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Designing of texture modified fruit juices using food hydrocolloids: Storage influence on viscosity

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ABSTRACT

Elderly individuals require special dietary considerations due to various physiological dysfunctions (such as dysphagia, constipation, etc.) and specific nutritional needs. Dysphagia, the difficulty associated with swallowing can lead to some challenges in containing and transitioning of food or liquids within the mouth, increasing the risk of aspiration pneumonia. Thickening fluid is an effective method for alleviating swallowing difficulties. It works by slowing down the flow of liquids during swallowing, thus reducing the risk of aspiration into the airway. The purpose of this research is to develop texture-modified (TM) fruit juices to cater to the needs of elderly individuals with impaired swallowing abilities. To achieve this goal, we created TM fruit juices thickened with hydrocolloids, specifically guar gum (GG), xanthan gum (XG), and starch (S), at different concentrations. The thickened liquids, classified at three National Dysphagia Diet levels, were stored at 4 °C for three months. Physicochemical analyzes of the fruit juices were performed before and after storage. The sensory differences and flow behaviors of orange juice samples containing ascending concentrations of all studied thickeners were investigated at the end of the three-month storage. The results indicated significant changes in the physicochemical properties of the samples, depending in the type of fruit, the hydrocolloid used, and the storage period. Sensory evaluation revealed that orange juices containing starch were more preferred compared to other samples. Therefore, using orange juice thickened with easily swallowed, and less viscous starch will be a safer option for the elderly and individuals with swallowing difficulties.

1. Introduction

In recent years, the proportion of people aged sixty over in the world's total population has been steadily increasing. With this rapid growth in the elderly population, there is an urgent need to address their specific food and nutrition requirements. The nutritional needs of the elderly are influenced by factors such as sensory enjoyment, safe eating patterns, physiologic changes in body composition, and special nutritional needs associated with aging. These anatomical and physiological changes often lead to difficulties in chewing and swallowing for the elderly [1]. Dysphagia refers to any disorder related to swallowing. Difficulty in chewing and swallowing can lead to malnutrition and aspiration pneumonia, especially among elderly and dysphagic patients. Such patients are at a higher risk of choking and food aspiration during meals. Consequently, there is an increasing demand for easily chewable and swallowable food products tailored to their needs [2,3]. Individuals with dysphagia can opt for texture-modified foods and thickened

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fluids are alternative choices. The thickeners can make liquids thicker by increasing their viscosity, which helps prevent aspiration [4, 5].

Texture-modified (TM) foods refer to foods with a soft texture and reduced particle size, as well as liquids thickened with various hydrocolloids, specifically designed for individuals with eating dysfunctions [6]. These soft-textured foods can be broken down and mixed in the mouth with tongue-palate pressure. TM foods are categorized according to several standards, including those set by the Japanese Society of Dysphagia Rehabilitation, the International Dysphagia Diet Standardization Initiative (IDDSI), National Dysphagia Diet (NDD) task force, and the guide developed by Swedish researchers [7]. These standards are used to identify viscosity level and food texture. The IDDSI framework is a continuum of eight levels (0–8) used to evaluate liquids and foods, ranging from levels 0 to 4 and for liquids and 3 to 7 for foods. The flow test assesses IDDSI levels 0 to 4 on the flow rate, while the fork pressure test assesses foods on a scale of 4–7 [8]. Thickened liquids are classified into three categories: mildly thick (50–150 cP), moderately thick (150–300 cP), and extremely thick (300–500 cP), according to the Japanese Dysphagia Diet Criteria.

Proteins, carbohydrates, and lipids form the fundamental building blocks in designing and producing most TM foods. Natural hydrocolloids have been employed to enhance the functional properties and stability of various food products, while also increasing their nutritional and health benefits. Recently, hydrocolloids have become the preferred choice in formulating of TM foods to create soft microgel particles and fibers. Plant-derived hydrocolloids, such as starch, pectin, gum, cellulose, as well as hydrocolloids from animal sources, like gelatin, chitosan, egg and whey proteins, are utilized to slow down the flow of TM liquids, preventing aspiration from the trachea during consumption [9,10]. Funami et al. [11] investigated the relationship between *in vivo* measurements during oral processing, sensory evaluation, and rheological analyses to enhance the knowledge on the texture design of foods for dysphagia patients. They utilized soft polysaccharide gels as a model for foods suitable for dysphagia patients, allowing them to be eaten by compressing them between the tongue and the hard palate without the need to bite with teeth. They concluded that the sound pressure ratio determined through acoustic analysis and the flow of the food mass could serve as objective parameters to describe the food texture, particularly cohesiveness. Moreover, they recommended the use of multiple hydrocolloids as the most practical approach in designing TM foods for dysphagia patients. In another study, Hayakawa et al. examined texture profiles of hydrocolloid gels as a food model to assess eating difficulty through descriptive sensory evaluations [12]. They found that resistance to fracture, stickiness, and flexibility were the most critical factors contributing to eating difficulties among all sensory parameters. Cho et al. [13] investigated the rheological properties of cold thickened beverages (bottled water, orange juice, apple juice, and whole milk) prepared with a commercially available gum-based food thickener (xanthan-guar gum mixture) at three different thickener concentrations (2, 3, and 4 %, w/w). They concluded that steady and dynamic rheological parameters of thickened beverages were significantly influenced by thickener concentration and the type of beverage prepared. Considering the necessity for thickened liquids in the nutrition of dysphagic individuals with impaired chewing and/or swallowing, further research on viscosity terminology used for standardizing TM liquids is essential.

The viscosity of hydrocolloids is influenced by various intrinsic factors such as structural features, concentration, average molecular weight, molecular weight distribution, solubility, as well as extrinsic factors like pH, temperature, processing steps, food matrix characteristics. From this point, paying particular attention to processing and storage treatments becomes crucial to maintain the integrity of the food ingredients. Studies have shown beverages prepared with β-glucan and β-glucan-xanthan gum exhibited a significant increase in viscosity and turbidity over time with storage, while beverages containing guar gum, and konjac-mannan showed a slight decrease in viscosity with storage time [14]. This change in viscosity over time can be attributed to how the fibers behavior in the solution and the molecular interactions between different polysaccharides. In another study, a fermented soy milk beverage with added apple juice was produced, and its rheological properties were measured immediately after production and during a 21-day storage period [15]. The results showed that both the concentration of apple juice and the storage period had an impact on the consistency of the fermented soy milk beverage. The effectiveness of the dysphagia treatment is dependent on the recommended viscosity. Any significant variability in the consistency of modified food or liquid can influence the health outcomes of patients with dysphagia. Therefore, it is essential to ensure that product consistency remains minimally affected under various conditions [16].

Studies conducted to date have mostly focused on examining commercially packaged, pre-thickened beverages and those prepared using ready-made food thickeners. Unlike these studies, in our study, it was aimed to produce new products for the dysphagia diet that are nutritious, easy to swallow, and can maintain their stability during storage. To date, no study has compared viscosity measurement variability among different TM liquids prepared using hydrocolloids as thickener, or the changes in their viscosities and some chemical properties during long-term storage. The objective of this study is multiple: (a) to develop texture-modified fruit juices to recommend appropriate food consistency for patients with dysphagia and elderly individuals. (b) to study three hydrocolloids for dysphagia; starch, xanthan gum and guar gum, regarding meaningful changes in viscosities, flow behaviour, some chemical and sensorial properties of three fruit juices. (c) to assess the stability of these products at cold temperature during long-term storage. (d) to compare differences between two standards by preparing thickened liquids from the three NDD levels and classifying them according to the IDDSI framework levels by using a flow test. At the end of the storage period, we conducted sensory analyses and rheological measurements to describe the textural characteristics of TM liquids thickened with different hydrocolloids.

2. Materials and methods

2.1. Materials and sample preparation

This study focused on investigating three different food thickeners: modified potato starch (E1414- Dr Gusto, acetylated starch phosphate obtained by cold process), xanthan gum (E415- Erlab) and guar gum (E412- Alfasol). The fruits used in this study (apple, orange and peach) were purchased from the local market in Fethiye, Muğla. After washing the fresh fruits and removing their seeds, fruit juices extracted using a fruit juicer. To eliminate fibrous particles, the fruit juices were filtered through a fine strainer. Glycerol was used to dissolve food thickeners at different concentrations to prevent agglomeration. To prepare the thickened fruit juices, different concentrations of food thickeners (as shown in Table 1) were added to the fruit juices while moderately stirring for 10 min at 400 rpm a magnetic stirrer. As seen in Table 1, to reach three viscosity levels recommended by the NDD, thickener concentrations added to the juices showed differences by thickener type. After adding thickeners, the samples were kept in a 4 °C refrigerator for 1 h to allow them to thicken completely. Subsequently, the fruit juices (250 mL in 330 mL bottles) were pasteurized at 95 °C for 5 min using a laboratory water bath (Samheung, SH-WB-22GDN). Once pasteurized, the samples were cooled to room temperature with tap water and then stored in a horizontal position in a refrigerator (Vestel, 16 TR A+) at 4 °C for 3 months until the analysis. Analysis of TM fruit juice samples were conducted at 0 and 3 months to observe changes that occurred during storage.

2.2. Measurement of viscosity

All thickened liquids were measured using a viscometer (B-one Plus, Lamy Rheology Instruments, Turkey) with ASTM R2 spindle (Ø: 46.93 mm). The measurements were conducted at a temperature of 25 ± 2 °C with a shear rate set to 50 $s^{-1.}$ The instrument provided an accuracy of (±1 %) and repeatability of (±2 %). Each sample underwent three repeated viscosity measurements.

2.3. Flow and fork drip test

The flow test was conducted in accordance with IDDSI guidelines [17]. Initially, the syringe plunger was removed and the nozzle of the syringe was covered with a finger to prevent sample leakage. The syringe was then filled up to the 10 ml mark and held perpendicular to the floor. Upon releasing the nozzle, the timer was started, and the liquid flow was stopped at 10 s by closing nozzle with a finger. The amount of remaining sample in the syringe was recorded. Each sample was tested three times to ensure more reliable results.

