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COMPREHENSIVE REVIEW

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Instrumental and sensory techniques to characterize the texture of foods suitable for dysphagic people: A systematic review

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Abstract
The interest to characterize texture-modified foods (TMFs) intended for people with oropharyngeal dysphagia (OD) has grown significantly since 2011. Several instrumental and sensory techniques have been applied in the analysis of these foods. The objective of the present systematic review was to identify the most appropriate techniques, especially for the food industry and clinical setting. The search was carried out in three online databases according to the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA). Across the multiple trials reviewed, Texture Profile Analysis and the Uniaxial Compression Test were most used as the instrumental technique for solid foods, and the Back Extrusion Test for fluid and semisolid foods. All trials used descriptive analysis as the sensory technique. However, the experimental conditions of the trials lacked standardization. Consequently, the results of the trials were not comparable. To properly characterize the texture of TMFs intended for OD by each technique, an international consensus is needed to establish standardized experimental conditions. Methods based on these techniques should also be validated by collaborative studies to verify repeatability, replicability, and reproducibility.

KEYWORDS
clinical setting, food industry setting, instrumental analysis, sensory analysis, texture-modified food

Abbreviations: AV, apparent viscosity; BCT, Bostwick Consistometer Test; BET, Back Extrusion Test; CATA, Check-All-That-Apply; CP, cerebral palsy; IDDSI, International Dysphagia Diet Standardization Initiative; LST, Line Spread Test; OD, oropharyngeal dysphagia; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; QDA®, Quantitative Descriptive Analysis; ROD, Remain Operative Details; TMFs, texture-modified foods; TPA, Texture Profile Analysis; UCT, Uniaxial Compression Test; VFS, videofluoroscopy.

1 INTRODUCTION

Oropharyngeal dysphagia (OD) is characterized by difficulty swallowing solid or liquid food effectively and safely as a result of degradation in the upper digestive tract. Uncontrolled OD increases the dehydration, malnutrition, pneumonia, and mortality risks. One of the most effective ways to reduce the negative effects of OD is to safely swallow using texture-modified foods (TMFs) (Sukkar et al., 2018). The availability of TMFs could improve the quality of life of people with OD and facilitate their social integration.

Over the past decade, research on TMFs intended for people with OD has grown. According to Scopus® database, fewer than 100 research articles, including the terms "texture-modified," "food," "oropharyngeal," or "dysphagia," were published before 2011. The number of publications increased in the following years, to exceed 420 in 2021. On the other hand, 340 articles are found when keywords as "thickener," "water," and "dysphagia" are considered, and most of them evaluated the effects of thickening agents in water (an "ideal model"). But the behavior of thickeners in water differs by comparison with a complex matrix as TFMs (Schmidt et al., 2021). In these documents, various instrumental and sensory methods were used to characterize the texture of TMFs.

Among instrumental techniques, rheometry, texture analyzer assessment, tribometry, optical and laser microscopy, and ultrasound were used. Rheometric methods are common tools in the analysis of gel-type foods, emulsions, or thickened liquids. Most of the works focused on measuring a steady-state property such as the apparent viscosity (AV). Other works quantified dynamic properties such as storage modulus or elastic component (G', stored energy in a deformation cycle) and loss modulus or viscous modulus (G'', energy dissipated in a deformation cycle) to assess the suitability of an OD-oriented food (Sukkar et al., 2018). The devices used in rheometric methods have two disadvantages, high initial expenditure, and the need for qualified staff. Therefore, rheometric methods are rarely used in the food industry and even less in the clinical setting of OD. Other methods, such as the Bostwick Consistometer Test (BCT) or the Line Spread Test (LST), are often used for their greater simplicity in comparison to the abovementioned ones (Hadde & Chen, 2021). BCT has been successfully applied to evaluate the rheological properties of 30 thickened beverages for OD treatment (Germain et al., 2006). The LST method combined with the Back Extrusion Test (BET) and descriptive sensory analysis has been used to characterize the consistency of 10 commercial purees intended for OD (Ettinger et al., 2014).

