, Extremely thick. Watanabe *et al.* describes that JDD2013 defines these thickened liquids as follows, mildly thick: flowing quickly with the tilting of a spoon, leaving a thin trace of residue in the cup after being poured, and suitable for mild cases of dysphagia; moderately thick: flowing slowly with the tilting of a spoon, leaving a film of residue in the cup after being poured, and suitable for moderately severe cases of dysphagia; extremely thick: maintaining most of its form with the tilting of a spoon, not flowing quickly after being poured, and suitable for more severe cases of dysphagia showing a risk of aspiration using moderately thick liquids [11].

The main causes of death in Japan are chronic diseases, such as malignant neoplasms, heart diseases, and cerebrovascular diseases, which are associated with chronic inflammation in many cases. Prevention of chronic inflammation is of utmost importance to maintain a healthy and long-living society. We have been exploring food functionality for the prevention of chronic inflammation by targeting the synthetic pathway of proinflammatory lipid mediators, such as prostaglandin (PG) E_2 and leukotrienes, derived from ω-6 arachidonic acid. In our previous study, we have demonstrated that *Dioscorea japonica*, a wild yam, suppresses the activity of cyclooxygenase-2 (COX-2) and microsomal prostaglandin E (PGE) synthase-1, which are key enzymes in the production of proinflammatory PGE_2, and has anti-inflammation and anti-carcinogenesis [12,13]. Recently, it is reported that diosgenin, a functional ingredient of *Dioscorea japonica,* downregulates COX-2 expression selectively in macrophages via glucocorticoid receptor and improves LPS-induced liver inflammation [14].

Dioscorea japonica is a relative of the *Dioscoreaceae* family that is native to Japan. The yam tubers of this species are usually considered edible and are beneficial for nutritional fortification [15,16]. Moreover, they have been shown to have other beneficial effects such as gastric mucosal protection and digestive enhancement. In some countries including Japan, the wild yam has been used as folk medicine against asthma, rheumatoid arthritis, bronchitis, and other diseases. *Dioscoreaceae* yam tubers have distinguishing physical properties, and among them, *Dioscorea japonica* yams have the highest viscosity. Previously, we elucidated about the rheological properties of *Dioscorea japonica* tuber and its potential application in dysphagia diets [17]. The our previous study shows that

Dioscorea japonica powder of 30% weight/volume (W/V) was suitable for all the items of hardness, cohesiveness, and adhesiveness in the standard (level II for dysphagia diet) of Texture Profile Analysis specified by the Ministry of Health, Labour and Welfare for dysphagia diet [17]. In addition, the rheological analysis indicated that 20%-30% (W/V) of *Dioscorea japonica* powder showed a rheological profile similar to that of 0.2% xanthan gum as a true polymer solution, and [18] that it was more suitable as a thickened liquid for dysphagia than grated raw *Dioscorea japonica* [18]. These results suggested that *Dioscorea japonica* powder has potential application in dysphagia diets. Furthermore, the physical property and swallowing compatibility of the paste of *Dioscorea japonica* powder was similar to those of yogurt, which is often used to swallowing training for patients with dysphagia, and the property of the paste was similar to that of xanthan gum and commercially available thickened liquids in the study of texture analysis and swallowing function evaluation [19]. These distinctive qualities of *Dioscorea japonica* in terms of food functionality and physical properties could be beneficially applied in a dysphagia diet of good quality. Moreover, whether its physical properties remain stable during cooking and food processing will need to be investigated. In the present study, we compared the viscosity of *Dioscorea japonica* paste with that of xanthan gum and commercially available thickened liquids under several conditions such as changes in temperature and pH, along with the addition of NaCl and α-amylase.

Methods

Sample preparation

Dioscorea japonica powder was purchased from Naturalskyway Co. (Tokyo, Japan). It was mixed with distilled water or 20 mM sodium phosphate buffer (pH 7.0) at 20°C±2°C using an electric mixer (bamixM250, ESGE Ltd, Mettlen, Switzerland) at room temperature for 5 min. The uniformly mixed *Dioscorea japonica* paste was kept as is for 20 min to remove any bubbles that were formed. Commercially available thickening agent A (TROMELIN V) containing dextrin, thickening polysaccharide, and potassium chloride was purchased from NUTRI Co., Ltd. (Yokkaichi, Japan); commercially available thickening agent B (TSURURINKO Quickly) containing dextrin, xanthan gum, calcium lactate, and trisodium citrate was purchased from CLINICO Co., Ltd. (Tokyo, Japan); and xanthan gum was purchased from Neosoft XR, Taiyo Kagaku Co., Ltd.