According to IDDSI guidelines, thick drinks and fluid foods can be tested by assessing whether they flow through the tines of a fork. Liquidized/moderately thick foods classified as Level 3 according to IDDSI standards drip slowly or in dollops through the fork's tines. For pureed/extremely thick food categorized as Level 4, a small amount of food is expected to flow through and form a short tail below the tines. These foods do not continuously dollop, flow or drip through the tines.

2.4. Total phenolic content of TM fruit juices

The total phenolic content of the fruit juices was determined using the Folin-Ciocalteu reagent, following the method outlined in the study by Singleton and Rossi [18]. For this analysis, a reaction mixture was prepared containing 0.5 mL of fruit juices, 0.2 mL of the Folin-Ciocalteu reagent and 0.5 mL of sodium carbonate solution (20 % w/v). The mixture was then adjusted to a final volume of 10 mL using distilled water. After allowing the reaction to proceed for 1 h, the absorbance at 765 nm was measured. A calibration curve was established using gallic acid (GA) as the standard. Phenolic content was quantified in milligrams of GA equivalents (GAE) per liter of the fruit juice.

2.5. Antioxidant activity by DPPH radical inhibition assay

The antioxidant activity was assessed using the DPPH radical scavenging method, following the modification by Ankolekar et al. [19]. To begin, 10 mL of thickened juice samples were centrifuged at 7000 rpm for 15 min. A 250-μL portion of the sample extract was then combined with 1250 μL of DPPH solution (60 μM in ethanol). This reaction mixture was incubated in darkness for 30 min. Subsequently, the absorbance was measured at 517 nm using a spectrophotometer (Agilent Cary 60 UV–Vis). The obtained readings were compared to controls that contained 95 % ethanol in place of the sample extract. The inhibition percentage was calculated by:

Table 1
Thickener concentration (%) added to the fruit juices investigated.

Liquid	Thickener	NDD Level		
		1 Thin	2 Nectar-like	3 Honey-like
Apple Juice	GG	0.07	0.30	0.53
	XG	0.03	0.20	0.53
	S	0.33	1.47	2.67
Orange Juice	GG	0.03	0.27	0.60
	XG	0.01	0.20	0.40
	S	0.33	1.47	2.67
Peach Juice	GG	0.03	0.25	0.53
	XG	0.01	0.20	0.47
	S	0.20	1.33	2.13

$$\% \text{ inhibition} = ((\text{Absorbans}_{\text{control}} - \text{Absorbans}_{\text{sample}}) / \text{Absorbans}_{\text{control}}) \times 100$$

2.6. Color analysis

The color analysis of fruit juice samples was carried out at 0 and 3 months during storage. The analysis was conducted at room temperature (25 °C) using a CR-10 Color Analyzer (HunterLab Co., Reston, Va., U.S.A). Prior to analysis, the colorimeter was calibrated using a white color standard. The color attributes were measured, with *L* indicating lightness, *a* representing redness and *b* indicating yellowness. Each sample underwent three measurements, and results were averaged for analysis.

2.7. pH measurements

First, TM juices were centrifuged at 9000 rpm. Subsequently, pH measurements of fruit juice samples were conducted by directly immersing the glass electrode of a pH meter (MettlerToledo, Fiveeasyplus FP20) into the sample at a temperature of 25 °C [20].

2.8. Determination of total acidity

The total acidity of fruit juices was determined using the titration method outlined by Sànchez-Moreno et al. [21]. To start, 5 mL of TM fruit juices were diluted with 100 mL of distilled water, and the mixture was then filtered using filter paper to eliminate solid particles. The total acidity was measured through titration, involving the addition 0.1 N NaOH to a 5 mL aliquot of fruit juices until a pink color appeared. The outcomes were presented as percentages of citric and malic acid content. These measurements were conducted in triplicate.

2.9. Sensorial analysis

In the food industry, application of two-step pasteurization and addition of food preservatives can increase the shelf life of orange juices to 12 months. In this study, orange juices were produced by squeezing and pasteurized under laboratory conditions. Pasteurization was applied once after bottling and no additives were added to the orange juices. Because of these all causes, storage was limited to three months so that sensory analyzes could be performed before any deterioration began in the orange juices. TM orange juices stored for three months, prepared at three different viscosity levels using S, GG, and XG, were employed for the sensory and preference tests. The panel for sensory evaluation consisted of ten adult and healthy participants from Fethiye Faculty of Health Sciences. The panelists were informed about the details and implications of participating in the experiment, and written consent was

Table 2
Viscosity values (cP), at 50 s^{-1} and 25 °C, for each fruit juice, thickener, and storage time.

Liquid	Viscosity of liquid without hydrocolloid (cP)	Thickener	Storage Time (Days)	NDD Level		
				Thin (1–50 cP)	Nectar-like (51–350 cP)	Honey-like (351–1750 cP)
Apple Juice	13.48 ± 0.33	GG	1	$20.03^{fg} \pm 0.17$	$153.43^{d} \pm 0.23$	$652.40^{fg} \pm 1.78$
			90	$19.93^{fg} \pm 0.98$	$200.94^{e} \pm 2.54$	$911.50^{\imath} \pm 1.73$
		XG	1	$17.07^{abc} \pm 0.54$	$244.70^{gh} \pm 4.51$	$1436.90^{j} \pm 1.77$
			90	$27.20^{i} \pm 0.66$	$267.90^{\imath} \pm 0.56$	$1252.67^{i} \pm 4.62$
		S	1	$17.66^{bcd} \pm 0.68$	$214.37^{f} \pm 3.78$	$669.07^{gh} \pm 7.15$
			90	$18.0^{cde} \pm 0.3$	$244.9^{h} \pm 8.3$	$319.0^{c} \pm 6.9$
Orange Juice	15.68 ± 0.15	GG	1	$18.99^{def} \pm 0.64$	$119.93^{c} \pm 0.15$	$377.67^{d} \pm 1.36$
			90	$16.53^{ab} \pm 0.22$	$44.48^{b} \pm 0.25$	$100.3^{a} \pm 0.3$
		XG	1	$21.78^{h\imath} \pm 0.64$	$195.20^{e} \pm 3.04$	$661.93^{g} \pm 5.59$
			90	$21.79^{h\imath} \pm 0.17$	$191.60^{e} \pm 3.44$	$551.53^{e} \pm 3.68$
		S	1	$20.63^{gh} \pm 0.52$	$146.93^{d} \pm 4.97$	$623.10^{f} \pm 3.67$
			90	$19.34^{efg} \pm 0.12$	$22.19^{a} \pm 0.07$	$354.5^{cd} \pm 13.5$
Peach Juice	20.53 ± 0.69	GG	1	$21.55^{h} \pm 0.14$	$119.30^{c} \pm 1.23$	$643.10^{fg} \pm 1.13$
			90	$20.78^{gh} \pm 0.17$	$112.43^{c} \pm 1.53$	$642.56^{fg} \pm 0.11$
		XG	1	$23.05^{\imath} \pm 0.51$	$304.30^{i} \pm 9.61$	$934.97^{\imath} \pm 5.76$
			90	$15.75^{a} \pm 0.27$	$306.73^{i} \pm 7.15$	$645.90^{fg} \pm 5.88$
		S	1	$45.25^{k} \pm 0.25$	$231.67^{g} \pm 5.05$	$699.97^{h} \pm 13.25$
			90	$42.90^{j} \pm 0.34$	$55.75^{b} \pm 0.18$	$265.10^{b} \pm 5.81$

Note: Mean ± SD. Different letters in the same column represent statistically significant differences ($P < 0.05$) by Tukey's multiple range test.

Table 3
The syringe residual amounts (mL) from IDDSI flow test.

	Liquid	Thickener	Storage Time (Days)	Thin remaining volume (mL)	Correspondence to IDDSI categories	Nectar-like remaining volume (mL)	Correspondence to IDDSI categories	Honey-like remaining volume (mL)	Correspondence to IDDSI categories
IDDSI Flow Test	Apple Juice	GG	1	0 ± 0	0	$2.2^{cd} \pm 0.3$	1	$7^{d} \pm 0$	2
			90	0 ± 0	0	$3^{e} \pm 0$	1	$8.2^{e} \pm 0.3$	3
		XG	1	0 ± 0	0	$4^{f} \pm 0$	2	$9.2^{f} \pm 0.3$	3
			90	0 ± 0	0	$4^{f} \pm 0$	2	$8^{e} \pm 0$	3
		S	1	0 ± 0	0	$3.8^{f} \pm 0.3$	1	$7^{d} \pm 0$	2
			90	0 ± 0	0	$2.5^{d} \pm 0$	1	$4.5^{c} \pm 0$	2
	Orange Juice	GG	1	0 ± 0	0	$1^{b} \pm 0$	1	$3^{b} \pm 0$	1
			90	0 ± 0	0	$0^{a} \pm 0$	0	$1.8^{a} \pm 0.3$	1
		XG	1	0 ± 0	0	$2.5^{d} \pm 0$	1	$7^{d} \pm 0$	2
			90	0 ± 0	0	$2^{c} \pm 0$	1	$7^{d} \pm 0$	2
		S	1	0 ± 0	0	$1^{b} \pm 0$	1	$7.3^{d} \pm 0.3$	2
			90	0 ± 0	0	$0^{a} \pm 0$	0	$3^{b} \pm 0$	1
	Peach Juice	GG	1	0 ± 0	0	$2.2^{cd} \pm 0.3$	1	$7^{d} \pm 0$	2
			90	0 ± 0	0	$2^{c} \pm 0$	1	$7^{d} \pm 0$	2
		XG	1	2 ± 0	1	$4^{f} \pm 0$	2	$9.2^{f} \pm 0.3$	3
			90	0 ± 0	0	$4^{f} \pm 0$	2	$8^{e} \pm 0$	3
		S	1	0 ± 0	0	$3.8^{f} \pm 0.3$	1	$7.0^{d} \pm 0.1$	2
			90	0 ± 0	0	$0^{a} \pm 0$	0	$3^{b} \pm 0$	1

Note: Mean ± SD. Different letters in the same column represent statistically significant differences ($P < 0.05$) by Tukey's multiple range test.