The analysis using a texture analyzer simulates chewing and swallowing according to empirical parameters. Understanding the relationships between the mechanical properties and perceived texture during chewing and swallowing could aid in the design of safe foods oriented to OD or foods that have a desired texture profile (Young et al., 2013). For example, texture analyzer assessment has been performed to characterize TMFs as pureed cakes for dysphagic patients (Houjaij et al., 2009), carrot purees with nine thickeners for elderly patients (Sharma et al., 2017), and three-dimensional (3D) printed carrots produced with different thickeners oriented to older adults (Strother et al., 2020).

Tribometer techniques allow the evaluation of the surface properties of food, properties associated with friction and lubrication at the beginning of swallowing (Chen & Stokes, 2012). The tribological devices are used to emulate the action of the tongue against hard palate. Tribometer techniques are also being applied to TMFs, but so far, only one study has been conducted on three beverages with different OD-oriented thickeners (Vieira et al., 2020).

Optical microscopy has been used to analyze the changes in the microstructure of liquid foods after adding thickeners intended for OD (Moret-Tatay et al., 2015). Laser microscopy has been used to verify modifications of the ultrastructure of a vegetable puree to which pectin was added in the range of 0.1%–0.3% (Olaru et al., 2021).

Techniques based on the use of ultrasounds were originally developed to monitor swallowing (Suzuki et al., 2019). In-line Pulsed Ultrasound Velocimetry combined with Pressure Drop, which mimics the tubular geometry in the pharynx, has been applied to characterize flow properties of many foods. This technique has been used in a single study to evaluate the rheometric properties of five commercial thickeners designed for dysphagic people (Waqas et al., 2017).

Methods supported by sensory analysis have been suggested as suitable for defining the organoleptic characteristics of OD-oriented TMFs. Descriptive methods allow the texture profile of such foods to be established. Quantitative Descriptive Analysis (QDA®) with trained assessors has been applied to evaluate beverages with three commercial thickeners (Chambers et al., 2017). Qualitative analysis such as the Check-All-That-Apply (CATA) method with untrained assessors has been used to identify and characterize home-made dishes oriented to OD (Merino et al., 2021). Finally, the combination of instrumental and sensory methods has been proposed to generate new knowledge about the texture of foods oriented to the OD (Guénard-Lampron et al., 2021).

A wide variety of instrumental and sensory techniques to characterize the texture of OD-oriented foods have been applied. However, their combined efficacy in establishing the textural characteristics of TMFs for OD has not been analyzed. The objective of this systematic review is to identify the most effective instrumental and sensory techniques to characterize the texture of foods and beverages intended for dysphagic people. The efficacy of the techniques was established, taking as a reference the swallowing safety (direct by videofluoroscopic and endoscopic techniques or surrogate by speech-language therapists' assessments). Finally, the suitability of these techniques according to the application context, industrial or clinical setting, was also assessed.

2 | METHODOLOGY

The review was carried out following the steps proposed by the "Preferred Reporting Items for Systematic Reviews and Meta-Analysis Statement" (PRISMA) (Moher et al., 2015) and updated by the PRISMA 2020 statement (Page et al., 2021). Figure S1 includes the flowchart for the steps followed in this systematic review.

2.1 | Information sources

Searches were performed using the online databases PubMed® (National Library of Medicine, NIH, Bethseda, MD, USA), Web of Science™ (Clarivate Analytics, London, UK), and Scopus® (Elsevier B.V., Amsterdam, The Netherlands).

2.2 | Search strategy

Searches were conducted to identify experimental studies in food or beverages for OD in which texture was characterized using instrumental and/or sensory techniques. Instrumental techniques focused on methods based on texture analyzers and rheometric devices. Sensory analysis methods were supported by descriptive techniques with both trained and untrained assessors. Works in which instrumental and sensory methods were used together were also considered. Table S1 includes the keywords, as well as the keyword strings for searching in each database and for each method.

2.3 | Information screening and study selection

Exclusion criteria were non-English documents, publications as reviews (narrative and systematic), books, chapters, patents, conference abstracts, conference communications, and letters. Inclusion criteria were research articles in which the instrumental and/or sensory characterization of the texture of foods and beverages oriented to the OD was carried out. The deadline for searching and updating information in all databases was August 15, 2021.

