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Dysphagia thickeners in context of use: Changes in thickened drinks viscosity and thixotropy with temperature and time of consumption

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Abstract

Dysphagia patients might need to thicken drinks. The viscosity of these thickened drinks varies among commercial thickeners and drinks compromising the ingesta safety. The aim of this study was to investigate how temperature and resting time affect the rheological properties of thickened drinks. Four commercial thickeners were used to thicken water, coffee, orange juice, and milk at two concentration levels used in dysphagia drinks (nectar and pudding). To study the effect of temperature, flow curves of thickened drinks at 10°C and 50°C were obtained and to study the effect of resting time, flow curves of thickened drinks at 25°C were obtained at different times (0, 30, and 60 min). All samples displayed shear-thinning and time-dependent behavior (thixotropy or antithixotropy). The effect of temperature on viscosity values and relative thixotropic area (RTA) depended on the thickener and the drink. Overall, apparent viscosity showed higher values at 50°C than 10°C, especially in thickeners containing starch and in drinks with higher soluble solids (milk and orange juice). This was attributed to the water absorption of pregelatinized starch granules favored by temperature. Antithixotropy was mainly observed at pudding concentration for the starch-containing thickeners, and decreased with temperature. The effect of resting time on apparent viscosity and RTA depended also on the drink and thickener. Mostly, apparent viscosity values increased with resting time and antithixotropic behavior decreased. Both effects, increase in viscosity and decrease of antithixotropy with time, indicated that thickening action was being developed over the resting time.

KEYWORDS
antithixotropy, apparent viscosity, dysphagia, temperature, thickened drinks, thixotropy

1 | INTRODUCTION

Dysphagia—from the Greek words *dys* (difficulty) and *phagia* (to eat)—is a mechanical disorder characterized by difficulty or impairment in

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swallowing (Alagiakrishnan, Bhanji, & Kurian, 2013; Lancaster, 2015). This disorder affects 8% of the world's population, being more common in the elderly population (Cichero et al., 2013). Moreover, in the elderly population, dysphagia is prevalent in the 11.4–33.7% of independently living elderly, and 51% of those elderly living under nursing care (Baijens et al., 2016; Serra-Prat et al., 2011).

In dysphagia, during the swallowing process, glottal closure is not efficient and food could enter the respiratory airways, causing dysphagia patients to suffer aspiration and choking (Logemann, 2007). The quality of drinking and eating is severely diminished, leading to reduced food intake and thus dehydration and malnutrition (Morris, 2006; Vivanti, Campbell, Suter, Hannan-Jones, & Hulcombe, 2009).

Because of the swallowing problems of these patients, they are prescribed to thicken the drinks and to modify food texture (Clavé et al., 2006; Steele, 2015). Logemann (2007) stated that the volume and viscosity of the bolus are critical characteristics to control swallowing. As increasing the volume and the viscosity of bolus the transit time will be slower, resulting in a safer swallowing process (Logemann, 2007). In practice, people having dysphagia, and according to their swallowing abilities, are prescribed drinks with thickened levels. The American Dietetic Association established in 2002 the National Dysphagia Diet (NDD) classification dividing thickened drinks into four thickened levels: liquid, nectar, honey and pudding (American Dietetic Association, 2002). A more up-to-date global standard, named the International Dysphagia Diet Standardization Initiative (IDDSI), has been developed by an international collaboration of professionals. Unlike the NDD, the IDDSI classifies thickened drinks into five different levels: thin, slightly thick, mildly thick, moderately thick, and extremely thick (IDDSI, 2019). However, the commercial dysphagia thickeners in the market are still using the terminology from the NDD (i.e., nectar, honey, and pudding classification) to describe the thickened level.

Thickeners used in dysphagia management are presented to the user as powder. To prepare the thickened drink, a quantity—stated on the products' label—needs to be dissolved in a liquid medium to be thickened. To date, the principal ingredients used as thickeners are modified maize starches in pre-gelatinized form and/or different gums, such as xanthan, guar, or tara (Garin et al., 2014; Matta, Chambers IV, Garcia, & Helverson, 2006).

During the last 10 years, research on the rheology of dysphagia thickeners has shown the difficulties in controlling the level of viscosity when preparing thickened drinks. Different commercial thickeners can give different drink viscosities, which can cause confusion and lead to incorrect/inconsistent thickened drinks for dysphagia patients if brands are changed. Furthermore, changes in viscosity have been observed when using the same thickener for different drinks, which contributes to the difficulty of controlling the thickened drinks' viscosity (Garin et al., 2014; Martínez, Troncoso, Robert, Quezada, & Zúñiga, 2019; Moret-Tatay, Rodríguez-García, Martí-Bonmatí, Hernando, & Hernández, 2015; Waqas, Wiklund, Altskär, Ekberg, & Stading, 2017).

Besides the changes in viscosity related to the thickener and the drink, the conditions of preparation and usage should also be considered, as hydrocolloids' rheological behavior depends usually on temperature, shearing, and resting time. Thickeners can be used in drinks consumed either hot (coffee, tea, and milk) or cold (juice, soda, and milk)· Most studies that have studied the effect of temperature, have usually compared a single temperature (hot or cold) respect to the room temperature (Garcia, Chambers IV, Matta, & Clark, 2005; Hadde, Nicholson, & Cichero, 2015; Koo, Narvasa, Bode, & Kim, 2019; Ng, Bogaardt, Tzannes, Collins, & Docking, 2021). Overall, this comparison between temperatures, did not show a clear viscosity trend (increase or decrease), as besides temperature, the viscosity changes were also influenced by the thickener and the drink. In addition, in a real context of use, a time-gap may occur between preparation and consumption of the thickened drinks. Garcia, Chambers IV, Matta, and Clark (2008) reported an increase of viscosity with time for starch-based thickeners, and stability for the gum-based. In contrast, Kim and Yoo (2018) reported an increase in viscosity with time in four xanthan gum-based thickeners.

Notably, Dewar and Joyce (2006) showed thickened drinks have complex time-dependent rheology, and they can exhibit either thixotropy or antithixotropy depending on the thickener and the concentration. Although no further attention has been paid to antithixotropy, our hypothesis is that is not a "true" antithixotropy but the result of the thickener activity, that still growing during flow measurements.

Therefore, the aim of this study is to investigate how factors such as changes in temperature (10°C and 50°C) and resting time affect the rheological properties of thickened drinks; further, to also consider different types of drinks and thickeners paying special attention to the time-dependence.

2 | MATERIALS AND METHODS

2.1 | Materials

Four commercial thickeners were used in this study to prepare thickened drinks for the management of dysphagia. The thickeners were purchased in a local pharmacy. Hereafter, they will be labeled as Thickener A (Resource ThickenUp Clear, Nestlé España S.A., Spain); Thickener B (NutAvant, Persan Distribuciones Farmacéuticas S.L., Spain); Thickener C (FontActiv, Laboratoires Grand Fontaine S.L., Spain), and Thickener D (Nutilis Powder, Nutricia S.R.L., Germany). The ingredients of each thickener are described in Table 1.

Four drinks were purchased from a local supermarket. The drinks were still water (Cortes de Arenoso, Spain), soluble coffee (Nescafé, Spain), orange juice (Hacendado, Spain), and whole milk (Hacendado, Spain). The pH values of drinks were 7.0 for water, 5.6 for milk, 4.5 for coffee, and 2.6 for orange juice.

2.2 | Preparation of the thickened drinks

The thickened drinks were prepared at two levels: nectar and pudding, following the thickener manufacturer instructions (Table 1). Two sets of thickened drinks were prepared:

TABLE 1 Commercial thickeners for dysphagia used in this study, its ingredients and the recommended amount of thickener for 100 ml

			Amount of thickener	
Commercial name of thickeners	Code	Ingredients	Nectar (g)	Pudding (g)
Resource ThickenUp clear	Thickener A	Maltodextrin, xanthan gum, and potassium chloride	1.2	3.6
NutAvant	Thickener B	Modified maize starch	4.1	8.2
FontActiv	Thickener C	Modified maize starch	4	8
Nutilis powder	Thickener D	Maltodextrin, thickeners (modified starch [maize], tara gum, xanthan gum, guar gum)	5	9

Set 1. To study the effect of temperature, drinks were prepared and measured at two temperatures (10°C and 50°C). The corresponding amount of thickener was dispersed in 100 ml of the liquid medium using a propeller stirrer (3 blades) at 240 rpm for 1 min for the nectar level, and 2 min for the pudding level.