Table 4
The changes in total phenol content (TPC, mg GAE/L) and antioxidant activity (inhibition %) of TM liquids during storage.

			IDDSI Level					
			Thin (1–50 cP)		Nectar-like (51–350 cP)		Honey-like (351–1750 cP)	
Liquid	Thickener	Storage Time	TPC (mg GAE/L)	Antioxidant activity (inhibition %)	TPC (mg GAE/L)	Antioxidant activity (inhibition %)	TPC (mg GAE/L)	Antioxidant activity (inhibition %)
Apple Juice	GG	1	1110.62^{i}±5.92	89.79^{h} ± 0.11	955.92^{d} ± 0.00	88.09^{h} ± 0.12	1083.85^{efghi}±2.86	89.40^{i}±0.18
		90	1008.90^{f}±9.13	92.71^{j}±0.10	967.67^{d} ± 7.94	91.05^{i}±0.17	807.22^{d} ± 0.28	93.65^{k}±0.05
	XG	1	1391.89^{k}±3.17	91.31^{i}±0.07	1640.31^{i}±7.91	91.55^{i}±0.14	1150.96^{i}±3.49	93.79^{k}±0.05
		90	1247.22^{j}±9.92	95.00^{l} ± 0.06	1116.48^{g} ± 19.66	95.24^{l} ± 0.12	722.94^{cd} ± 8.32	91.50^{j}±0.07
	S	1	1390.67^{k}±0.42	85.61^{e}±0.14	1434.01^{i}±3.23	80.31^{d} ± 0.06	1284.14^{i}±4.99	71.22^{d} ± 0.14
		90	1083.92^{h} ± 2.39	92.15^{i}±0.07	1059.06^{ef}±15.35	82.54^{f}±0.18	1100.03^{ghi}±1.26	86.65^{g} ± 0.17
Orange Juice	GG	1	1173.34^{i}±6.65	84.42^{c}±0.02	1070.52^{f}±14.55	92.90^{k}±0.13	686.30^{bc}±8.63	91.51^{j}±0.14
		90	1123.23^{i}±12.08	68.62^{a}±0.07	1102.33^{g} ± 1.66	80.65^{e}±0.10	1086.40^{fghi}±0.92	78.02^{e}±0.07
	XG	1	1245.56^{j}±3.01	86.55^{f}±0.29	1310.78^{h} ± 6.97	96.34^{m} ± 0.15	1126.37^{hi}±1.16	95.76^{m} ± 0.04
		90	1037.94^{g} ± 4.65	69.49^{b} ± 0.07	1031.80^{e}±2.75	73.05^{b} ± 0.08	1018.83^{efgh}±8.54	80.35^{f}±0.07
	S	1	1390.67^{k}±0.42	85.63^{e}±0.12	1434.01^{i}±3.23	83.51^{g} ± 0.08	1284.14^{i}±4.99	90.87^{i}±0.14
		90	1128.98^{i}±6.34	86.78^{f}±0.20	1071.38^{f}±5.54	76.18^{c}±0.10	1030.89^{efgh}±1.29	70.92^{d} ± 0.10
Peach Juice	GG	1	891.57^{c}±5.58	92.40^{ij}±0.08	980.39^{d} ± 6.01	96.06^{m} ± 0.02	970.07^{e}±4.14	64.67^{b} ± 0.01
		90	824.01^{b} ± 9.24	85.17^{d} ± 0.04	598.84^{c}±5.89	92.39^{j}±0.06	580.38^{ab} ± 8.20	87.49^{h} ± 0.02
	XG	1	969.11^{e}±10.72	93.51^{k}±0.03	1128.10^{g} ± 6.91	96.30^{m} ± 0.07	988.40^{efg}±5.24	91.46^{j}±0.14
		90	662.40^{a}±1.75	89.68^{h} ± 0.01	552.43^{b} ± 7.88	93.08^{k}±0.14	553.34^{a}±4.14	94.53^{l} ± 0.11
	S	1	925.36^{d} ± 4.21	87.36^{g} ± 0.02	1028.80^{e}±5.67	60.39^{a}±0.02	978.25^{ef}±7.09	45.18^{a}±0.09
		90	923.61^{d} ± 1.26	85.08^{d} ± 0.07	500.66^{a}±6.34	82.51^{f}±0.02	553.34^{a}±4.14	70.19^{c}±0.08

Note: Mean ± SD. Different letters in the same column represent statistically significant differences ($P < 0.05$) by Tukey's multiple range test.

obtained from all participants. The participants took the preference tests of appearance, aroma, taste, color, texture and overall acceptability using a 5-point hedonic scale (1: Extremely dislike, 5: Extremely like). Sensory properties were assessed in terms of viscosity and swallowing difficulty on a 9-point hedonic scale, where 1 represented least viscous and most easily swallowed, and 9 represented most viscous and most difficult to swallow, respectively. This protocol was performed with the approval of Muğla Sıtkı Koçman University Ethics Committee.

2.10. Statistical analysis

The data collected from parallel measurements of both physicochemical and sensory properties of the studied samples were expressed as mean ± standard deviation (SD). All data underwent analysis through one-way analysis of variance using the Minitab Statistical Software (Minitab Version 21.0). The significant differences between means were determined using Tukey's multiple range tests ($P < 0.05$).

3. Results

3.1. Viscosity

Table 2 displays the average viscosity for each combination of liquid, thickener, and storage time, considering products thickened to thin, nectar and honey-like consistencies. The hydrocolloid thickeners used in this study exhibited varying viscosity levels ranging from 15.75 to 1436.90 cP. Higher mean values indicate thicker/more viscous liquids, while lower mean values indicate thinner/less viscous liquids. The results of the viscosity measurements suggest that the viscosities of most texture-modified liquids were significantly affected by the storage period. The impact of storage on the classification levels was explored in fruit juice samples that were thickened to specific levels (Level 1; 0–50 cP, Level 2; 51–350 cP, Level 3; 351–1750 cP) according to NDD standards. For instance, upon initial preparation, honey-like apple juice sample thickened with starch exhibited a measured viscosity of 669.07 cP. However, by the end of the storage period, its viscosity was measured as 319.0 cP, leading to reclassification as nectar-like apple juice. While the category levels of the orange juice samples containing xanthan gum remained consistent, the viscosity values of the nectar-like orange juices thickened with guar gum and starch experienced notable decreases of 63 % and 85 %, respectively, leading to their reclassification as thin orange juices. Similarly, the viscosity values of the honey-like orange juices decreased by 73 %, resulting in their classification as nectar-like juices. Turning to the peach juice samples, only the viscosity of the honey-like peach juice samples thickened with starch decreased by 62 %, causing them to shift to category Level 2. Upon closer examination, it is evident that the viscosities of certain fruit juices prepared in accordance with NDD levels prior to storage decreased significantly by the end of storage period. This considerable reduction in viscosity led to their reclassification. Such substantial changes in juice viscosity during storage can prompt alterations in swallowing patterns, highlighting the potential risks associated with the feeding process.

3.2. Flow and fork drip test

In the preparation of fruit juice samples at specific viscosity levels (Level 1; 0–50 cP, Level 2; 51–350 cP, Level 3; 351–1750 cP), NDD categories were utilized. Differences among juice samples thickened with xanthan gum, guar gum and starch were assessed based on the storage conditions, using the syringe flow test as outlined by the IDDSI (Table 3). Notably, it was observed that NDD categories employed for sample preparation and the categories suggested by IDDSI through the syringe flow test were different. Specifically, it was found that 78 % of the samples prepared based on the NDD categories prior to storage and 67 % of the samples post-storage did not match the recommended levels within the IDDSI framework.

3.3. Total phenolic content of TM fruit juices

The data presented in Table 4 illustrates the variations in total phenolic content of TM liquids over a three-month storage period. Notably, there was a significant reduction in total phenolic content across all fruit juice samples, regardless of thickening agents used, after three months. Table 4 highlights the noteworthy impact of fruit and hydrocolloid types, as well as storage duration, on the phenolic content of TM liquids. Examining the influence of fruit type, it becomes evident that the orange and apple juices exhibited higher phenolic content compared to peach juice samples. Upon analyzing all fruit juice samples, it becomes evident that the maximum total phenolic content was observed in the apple juice sample, which was thickened using xanthan gum, measuring 1640.31 ± 7.91 mg GAE/L. In contract, the lowest phenolic content was found in the peach juice sample thickened with starch, measuring at 500.66 ± 6.34 mg GAE/L.

3.4. Antioxidant activity by DPPH radical inhibition assay

The outcomes regarding the antioxidant activity of TM liquids, formulated using three distinct hydrocolloids at various concentrations, are outlined in Table 4. The alterations in antioxidant activity values of fruit juices during storage exhibited variations contingent on the type of fruit type. Notably, the behavior of antioxidant activity in TM apple juices demonstrated a general increase over the storage period, while in stark contrast; a significant decline was noted in the activity of orange juices.

Table 5
The changes in color parameters of TM liquids during storage.