Results were collected and screened using a Microsoft Excel® spreadsheet. A list of research articles meeting the inclusion criteria was created. Duplicate documents within the same database and between databases were deleted. The first screening was performed by reviewing titles and abstracts (Page et al., 2021). If the information obtained did not clearly fulfill the inclusion criteria, the material and methods section was reviewed. Articles in which OD-oriented foods or beverages were evaluated were chosen. The studies focused on facilitated swallowing of tablets, pills, and medical capsules and the articles that are based on an "ideal model" (water with thickening agents) were rejected in the present review. However, a valuable information could be obtained on the latter topic through a separate review. Bibliographic references of the articles included in this review were managed using the Zotero software version 5.0.

2.4 | Qualitative synthesis

Data extraction and analysis were performed following the initial screening activities. The type of food or drink, experimental conditions, and results obtained were considered for each technique used, both instrumental and sensory. All information was collected as a narrative review to identify the most relevant experimental parameters. The advantages and disadvantages of each technique were assessed.

3 | RESULTS AND DISCUSSION

Figure S2 summarizes the number of research articles according to the database and all methods considered in present review.

3.1 | Instrumental methods

3.1.1 | Analysis using a texture analyzer

Texture Profile Analysis

Of the 490 articles based on Texture Profile Analysis (TPA) initially identified, 33 met the inclusion criteria. Five additional documents were added after subsequent searches. A total of 38 TPA articles were included in the present systematic review (Table S2). All food products investigated in these studies were semisolid gel-type foods, commercial products, or TMFs.

The TPA method was first described by Friedman et al. (1963), who defined five parameters (hardness, cohesiveness, adhesiveness, gumminess, and elasticity) after applying a consecutive double compression to the sample. The authors proposed a standardized experimental condition for the execution of the trial. Specimens should have at least the same diameter as the probe and a height of 12.75 mm. Other conditions were 75% for compression and 17.78 mm/s for crosshead speed. The present review does not address these parameters but rather discusses the idea of standardizing the parameters of the characterization methods.

The application of TPA in OD-oriented TMFs is relatively recent. TPA was first used by Igarashi et al. (2002) to characterize thickened fruit juices with two agar types and gelatin at different concentrations. The measurements were made at two temperatures (13°C and 20°C) with cylindrical geometry samples. The TPA method made it possible to differentiate the TMFs according to the thickener and the quantities added. Since then, 37 other studies have been conducted using TPA in OD-oriented foods.

The results obtained with TPA according to the experimental conditions are summarized in Table 1. Three types of geometry stood out, polyhedral, cylindrical, and others undescribed or uncommon (hereinafter referred to as “other geometries”). The geometry of the sample is a parameter that can influence the results of the technique (Bourne, 2002). For example, Chen, Zhang, and Rao (2021) characterized 3D surimi gels using samples with cubic and hollow cylindrical geometries. Firmness values were practically double in cubic geometry samples compared to hollow cylindrical geometry samples.

Firmness (originally named hardness) showed 40% lower values in each treatment applied to cylindrical geometry samples. With this geometry, a maximum value of 230 N was reported in biscuit bolus (Young et al., 2013). However, the greatest differences were recorded in polyhedral geometry samples, from 0.31 N in pureed carrots with gums (Strother et al., 2020) to 410.10 N in cooked sous-vide beef (Pematilleke et al., 2021). The safety for swallowing TMFs with high firmness should be verified since these values are more typical of chewing in adults, up to 405 N (Palinkas et al., 2010), than tongue strength during swallowing, which does not exceed 52 N (Arakawa et al., 2021).

Cohesiveness, the ratio between the first and second compression areas, takes values in the range between 0 and 1. In the works included in this review, values from 0.10 (with 60% of strain level) were indicated in cylindrical geometry samples of gels made with agar (Igarashi et al., 2002) to 0.97 (with unknown strain level) in samples of indefinite geometry of white rice with modified texture (Park et al., 2017). In other geometries, there were no relevant differences. Since cohesiveness is related to the extensibility of homogeneous foods, it has been hypothesized that highly cohesive fluids are less fragmented into smaller particles in the oropharyngeal and are safer than fluids with lower cohesiveness (Nishinari et al., 2019). For this reason, it is necessary to propose cohesiveness values of TMFs to adapt them to the different levels of dysphagia.