Set 2. To study the effect of resting time, drinks were prepared at room temperature as described for Set 1. Measurements of the prepared thickened drinks were made at 0, 30, and 60 min of resting time.

2.3 | Rheological properties of samples

For nectar level, flow curves were measured in a Haake VT 550 viscometer (Thermo Haake, Karlsruhe, Germany) with a concentric cylinder sensor MV1 (rotor radius = 20.04 mm and cup radius = 21 mm), monitored by Rheowin Job Manager Software v.4.63. During measurements, temperature was controlled using a Haake DC30 temperature control module (Thermo Haake) and a Haake K15 bath (Thermo Haake).

For pudding level, flow curves were measured in a controlled stress rheometer (RheoStress 1, Thermo Haake) monitored by Rheowin Job Manager Software v.4.63 with a parallel-plate sensor system (60 mm) and a gap of 1 mm between plates. During measurements, temperature was controlled using a Haake SC150 temperature control module (Thermo Scientific, Karlsruhe, Germany) and a Haake A10 bath (Thermo Scientific).

Flow curves were obtained registering continuously the shear stress values when shearing samples increased shear rates from 1 to 200 s^{-1} and then when decreased from 200 to 1 s^{-1} to analyze flow behavior and its time dependence (thixotropy and antithixotropy).

For nectar level, data from the upstream curve were fitted to the Ostwald–de-Waele model ($\sigma = k\dot{\gamma}^n$) where, σ is the shear stress (Pa), k is the consistency index (Pa s^n), $\dot{\gamma}$ is the shear rate (s^{-1}), and n is the flow index (dimensionless). For pudding level, data from the upstream curve were fitted to the Herschel–Bulkley model ($\sigma = \sigma_0 + k\dot{\gamma}^n$) since some samples showed yield shear stress that is expressed as σ_0 (Pa) in the model. The other parameters are the same as those used in the Ostwald–de-Waele model.

The apparent viscosity at 50 s^{-1} (η_{50}) of the upstream shear curve was obtained for comparing the viscosity among conditions. In addition, to quantify time-dependence the relative thixotropic area (RTA) was calculated as the value of the hysteresis area divided by the area under the upstream shear curve, as it is a more suitable parameter when comparing products with different viscosity levels (Dolz, Gonzlez, Delegido, Hernndez, & Pellicer, 2000).

2.4 | Data analysis

To study the effect of temperature on the apparent viscosity η_{50} and the time-dependence (RTA) of the thickened drinks, two independent three-way ANOVAs (temperature, thickener, and drink) with interactions were used separately for thickened drinks at the nectar level and at the pudding level.

To study the effect of resting time on the apparent viscosity η_{50} and the time-dependence (RTA) of the thickened drinks, two independent three-way ANOVAs (resting time, thickener, and drink) with interactions were used for thickened drinks at nectar level at pudding level.

Post-hoc Fisher tests were applied to determine significant differences among mean values. All calculations were conducted with XLSTAT version April 1, 2020 software (Addinsoft, Paris, France).

3 | RESULTS AND DISCUSSION

3.1 | Flow behavior of thickened drinks at two temperatures

The flow curves obtained at 10°C and 50°C for some of the thickened drinks are shown as examples in Figures 1 and 2 for nectar and pudding levels, respectively. Flow curves of the thickened drinks displayed shear-thinning behavior, which is the usual for polysaccharides and their mixtures in water (Ong, Steele, & Duizer, 2018; Wei, Guo, Li, Ma, & Zhang, 2021). The flow behavior of the thickened drinks (upstream curve data) was characterized using the Ostwald–de-Waele model for nectar level samples that fitted well the model (r = .97–.99). For pudding samples, the data fit well to the Herschel–Bulkley model (r = .91–.99), except in three cases at 50°C, where drinks (water, coffee and orange juice) with Thickener A (r = .81–.86) showed curves with initial high shear stress increase, but after 50 s^{-1} the increase in shear stress with shear rate was very low. The yield stress, the consistency index and flow index also were obtained

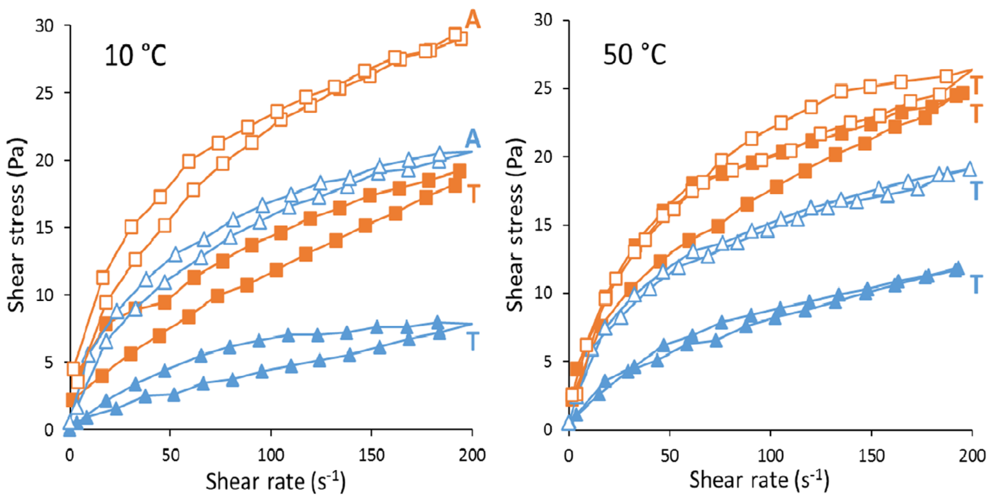

FIGURE 1 Flow behavior of the nectar level of water (Δ) and orange juice (□) for thickener B (filled symbols) and thickener D (open symbols) at 10°C and at 50°C. Letter T indicates thixotropic behavior and letter A indicates antithixotropic behavior. Identification of thickeners in Table 1

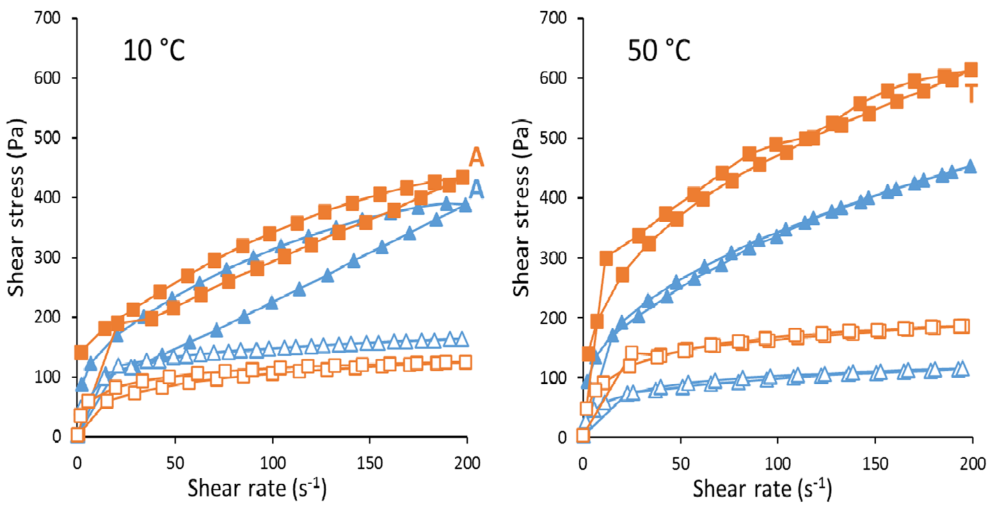

FIGURE 2 Flow behavior of the pudding level of water (Δ) and orange juice (□) for thickener B (filled symbols) and thickener D (open symbols) at 10°C and at 50°C. Letter T indicates thixotropic behavior and letter A indicates antithixotropic behavior. Identification of thickeners in Table 1