(Yokkaichi, Japan). They were added to distilled water or 20 mM sodium phosphate buffer (pH 7.0) at 20°C±2°C and stirred manually with a spatula approximately 60 times/min for 1 min. Next, the thickened liquid A and B and liquid xanthan gum were kept as is for 20 and 50 min, respectively, at 20°C±2°C. *Dioscorea japonica* paste and the thickened liquids were stirred manually 10 times before the viscosity analysis.

Viscosity analysis

Viscosity of the thickened liquids was analyzed according to the method established by JDD2013 (the Japanese Society of Dysphagia Rehabilitation (JSDR) dysphagia diet committee) [10], using a cone and plate viscometer (VISCOMETER TV-25; Toki Sangyo, Co., Ltd., Tokyo, Japan) having a cone diameter and angle of 28 mm and 3°, respectively. Viscosity of all thickened liquids was measured after 1 min under the following setting: temperature of 20°C and shear rate of 50 s^{-1}.

Line spread test

The line spread test (LST), another simple viscosity test established by JDD2013 [10], was performed using a flat plate with concentric circles (Saraya Co., Ltd., Osaka, Japan). A hollow ring having an internal diameter of 30 mm and height of 28 mm was filled with 20 mL of the sample and was left to stand for 30 s. The hollow ring was then lifted and the sample was allowed to spread for 30 s. The distance covered by the liquid along the six axes were read and averaged [20]. This test was performed three times each, and each value was averaged and evaluated.

Effect of temperature on the viscosity of the thickened liquids

The prepared samples were kept for 20 min at 10, 20, 40, or 60°C before conducting the viscosity analysis. All samples were adjusted to 150–300 mPa·s as moderately thick according to JDD2013 by the JSDR dysphagia diet committee [10].

Effect of pH on the viscosity of the thickened liquid

After preparation of the thickened liquids, pH of all samples was changed by addition of the following buffers (final concentration of 20 mM): sodium acetate buffer (pH 4.0), sodium phosphate buffer (pH 7.0), and glycine buffer (pH 9.0).

Assessment of α-amylase resistance

After preparation of the thickened liquids, they were incubated with α-amylase (1–1,000 μg/mL, Wako Pure Chemical Industries, Ltd., Osaka, Japan) in 20 mM sodium phosphate buffer (pH 7.0) at 37°C for 10 min. Potato starch liquid (5.3%) was used for comparison. Their viscosities were then measured at 20°C for 1 min, as previously described.

Statistics

Data were statistically evaluated by ANOVA using Bonferroni test or Dunnett's test using a significance level of $p < 0.01$.

Results

Correlation between concentration and viscosity of *Dioscorea japonica* paste and thickened liquids

Several commercially available thickened liquids have individual physical properties, with different viscosities and textures even at the same concentration [21,22]. The correlation between concentration and viscosity of *Dioscorea japonica* paste, liquid xanthan gum, and commercially available thickened liquids A and B was confirmed (Fig. 1). Table 1 shows the comparative concentration of each thickener based on the three-stage classification by established standard viscosity of JDD2013, “mildly thick,” “moderately thick,” and “extremely thick” [10]. *Dioscorea japonica* paste (9.5%, 14%, and 17%), liquid xanthan gum (0.5%, 1.4%, and 2.0%), thickened liquid A (1.0%, 1.8%, and 2.5%), and thickened liquid B (1.0%, 2.0%, and 3.0%) were prepared to the median of each standard viscosity. Their viscosities and LST values were measured (Table 2) and whether they matched with the criteria established by JDD2013 was evaluated. In the subsequent experiments, the concentration adjusted to “moderately thick” was used.