Adhesiveness, another parameter used to establish the suitability of OD-oriented foods (Park et al., 2020), recorded maximum values of close to 0 N·s in beef treated with transglutaminase (Pematilleke et al., 2022) and minimum values of −235.0 N·s in biscuit boluses (Young et al., 2013). These foods should be analyzed using videofluoroscopy (VFS) techniques to establish a value for safe adhesiveness of TMFs intended for OD. Springiness (originally named elasticity) affects the ability of the food sample to return to its original shapes after tongue compression against the hard palate (Houjaij et al., 2009). This parameter did not exceed 0.9 mm in polyhedral geometry samples or other geometries. In contrast, samples of cylindrical geometry were reported up to 8.86 mm. With this range of values, it was not possible to make a recommendation for OD-oriented TMFs. Such range of values is caused by the variability of the method parameters (Table 1). This variability does not facilitate the comparison between articles and recommendations to obtain the most suitable characteristics of OD-oriented TMFs. The standardization of method parameters is required in order to obtain the aptitude of TMFs for each type of OD.

Some parameters of TMFs (firmness, chewiness, and adhesiveness) have been associated with homologous organoleptic attributes. In contrast, cohesiveness and springiness did not show correlations (Pematilleke et al., 2022). According to Young et al. (2016a), adhesiveness and cohesiveness may be measuring, amongst others, a mixture of adhesion and cohesion properties. On the other hand, Matsuyama et al. (2021) established a correlation of firmness (−0.85) and cohesiveness (0.66) with the perceived ease of swallowing. Even so, firmness, cohesiveness, and adhesiveness have been established as the most relevant organoleptic attributes for foods destined for OD (Pure et al., 2021). These attributes could be estimated using the homologous parameters of TPA.

The efficacy of TPA to establish the suitability of TMFs for OD was performed in only five studies evaluating their safety for swallowing by VFS. A study in rice gruel for the elderly with impaired swallowing showed correlations of vallecular aggregation time with the firmness (0.968) values of 226–6.2 × 10^4 N/m^2 and with the adhesiveness (−0.999) of −0.55 to −2.37 N·s. Therefore, these parameters would be associated with swallowing activation reflex and

TABLE 1 Summary of methods to characterize food texture for oropharyngeal dysphagia using a texture analyzer: Texture Profile Analysis (TPA), Uniaxial Compression Test (UCT), and Back Extrusion Test (BET)