TABLE 2 Ostwald–de Waele fit of flow curves of water, coffee, orange juice and milk thickened at nectar level with four commercial thickeners (A–D) at two temperatures (10°C and 50°C)

Drink	T^a	Thickener A		Thickener B		Thickener C		Thickener D	
		K (Pa.s^n)	*n*	*K* (Pa s^n)	*n*	*K* (Pa s^n)	*n*	*K* (Pa s^n)	*n*
Water	10°C	1.81 (0.39)	0.311 (0.019)	0.96 (0.14)	0.450 (0.003)	0.52 (0.08)	0.427 (0.038)	2.07 (0.50)	0.453 (0.022)
	50°C	1.12 (0.34)	0.279 (0.042)	0.88 (0.19)	0.481 (0.021)	0.51 (0.07)	0.514 (0.017)	2.51 (0.18)	0.378 (0.006)
Coffee	10°C	0.99 (0.23)	0.441 (0.033)	0.83 (0.29)	0.480 (0.065)	0.76 (0.16)	0.462 (0.022)	1.15 (0.47)	0.529 (0.052)
	50°C	1.27 (0.43)	0.279 (0.022)	1.35 (0.17)	0.391 (0.030)	0.84 (0.06)	0.427 (0.026)	3.83 (1.30)	0.337 (0.045)
Orange juice	10°C	0.24 (0.15)	0.678 (0.084)	1.79 (0.83)	0.487 (0.076)	1.10 (0.06)	0.450 (0.040)	1.93 (0.94)	0.505 (0.070)
	50°C	0.60 (0.34)	0.457 (0.058)	3.71 (0.65)	0.349 (0.006)	2.85 (0.15)	0.378 (0.014)	3.26 (0.44)	0.401 (0.020)
Milk	10°C	0.04 (0.02)	0.879 (0.075)	0.67 (0.03)	0.525 (0.024)	1.60 (0.46)	0.411 (0.016)	0.14 (0.01)	0.761 (0.029)
	50°C	0.49 (0.06)	0.500 (0.046)	2.87 (0.46)	0.347 (0.017)	2.16 (0.64)	0.374 (0.017)	1.82 (0.50)	0.495 (0.036)

Note: Identification of thickeners in Table 1.
[a]Values are means of three measurements and *SD* (in parentheses).

(Table 2 for nectar samples and Table 3 for pudding samples). Nectar samples did not show yield stress but for pudding samples, the yield stress values ranged from 0 to 71.2 Pa. The effect of temperature depended on the thickener where thickeners B and C showed high values of yield stress while it was 0 or negligible for thickeners A and D. For thickener C, yield stress values did not change with temperature and for thickener B, yield stress values were higher at 10°C than at 50°C. For both thickeners, the exception was coffee. The

TABLE 3 Herschel–Bulkley fit of flow curves of water, coffee, orange juice, and milk thickened at pudding level with four commercial thickeners (A–D) at two temperatures (10°C and 50°C)

Drink	T^a	Thickener A			Thickener B			Thickener C			Thickener D		
		σ_0 (Pa)	K (Pa s^n)	n	σ_0 (Pa)	K (Pa s^n)	n	σ_0 (Pa)	K (Pa s^n)	n	σ_0 (Pa)	K (Pa s^n)	n
Water	10°C	–	17.05 (2.77)	0.133 (0.029)	71.2 (10.2)	2.16 (0.03)	0.946 (0.006)	21.7 (3.9)	9.47 (4.30)	0.618 (0.083)	–	42.20 (18.60)	0.255 (0.064)
	50°C	–	16.94 (5.19)	0.114 (0.020)	35.0 (9.3)	29.13 (14.65)	0.500 (0.072)	31.9 (7.3)	19.88 (8.13)	0.536 (0.092)	–	47.62 (12.50)	0.230 (0.018)
Coffee	10°C	–	21.86 (3.86)	0.151 (0.012)	31.9 (10.5)	19.58 (13.18)	0.470 (0.117)	7.8 (1.7)	24.56 (3.72)	0.435 (0.011)	–	31.58 (12.85)	0.269 (0.049)
	50°C	–	23.67 (4.29)	0.105 (0.012)	32.7 (1.8)	40.41 (2.75)	0.435 (0.002)	38.3 (7.6)	26.12 (6.39)	0.503 (0.039)	–	66.43 (3.02)	0.166 (0.004)
Orange juice	10°C	3.3 (1.3)	10.67 (1.45)	0.296 (0.017)	58.1 (3.9)	23.31 (4.87)	0.535 (0.040)	28.2 (3.7)	30.60 (6.98)	0.490 (0.030)	–	24.30 (3.52)	0.317 (0.028)
	50°C	–	30.12 (0.80)	0.116 (0.002)	10.6 (3.4)	126.37 (12.76)	0.281 (0.023)	30.9 (14.0)	62.10 (15.07)	0.396 (0.037)	–	79.18 (14.62)	0.187 (0.013)
Milk	10°C	2.0 (0.5)	11.69 (0.71)	0.303 (0.003)	39.1 (6.8)	22.73 (4.79)	0.699 (0.048)	12.0 (4.2)	84.34 (20.51)	0.389 (0.020)	7.8 (3.5)	4.13 (0.92)	0.704 (0.063)
	50°C	–	19.04 (4.76)	0.164 (0.008)	3.5 (1.6)	130.10 (30.10)	0.302 (0.033)	13.5 (6.6)	60.49 (10.01)	0.385 (0.030)	–	71.27 (9.78)	0.212 (0.021)

Note: Identification of thickeners in Table 1.
[a]Values are means of three measurements and SD (in parentheses).

consistency index values ranged from 0.04 to 3.8 Pa s^n and 2.2 to 130.1 Pa s^n for drinks thickened at the nectar level and at the pudding level, respectively; furthermore, the values were often higher at 50°C than at 10°C. The flow index values also differed among the thickened drinks, ranging from 0.28 to 0.88 for nectar level and from 0.12 to 0.95 for pudding level. Flow index values decreased with temperature, indicating that pseudoplasticity was higher at 50°C than at 10°C. To analyze the differences in viscosity among thickened drinks and the effect of temperature, the apparent viscosity values at 50 s^{-1} (η_{50}) were used.

As observed in Figures 1 and 2, usually the upstream and the downstream flow curves do not coincide and show a loop indicating the flow was also time-dependent. Depending on the sample and condition, the time-dependent behavior was thixotropic (viscosity or shear stress values decrease with time of shearing) or antithixotropic (viscosity or shear stress values increase with time of shearing). To quantify time-dependence and to study the effect of temperature, the values of the RTA were used.

3.2 | Effect of temperature on apparent viscosity and relative thixotropic area

For drinks thickened at nectar and pudding levels, ANOVA results indicated that the values of apparent viscosity were affected by the temperature, thickener, and drink, as well as their binary and ternary interactions (Table 4). These interactions indicate that the effect of temperature on viscosity values depended on the thickener and drink.

Apparent viscosity values were higher at 50°C than at 10°C (Figure 3) but this effect was not shown with Thickener A, that showed minor changes in viscosity only with temperature. For thickeners B, C, and D, the viscosity changes with temperature were higher, although the magnitude of the change depended on the drink. For water and coffee, the effect was mainly significant at pudding level but not at nectar level and for the milk it was just significant for thickeners B and D. In orange juice, the increase in viscosity with temperature was significant for all the three thickeners.