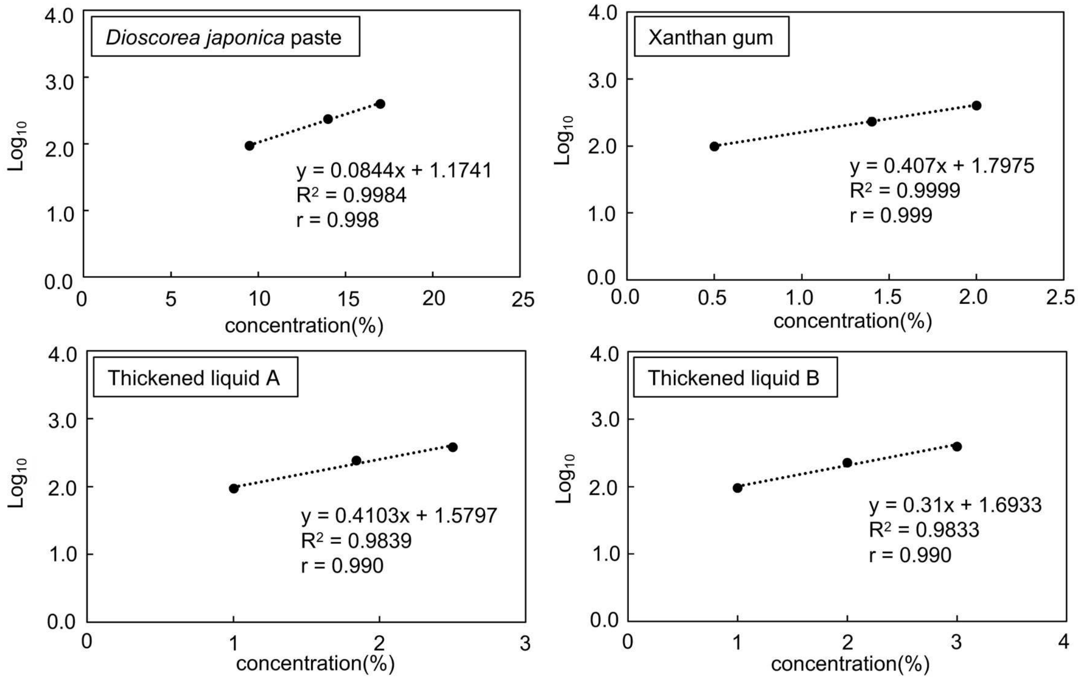

Fig. 1 Relationship between concentration and viscosity in each sample

Dioscorea japonica paste was evaluated at concentrations of 9.5%, 14%, and 17%. Xanthan gum was evaluated at concentrations of 0.5%, 1.4%, and 2.0%. Thickened liquid A was evaluated at concentrations of 1.0%, 1.8%, and 2.5%. Thickened liquid B was evaluated at concentrations of 1.0%, 2.0%, and 3.0%. The solutes were dissolved in distilled water. The viscosity of all samples was assessed using a viscometer at 20°C after five independent measurements. The viscosity is indicated as the values of common logarithm.

Table 1 Sample concentration on each viscosity

Viscosity (mPa･s)	*Dioscorea japonica* paste (%)	Xanthan gum (%)	Thickened liquid A (%)	Thickened liquid B (%)
Mildly thick (50-150)	6.22-11.87	<0.93	0.29-1.45	0.02-1.56
Moderately thick (150-300)	11.87-15.44	0.93-1.67	1.45-2.19	1.56-2.53
Extremely thick (300-500)	15.44-18.07	1.67-2.21	2.19-2.73	2.53-3.24

According to Fig. 1, the concentration of each sample fitted to the standard viscosity was determined. The solutes were dissolved in distilled water. The viscosity of all samples was measured using a viscometer at 20°C. Viscosity was categorized in three levels, as established by the Japanese Dysphagia Diet 2013 (JDD2013) [10].

Table 2 The standard of viscosity and LST by Japanese Dysphagia Diet 2013 and measured values

	Mildly thick	Moderately thick	Extremely thick
Standard viscosity (mPa·s) [10]	50-150	150-300	300-500
Measured viscosity (mPa·s)			
Dioscorea japonica paste	92.96 ± 0.10	235.90 ± 0.36	401.84 ± 0.93
Xanthan gum	100.18 ± 0.16	236.12 ± 0.64	404.58 ± 0.29
Thickened liquid A	93.76 ± 0.52	242.28 ± 0.35	382.54 ± 0.57
Thickened liquid B	95.84 ± 0.20	229.92 ± 0.22	394.28 ± 0.32
Standard LST (mm) [10]	36-43	32-36	30-32
Measured LST (mm)			
Dioscorea japonica paste	39.11 ± 0.93	34.56 ± 0.31	31.39 ± 0.06
xanthan gum	39.39 ± 0.24	32.83 ± 0.00	31.56 ± 0.56
thickened liquid A	42.78 ± 0.47	34.33 ± 0.48	31.39 ± 0.24
thickened liquid B	42.06 ± 0.29	34.78 ± 0.24	30.94 ± 0.20

Standard viscosity and LST categorized in three levels, as established by the Japanese Dysphagia Diet 2013 (JDD2013) [10]. *Dioscorea japonica* paste was used at concentrations of 9.5%, 14%, and 17%. Xanthan gum was used at concentrations of 0.5%, 1.4%, and 2.0%. Thickened liquid A was used at concentrations of 1.0%, 1.8%, and 2.5%. Thickened liquid B was used at concentrations of 1.0%, 2.0%, and 3.0%. The solutes were dissolved in distilled water. Viscosity of each sample was measured using a viscometer at 20°C in five separate measurements. LST of each sample was measured using a flat plate with concentric circles at 20°C after three independent measurements.