Method	Sample geometry	Test parameters' ranges	Foodstuffs analyzed	Range of results	Findings	Reference
TPA	Polyhedral ($h \times l \times w$, mm): 6 × 6 × 6 to 30 × 30 × 20	Speed (mm/s): 0.42–3.00 Probe (Ø × h, mm): 2.5 × – to 50 × – Probe material: aluminum Strain level (%): 33.3–80 (both) Time interval (s): 10 Trigger force (g): 5 Load cell (kg): 50 Temperature (°C): 12–55	3D printed foods, and first, second, and dessert commercial courses for OD.	Firmness (N): 0.31 to 410.13 Cohesiveness: 0.16 to 0.93 Adhesiveness (N s): −0.912 to 0.0 Springiness (mm): 0.35 to 0.90 Gumminess (N): 0.25 to 0.7 Chewiness: 51 to 790 Viscosity index (g s): 667.5 to 1151.9	Good method to characterize firm/chewiness foods. High correlations with sensory analysis and other instrumental methods as rheology, good to design suitable food for OD. Needs for standardization of parameter's units.	Houjaij et al., 2009; Kim & Joo, 2020; Park et al., 2017; Pematilleke et al., 2021; Pematilleke et al., 2022; Stangierski & Kawecka, 2019; Strother et al., 2020; Suebsaen et al., 2019
	Cylinder (Ø × h, mm): 20 × 20 to 45 × 62	Speed (mm/s): 1–10 Probe (Ø × h, mm): 15 × – to 50 × – Probe material: stainless, acrylic, plastic, resin, and polyacetal Strain level (%): 16.1–80 (both) Time interval (s): – Trigger force (g): 2 Load cell (kg): 1–102 Temperature (°C): 13–22	Meat, vegetables, and mix of ingredients in hydrogels. Pureed foods. Bolus of chewed foods.	Hardness/Firmness (N): 0.45–230 Cohesiveness: 0.1–0.9 Adhesiveness (N s): −0.11 to −235 Springiness (mm): 0.811–8.86 Gumminess (N): 0.4–1.3 Chewiness: 1365.0–2845.6 Viscosity index (g s): not assessed	Good method to complement other sensory or instrumental methods as the rheology to classify and to evaluate the suitability of the OD-oriented food. Needs for standardization of parameter's units.	Chen, Zhang, & Rao, 2021; Guo et al., 2017; Igarashi et al., 2002; Kohyama et al., 2007; Kunimaru et al., 2021; Leon et al., 2019; Manda et al., 2019; Matsuyama et al., 2021; Okita et al., 2021; Olaru et al., 2021; Sharma et al., 2017; Young et al., 2013
	Other geometries or not geometry 4.0 g balls and others	Speed (mm/s): 1–10 Probe (Ø × h, mm): 2 × – to 100 × – Probe material: – Strain level (%): 25–70 (both) Time interval (s): 2–10 Trigger force (g): 3–510 Load cell (kg): 5–50 Temperature (°C): 5–60	Meat balls, semisolid commercial foods, and 3D printed foods.	Firmness (N): 0.13–43.62 Cohesiveness: 0.18–0.97 Adhesiveness (N s): −0.08 to −6.90 Springiness (mm): 0.35–0.57 Gumminess (N): 0.17–3.10 Chewiness: 4.81–89.01 Viscosity index (g s): not assessed	TPA facilitates the selection of the appropriate 3D method to elaborate suitable products for OD. Poor correlations with IDDSI parameters (5–7 levels). Heterogeneity in the parameter's units, firmness, or adhesiveness	Chen, Zhang, & Phuhongsung, 2021; Dick et al., 2019, 2020, 2021a, 2021b; Hayashi et al., 2016; Iida et al., 2011; Kim & Joo., 2020; Kwak et al., 2021; Momosaki et al., 2013; Nakatsu et al., 2012; Pant et al., 2021; Park et al., 2017, 2020; Pure et al., 2021; Rungraung et al., 2020; Sano et al., 2015; Tokifuji et al., 2013; Umene et al., 2015; Wilson et al., 2020

(Continues)

TABLE 1 (Continued)

Method	Sample geometry	Test parameters' ranges	Foodstuffs analyzed	Range of results	Findings	Reference
UCT	Cylindrical geometry (Ø × *h*, mm): 10.4 × 10.8 to 25.0 × 20.0	Speed (mm/s): 0.83–10.00 Probe (Ø × *h*, mm): 1.78 × – to 75.00 × – Probe material: Acrylic, Perspex, and aluminum Strain level (%): 10–90 Temperature (°C): 20–22 Trigger force (N): 0.003–0.1 Load cell (kg): 5–50	Thickened liquids, and softened foods.	Firmness (N): 0.0–180.0 Cohesiveness (N): 0.41–0.69 Adhesiveness (N): 1.0–15.1 Young modulus (kPa): 1.0–256.3	Usually, it has been used to measure the hardness, cohesiveness, and adhesiveness. Some references calculated the Young's modulus. Complemented with other methods as BET or TPA, it is useful to characterize the food for dysphagic people.	Alsanei et al., 2015; Groher et al., 2006; Guo et al., 2013; Jeong et al., 2021; Lee et al., 2021; Leon et al., 2016, 2019; Matsuyama et al., 2021; Sakamoto et al., 2006; Stading, 2021; Vallons et al., 2015
BET	Cylindrical geometry (Ø × *h*, mm): 3.9 × 25 to 50 × 115	Speed (mm/s): 0.05–1000 Probe (Ø × *h*, mm): 3.75 × – to 75 × – Probe material: metal and acrylic Strain level (%): 35–80 Temperature (°C): 22–55 Trigger force (N): unknown Load cell (kg): 5	Semisolid commercial products, gel and microgels, and therapeutic dishes/foods manufactured for OD.	Firmness (N): 0.35–36.5 Apparent stress (kPa): 1.3–1239.7 Minimum force (N): –11.5 to –1.0	Some BET derivative methods as "Ball Back Extrusion" improve the results of conventional BET. Useful to calculate the point of swallow. The method needs to be complemented by other methods to characterize the texture.	Chen, Hadde, et al., 2021; Dick et al., 2020; Ettinger et al., 2014; Ibañez et al., 2019; Leon et al., 2016, 2019; Merino et al., 2020; Syahariza & Yong, 2017; Young et al., 2013, 2016b