For liquid foods and according to Arrhenius equation, viscosity values are expected to be higher at lower temperature. However, the opposite is observed for some of the thickened drinks in this and previous studies (Garcia et al., 2008; Martínez González et al., 2016). In the two previous studies, thickeners contained mainly starch, similarly to thickeners B, C, and D of this study. The increase in viscosity values with temperature can be thus attributed to the water absorption of pregelatinized starch granules favored by temperature. Although dysphagia thickeners are designed to thicken at cold temperatures, the thickening capacity of starch-containing thickeners is greater at warm temperatures. The viscosity values did not change with temperature for Thickener A, that does not contain starch (based in maltodextrin and xanthan gum), and supports the role of the starch in the increase of viscosity with temperature of thickened drinks.

Viscosity values when using the starch-containing thickeners (B, C, and D) also varied with the type of drink. The viscosity values

TABLE 4 Effects of thickener (A–D), drink (water, coffee, orange juice and milk) and temperature (10°C and 50°C) on values of the apparent viscosity η_{50} and relative thixotropic area for nectar and pudding levels

	Apparent viscosity η_{50}, *F*-ratio (*p*)		Relative thixotropic area, *F*-ratio (*p*)	
Effects	**Nectar**	**Pudding**	**Nectar**	**Pudding**
Thickener	85.5 (<.001)	556.7 (<.001)	550.8 (<.001)	14.5 (<.001)
Drink	28.2 (<.001)	97.5 (<.001)	20.6 (<.001)	16.9 (<.001)
Temperature	38.8 (<.001)	127.5 (<.001)	0.1 (.709)	299.4 (<.001)
Thickener × drink	13.0 (<.001)	28.0 (<.001)	9.5 (<.001)	10.7 (<.001)
Thickener × temperature	7.9 (<.001)	17.2 (<.001)	87.2 (<.001)	22.5 (<.001)
Drink × temperature	12.8 (<.001)	5.0 (.004)	16.8 (<.001)	18.9 (<.001)
Thickener × drink × temperature	3.1 (.004)	2.8 (.009)	4.2 (<.001)	7.6 (<.001)

Note: *F*-ratio (F) and probability (*p*) values.

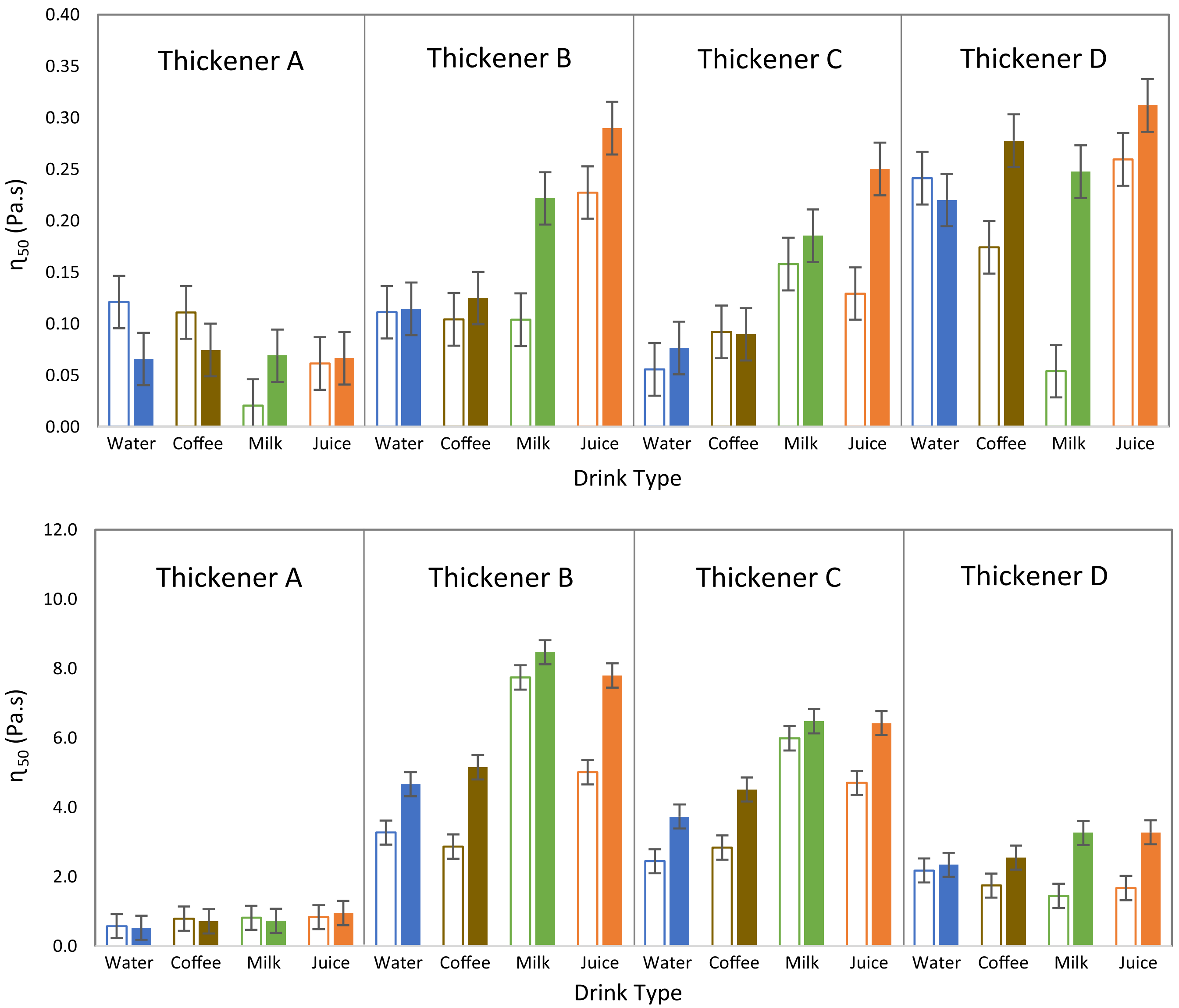

FIGURE 3 Apparent viscosity η_{50} (Pa s) means values of nectar and pudding levels samples, respectively, for the four different thickeners (A–D) dissolved in the four drinks (water, coffee, milk, and orange juice) at 10°C (open) and 50°C (filled). Error bars indicate the Least significant difference (LSD) interval according to Fisher test ($p = .05$). Identification of thickeners in Table 1

were higher for milk and orange juice, already attributed to soluble solids in the disperse media that more effectively allowed starch water absorption (Garcia et al., 2005; Sopade et al., 2008a, 2008b). In this study, the effect of temperature on viscosity also depended on the drink. As shown in Figure 3, the increase in viscosity with temperature was much higher for milk and orange juice, which supports the hypothesis that the effect of temperature on viscosity is also related to the water absorption by starch granules.

Regarding time-dependence, ANOVA results showed that RTA values were significantly affected by the temperature, thickener, and drink, as well as their binary and ternary interactions (Table 4). The effect of temperature on the thixotropic behavior of thickened drinks depended on the type of drink and thickener. As Figure 4 shows, it was different depending on the level of concentration of the thickener (nectar or pudding).

At nectar level, drinks with thickeners B and C were thixotropic with high RTA values that decreased when increasing temperature. For Thickener D, RTA values were low, indicating flow was not time-dependent. For Thickener A, some drinks showed slightly antithixotropy (negative values of RTA).