Effect of temperature change on the viscosity of thickened liquids

Changes in viscosity of the thickened liquids, *Dioscorea japonica* paste, liquid xanthan gum, thickened liquid A, and thickened liquid B ("moderately thick," 229-242 mPa·s) were measured under various temperature conditions (10, 20, 40, and 60°C) (Fig. 2A). With respect to temperature change, thickened liquid B was extremely stable without a significant difference and liquid xanthan gum was relatively stable with increase less than 14% at each temperature. In contrast, the viscosity of *Dioscorea japonica* paste increased by 16% at 10°C and decreased by approximately 20% at 40°C and 60°C. Thickened liquid A was more likely to be affected by change in temperature than *Dioscorea japonica* paste, and the viscosity of thickened liquid A increased by 11% at 10°C and decreased by 22% and 54%, respectively at 40°C and 60°C.

Effect of pH change on the viscosity of thickened liquids

The effect of change in pH (pH 4.0, 7.0, and 9.0) on the viscosity of the thickened liquids was investigated (Fig. 2B). Thickened liquid A was stable under the testing pH conditions. The viscosity of *Dioscorea japonica* paste marginally increased (within 7%) at pH 4.0 and 9.0 compared with pH 7.0. The viscosity of thickened liquid B showed a decrease of 16% at pH 9.0. Among the viscosities of all thickened liquids, that of liquid xanthan gum was the most unstable in terms of change in pH for pH 4.0 and 9.0, showing significant decreases of 30% at pH 4.0 and 45% at pH 9.0.

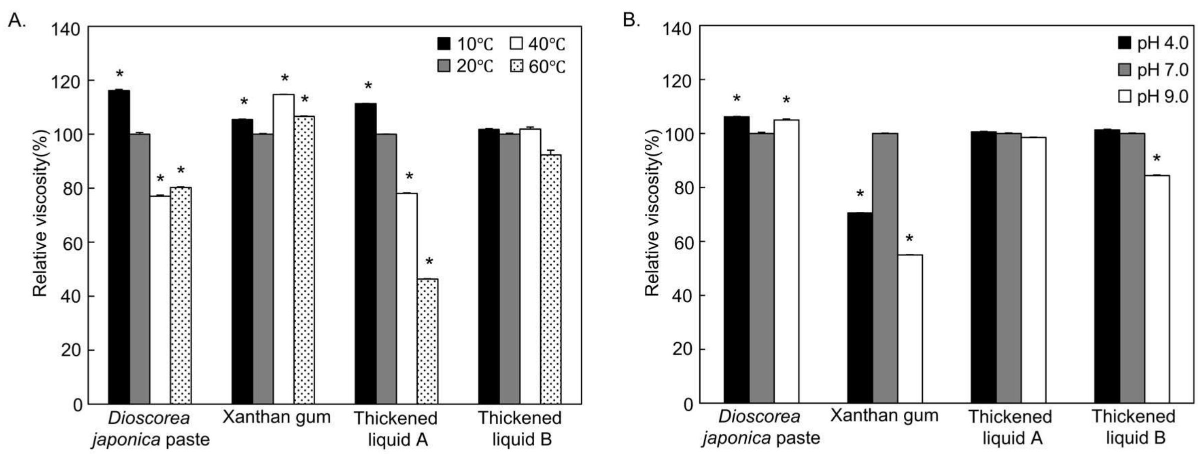

Fig. 2 Effects on stability after temperature and pH changes to viscosity for each sample

A: The viscosity of each sample was measured at 10, 20, 40, and 60°C using a viscometer after five independent measurements. The solutes were dissolved in distilled water. B:

Each sample was prepared with sodium acetate buffer, sodium phosphate buffer, and glycine buffer at pH 4.0, 7.0, and 9.0, respectively. Sample concentration: *Dioscorea japonica* paste 12% (A) and 13.5% (B), xanthan gum 0.7%, thickened liquid A 1.8%, thickened liquid B 2.1%. The values of relative viscosities are means ± SE represented as relative values with respect to the amount at 20°C (A) or pH = 7.0 (B) as 100%. *$p < 0.01$ compared with 20°C (A) or pH = 7.0 (B).