ease of TMF swallowing (Park et al., 2017). Other authors concluded cohesiveness has an influence on the residues the food leaves in the pharynx and gumminess on the risk of aspiration (Momosaki et al., 2013). However, the results of the study are not conclusive due to the lack of diversity in the characteristics of the evaluated foods. The remaining studies did not correlate the results obtained by both techniques (Iida et al., 2011; Kwak et al., 2021; Tokifuji et al., 2013). Nevertheless, food analyzed by TPA would be suitable for OD when firmness and adhesiveness values are low (below 2×10^4 N/m^2 and between 5 and 10 J/m^3, respectively) and cohesiveness values are moderate (0.3–0.4) (Tokifuji et al., 2013). These values correspond to pressurized and heat-treated pork meat gel and cannot be extended to processed or characterized food outside of that work.

TPA is revealed as an appropriate method for the food industry for its help in the production of safe foods in a standardized way (Suebsaen et al., 2019). In addition, the correlations between parameters such as firmness, cohesiveness, and adhesiveness with VFS parameters show their potential efficacy as a method to establish the suitability of TMFs for OD. But there are physiological factors such as insalivation degree or oral cavity temperature that contribute to the swallowing action. These factors limit the results obtained with TPA (Park et al., 2020). It is therefore necessary to investigate the relationships of TPA and VFS to define the most relevant parameters and quantify their values for better applicability of the method. On the other hand, TPA is less practical in the clinical setting due to its high initial cost, the need for trained assessors, as well as the time to prepare the samples and to carry out their measurement.

Uniaxial Compression Test

Of the 104 publications about the Uniaxial Compression Test (UCT) method initially identified, four met the inclusion criteria. Eight additional publications were added after subsequent searches. A total of 12 UCT articles were included in the present systematic review (Table S3).

UCT can be considered a particular case of TPA as a single compression is applied to the sample. In addition to the firmness of the evaluated product, UCT allows estimate parameters such as consistency, cohesiveness, and adhesiveness. In the OD field, Sakamoto et al. (2006) applied UCT for the first time in foods rich in dietary fiber (burdock roots) treated enzymatically. The authors called the positive area of the graph hardness and obtained a value of 80 kPa in samples with 0.05% (cellulosin ME). This value exceeds the maximum pressure of 63.9 kPa that can be exerted by the tongue of nondysphagic adults (Youmans & Stierwalt, 2006) and the tongue strength of people with OD, which is between 1 and 30 kPa (Hasegawa et al., 2017; Lee et al., 2016; Minagi et al., 2018).

Similar to TPA, a wide range of values was observed in TMFs evaluated by UCT (Table 1). Firmness of the products ranged from close to 0 of mashed potato (Alsanei et al., 2015) to 180.0 N of carrot gels with 40% starch added. This last value is below the chewing ability of nondysphagic people (300–600 N). In any case, the product would be suitable for the elderly as its bite force is of the order of 120 N (Bakke, 2006). It is certain the product would not be suitable for dysphagic people as it exceeds the 30 N the tongue can exert against the hard palate.

According to Olaru et al. (2021), cohesiveness varied between 0.41 and 0.69 N for *courgettes* puree without and with 0.3% thickener, respectively. With respect to adhesiveness, Groher et al. (2006) indicated values from 1.0 N (apple sauce with vegetable oil) to values of 15.1 N (samples with corn oil). Since these samples were classified as safe by VFS, these values correspond to OD suitable products.