			IDDSI Level								
			Thin (1–50 cP)			Nectar-like (51–350 cP)			Honey-like (351–1750 cP)		
Liquid	Thickener	Storage Time	L	a	b	L	a	b	L	a	b
Apple Juice	GG	1	31.63^{j}±0.06	0.07^{de} ± 0.06	8.0^{ef}±0.1	21.43^{a}±1.76	−0.17^{f}±0.06	3.77^{a}±0.06	23.60^{b} ± 0.17	0.13^{e}±0.06	4.2^{a}±0.1
		90	24.5^{bcd} ± 0.1	1.63^{gh} ± 0.06	7.17^{cd} ± 0.15	22.17^{ab} ± 0.15	−0.57^{e}±0.06	4.67^{b} ± 0.15	23.13^{b} ± 0.15	1.33^{g} ± 0.06	6.93^{d} ± 0.15
	XG	1	23.93^{bc}±0.06	0.23^{e}±0.06	6.67^{bc}±0.15	26.27^{de} ± 0.06	0.3^{gh} ± 0.0	7.77^{de} ± 0.06	25.33^{de} ± 0.15	0.2^{e}±0.0	6.37^{cd} ± 0.06
		90	23.9^{abc}±0.0	1.67^{gh} ± 0.06	7.10^{cd} ± 0.26	23.47^{bc}±0.23	2.17^{jk}±0.06	7.47^{d} ± 0.15	23.77^{bc}±0.12	2.93^{i}±0.06	8.93^{f}±0.35
	S	1	33.63^{k}±0.15	−0.17^{d} ± 0.06	5.5^{a}±0.4	30.3^{f}±0.1	−0.27^{ef}±0.06	4.77^{b} ± 0.06	29.23^{g} ± 1.76	−0.13^{d} ± 0.06	6.33^{cd} ± 0.21
		90	24.67^{cd} ± 0.25	1.43^{g} ± 0.06	6.33^{b} ± 0.15	25.10^{d} ± 0.10	0.0^{fg} ± 0.1	5.0^{b} ± 0.1	25.13^{cd} ± 0.21	−0.13^{d} ± 0.06	5.27^{b} ± 0.12
Orange Juice	GG	1	27.57^{hi}±0.75	−1.73^{a}±0.06	12.60^{h} ± 0.36	25.33^{d} ± 0.06	−1.67^{c}±0.06	10.97^{f}±0.12	26.8^{f}±0.4	−1.57^{b} ± 0.12	11.07^{h} ± 0.15
		90	28.3^{ii}±0.1	−1.73^{a}±0.06	14.07^{i}±0.15	27.40^{e}±0.17	−2.13^{a}±0.06	13.70^{g} ± 0.53	26.7^{ef}±0.1	−1.63^{b} ± 0.06	11.1^{h} ± 0.2
	XG	1	24.57^{cd} ± 0.12	−1.2^{b} ± 0.0	13.33^{i}±0.12	26.37^{de} ± 0.06	−1.23^{d} ± 0.06	14.37^{h} ± 0.06	26.4^{def}±0.1	−1.23^{c}±0.06	14.8^{i}±0.2
		90	26.9^{gh} ± 0.1	−0.7^{c}±0.1	13.23^{i}±0.21	25.33^{d} ± 0.12	−1.73^{bc}±0.12	10.87^{f}±0.21	25.43^{def}±0.12	−2.27^{a}±0.06	11.83^{i}±0.15
	S	1	28.73^{i}±0.46	−1.9^{a}±0.1	14.9^{j}±0.1	27.13^{e}±0.29	−2.07^{ab} ± 0.12	13.23^{g} ± 0.06	26.17^{def}±0.06	−2.13^{a}±0.06	11.9^{i}±0.1
		90	28.23^{ii}±0.15	−0.7^{c}±0.1	14.07^{i}±0.15	30.13^{f}±0.15	−1.83^{abc}±0.06	15.93^{i}±0.15	32.6^{h} ± 0.2	−2.1^{a}±0.1	17.87^{j}±0.15
Peach Juice	GG	1	25.0^{de} ± 0.0	1.97^{i}±0.15	8.53^{fg} ± 0.06	23.33^{bc}±0.21	2.0^{j}±0.1	7.33^{d} ± 0.06	25.30^{de} ± 0.36	2.5^{i}±0.1	9.0^{f}±0.2
		90	23.77^{ab} ± 0.25	1.87^{hi}±0.06	7.27^{d} ± 0.15	21.7^{a}±0.2	0.67^{h} ± 0.06	6.00^{c}±0.17	21.57^{a}±0.23	0.8^{f}±0.0	6.07^{c}±0.38
	XG	1	24.17^{bc}±0.12	1.73^{hi}±0.12	7.5^{de} ± 0.2	23.60^{c}±0.36	2.43^{k}±0.06	7.80^{de} ± 0.17	26.4^{def}±0.4	2.1^{h} ± 0.0	10.23^{g} ± 0.06
		90	23.13^{a}±0.29	2.47^{i}±0.06	7.33^{d} ± 0.15	23.33^{bc}±0.35	1.13^{i}±0.06	7.57^{de} ± 0.32	22.57^{ab} ± 0.45	0.6^{f}±0.1	5.83^{bc}±0.23
	S	1	25.7^{ef}±0.2	1.0^{f}±0.1	8.83^{g} ± 0.06	30.37^{f}±0.12	1.53^{i}±0.06	11.3^{f}±0.1	25.47^{def}±0.06	1.13^{g} ± 0.15	8.30^{e}±0.26
		90	26.33^{fg} ± 0.15	1.93^{i}±0.11	8.47^{fg} ± 0.12	25.20^{d} ± 0.26	1.33^{ii}±0.46	8.03^{e}±0.06	26.33^{def}±0.15	1.93^{h} ± 0.12	8.47^{ef}±0.12

Note: Mean ± SD. Different letters in the same column represent statistically significant differences ($P < 0.05$) by Tukey's multiple range test.

3.5. Color analysis

The color of both fresh and processed foods stands as the foremost quality parameter assessed by consumers, offer serving as the basis for accepting or rejecting a food item [22]. To articulate the color of an object, diverse color coordinate systems have been employed. In our study, for the purpose of color characterization, coordinates based on the Hunter L a b were used: *L* (lightness), *a*, and *b*, where + *a* represents red; −*a*, green; +*b*, yellow; and −*b* blue. Table 5 shows the changing color parameters of three fruit juices prepared with different hydrocolloids during storage.

3.6. pH measurements and determination of total acidity

Table 6 illustrates the influence of storage duration on pH and total acidity of the prepared TM fruit juices. There was a significant escalation in pH values over the storage period, particularly noticeable in the apple juice samples. In terms of fruit types, apple juice samples displayed the highest average pH values. The pre-storage maximum pH value of 4.11 was recorded for apple juice prepared using guar gum at Level 2, while post-storage, the highest value of 4.46 was observed for apple juice samples thickened with guar gum and starch at Level 3. Table 6 also provides data regarding the acidity (%) across different fruit juices on Day 0 and 90. Orange juice samples exhibited considerably higher acidity when compared to both apple and peach juice samples. However, it was established that the acidity of orange juices witnessed a significant decline with the progression of storage.

3.7. Sensorial analysis

Table 7 presents the average acceptance scores for various attributes (appearance, aroma, taste, texture, color and overall acceptance) of TM orange juices prepared using different thickeners at specific levels, following the storage period. The products were rated on a 5-point scale, with scores ranging from 1.80 to 4.65, indicating that the panelists were indifferent to some formulations. The incorporation of hydrocolloids did not exert a significant influence on the acceptance of orange juice in specific aspects, such as aroma, taste, and texture ($P > 0.05$). However, it is worth noting that the introduction of starch across all levels to a noticeable enhancement in both appearance and overall acceptance ($P < 0.05$). The scores attributed to the viscosity and ease of swallowing for the TM orange juices are graphically depicted in Fig. 1.

4. Discussion

4.1. Viscosity

As demonstrated in Table 1, achieving the viscosity classifications recommended by the NDD required varying amounts of hydrocolloids to be added to the juices, with discrepancies arising based on the type of hydrocolloid employed. It was notable that the desired levels of viscosity necessitated significantly higher concentrations of starch compared to other hydrocolloids for all the investigated fruit juices. Starches and gums, due to their adeptness at water gel formation and binding, find utility across industries encompassing food, pharmaceuticals, and cosmetics. The length of polymer chains and the degree of polymerization in hydrocolloids have impacts on the viscosity of food products. Consequently, hydrocolloids based on gums, boasting substantial molecular masses,

Table 6
The changes in pH value and acidity (%) of TM liquids during storage.

			IDDSI Level					
			Thin (1–50 cP)		Nectar-like (51–350 cP)		Honey-like (351–1750 cP)	
Liquid	Thickener	Storage Time	pH	Acidity (%)	pH	Acidity (%)	pH	Acidity (%)
Apple Juice	GG	1	$4.03^{i}\pm0.01$	$0.50^{bc}\pm0.09$	$4.11^{j}\pm0.01$	$0.4^{ab}\pm0.09$	$4.09^{k}\pm0.01$	$0.25^{a}\pm0.09$
		90	$4.34^{k}\pm0.00$	$0.50^{bc}\pm0.09$	$4.4^{l}\pm0.0$	$0.6^{bc}\pm0.0$	$4.46^{m}\pm0.01$	$0.75^{b}\pm0.00$
	XG	1	$3.91^{h}\pm0.01$	$0.35^{ab}\pm0.09$	$3.97^{i}\pm0.01$	$0.5^{abc}\pm0.09$	$3.98^{i}\pm0.01$	$0.3^{a}\pm0.0$
		90	$4.31^{j}\pm0.01$	$0.6^{cd}\pm0.0$	$4.32^{k}\pm0.01$	$0.65^{c}\pm0.09$	$4.33^{l}\pm0.01$	$0.70^{b}\pm0.09$
	S	1	$3.93^{h}\pm0.01$	$0.45^{abc}\pm0.00$	$4.06^{i}\pm0.01$	$0.35^{a}\pm0.09$	$4.05^{j}\pm0.00$	$0.3^{a}\pm0.0$
		90	$4.29^{i}\pm0.00$	$0.6^{cd}\pm0.0$	$4.40^{l}\pm0.01$	$0.6^{bc}\pm0.0$	$4.46^{m}\pm0.01$	$1.34^{cd}\pm0.00$
Orange Juice	GG	1	$3.20^{b}\pm0.01$	$2.42^{h}\pm0.14$	$3.26^{cd}\pm0.01$	$1.62^{f}\pm0.08$	$3.26^{def}\pm0.01$	$1.47^{d}\pm0.09$
		90	$3.27^{d}\pm0.00$	$1.23^{f}\pm0.08$	$3.27^{d}\pm0.01$	$1.19^{e}\pm0.08$	$3.25^{de}\pm0.01$	$1.14^{c}\pm0.00$
	XG	1	$3.19^{b}\pm0.01$	$1.61^{g}\pm0.17$	$3.23^{b}\pm0.01$	$1.66^{f}\pm0.16$	$3.21^{b}\pm0.01$	$2.13^{e}\pm0.00$
		90	$3.23^{c}\pm0.01$	$1.23^{f}\pm0.08$	$3.25^{c}\pm0.00$	$1.28^{e}\pm0.00$	$3.26^{ef}\pm0.00$	$1.23^{c}\pm0.09$
	S	1	$3.08^{a}\pm0.01$	$1.66^{g}\pm0.08$	$3.1^{a}\pm0.0$	$1.76^{f}\pm0.08$	$3.16^{a}\pm0.01$	$1.52^{d}\pm0.17$
		90	$3.23^{c}\pm0.01$	$1.57^{g}\pm0.00$	$3.25^{c}\pm0.00$	$1.66^{f}\pm0.08$	$3.27^{f}\pm0.00$	$1.47^{d}\pm0.09$
Peach Juice	GG	1	$3.27^{de}\pm0.01$	$0.55^{bcd}\pm0.09$	$3.29^{e}\pm0.01$	$0.65^{c}\pm0.09$	$3.29^{g}\pm0.00$	$0.75^{b}\pm0.00$
		90	$3.33^{f}\pm0.00$	$0.75^{de}\pm0.00$	$3.35^{h}\pm0.00$	$0.6^{bc}\pm0.0$	$3.34^{hi}\pm0.01$	$0.6^{b}\pm0.0$
	XG	1	$3.31^{f}\pm0.01$	$0.25^{a}\pm0.09$	$3.32^{fg}\pm0.01$	$0.45^{abc}\pm0.00$	$3.24^{cd}\pm0.00$	$0.70^{b}\pm0.09$
		90	$3.39^{g}\pm0.01$	$0.89^{e}\pm0.00$	$3.33^{g}\pm0.01$	$0.65^{c}\pm0.09$	$3.33^{h}\pm0.01$	$0.6^{b}\pm0.0$
	S	1	$3.26^{d}\pm0.01$	$0.45^{abc}\pm0.00$	$3.24^{c}\pm0.01$	$0.6^{bc}\pm0.0$	$3.23^{bc}\pm0.01$	$0.35^{a}\pm0.09$
		90	$3.29^{e}\pm0.00$	$0.89^{e}\pm0.00$	$3.31^{f}\pm0.01$	$0.94^{d}\pm0.09$	$3.36^{i}\pm0.00$	$0.6^{b}\pm0.0$