Effect of NaCl addition on the viscosity of thickened liquids

Because thickening agents are frequently added to foods that contain salt, the effect of NaCl addition (1% and 5%, W/V) on the viscosity of the thickened liquids was investigated (Fig. 3A). A suitable NaCl concentration for soups or other relevant food items is approximately 0.9%, with 5% NaCl usually considered as being outside the normal accepted range. Among all the thickened liquids, the viscosity of *Dioscorea japonica* paste was the most stable with NaCl addition, although its viscosity slightly increased (12%) with the addition of 5% NaCl. In contrast, the viscosities of liquid xanthan gum and thickened liquids A and B significantly decreased approximately 50%

and 80% with the addition of 1% and 5% NaCl, respectively.

Resistance of the viscosity of thickened liquids to α-amylase addition

Starch-based thickeners are also commonly used in the management of dysphagia; however, the viscosity of such fluids can reduce on contact with saliva containing α-amylase. Therefore, at present, many commercially available thickening agents demonstrate resistance to salivary digestion. To examine the direct effect of α-amylase on the viscosity of thickened liquids, the resistance of *Dioscorea japonica* paste to α-amylase was compared with the resistance of other thickened liquids to α-amylase in the viscosity analysis (Fig. 3B). Addition of α-amylase (1 μg/mL and 1 mg/mL) significantly decreased the viscosity of potato starch liquid to 18% and 0.02%, respectively, after 10 min. In contrast, the viscosity of *Dioscorea japonica* paste was extremely resistant to α-amylase, which was similar to those observed for liquid xanthan gum and commercially available thickened liquids.

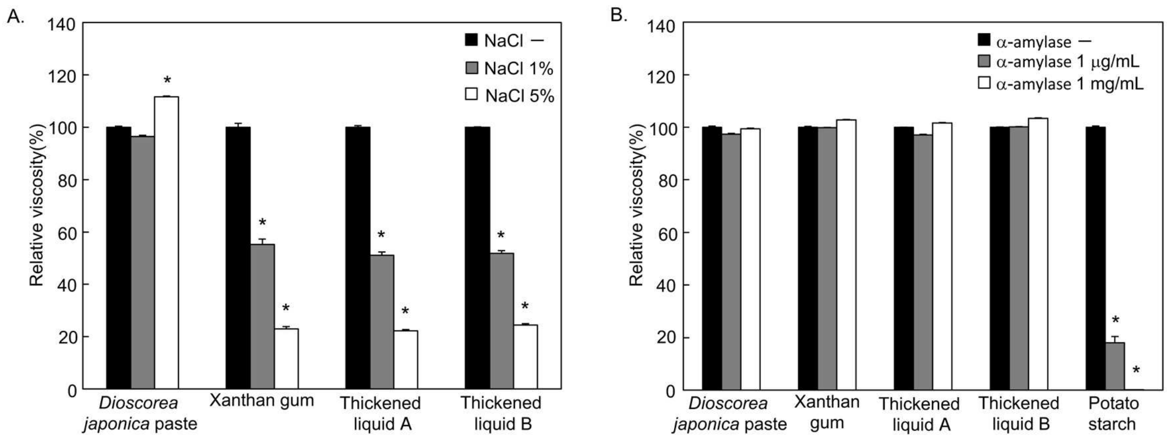

Fig. 3 Effects on stability after NaCl addition and resistance on α-amylase activity to viscosity of each sample

A: In each sample (pH = 7.0), 0%, 1%, or 5% NaCl in 20 mM sodium phosphate buffer was added. The viscosity of all samples was measured using a viscometer at 20°C after five independent measurements. B: Potato starch was used at a concentration of 5.3%. In each sample or potato starch as a positive control, 0, 1, or 1,000 μg/mL of α-amylase was added. The solutes were dissolved in distilled water. The viscosity of all samples was measured using a viscometer at 20°C after five independent measurements. Sample concentration: *Dioscorea japonica* paste 15% (A) and 12% (B), xanthan gum 0.7%, thickened liquid A 1.8%, thickened liquid B 2.1%. The values of relative viscosity are means ± SE represented as relative values with respect to the amount without NaCl (A) or α-amylase (B). *$p < 0.01$ compared with 0% NaCl (A) or 0 μg/ml α-amylase (B).

Discussion

In the present study, the application of *Dioscorea japonica* paste as a thickened liquid was investigated. *Dioscorea japonica* has multimodal functionality, which includes prevention of chronic inflammation. In Japan, the most dominant standard for thickened liquids is formulated by JDD2013 and categorized on the basis of viscosity. In this study, we compared the usefulness of *Dioscorea japonica* paste as a thickened liquid with that of commercially available thickening agents by viscosity analysis. The viscosity of *Dioscorea japonica* paste was measured according to a measuring method suggested by JDD2013; furthermore, variations in its viscosity were measured under various conditions. The viscosity of *Dioscorea japonica* paste could be easily adjusted by altering its blending and temperature conditions, and its stability against changes in pH and α-amylase activity was similar to that of commercially available thickened liquids. In the presence of NaCl, the viscosity of commercial thickened liquids decreased significantly depending on the concentration, whereas that of *Dioscorea japonica* paste showed superior stability. Based on the above, the physical characteristics of *Dioscorea japonica* paste in the viscosity analysis were found to be exceptional, and *Dioscorea japonica* paste may be suitable as a thickened liquid for patients with dysphagia.