At pudding level, thickeners A and C presented low RTA values showing low time-dependence. For thickeners B and D, RTA values

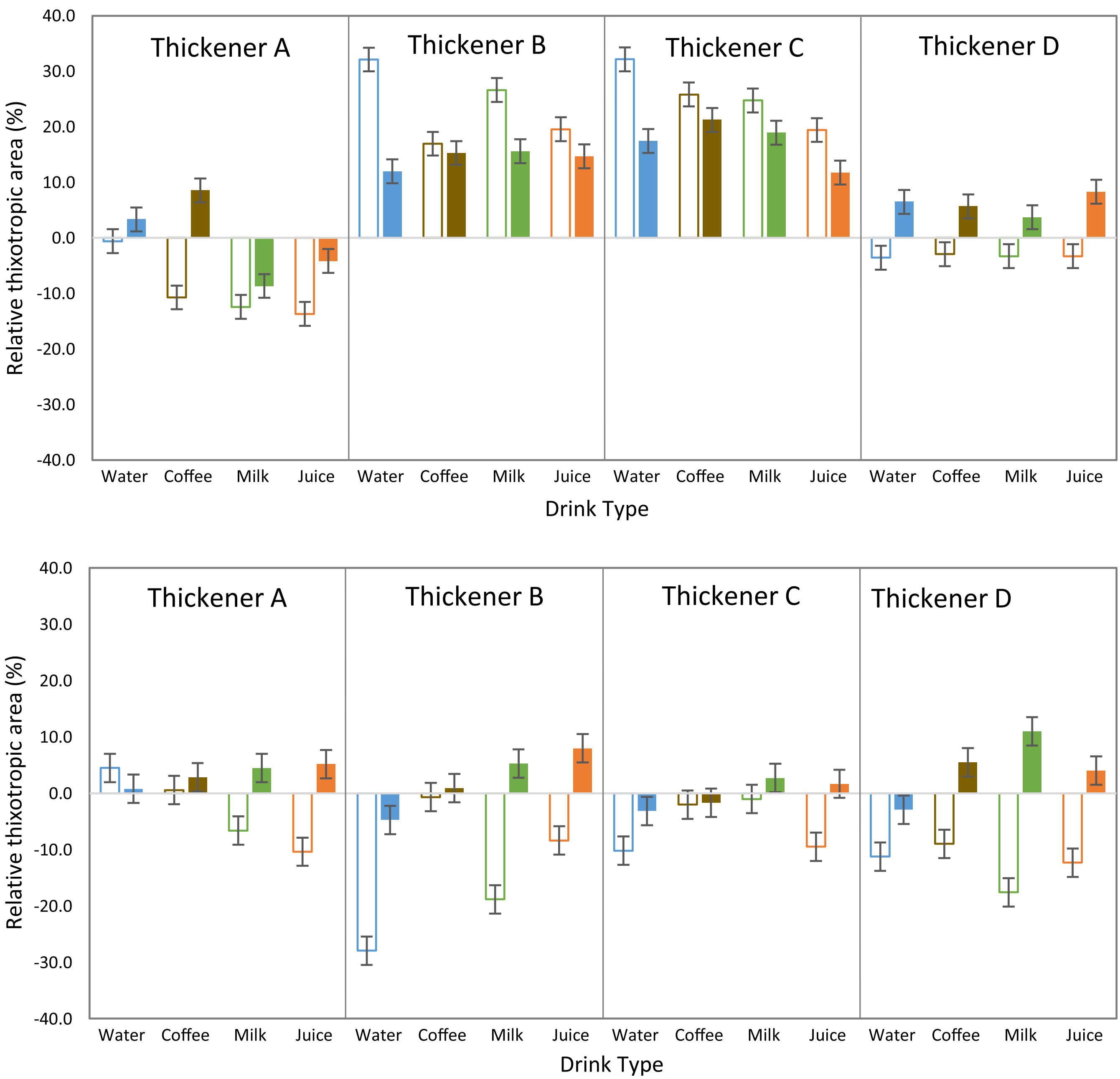

FIGURE 4 Relative thixotropic area means values of nectar and pudding levels samples, respectively, for the four different thickeners (A–D) dissolved in the four drinks (water, coffee, milk and orange juice) at 10°C (open) and 50°C (filled). Error bars indicate the LSD interval according to Fisher Test ($p = .05$). Identification of thickeners in Table 1

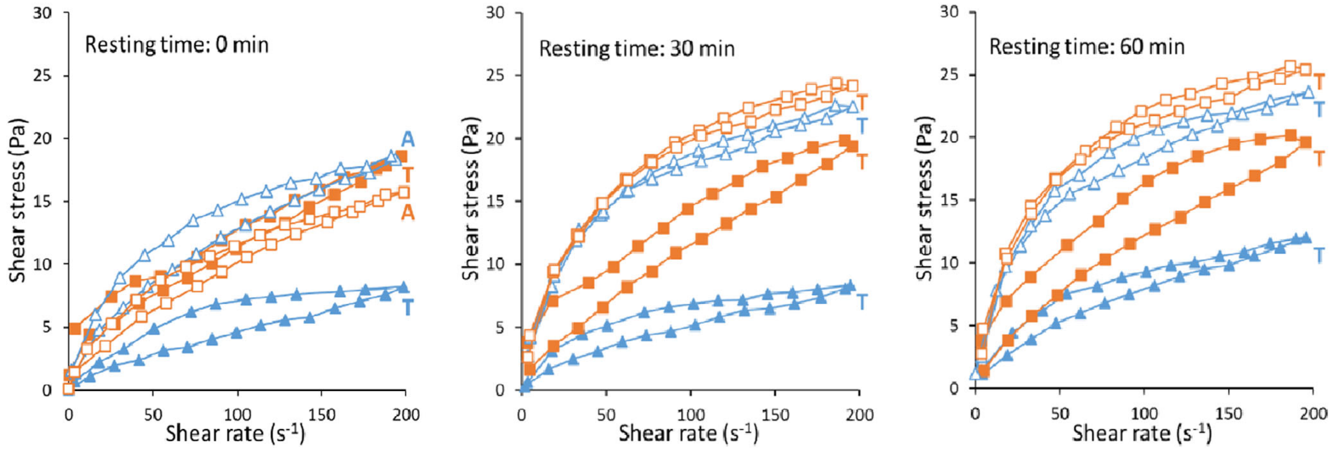

FIGURE 5 Flow behavior of the nectar level of water (Δ) and orange juice (□) for thickener B (filled symbols) and thickener D (open symbols) at a resting time of 0, 30, and 60 min. Letter T indicates thixotropic behavior and letter A indicates antithixotropic behavior. Identification of thickeners in Table 1

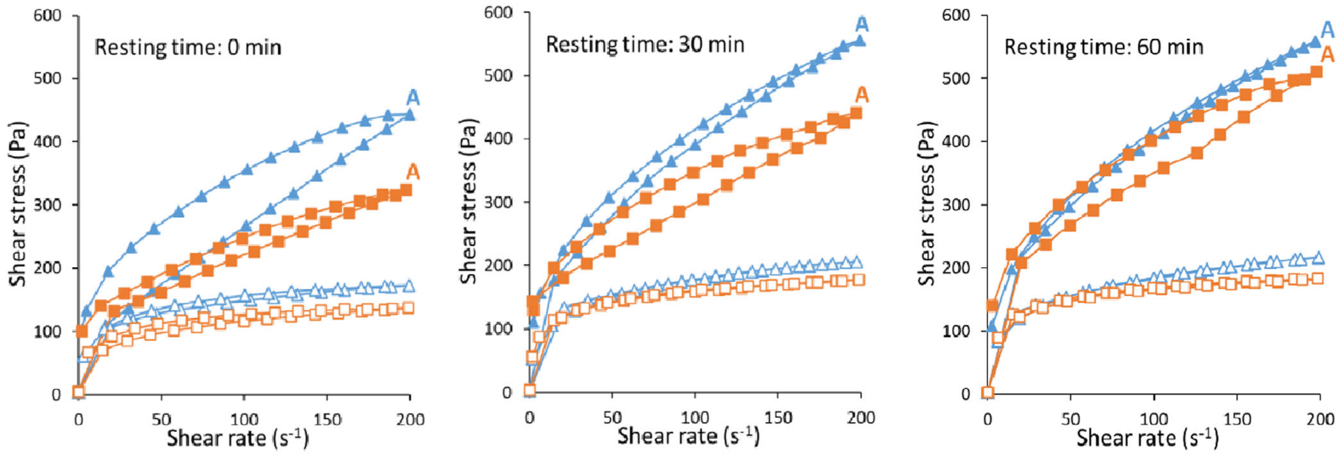

FIGURE 6 Flow behavior of the pudding level of water (Δ) and orange juice (□) for thickener B (filled symbols) and thickener D (open symbols) at a resting time of 0, 30, and 60 min. Letter T indicates thixotropic behavior and letter A indicates antithixotropic behavior. Identification of thickeners in Table 1