Note: Mean ± SD. Different letters in the same column represent statistically significant differences ($P < 0.05$) by Tukey's multiple range test.

Table 7
The average acceptance scores of the TM orange juices.

TM Orange Juice	Appearance	Aroma	Taste	Texture	Color	Overall Acceptance
OG1	$2.90^{a}\pm1.12$	$3.25^{ab}\pm0.97$	$3.05^{b}\pm1.05$	$3.55^{ab}\pm0.89$	$3.10^{a}\pm0.91$	$3.15^{a}\pm0.81$
OG2	$2.80^{a}\pm1.15$	$3.10^{ab}\pm1.17$	$2.90^{b}\pm0.91$	$3.60^{ab}\pm0.88$	$2.95^{a}\pm0.94$	$3.25^{a}\pm0.72$
OG3	$3.00^{a}\pm0.92$	$2.75^{a}\pm1.12$	$2.95^{b}\pm1.39$	$3.25^{ab}\pm0.91$	$3.00^{a}\pm0.97$	$2.90^{a}\pm0.91$
OX1	$2.80^{a}\pm1.24$	$3.05^{ab}\pm0.83$	$2.90^{b}\pm0.85$	$3.60^{ab}\pm1.05$	$2.90^{a}\pm0.91$	$3.15^{a}\pm0.81$
OX2	$3.4^{a}\pm1.1$	$3.15^{ab}\pm0.88$	$2.80^{b}\pm1.02$	$3.10^{a}\pm1.07$	$3.45^{ab}\pm0.89$	$3.15^{a}\pm0.81$
OX3	$3.5^{ab}\pm1.1$	$3.00^{a}\pm1.21$	$1.80^{a}\pm0.77$	$2.65^{a}\pm1.27$	$4.00^{bc}\pm0.79$	$2.90^{a}\pm0.85$
OS1	$4.45^{c}\pm0.69$	$3.75^{ab}\pm0.91$	$3.50^{b}\pm0.69$	$4.15^{b}\pm1.04$	$4.6^{c}\pm0.6$	$4.05^{b}\pm0.69$
OS2	$4.6^{c}\pm0.6$	$4.1^{b}\pm1.0$	$3.60^{b}\pm0.94$	$4.20^{b}\pm0.77$	$4.65^{c}\pm0.75$	$4.2^{b}\pm0.7$
OS3	$4.40^{bc}\pm0.82$	$3.60^{ab}\pm1.12$	$2.90^{b}\pm1.02$	$3.4^{ab}\pm1.1$	$4.6^{c}\pm0.6$	$3.50^{ab}\pm0.76$

Note: Mean ± SD. Different letters in the same column represent statistically significant differences ($P < 0.05$) by Tukey's multiple range test. OG1, OG2, OG3: Orange with GG (Level 1-2-3); OX1, OX2, OX3: Orange with XG (Level 1-2-3); OS1, OS2, OS3: Orange with S (Level 1-2-3).

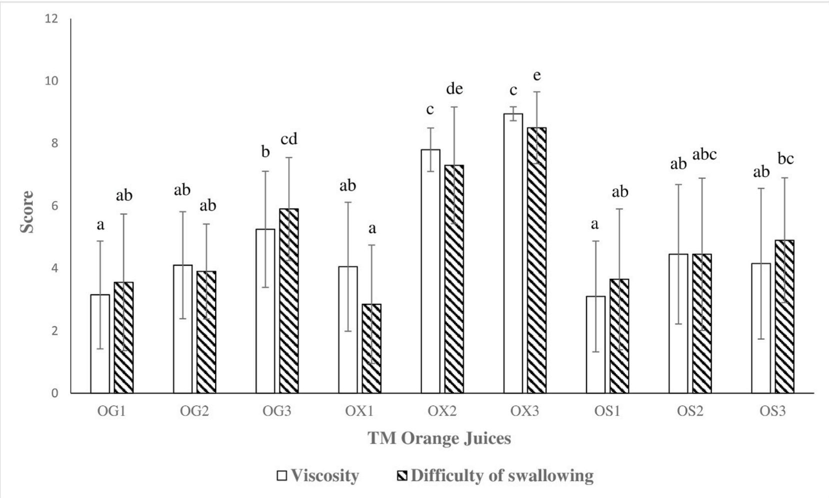

Fig. 1. The scores of the TM orange juices in terms of viscosity and swallowing difficulty. Mean ± SD. OS1, OS2, OS3: Orange with S (Level 1-2-3); OG1, OG2, OG3: Orange with GG (Level 1-2-3); OX1, OX2, OX3: Orange with XG (Level 1-2-3).

yield solutions characterized by considerably greater viscosity than those containing starch within the food matrix [6,10]. Regarding the viscosities of thinner apple juice samples (Level 1), the influence of storage was relatively muted. However, an exception was observed in the case of apple juice samples thickened with xanthan gum at Level 1, where viscosity experienced an augmentation over the storage period. The viscosities of nectar-like apple juice samples (Level 2) displayed a notable increase by the end of the storage period ($P < 0.05$). Conversely, honey-like apple juice samples (Level 3) thickened with xanthan gum and starch exhibited a marked reduction in viscosity at the end of storage, whereas honey-like apple juice samples thickened with guar gum exhibited a substantial increase. Similar observations were reported by Ibrahim et al. [23], who studied the viscosity changes in apple fluids thickened with xanthan gum over two-week duration. They noted a significant decrease in viscosity across all samples at the end of the storage period, attributing this decline to electrostatic repulsion. Researchers elucidated that introduction of negatively charged hydrocolloids into fruit juices consisting negatively charged particles heightened the electrostatic repulsion forces between them. In terms of orange juice with modified texture, no significant differences were identified in the viscosities of thin orange juice samples (Level 1) with respect to storage. The viscosity of both nectar-like (Level 2) and honey-like (Level 3) orange juice samples exhibited a notable decrease following a 3-month storage period. The storage duration exerted a significant impact on the viscosity in orange juice samples ($P < 0.05$). Notably, the viscosity values of both Level 2 and Level 3 orange juices, formulated using guar gum and starch, experienced a marked reduction. Contrastingly, a contradictory trend was highlighted by Liang et al. [24], where they reported a more pronounced reduction in viscosity of carrot juice samples containing xanthan gum, as opposed to those with guar gum, after two months of storage. These findings underscore the reality that fluidity characteristics of thickened beverages can be subject to alteration due to the interactions between the constituents in fruit juices and macromolecules present in hydrocolloids [13]. The results gleaned from the study indicate that the viscosity of thin, nectar-like, and honey-like peach juice samples thickened with guar gum remained relatively stable throughout the storage period. In contrast, statistically significant differences were evident in the viscosities of peach juice samples thickened with starch at the end of the storage period. At the commencement of storage, the mean viscosity of nectar-like (Level 2) and honey-like (Level 3) peach juice, when prepared with starch, stood at 231.67 and 699.97 cP, respectively. Over a span of 3 months, these viscosities exhibited a substantial reduction, dropping to 55.75 cP and 265.10 cP, respectively. Our study highlighted that the most important pronounced drop in viscosity with storage occurred within samples featuring elevated concentrations of hydrocolloids. Remarkably, among the levels, the honey-like peach juice samples with starch experienced a more pronounced decline in viscosity. The findings resonate with those of Tiruneh et al. [25], who reported that viscosities of pineapple juice samples enriched with 1 %, 2 % and 5 % potato and anchote starch registered significant decreases during storage at 4 °C over a 15-day span. The propensity of xanthan gum, guar gum, and starch to exhibit pseudoplastic properties in suspension systems is noteworthy. These substances have a tendency to deform under the storage conditions, which consequently contributed to viscosity reduction [14]. Upon a comprehensive evaluation of the data, it can be concluded that the viscosities of fruit juices thickened with xanthan gum displayed greater stability during storage. On the contrary, the viscosities of samples prepared with starch exhibited a substantial decrease over the storage period. In this research, three types of hydrocolloids and fruits were used to design TM liquids and only the apparent viscosities of the developed products were determined. Hence, determining the dynamic properties of the products using a stress-controlled rheometer are required to reveal whether the products can be easily consumed by the target group.