In recent years, xanthan gum-based thickened liquids, which are more stable than starch-based ones, have mainly been used [23]. The two types of thickened liquids used in this study (thickened liquid A and B) were also prepared using xanthan gum-based thickening agents. The two commercially available thickened liquids evaluated in this study mainly contain dextrin and a thickening polysaccharide, but their viscosity is believed to differ because the type and blending rate are different depending on the manufacturer [24,25]. Moreover, as with liquid xanthan gum and commercially available thickened liquids, *Dioscorea japonica* paste displayed a positive correlation between the added concentration and the common logarithmic value of viscosity, indicating that the viscosity can be adjusted proportionally to the amount added. The thickened liquids were then evaluated using the LST method and all the samples were matched with the criteria of the LST value established by JDD2013 (Table 2). The LST method is a simple and inexpensive viscosity measurement method for convenient instrument preparation that has low variability within the experiments [20]. Although some aspects regarding the accuracy of the LST method should be taken into account [26], the LST values of the *Dioscorea japonica* paste and commercially available thickened liquids investigated in this study matched the JDD 2013 criteria as well as the viscosity assessment.

Elderly people, particularly those who need meal assistance require more time to eat, and even if a thickening agent is added to warm foods to adjust the viscosity to an appropriate level, the viscosity often changes before eating. Therefore, it is essential that the viscosity of thickened liquids is stably maintained under conditions of change in temperature. Deto *et al.* [24] reported that the viscosity of liquid xanthan gum does not change significantly from 10°C to 90°C and therefore it is used as a raw material for commercially available thickened liquids. Nevertheless, in the present study, the viscosity showed the tendency to increase slightly at low or high temperatures (Fig. 2A). This is thought to be due to a difference in determination method of physical property, i.e., our viscosity analysis and their texture analysis. Hong *et al*. [7] reported that the viscosity of xanthan gum-based thickened liquids is temperature-dependent. Indeed, in the present study, the viscosity of the xanthan gum-based thickened liquid A showed a significant decrease at high temperatures, whereas xanthan gum-based thickened liquid B was relatively stable in terms of viscosity in response to temperature changes. Although details of the ingredients present in the commercially available thickening agents have not been published, other ingredients have been added to some thickened liquids, such as thickened liquid B, to improve them so that their viscosity if not considerably affected change in temperature. Compared with these thickened liquids, the *Dioscorea japonica* paste showed a trend of having a slightly higher viscosity at low temperatures and a slightly lower viscosity at high temperatures; however, this trend was not as significant as that observed for commercially available thickened liquid A. The viscous component of yam, including *Dioscorea japonica*, is derived from glycoproteins [27,28], and it has been reported that proteins are denatured by heating and are insolubilized to decrease their viscosity [29]. So the viscosity of *Dioscorea japonica* paste derived from the glycoprotein moiety might be decreased at high temperatures in the present study.

Considering the stability of a thickened liquid, maintaining the viscosity of foods and beverages even with changes in their pH is crucial. As shown in Fig. 2B, the viscosity of *Dioscorea japonica* paste showed a slight increasing trend under acidic and alkaline conditions (within +7%). In contrast, the viscosity of xanthan gum showed a considerable decrease of approximately 30% and 45% at pH 4.0 and 9.0, respectively, and that of thickened liquid B showed decrease of approximately 15% at pH 9.0. However, xanthan gum-based thickened liquids have been reported to be tolerant to pH changes [30], and so, we re-experimented with the same xanthan gum preparation method as that mentioned in the reference [30]; however, the results did not show much difference with the present study (data not shown). Furthermore, the effects of pH change varied for the two commercially available xanthan gum-based agents. Yoon *et al*. [9] reported that pH has different viscoelastic effects depending on the type of thickened liquids, and indeed, the present study showed the differences among the xanthan gum and two commercially available xanthan gum-based agents. By contrast, the viscosity of the *Dioscorea japonica* paste was derived from glycoprotein and was shown to be relatively stable with change in pH.