Young's modulus is an estimation of the elasticity of deformed foods by compression. Alsanei et al. (2015) recorded the lowest value (1 kPa) in samples with mashed potato 8% and thickener 1.4%. The authors correlated positively these results with those of the tongue strength analysis during the swallowing process. Therefore, the samples were considered suitable for the elderly. Guo et al. (2013) reported the highest value (256.3 kPa) in whey protein gels with NaCl. In turn, these gels reached 77.8 N in firmness and were suitable only for people with chewing difficulties.

UCT allowed quantification of the energy needed to deform food and was able to distinguish between foods with different thickeners or concentrations of thickeners (Alsanei et al., 2015; Leon et al., 2016). According to Groher et al. (2006), UCT correctly characterized the cohesiveness and adhesiveness of the analyzed samples. These authors also evaluated samples using VFS. Although the results should be interpreted with caution as the techniques were not directly correlated, the identification of safe foods for people with impaired swallowing was made easier. These foods presented low adhesiveness (1.0–1.9 N) and moderate cohesiveness (0.459–0.458); higher values would increase the risk of residues. Again, these values are valid only for the described work.

According to Tokifuji et al. (2013), UCT quantified the three parameters considered critical in food for OD. Nevertheless, this technique should be complemented with BET, TPA, rheology, or the penetration test for a better characterization of TMFs (Jeong et al., 2021; Leon et al., 2019; Matsuyama et al., 2021; Stading, 2021). For these reasons, UCT is proposed as a fast and effective method for the industrial setting. In the clinical setting, UCT requires an expensive device and specialized training but could be interesting for its ease and speed of use.

Back Extrusion Test

Of the 108 publications about the Back Extrusion Test (BET) initially identified in the three databases, 88 remained after duplication removal. Of these, 10 met the inclusion criteria. Five additional publications were added after subsequent searches. A total of 15 BET publications were included in the present systematic review (Table S4).

BET is performed by applying a uniaxial deformation to a sample retained in a cylindrical cell or container. This test resembles the action exerted by the tongue against the hard palate to deform the food prior to swallowing. It should be kept in mind the tongue of nondysphagic adults exerts a force of between 5 and 30 N (Miller & Watkin, 1996; Posen, 1972; Sha et al., 2000) and this strength decreases with age (Crow & Ship, 1996; Mortimore et al., 1999; Youmans & Stierwalt, 2006), OD, and cardiovascular accidents (Hirota et al., 2010; Robinovitch et al., 1991). Therefore, foods with firmness greater than 50 N will not be indicated for the OD.

BET was developed to model the behavior of fluid foods (Osorio & Steffe, 1987). In the OD setting, Groher et al. (2006) applied BET to characterize 20 liquid products whose viscosity ranges, adhesiveness, and cohesiveness were selected by two speech-language therapists among other professionals. They also used VFS to confirm the swallowing safety of the materials in 32 dysphagic patients. The authors found a correspondence of the viscosity range between clinical and instrumental assessment.

The TMFs tested in the included studies were fluid, semisolid, or gel-like type (Table 1). The range of firmness collected in the present review was wide (0.25–36.5 N). Minimum firmness was registered in rice porridge that proved suitable for OD (Syahariza & Yong, 2017). The maximum firmness was obtained in bread puree by Ettinger et al. (2014). Considering the tongue of nondysphagic people exerts forces not exceeding 50 N, it could deform this product. Samples of gelled apple with 23.5 N of firmness have been cataloged by expert speech therapists as suitable for OD associated with cerebral palsy (CP) (Ibañez et al., 2019). Therefore, this would be the maximum firmness of the products intended for the feeding of these people. It has already been pointed out that insufficient characterization of fluid foods and thickened liquids can be dangerous for people with OD (Barbon & Steele, 2018).