4.2. Flow and fork drip test

It was observed that achieving Level 1 (“slightly thick” or remaining volume ranging from 1 to 4 mL, as per IDDSI categories) with xanthan gum for peach juice, prior to storage, was only partially successful. However, following the storage period, peach juice thickened with xanthan gum transitioned from Level 1 to Level 0 (“thin” or complete liquid flow from the syringe). In contrast, for all apple juice samples thickened to Level 2 (“mildly thick” or remaining volume from 4 to 8 mL), there was no significant changes in their level classification after 3-month storage duration. Notably, it is worth highlighting that achieving Level 2 using xanthan gum was only partially realized for both apple and peach juices, both before and after storage. When considering samples initially prepared as nectar-like based on NDD categories, changes in levels, as determined through the syringe flow test, were particularly notable for orange and peach juices thickened with starch (These samples began at Level 1 and transitioned to Level 0 by the end of the storage period). Data illustrated that apple juice thickened to meet honey-like with guar gum and xanthan gum, as well as peach juice thickened to honey-like with xanthan gum correspond closely to categories derived from the syringe flow test (Table 3). Regarding our data pertaining to samples prepared as honey-like in accordance with NDD categories, orange and peach juices thickened with starch exhibited shifts in categories “mildly thick” to “slightly thick” as determined by the syringe flow test over the course of storage. In contrast, for apple juice samples thickened with guar gum, the syringe flow test resulted in a level escalation from “mildly thick” to “moderately thick over a 3-month period. These changes are in line with the assessment of consistency differences between the methodologies (viscometer and flow) stipulated by NDD and IDDSI, as highlighted in the study conducted by Machado et al. [26]. They conducted an investigation where they utilized seven commercial thickeners to create products, subsequently subjecting them to both viscosity analysis using a viscometer and the IDDSI flow test. Their evaluation underscored the challenge in establishing a direct correlation between viscosity classifications as defined by NDD and IDDSI. The outcomes obtained by Yokote et al. [27], revealing variations in viscosity ranges between the Japanese Dysphagia Diet (JDD2013) and the IDDSI framework, suggest that these differences could potentially arise from human errors occurring during stages such as reading the syringe scale and determining the precise moment to halt the stopwatch. A more comprehensive investigation into the IDDSI flow test is required to ensure uniform accuracy in viscosity classifications on a global scale. Following the application of the syringe flow test, liquids classified as moderately thick (Level 3) as per IDDSI standards were further subjected to the fork drip test, as outlined in IDDSI guidelines. However, since no moderately thick (Level 3) samples were available for orange juice, fork drip test was not applicable to these samples. Only apple and peach juices meeting the criteria of Level 3, prepared with xanthan gum based on NDD categories, underwent the fork drip test. The findings unveiled that apple juice samples thickened with xanthan gum, prepared before storage, formed a short tail beneath the fork and were categorized as Level 4 (extremely thick). Conversely, these samples exhibited a tendency to slowly drip through the prongs of the fork when measured after storage. Consequently, apple juice samples thickened with xanthan gum were categorized as level 3 in both the syringe flow test and the fork drip test. Similarly, peach juice samples thickened with xanthan gum displayed flow through the fork, forming a short tail, leading to their categorization as Level 4 in accordance with IDDSI guidelines.

Upon conducting the flow test, we observed that apple and peach juices thickened with xanthan gum aligned with the viscosity classifications recommended by NDD. Also, these fruit juices retained their category status even at the end of the storage period. This outcome underscores the stability of apple and peach juices thickened with xanthan gum. In contrast, the samples that displayed the greatest inconsistency between NDD and IDDSI standards were the orange and peach juices thickened with starch, following a three-month storage period. The IDDSI framework describes the flow of liquids at Level 0 (thin) as like water. It also characterizes these liquids as ‘can drink with any teat/nipple, cup or straw, appropriate to age and skills’. It highlights the need for functional ability to safely manage liquids of all types for this level of thickness. Based on the IDDSI frame work definitions, we can conclude that designed fruit juices classified into Level 0 (thin) according to IDDSI flow test are not confident for patients with mild and severe dysphagia.

4.3. Total phenolic content of TM fruit juices

Storing TM liquids for a duration of 3 months lead to a decrease in total phenolic content. This was consistent with the findings reported by Handayani [28], who documented a significant reduction in total phenolic levels within pineapple papaya jelly drink enriched with of agar and carrageenan, during cold storage. The extended storage period is believed to trigger chemical and enzymatic oxidation of phenolic compounds, ultimately contributing to the decline in total phenolic content. Our study unveiled that the type and quantity of hydrocolloid employed notably impacted the phenolic content of both apple and peach juices, particularly following storage (Table 4). Among post-storage apple juice samples, those thickened with guar gum exhibited lower phenolic contents compared to samples with xanthan gum and starch additions. When comparing apple juice samples after storage, those thickened to Level 3 using guar gum (807.22 ± 0.28 mg GAE/L) and xanthan gum (722.94 ± 8.32 mg GAE/L) displayed lower total phenolic content than samples thickened to Level 2 (967.67 ± 7.94 and 1116.48 ± 19.66 mg GAE/L). Similarly, the phenolic contents of the Level 2 and Level 3 peach juices, regardless of hydrocolloid employed, exhibited a decrease when compared to the Level 1 samples. Conversely, when focusing on the orange juice samples, the data gathered at the end of the storage period revealed that the phenolic contents remained consistent across all samples, irrespective of the type or quantity of hydrocolloid used. Notably, the reduction in the phenolic content for orange juices following storage was comparatively lower than for other juice samples. Hydrocolloids have been recognized to exert an influence on the stability, bioavailability and bioactivity of polyphenols within food products. Additionally, the interaction between hydrocolloid hydroxyl groups and phenolic compounds has been shown to lead to a decrease in total phenol content and antioxidant activity [10]. In our study, a discernible decline in total phenolic values was particularly noted in the samples containing high concentration of hydrocolloid. The outcomes derived from this study align with those of previous research, which clearly demonstrated a significant reduction in the total phenolic content of the apple juices thickened with xanthan gum, pectin and carboxymethyl cellulose (CMC) over two-week period [23]. This earlier study also highlighted that alterations in phenolic content and degradation were more pronounced at higher concentrations of thickeners. However, contrasting findings were reported by Kraithong and Rawdkuen [29]. Their study focused on red Jasmine rice flour noodles prepared using hydrocolloids, namely guar gum (GG), carboxymethyl cellulose (CMC), and xanthan gum (XG), revealing that these hydrocolloids did not impact the total phenolic contents of the noodles.

4.4. Antioxidant activity by DPPH radical inhibition assay

The findings revealed a notable increase in antioxidant activities across all TM apple juices during storage (Table 4). Interestingly, our results deviated from a previous study that suggested radical-scavenging activities of apple juice follow a dose-dependent pattern and decline with prolonged storage time [23]. Nonetheless, employing low temperatures can potentially extent juice shelf life while preserving their scavenging activity. Ali et al. [30] demonstrated that the free radical scavenging activity remained relatively stable when fruit juices were stored at 4 °C for up to 4 days. Furthermore, their study concluded that decline in scavenging activity under varying conditions is contingent on the type of fruit. A separate study by Klimczak et al. [31] reported a reduction in the antioxidant activity, measured with the use of DPPH method, of orange juice stored at temperatures of 18 °C, 28 °C and 38 °C for 2, 4 and 6 months, respectively. The decline was linked to the reduction in polyphenols and vitamin C content within orange juice.

When considering the texture-modified peach juices, it becomes evident that the antioxidant activities of the samples thickened to the Level 2 and Level 3 using starch exhibited an increase during storage. As depicted in Table 4, apple juices showcased the highest antioxidant activity, while the orange juices exhibited the lowest. Notably, significant differences were observed across all fruit juices that were thickened using various hydrocolloids ($P < 0.05$), underscoring profound impact of hydrocolloid type on antioxidant activity. A distinct trend emerges, with apple and peach juices thickened using xanthan gum displaying the highest antioxidant activity, while starch-thickened juices registering the lowest. A related study evaluated the influence of 90 days of storage at room temperature on the stability of phenolics, carotenoids, and antioxidant activity of pasteurized peach products [32]. This research reported a 50 % decrease in antioxidant activity, expressed in terms of ascorbic acid equivalents, during the 90-day storage period following pasteurization.

The decline in scavenging activity under different conditions hinges on the type of fruit. Freshly prepared juices contain a diverse array of antioxidants and beneficial nutrients, making them particularly susceptible to the influence of air, heat, and light. In our study, the reduction in antioxidant activity can be attributed to the loss of polyphenol and ascorbic acid due to the thermal and mechanical processes involved in thickening the fruit juices. Stored and heat-treated fruit juices may have lower contents of vitamin C and phenolic compounds compared to their fresh counterparts. Given that the presence of vitamin C plays a pivotal role in antioxidant activity, reductions in vitamin C content contribute to the decline in antioxidant activity [30,33,34].