Considering the addition of thickened liquids to foods containing salt, such as soups, it is crucial that the viscosity is not considerably affected by the addition of salt. In this study, changes in viscosity with the addition of 1% or 5% NaCl was also evaluated and analyzed, showing that the viscosity of liquid xanthan gum and xanthan gum-based commercially available thickened liquids decreased proportionally to the amount of NaCl added (Fig. 3A). The NaCl concentration of a typical soup is approximately 0.8%–0.9%, but even at 1% NaCl, which is close to the aforementioned value, a decrease in viscosity of 40-%–50% was observed in liquid xanthan gum and commercially available thickened liquids. The viscosity of xanthan gum, which has a wide variety of structures with many side chains surrounding the main chain [31], stabilizes after addition of salt at low concentrations (1% or less) [32,33]. However, the present study showed that addition of 1% or more NaCl caused a decrease in the viscosity of liquid xanthan gum, indicating that the thickening effect of xanthan gum was affected by NaCl concentration of the food. In addition, it is known that the addition of NaCl has a notable effect on the rheological properties of xanthan gum-based thickened liquids [34]. Analysis of the viscosity 2h and 4 h after the addition of NaCl showed little difference from the present data of Fig.3A (data not shown). Although the viscosity of the *Dioscorea japonica* paste increased by approximately 10% with the addition of 5% NaCl, it showed exceptional stability compared with the commercially available thickened liquids; moreover, the *Dioscorea japonica* paste was barely affected by the addition of 1% NaCl (which is close to the NaCl concentration of a typical soup). In previous study of tsukuneimo, ichoimo, and nagaimo, which are types of wild yams, addition of more than 0.1 M (≒0.58%, W/V) NaCl decreased their viscosity by more than 20% [29]. These results were different in the case of *Dioscorea japonica* paste, but the content of the viscous component may individually vary among the yam family [28]. In particular, a stability of the viscosity of *Dioscorea japonica* paste against addition of NaCl is superior physical properties, and it may be useful in cooking and food processing of swallowing-adjusted foods.

Salivary α-amylase hydrolyzes α-1,4-glycosidic bonds of polysaccharides, such as starch, and immediately decreases the viscosity of food and liquid thickened by starch. However xanthan gum, whose main chain is composed of β-1,4-glycosidic bonds, and xanthan gum-based commercial thickened liquids are resistant to α-amylase, and their viscosity does not change with the addition of α-amylase. Although the viscous component of *Dioscorea japonica* is different from that of xanthan gum, *Dioscorea japonica* paste showed strong resistance to α-amylase, similar to liquid xanthan gum or commercial thickened liquids; thus, the paste would be useful as a thickened liquid for dysphagia diets (Fig. 3B).

In the current study, on comparing the change in viscosity of various thickened liquids, each liquid was found to have unique characteristics. However, even after summarizing these characteristics, the *Dioscorea japonica* paste showed usefulness that was comparable to that of commercially available thickened liquids.

Conclusion

Our previous study demonstrated that *Dioscorea japonica* suppressed PGE_2 synthetic pathway, which is associated with acute/chronic inflammation [12–14], and additionally had potential applicability in the development of dysphagia diets [17,19]. In the present study, we demonstrated the usefulness of *Dioscorea japonica* paste as a thickened liquid, which has excellent suitability compared with commercial thickened liquids. In addition, *Dioscorea japonica* showed high versatility because the viscosity of *Dioscorea japonica* paste could be easily adjusted by modifying its blending amount and temperature. Therefore, we believe that *Dioscorea japonica* paste would be a novel thickened liquid with adequate food functionality for the prevention of proinflammatory lipid mediators-related diseases.

Abbreviations

JDD2013: Japanese Dysphagia Diet 2013; PGE_2: prostaglandin E_2; W/V: weight/volume; JSDR: Japanese Society of Dysphagia Rehabilitation; LST: line spread test

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Authors' contributions

Y.K. performed the experiments, analyzed data, and drafted the manuscript. I.T. and M.O. prepared samples and conducted viscosity measurement. T.K. and K.I. conceptualized the study and interpreted data. T.S-Y. supervised the work, conceived and designed the studies, interpreted the data, and drafted the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used in the current study are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

All experiments complied with current laws of Japan.

Consent for publication

Not applicable.

Competing interests

The authors have no competing interests to declare.

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Figure legends

Fig. 1 Relationship between concentration and viscosity in each sample

Dioscorea japonica paste was evaluated at concentrations of 9.5%, 14%, and 17%. Xanthan gum was evaluated at concentrations of 0.5%, 1.4%, and 2.0%. Thickened liquid A was evaluated at concentrations of 1.0%, 1.8%, and 2.5%. Thickened liquid B was evaluated at concentrations of 1.0%, 2.0%, and 3.0%. The solutes were dissolved in distilled water. The viscosity of all samples was assessed using a viscometer at 20°C after five independent measurements. The viscosity is indicated as the values of common logarithm.