TABLE 5 Ostwald–de Waele fit of flow curves of water, coffee, orange juice, and milk thickened at nectar level with four commercial thickeners (A–D) and obtained at 0, 30, and 60 min resting time after preparation

		Thickener A		Thickener B		Thickener C		Thickener D	
Drink	Time	*K* (Pa s^n)	*n*	*K* (Pa s^n)	*n*	*K* (Pa s^n)	*n*	*K* (Pa s^n)	*n*
Water	0 min	2.47 (0.25)	0.234 (0.018)	0.72 (0.07)	0.476 (0.028)	0.51 (0.11)	0.486 (0.029)	0.96 (0.26)	0.574 (0.036)
	30 min	2.94 (0.37)	0.203 (0.012)	1.11 (0.18)	0.385 (0.025)	0.71 (0.11)	0.432 (0.016)	3.54 (0.69)	0.368 (0.024)
	60 min	3.12 (0.40)	0.196 (0.017)	1.44 (0.05)	0.397 (0.014)	0.87 (0.15)	0.416 (0.025)	4.12 (0.66)	0.349 (0.012)
Coffee	0 min	0.32 (0.08)	0.588 (0.043)	1.19 (0.09)	0.368 (0.011)	0.67 (0.06)	0.490 (0.054)	0.62 (0.11)	0.608 (0.018)
	30 min	2.90 (0.24)	0.220 (0.013)	1.12 (0.34)	0.409 (0.056)	1.01 (0.05)	0.391 (0.024)	2.11 (0.46)	0.427 (0.027)
	60 min	3.19 (0.14)	0.207 (0.001)	1.36 (0.23)	0.408 (0.041)	1.26 (0.31)	0.385 (0.045)	3.01 (0.46)	0.377 (0.017)
Orange juice	0 min	0.10 (0.02)	0.766 (0.043)	1.26 (0.41)	0.490 (0.012)	1.49 (0.23)	0.487 (0.032)	0.83 (0.19)	0.602 (0.034)
	30 min	1.33 (0.15)	0.378 (0.009)	1.53 (0.45)	0.452 (0.046)	2.76 (0.44)	0.364 (0.022)	3.12 (0.65)	0.401 (0.022)
	60 min	2.24 (0.27)	0.304 (0.009)	2.40 (0.43)	0.424 (0.025)	3.49 (0.43)	0.320 (0.009)	4.32 (0.78)	0.352 (0.018)
Milk	0 min	0.02 (0.00)	0.910 (0.043)	0.83 (0.22)	0.408 (0.025)	2.10 (0.51)	0.344 (0.025)	0.27 (0.08)	0.728 (0.039)
	30 min	0.17 (0.01)	0.571 (0.043)	3.29 (0.37)	0.324 (0.028)	1.87 (0.17)	0.355 (0.013)	0.67 (0.19)	0.621 (0.028)
	60 min	0.93 (0.04)	0.425 (0.023)	3.61 (0.31)	0.346 (0.015)	1.97 (0.28)	0.378 (0.011)	2.50 (0.20)	0.494 (0.009)

Note: Identification of thickeners in Table 1. Values are means of three measurements and *SD* (in parentheses).

were negative at 10°C for most drinks, indicating antithixotropic behavior, and were positive at 50°C, indicating thixotropic behavior.

Dewar and Joyce (2006) already described both thixotropic and antithixotropic behavior for starch-based thickener solutions in water. According to the authors, the type of time-dependence is different depending on the concentration of the starch-based thickener. At low concentrations, thixotropic behavior is exhibited because when the weak matrix (formed by starch granules, the amylose, and the insoluble amylopectin micelles) in water is sheared, the matrix changes from a structured to non-structured state offering less resistance to flow (lower viscosity). The antithixotropic behavior they observed at high concentrations was attributed to the starch swelling caused by shearing forces. However, our hypothesis is that it is not a true antithixotropy, due to the fact that at high concentrations the pre-gelatinized starch hydration is slow over time and the thickening capacity has not been reached when starting measurements, so the viscosity values continue increasing during flow measurement and thus are higher after shearing. In addition, antithixotropy is observed mainly at 10°C. This reinforced our hypothesis, as at lower temperatures, water absorption into the starch granules is limited and thus the fully thickened capacity takes more time to be reached.

3.3 | Flow behavior of thickened drinks at different resting time

Flow behavior of water and orange juice at 0, 30, and 60 min resting time for thickeners B and D at nectar and pudding levels are shown as examples in Figures 5 and 6. As observed at 10°C and 50°C, all thickened drinks displayed shear-thinning and time-dependent behavior (thixotropy or antithixotropy).

Flow of thickened drinks fitted well to the Ostwald–de Waele model for nectar level samples ($r = .96$–$.99$). The Herschel–Bulkley model was used and fit well for pudding level samples ($r = .90$–$.99$), except again in two cases of coffee (after 30 and 60 min) with thickener A ($r = .86$). Tables 5 and 6 show the mean values of the yield stress, consistency index and flow index at nectar and pudding level, respectively. Nectar samples, as in temperature, did not show yield stress and the yield stress values of pudding samples ranged from 0 to 53.1 Pa. Once again, yield stress values were only relevant for thickeners B and C, and the effect of resting time depended on the thickener and the drink. Consistency index values varied from 0.02 to 4.3 Pa s^n for nectar level and from 2.4 to 216.7 Pa s^n for pudding level. The flow index values varied from 0.20 to 0.91 for nectar level and from 0.11 to 0.79 for pudding level. Consistency index values increased with resting time and flow index values decreased, indicating that flow of the thickened drinks became more consistent and pseudoplastic with increasing resting time. For analyzing differences among thickened drinks and the effect of resting time, the apparent viscosity values at 50 s^{-1} (η_{50}) and the RTA values were used.

TABLE 6 Herschel–Bulkley fit of flow curves of water, coffee, orange juice, and milk thickened at pudding level with four commercial thickeners (A–D) and obtained at 0, 30, and 60 min resting time after preparation

		Thickener A			Thickener B			Thickener C			Thickener D		
Drink	Time	σ_0 (Pa)	K (Pa s^n)	n	σ_0 (Pa)	K (Pa s^n)	n	σ_0 (Pa)	K (Pa s^n)	n	σ_0 (Pa)	K (Pa s^n)	n
Water	0 min	-	17.91 (0.84)	0.134 (0.008)	50.9 (2.7)	5.82 (0.96)	0.788 (0.043)	28.0 (6.9)	9.47 (0.98)	0.618 (0.020)	-	52.92 (4.35)	0.221 (0.014)
	30 min	-	18.48 (1.39)	0.129 (0.008)	45.8 (5.4)	29.49 (0.22)	0.527 (0.016)	40.0 (9.6)	9.43 (1.93)	0.654 (0.025)	-	64.49 (1.66)	0.214 (0.010)
	60 min	-	18.65 (1.12)	0.129 (0.002)	24.4 (1.2)	45.64 (1.74)	0.453 (0.015)	37.5 (5.7)	9.43 (0.75)	0.656 (0.033)	-	63.39 (3.45)	0.222 (0.016)
Coffee	0 min	-	23.91 (0.28)	0.131 (0.003)	31.2 (3.5)	8.22 (2.65)	0.604 (0.077)	15.3 (7.0)	19.83 (7.82)	0.468 (0.045)	-	32.65 (3.34)	0.263 (0.013)
	30 min	-	26.46 (1.82)	0.111 (0.002)	31.8 (8.6)	24.93 (8.11)	0.461 (0.066)	21.6 (2.8)	24.19 (6.15)	0.443 (0.024)	-	58.40 (4.95)	0.192 (0.007)
	60 min	-	25.89 (1.04)	0.113 (0.001)	34.2 (4.3)	22.83 (6.30)	0.495 (0.054)	17.9 (0.1)	37.58 (14.3)	0.397 (0.065)	-	63.54 (3.31)	0.184 (0.004)
Orange juice	0 min	-	13.63 (2.43)	0.263 (0.034)	32.7 (1.1)	13.15 (3.76)	0.782 (0.185)	1.3 (0.8)	94.96 (8.10)	0.336 (0.021)	9.8 (1.8)	2.41 (0.70)	0.779 (0.038)
	30 min	-	25.44 (0.50)	0.172 (0.005)	-	181.95 (33.59)	0.255 (0.016)	-	163.20 (6.15)	0.235 (0.004)	8.5 (4.3)	18.88 (4.79)	0.455 (0.049)
	60 min	-	29.18 (1.05)	0.149 (0.005)	-	216.67 (10.23)	0.230 (0.004)	-	167.43 (15.26)	0.234 (0.015)	2.0 (0.8)	31.01 (4.19)	0.372 (0.024)
Milk	0 min	-	19.46 (4.06)	0.201 (0.033)	42.6 (6.6)	15.12 (3.59)	0.576 (0.026)	39.4 (15.7)	35.80 (3.48)	0.471 (0.021)	-	29.64 (4.99)	0.287 (0.025)
	30 min	-	34.58 (1.17)	0.128 (0.008)	35.6 (18.9)	33.99 (15.46)	0.587 (0.123)	51.9 (5.0)	31.99 (6.89)	0.509 (0.021)	-	59.67 (4.98)	0.205 (0.009)
	60 min	-	5.82 (0.96)	0.121 (0.005)	53.1 (0.7)	33.33 (5.39)	0.496 (0.029)	47.2 (11.4)	46.57 (13.10)	0.447 (0.024)	-	70.36 (3.13)	0.187 (0.007)