4.5. Color analysis

It is worth noting that significant alterations in the color coordinates of the samples emerged as a consequence of storage (Table 5). In terms of apple juices, the lightness value (*L*) of samples thickened with xanthan gum and starch, in particular, exhibited a decrease during storage. Conversely, there was a noteworthy increase in the lightness (*L*) of orange juices, especially those thickened with starch, after undergoing a 3-month storage period. As we delve into the color parameters of the prepared TM peach juices, it becomes evident that the *L* value of the samples thickened with xanthan gum and guar gum demonstrated a statistically significant decline with storage. Furthermore, it is worth highlighting that the *a* value exhibited instability for the apple juice samples thickened with guar gum and starch during storage, whereas the *a* value for apple juices thickened with xanthan gum notably increased. In the case of orange juice samples thickened with xanthan gum, the *a* value witnessed a sharp decrease, leading to *a* transition from red to green (from −1.23 to −1.73 and from −1.23 to −2.27 for nectar-like and honey-like samples, respectively). The findings highlight a substantial impact of storage on the *a* value of the peach juices. Particularly the *a* value exhibited a significant decrease for peach juices thickened with guar gum and xanthan gum after a 3-month storage period. Conversely, the *a* value of peach samples thickened with starch showed an increase with storage. When evaluating the changing *b* value with storage, no distinct trend was evident for apple juice samples. In the case of orange juice samples, it became apparent that the *b* values of samples prepared with guar gum and starch generally underwent an increase, while those prepared with xanthan gum experienced a decrease. As the three-month storage period concluded, there was a significant reduction in *b* values across all peach juices, particularly thickened with guar gum. Overall, a comprehensive assessment of the data underscores the significant influence of fruit type and hydrocolloid choice on the color coordinates of the samples. The duration of storage led to a decrease in *L* value and an increase in *a* value (resulting in a more reddish hue) of apple juices, indicating that the liquids adopted a darker and more reddish color over time. In contrast, storage brought about lighter and greener shades in orange juices (evidenced by lower *a* values), while the peach juices exhibited a darker and bluish color (as indicated by lower *L* and *b* values). In a study conducted by Gössinger et al. [35], varying amounts of xanthan gum were introduced to apple juices, and subsequent analyses based on the physicochemical properties were carried out after storing the samples for 6 weeks. The study revealed that the *L* and *a* values of the examined samples decreased as the concentration of the hydrocolloid increased, resulting in a darker and greener color profile during storage. Teleszko, Nowicka and Wojdyło conducted an experiment involving the addition of 0.2 % and 0.3 % CMC, GG and, XG to strawberry juices, which were subsequently stored the products in 4 °C for 6 months [36]. The outcome of this storage revealed an increase in both *L* and *b* values across all samples, while *a* values experienced a significant decrease. A separate study by Wu et al. [37] highlighted that, following 28 days of cold storage, pineapple juice samples exhibited a tendency towards decreasing *L* and *a* values, accompanied by an increase in *b* values. These variances in the observed shifts in color values are believed to be associated with storage duration, the type and quantity of hydrocolloid used. The alterations in color parameters could be attributed to enzymatic and Maillard reaction, as well as the degradation or polymerization of polyphenols. The formation of oligomer and polymer in stored fruit and vegetable products can be a contributing factor to color changes. Additionally, an increase in turbidity due to the condensation resulting from formed by the addition of hydrocolloid is thought to influence color parameters [38].

4.6. pH measurements and determination of total acidity

In this study, the pH of all fruit juice samples exhibited a statistically significant increase ($P < 0.05$) during storage (Table 6). This outcome contrasts with findings from similar studies in the literature, which generally report a decrease in pH over storage time. For instance, a study in the literature documented that the pH values of pineapple juice samples, prepared with varying concentrations of potato and anchote starch, exhibited a notable reduction after 15 days of storage at 4 °C [25]. A comparable decline in pH values was also observed in tomato-carrot juices, as reported by Nwaokoro and Akanbi [39]. Researchers have associated this decline to the production organic acids through fermentation during storage. Furthermore, existing literature contains studies that align with the results of our research. Hassan et al. [40] observed a significant rise in the pH values of the fruit juices obtained from the phalsa fruit after 10 days of storage. The elevation in pH is believed to stem from the consumption of organic acids in fruit juices. Simultaneously, the decline in vitamin C content is influenced by various storage conditions, including light, temperature, oxygen, as well as variations among different fruit juices. The impact of hydrocolloid type and quantity on pH values for various fruit juices was demonstrated by Mahomud et al. [41], who revealed that pH values of samples increased as the added hydrocolloid amount rose. In our study, there were no statistically significant deviations in the pH values of fruit juices based on hydrocolloid type and concentration. This finding aligns with the report of Tiruneh et al. [25], which concluded that both type and increasing levels of starch had no significant effect on pH.

The variations in acidity of orange juice samples, based on the employed hydrocolloid, revealed that that samples prepared with starch exhibited greater stability than the others. Notably, a statistically significant increase (from 0.30 to 1.34) in the initial acidity, especially after 3-month storage period for apple juices prepared with starch at Level 3 was observed ($P < 0.05$). The data unveiled that the changes in percentage of acidity for peach juices displayed inconsistency (Table 6). While the acidity percentage of peach juices thickened with starch and xanthan gum increased with storage, that of those prepared with guar gum decreased. For peach juices, the impact of the quantity of thickeners on acidity was found to be statistically significant. As previous studies reported, a notable connection exists between the gradual rise in acidity of fruit juices during storage and the production of organic acids. This relationship implies that the total acidity of fruit juices tends to increase with extended storage time [42,43]. In particular, the elevated acidity values observed in peach and apple juices can be interpreted as indicative of deterioration and fermentation on storage. Additionally, the reduction in acidity values of orange juices over storage can be attributed to the degradation of ascorbic acid.

4.7. Sensorial analysis

Texture modified liquids produced in this study were developed and evaluated for individuals with difficulties in swallowing and for elderly people on a dysphagia diet. However, it should further be noted that the sensorial panel consisted of healthy individuals with no chewing or swallowing disorders. The reason for this situation is to prevent possible health problems during the analysis and to make sensory evaluation more accurately. In order to fully reflect the relevant health effects of the methodological and conceptual approach in this study, future works on the imitation of oral behavior or the viscosity change in post-consumption are needed.

In orange juices prepared by adding starch, notably high overall acceptance scores were recorded as 4.05, 4.2 and 3.50 (Level 1, Level 2 and Level 3, respectively). Fig. 1 illustrates the outcomes of sensory evaluations for viscosity and swallowing difficulty, rated on a 9-point hedonic scale. The panelists' assessment revealed that as the concentration of all thickeners increased, the fluidity of the products diminished, leading to an elevated level of swallowing difficulty. In terms of viscosity, it was observed that xanthan gum-based orange juices exhibited higher viscosities compared to their starch-based and guar gum-based counterparts at the equivalent concentrations. The orange juice samples thickened to Levels 2 and 3 with xanthan gum garnered the highest swallowing difficulty scores (7.3 and 8.5). Wendin et al. [44] similarly concluded that high-viscosity fluids containing a starch-based thickener were perceived as more melting, easier to swallow, and possessing a creamy texture. These findings are in line with the outcomes of our study, as TM orange juices prepared with starch were perceived as having a smoother consistency and being more manageable to swallow compared to the other samples. Martinez et al. [5] also emphasized that the sensory evaluations influenced not only by the concentration of the thickening agent but also by the type of hydrocolloids used and their physicochemical behavior, which impacts sensory perception. The results further indicated that texture-modified orange juices displayed no differences in certain sensory properties, such as aroma, taste, and texture, based on the type of hydrocolloids used. However, in terms of appearance, color and overall acceptance scores, TM orange juices prepared with starch scored statistically higher than other samples. The color scores of the samples prepared with starch remained consistently high across all levels. This outcome corresponds with the results of the color analysis, which demonstrated an increase in the *L* (lightness) and *b* (yellow) values of these samples increased at the end of storage period. The scores of overall acceptability, viscosity, and swallowing difficulty exhibited a significant influence based on the type and concentration of hydrocolloids utilized. Orange juices formulated with starch garnered higher preference among the panelists due to their lower viscosity, ease of swallowing, and more favorable sensory attributes. The outcomes of the viscosity analysis also echoed in this sentiment, showcasing a notable reduction in viscosity values by the end of storage period, particularly in the case of orange juice samples prepared with starch. This decline in viscosity played a positive role in enhancing panelist preferences during the sensory analysis.

Despite high overall acceptance scores of orange juice samples thickened with starch, it should be noted that these samples showed inconsistency between NDD and IDDSI standards. Indeed, for orange juice samples thickened with starch based on the NDD categories, thin liquids were classified into levels 0, nectar-like liquids were levels 0 and 1, and honey-like liquids were levels 1 and 2 after application of the syringe flow test. Such high-viscosity variety leads to different patterns of swallowing resulting with the risk of aspiration. For this reason, it is important that texture-modified food must be defined by conducting rheological measurements and sensory analysis to recommend appropriate food textures for patients with dysphagia.

5. Conclusion

We formulated thickened fruit juices by using various hydrocolloids and categorized them according to the levels set by NDD standards, determined by their measured viscosities. Upon conducting the syringe flow test according to the IDDSI framework, it became evident that there was a lack of congruence between viscosity classifications offered by NDD and IDDSI. Substantial alterations were observed in the viscosity values of the texture-modified fruit juices after three months of storage. Among the hydrocolloids, it was observed that the viscosity imparted by starch was the most significantly affected by storage, leading to a noticeable decrease. The storage period, as well as type and quantity of hydrocolloid used, exerted a significant influence on total phenol content and antioxidant capacity. In addition, performing analyzes at more frequent intervals and during longer storage periods will be useful for investigating the effects of storage more clearly and thus increasing the accuracy and reliability of the results. Through a combination of sensory evaluations and physicochemical analyses, we were able to assess the stability of the prepared TM fruit juices during storage. Our findings indicated that orange juices thickened with starch received higher preference ratings in terms of appearance, color, overall acceptability, and aroma criteria. Ensuring the stability of viscosity and texture of foods and liquids is of paramount importance for individuals with swallowing difficulties. The development of safe standardized recipes for dysphagic patients necessitates a comprehensive consideration of all preparation and storage conditions that impact TM foods and fluids. Establishing optimal storage time and conditions for thickened fruit juices can help minimize changes in the textural and sensory attributes of final product, thereby reducing risks for dysphagic patients.

Ethics statement

This study was reviewed and approved by [Muğla Sıtkı Koçman University Ethics Committee], with the approval number: [210109]. The consent of the panelists was obtained to carry out the sensorial analysis.

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Data availability statement

The data will be made available on request.