Fig. 2 Effects on stability after temperature and pH changes to viscosity for each sample

A: The viscosity of each sample was measured at 10, 20, 40, and 60°C using a viscometer after five independent measurements. The solutes were dissolved in distilled water. B: Each sample was prepared with sodium acetate buffer, sodium phosphate buffer, and glycine buffer at pH 4.0, 7.0, and 9.0, respectively. Sample concentration: *Dioscorea japonica* paste 12% (A) and 13.5% (B), xanthan gum 0.7%, thickened liquid A 1.8%, thickened liquid B 2.1%. The values of relative viscosities are means ± SE represented as relative values with respect to the amount at 20°C (A) or pH = 7.0 (B) as 100%. *$p < 0.01$ compared with 20°C (A) or pH = 7.0 (B).

Fig. 3 Effects on stability after NaCl addition and resistance on α-amylase activity to viscosity of each sample

A: In each sample (pH = 7.0), 0%, 1%, or 5% NaCl in 20 mM sodium phosphate buffer was added. The viscosity of all samples was measured using a viscometer at 20°C after five independent measurements. B: Potato starch was used at a concentration of 5.3%. In each sample or potato starch as a positive control, 0, 1, or 1,000 μg/mL of α-amylase was added. The solutes were dissolved in distilled water. The viscosity of all samples was measured using a viscometer at 20°C after five independent measurements. Sample concentration: *Dioscorea japonica* paste 15% (A) and 12% (B), xanthan gum 0.7%, thickened liquid A 1.8%, thickened liquid B 2.1%. The values of relative viscosity are means ± SE represented as relative values with respect to the amount without NaCl (A) or α-amylase (B). *$p < 0.01$ compared with 0% NaCl (A) or 0 μg/ml α-amylase (B).

Table 1 Sample concentration on each viscosity

Viscosity (mPa･s)	*Dioscorea japonica* paste (%)	Xanthan gum (%)	Thickened liquid A (%)	Thickened liquid B (%)
Mildly thick (50-150)	6.22-11.87	<0.93	0.29-1.45	0.02-1.56
Moderately thick (150-300)	11.87-15.44	0.93-1.67	1.45-2.19	1.56-2.53
Extremely thick (300-500)	15.44-18.07	1.67-2.21	2.19-2.73	2.53-3.24

According to Fig. 1, the concentration of each sample fitted to the standard viscosity was determined. The solutes were dissolved in distilled water. The viscosity of all samples was measured using a viscometer at 20°C. Viscosity was categorized in three levels, as established by the Japanese Dysphagia Diet 2013 (JDD2013) [10].

Table 2 The standard of viscosity and LST by Japanese Dysphagia Diet 2013 and measured values

	Mildly thick	Moderately thick	Extremely thick
Standard viscosity (mPa·s) [10]	50-150	150-300	300-500
Measured viscosity (mPa·s)			
Dioscorea japonica paste	92.96 ± 0.10	235.90 ± 0.36	401.84 ± 0.93
Xanthan gum	100.18 ± 0.16	236.12 ± 0.64	404.58 ± 0.29
Thickened liquid A	93.76 ± 0.52	242.28 ± 0.35	382.54 ± 0.57
Thickened liquid B	95.84 ± 0.20	229.92 ± 0.22	394.28 ± 0.32
Standard LST (mm) [10]	36-43	32-36	30-32
Measured LST (mm)			
Dioscorea japonica paste	39.11 ± 0.93	34.56 ± 0.31	31.39 ± 0.06
xanthan gum	39.39 ± 0.24	32.83 ± 0.00	31.56 ± 0.56
thickened liquid A	42.78 ± 0.47	34.33 ± 0.48	31.39 ± 0.24
thickened liquid B	42.06 ± 0.29	34.78 ± 0.24	30.94 ± 0.20

Standard viscosity and LST categorized in three levels, as established by the Japanese Dysphagia Diet 2013 (JDD2013) [10]. *Dioscorea japonica* paste was used at concentrations of 9.5%, 14%, and 17%. Xanthan gum was used at concentrations of 0.5%, 1.4%, and 2.0%. Thickened liquid A was used at concentrations of 1.0%, 1.8%, and 2.5%. Thickened liquid B was used at concentrations of 1.0%, 2.0%, and 3.0%. The solutes were dissolved in distilled water. Viscosity of each sample was measured using a viscometer at 20°C in five separate measurements. LST of each sample was measured using a flat plate with concentric circles at 20°C after three independent measurements.