Note: Identification of thickeners in Table 1. Values are means of three measurements and SD (in parentheses).

TABLE 7 Effects of thickener (A–D), drink (water, coffee, orange juice, and milk) and resting time (0, 30, and 60 min) on values of the apparent viscosity η_{50} and relative thixotropic area for nectar and pudding levels

	Apparent viscosity η_{50} *F*-ratio (*p*)		Relative thixotropic area *F*-ratio (*p*)	
Effects	**Nectar**	**Pudding**	**Nectar**	**Pudding**
Thickener	241.8 (<.001)	1,520.9 (<.001)	1,394.8 (<.001)	155.9 (<.001)
Drink	63.3 (<.001)	365.5 (<.001)	85.5 (<.001)	30.1 (<.001)
Resting time	202.4 (<.001)	210.3 (<.001)	264.8 (<.001)	312.0 (<.001)
Thickener × drink	40.3 (<.001)	160.5 (<.001)	20.4 (<.001)	63.2 (<.001)
Thickener × resting time	23.7 (<.001)	50.4 (<.001)	82.9 (<.001)	22.0 (<.001)
Drink × resting time	9.8 (<.001)	20.3 (<.001)	24.4 (<.001)	31.6 (<.001)
Thickener × drink × resting time	6.0 (<.001)	9.0 (<.001)	11.0 (<.001)	11.3 (<.001)

Note: *F*-ratio (*F*) and probability (*p*) values.

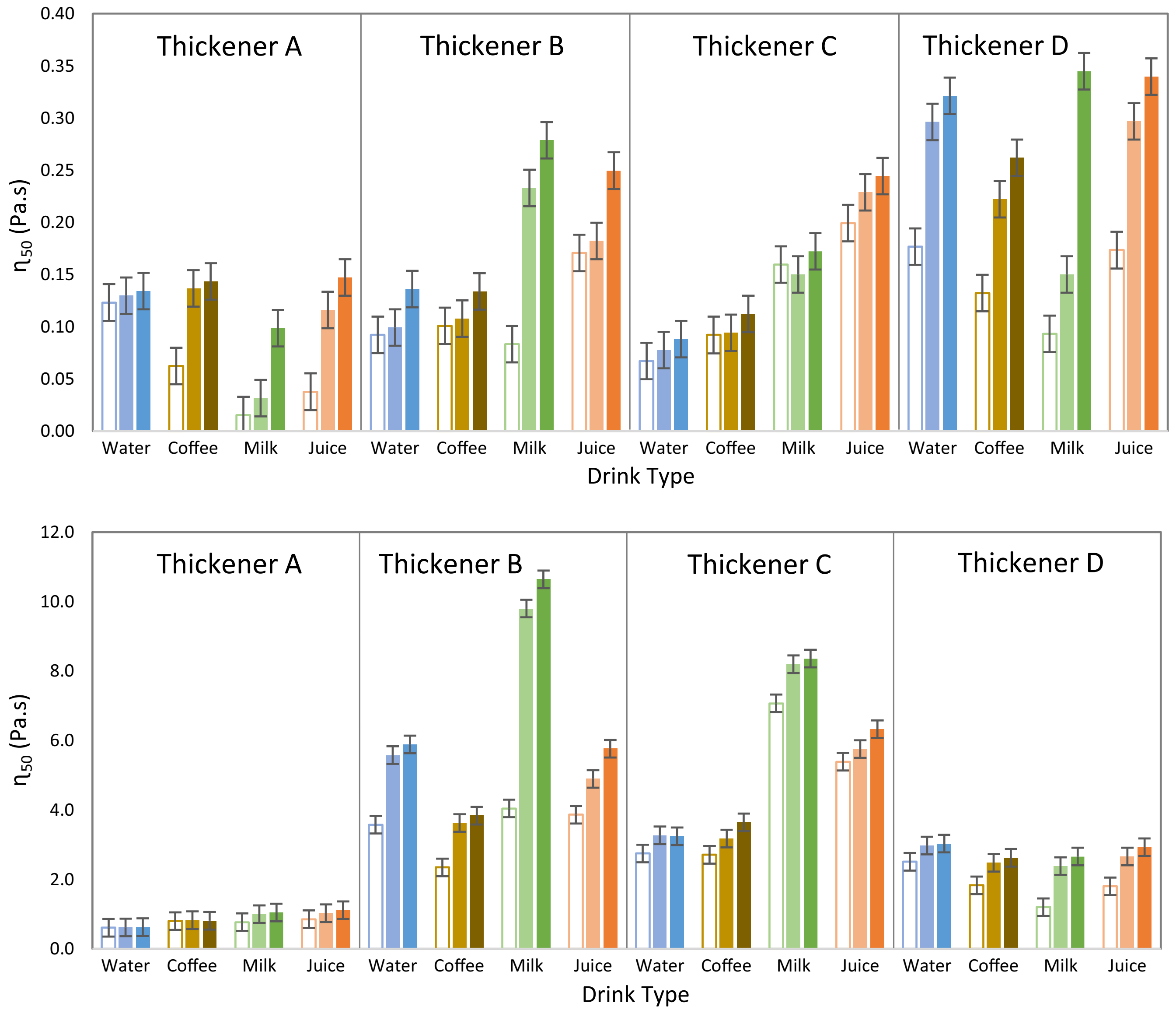

FIGURE 7 Apparent viscosity η_{50} (Pa s) mean values of nectar and pudding levels samples, respectively, for the four different thickeners (A–D) dissolved in the four drinks (water, coffee, milk and orange juice) at a resting time of 0 min (open), 30 min (semi-filled) and 60 min (filled). Error bars indicate the LSD interval according to Fisher test ($p = .05$). Identification of thickeners in Table 1

3.4 | Effect of resting time on apparent viscosity and relative thixotropic area

ANOVA results (Table 7) showed that the values of apparent viscosity η_{50} significantly depended on the three factors (resting time, drink, and thickener) and their binary and ternary interactions indicating the effect of resting time was different depending on the drink and thickener.

Figure 7 shows the η_{50} values of the thickened drinks at the different resting times of nectar and pudding levels. Overall, the apparent viscosity values increased with resting time, but the effect depended on the drink type and the thickener. At nectar level, viscosity values increased with the resting time for thickeners A, B, and D, and the increase was higher for milk and orange juice. However, for Thickener C viscosity values did not significantly change with resting time. At pudding level, viscosity increased with resting time for thickeners B, C, and D but remained stable for Thickener A.