CRediT authorship contribution statement

Buse Akçay: Formal analysis, Investigation, Resources, Visualization. **Derya Alkan:** Conceptualization, Investigation, Methodology, Validation, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

[1] J.M. Aguilera, D.J. Park, Texture-modified foods for the elderly: status, technology and opportunities, Trends Food Sci. Technol. 57 (2016) 156–164, https://doi.org/10.1016/j.tifs.2016.10.001.
[2] L. Sura, et al., Dysphagia in the elderly: management and nutritional considerations, Clin. Interv. Aging 7 (2012) 287–298, https://doi.org/10.2147/CIA.S23404.
[3] E. Emami, et al., The impact of edentulism on oral and general health, Int. J. Dent. (2013) 1–7, https://doi.org/10.1155/2013/498305. Article 498305.
[4] S. Sungsinchai, et al., Texture modification technologies and their opportunities for the production of dysphagia foods: a review, Compr. Rev. Food Sci. Food Saf. 18 (2019) 1898–1912, https://doi.org/10.1111/1541-4337.12495.
[5] O. Martínez, et al., Sensory perception and flow properties of dysphagia thickening formulas with different composition, Food Hydrocolloids 90 (2019) 508–514, https://doi.org/10.1016/j.foodhyd.2018.12.045.
[6] J.A.Y. Cichero, Thickening agents used for dysphagia management: effect on bioavailability of water, medication and feelings of satiety, Nutr. J. 12 (54) (2013), https://doi.org/10.1186/1475-2891-12-54.
[7] J.A.Y. Cichero, Adjustment of food textural properties for elderly patients, J. Texture Stud. 47 (2016) 277–283, https://doi.org/10.1111/jtxs.12200.
[8] International Dysphagia Diet Standardization Initiative, Retrieved from, https://iddsi.org/Framework, 2023. (Accessed 9 January 2023).
[9] K. Nishinari, et al., The food colloid principle in the design of elderly food, J. Texture Stud. 47 (2016) 284–312, https://doi.org/10.1111/jtxs.12201.
[10] A. Yemenicioglu, et al., A review of current and future food applications of natural hydrocolloids, Int. J. Food Sci. Technol. 55 (2019) 1389–1406, https://doi.org/10.1111/ijfs.14363.
[11] T. Funami, et al., Texture design for products using food hydrocolloids, Food Hydrocolloids 26 (2012) 412–420, https://doi.org/10.1016/j.foodhyd.2011.02.014.
[12] F. Hayakawa, et al., Characterization of eating difficulty by sensory evaluation of hydrocolloid gels, Food Hydrocolloids 38 (2014) 95–103, https://doi.org/10.1016/j.foodhyd.2013.11.007.
[13] H.M. Cho, W. Yoo, B. Yoo, Steady and dynamic rheological properties of thickened beverages used for Dysphagia diets, Food Sci. Biotechnol. 21 (2012) 1775–1779, https://doi.org/10.1007/s10068-012-0237-4.
[14] E. Paquet, et al., Effect of processing treatments and storage conditions on stability of fruit juice based beverages enriched with dietary fibers alone and in mixture with xanthan gum, LWT–Food Sci. Technol. 55 (2014) 131–138, https://doi.org/10.1016/j.lwt.2013.08.014.
[15] F. İçier, Changes on some quality characteristics of fermented soy milk beverage with added apple juice, LWT–Food Sci. Technol. 63 (2015) 57–64.
[16] B. Adeleye, C. Rachal, Comparison of the rheological properties of ready-to-serve and powdered instant food–thickened beverages at different temperatures for dysphagic patients, J. Am. Diet Assoc. 107 (2007) 1176–1182.
[17] International Dysphagia Diet Standardization Initiative, Retrieved from, https://iddsi.org/Testing-Methods, 2023. (Accessed 10 January 2023).
[18] V.L. Singleton, J.A. Rossi, Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents, AJEV (Am. J. Enol. Vitic.) 16 (1965) 144–158.
[19] C. Ankolekar, et al., In vitro bioassay based screening of antihyperglycemia and antihypertensive activities of *Lactobacillus acidophilus* fermented pear juice, IFSET 13 (2012) 221–230, https://doi.org/10.1016/j.ifset.2011.10.008.
[20] B. Cemeroglu, Food Analysis. Ankara: Food Technology Association Publications.
[21] C. Sánchez-Moreno, Quantitative bioactive compounds assessment and their relative contribution to the antioxidant capacity of commercial orange juices, J. Sci. Food Agric. 83 (2003) 430–439, https://doi.org/10.1002/jsfa.1392.
[22] P.B. Pathare, U.L. Opara, F.A. Al-Said, Colour measurement and analysis in fresh and processed foods: a Review, Food Bioprocess Technol. 6 (2013) 36–60, https://doi.org/10.1007/s11947-012-0867-9.
[23] G.E. Ibrahim, et al., Effect of clouding agents on the quality of apple juice during storage, Food Hydrocolloids 25 (2011) 91–97, https://doi.org/10.1016/j.foodhyd.2010.05.009.
[24] C. Liang, et al., Effect of hydrocolloids on pulp sediment, white sediment, turbidity and viscosity of reconstituted carrot juice, Food Hydrocolloids 20 (2006) 1190–1197, https://doi.org/10.1016/j.foodhyd.2006.01.010.
[25] A.T. Tiruneh, A.A. Negatu, N. Satheesh, Effect of anchote (*Coccinia abyssinica*) and potato starch addition on colloidal stability of pineapple juice, Int. J. Food Sci. (2021), https://doi.org/10.1155/2021/6615273. Article 6615273.
[26] A.S. Machado, et al., Lack of standardization in commercial thickeners used in the management of dysphagia, Ann. Nutr. Metab. (2019), https://doi.org/10.1159/000504334.
[27] Y. Yokote, et al., Comparison of viscosity classifications between the Japanese dysphagia diet 2013 criteria and the international dysphagia diet standardisation initiative, ECNU 10 (5) (2017) 185–194.
[28] I. Handayani, The effect of hydrocolloid on stability of Papaya-Pineapple jelly drink during storage, IOP Conf. Ser. Earth Environ. Sci. 653 (2021), 012056, https://doi.org/10.1088/1755-1315/653/1/012056.
[29] S. Kraithong, S. Rawdkuen, Effects of food hydrocolloids on quality attributes of extruded red Jasmine rice noodle, PeerJ (2020), e10235, https://doi.org/10.7717/peerj.10235. Article 8.
[30] I. Ali, et al., Processing and storage influence on scavenging activity of fruit juices, Marmara Pharm. J. 21 (2) (2017) 298–304, https://doi.org/10.12991/marupj.300773.
[31] I. Klimczak, et al., Effect of storage on the content of polyphenols, vitamin c and the antioxidant activity of orange juices, J. Food Compos. Anal. 20 (3–4) (2007) 313–322, https://doi.org/10.1002/jsfa.7880.
[32] A. Oliveira, M. Pintado, D.P.F. Almeida, Phytochemical composition and antioxidant activity of peach as affected by pasteurization and storage duration, LWT–Food Sci. Technol. 49 (2012), 202207, https://doi.org/10.1016/j.lwt.2012.07.008.
[33] V. Kabasakalis, D. Siopidou, E. Moshatou, Askorbic acid content of commercial fruit juices and its rate of loss upon storage, Food Chem. 70 (2000) 325–328, https://doi.org/10.1016/S0308-8146(00)00093-5.
[34] M. Ros-Chumillas, et al., Quality and shelf life of orange juice aseptically packaged in PET bottles, J. Food Eng. 79 (2007) 234–242, https://doi.org/10.1016/j.jfoodeng.2006.01.048.

[35] M. Gössinger, et al., Effect of xanthan gum on typicity and flavour intensity of cloudy apple juice, J. Food Process. Preserv. Article 42 (2018), e13737, https://doi.org/10.1111/jfpp.13737.

[36] M. Teleszko, P. Nowicka, A. Wojdyło, Effect of the addition of polysaccharide hydrocolloids on sensory quality, color parameters, and anthocyanin stabilization in cloudy strawberry beverages, Pol. J. Food Nutr. Sci. 69 (2) (2019) 167–178, https://doi.org/10.31883/pjfns-2019-0014.

[37] W. Wu, et al., Effects of high pressure and thermal processing on quality properties and volatile compounds of pineapple fruit juice, Food Control 130 (2021), https://doi.org/10.1016/j.foodcont.2021.108293. Article 108293.

[38] J. Szczepańska, et al., Effect of static and multi-pulsed high pressure processing on the rheological properties, microbial and physicochemical quality, and antioxidant potential of apple juice during refrigerated storage, Food Sci. Technol. 150 (2021), https://doi.org/10.1016/j.lwt.2021.112038. Article 112038.

[39] O.G. Nwaokoro, C.T. Akanbi, Effect of the addition of hydrocolloids to tomato-carrot juice blend, JNHFS (2015), https://doi.org/10.15226/JNHFS.2015.00134.

[40] H. Hassan, et al., Nutritional functions and antioxidative enzymes in juice extract from two different maturity stages of low temperature stored phalsa (*Grewia subinaequalis D.C.*) fruit, Food Technol. 153 (2022), https://doi.org/10.1016/j.lwt.2021.112552.

[41] M. Mahomud, et al., Effect of starch and carboxymethtyl cellulose on physico-chemical properties of tomato juice, Progress Agric 18 (2) (2007) 235–240, https://doi.org/10.3329/pa.v18i2.18245.

[42] S. Ghafari, S. Ansari, Microbial viability, physico-chemical properties and sensory evaluation of pineapple juice enriched with *Lactobacillus casei, Lactobacillus rhamnosus* and inulin during refrigerated storage, J. Food Meas. Char. 12 (2018) 2927–2935, https://doi.org/10.1007/s11694-018-9908-z.

[43] R. Shamsudin, et al., Physicochemical properties of the josapine variety of pineapple fruit, Int. J. Food Eng. 3 (5) (2007), https://doi.org/10.2202/1556-3758.1115.

[44] K. Wendin, et al., Objective and quantitative definitions of modified food textures based on sensory and rheological methodology, Food Nutr. Res. 54 (2010) 5134, https://doi.org/10.3402/fnr.v54i0.5134.