The increase in viscosity with resting time indicates that thickener action is being developed with time until the full thickening capacity is reached. Garcia et al. (2008) already showed this same effect for starch-based thickeners, attributed to a progressive water uptake by starch granules during resting time, but not for gum-based thickeners.

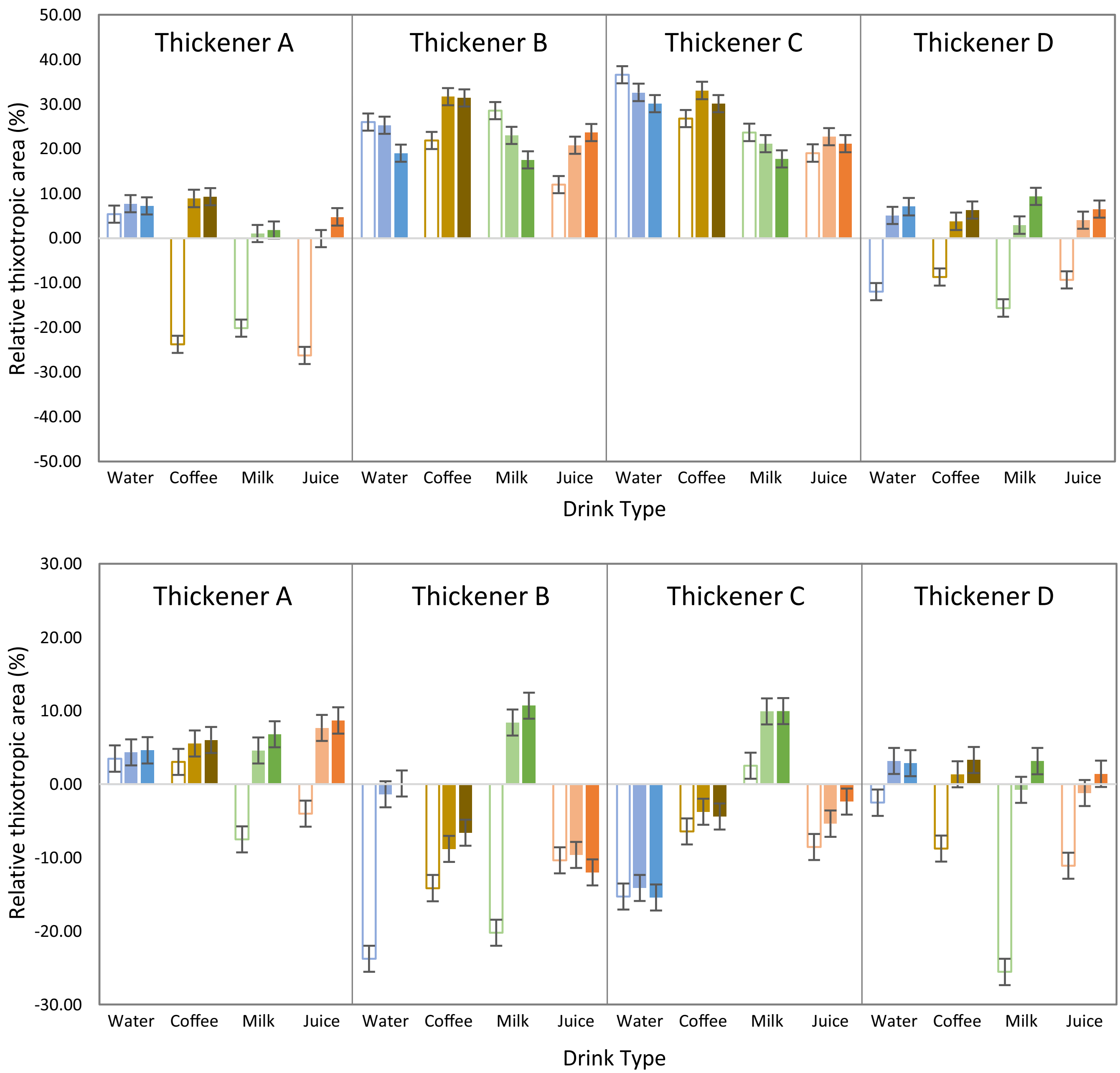

FIGURE 8 Relative thixotropic area means values of nectar and pudding levels samples, respectively, for the four different thickeners (A–D) dissolved in the four drinks (water, coffee, milk and orange juice) at a resting time of 0 min (open), 30 min (semi-filled), and 60 min (filled). Error bars indicate the LSD interval according to Fisher test ($p = .05$). Identification of thickeners in Table 1

In this study, an increase in viscosity with time has been also observed for the gum-based thickener (A) at nectar level, which can be attributed to the time need for chain entanglements or bindings to occur in xanthan gum solutions at low thickener concentrations (Cho & Yoo, 2015).

ANOVA (Table 7) also showed that the effect of resting time on RTA values depended on the drink and the thickener (significant binary and ternary interactions). As Figure 8 shows, thickeners A and D, in most cases, change with resting time from antithixotropic (at 0 min) to non-time-dependent behavior (after 30 and 60 min). Thickeners B and C showed thixotropic behavior at low concentration (nectar level) that remained almost constant over all resting periods. However, at pudding level they showed antithixotropic behavior that decreased with resting time, probably because the full thickening capacity had been already reached.

Both the increase in viscosity and the decrease of the antithixotropy with time confirm our hypothesis that antithixotropic behavior happens because thickening action is still being developed during the measurement.

These results indicate that a resting time is advisable (at least 30 min) to allow thickened drinks to stabilize viscosity values, as already elucidated in two previous studies (Cho & Yoo, 2015; Kim & Yoo, 2018). Despite this, the preparation instructions of the commercial thickeners used in this study did not mention a resting time or indicated only a resting time of few seconds or minutes. It should be considered that having a resting time is not always easy to manage in a real context, and it is not advisable to keep people living with dysphagia waiting as they might already experience dehydration problems. IDDSI has proposed the use of syringe, as a tool that allows to measure an index of viscosity by controlling the flow out of a syringe over 10 s (Cichero et al., 2017). However, it would be also desirable having a direct and easier tool to check and measure directly and repeatedly if necessary the suitable viscosity of the thickened drinks.

4 | CONCLUSIONS

When preparing thickened drinks for dysphagia patients, context factors such as drink temperature and resting time should be considered, as viscosity is highly influenced by both factors. This add complexity to managing the viscosity level of the drink that, as previously reported, is also difficult because of the changes in viscosity when using different thickeners or drinks.

Changes in viscosity with temperature are relevant when using starch-containing thickeners. For these thickeners and contrary to what is expected for a polysaccharide matrix, the viscosity of drinks was higher when prepared at warm temperature (50°C) than at cold temperature (10°C). The effect was greater for more concentrated media (orange juice and milk) than for water and coffee.

For both starch and gum-based thickeners, the viscosity of drinks increases over time, because thickening activity is being developed. The time to reach a constant viscosity depends on the type of drink and the thickener, but it can take over 30 min.

Antithixotropic behavior (increase in viscosity with shearing time) is observed in the flow of thickened drinks, especially at high thickener concentration (pudding level) and at 10°C. Antithixotropy decreases or disappears with increased resting time, because of a constant viscosity not being reached and thickening activity is still developing during flow measurements.

All changes in viscosity and time-dependence with the temperature and the resting time observed for the thickened drinks, highlights the need of looking for new solutions for verifying suitable viscosity values in thickened drinks directly in the glass preparation.

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AUTHOR CONTRIBUTIONS

Celia Badia-Olmos: Investigation (equal); writing – original draft (equal). **Laura Laguna:** Conceptualization (lead); funding acquisition (equal); investigation (equal); resources (equal); supervision (equal). **Arantxa Rizo:** Supervision (equal); writing – review and editing (equal). **Amparo Tárrega:** Formal analysis (equal); funding acquisition (equal); supervision (equal); writing – original draft (equal); writing – review and editing (equal).

ETHICAL STATEMENTS

Conflict of Interest: The authors declare that they do not have any conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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