Minimum force has been defined as the force necessary to separate the sample and the probe (Ibañez et al., 2019). For this reason, the parameter should be called adhesive force or adhesiveness. According to a study by Merino et al. (2020), the parameter ranged from −1.0 N in crushed samples of lentils with rice to −11.5 N in samples of chicken stew with thickeners. That is, the last TMF was 11 times more adhesive than the first and considered suitable by speech therapists. As previously mentioned, adhesiveness is one of the critical parameters for establishing the safety of food for OD (Pure et al., 2021). It is recommended that it adopt the lowest possible values. Therefore, discrepancies in the values must be analyzed and the suitability of TMFs must be confirmed by techniques that corroborate the safety of TMF swallowing.

BET is an appropriate method to characterize semisolid and fluid food. Some authors suggest it is even more suitable than TPA for heterogeneous and semisolid foods such as thickened rice porridge (Syahariza & Yong, 2017), although others disagree (Nishinari et al., 2019). More research is necessary in this regard. It is a technique whose methodology is evolving. For example, Chen, Zhang, and Rao (2021) used a spherical probe instead of a flat probe. It prevented the accumulation of bubbles under the probe and effectively measured the flow and apparent tension. For their part, Leon et al. (2016) applied BET in gels made with dairy proteins. To do this, they placed the samples in an acrylic cell for BET. Another modification has been to apply two extrusion cycles to protein gels (Leon et al., 2019). BET is a fast and objective technique whose parameters have been related to the triggers of swallowing (Young et al., 2013) and interesting to perform quality controls on Newtonian and non-Newtonian fluids (Chen, Hadde, et al., 2021).

The efficacy of BET has been evaluated through studies in which VFS was used or in which speech therapists experienced in dysphagia or swallowing participated. For example, research on 20 test materials (liquids and semisolids) analyzed using BET and VFS concluded products with high viscosities presented greater cohesiveness and moved more slowly. Therefore, these products, with viscosities between 1.4 and 2.94 $\times$ 10^3 mPa, were considered safe for OD (Groher et al., 2006). Nevertheless, an excess of thickener increases cohesiveness and causes more food residues after swallowing. In a study of TMFs oriented to OD associated with CP, performed by BET and speech therapist experts in dysphagia, the conclusion was that products with low-moderate firmness (6.2–18.9 N) and small negative force (−3.9 to −9.2) were appropriate for safe swallowing (Merino et al., 2020). The authors explain in their manuscript that these values are valid only in the context of their particular work.

BET, complemented with other instrumental methods, could be used in the food industry setting for its ability to classify semisolid foods (Ibañez et al., 2019). In the clinical setting, BET is proposed as a quick and simple method, although it requires training and the initial cost for the acquisition of the device. But the filling of load cells and their use are quick and their relationship with swallowing triggers has already been mentioned, so it could complement current methods.

3.1.2 | Analysis by rheometric devices

Viscosity is the most used parameter to characterize the texture of OD-oriented fluid foods and thickened beverages. In the research setting, complex devices such as viscometers and rheometers are usually used for their greater effectiveness in controlling experimental conditions. With rotational viscometers, the AV is estimated, and with rheometers different physical properties such as viscosity, pseudoplasticity, and viscoelasticity are evaluated. In contrast, in the clinical setting, simple devices are used because they do not require a special qualification for their use. Examples are the LST (Lund et al., 2013), BCT (Germain et al., 2006), and Syringe Test of International Dysphagia Diet Standardization Initiative (IDDSI) (Villiers et al., 2019). However, each of these methods has limitations with very heterogeneous foods or with suspended particles (Claes et al., 2011).

Shear Rheology Test

Studies based on beverages, purees, or pastas were considered. Fifty-seven publications were initially selected after screening. Two publications were excluded after reading the results. Three additional publications were added after subsequent searches. A total of 58 publications were included in the present systematic review (Table S5). Of these, 13 focused on the rotational viscometer method. The remaining 45 articles were divided into 11 dedicated to the disc rheometer, 16 to the parallel plates, 13 to the cone-plate type, and five to other different methods. Viscometers were used to evaluate gels, purees, liquid foods, thickened liquids, and semisolids. With this criterion, methods were classified in the present review (Table 2).

Rotational viscometer is a simple system that made it possible to detect changes in viscosity even when the amount of thickener added was as low as 0.16% (Garcia & Chambers, 2019). The studies included in the review recorded a very wide range of viscosities (Table 2). This range was extended from close to 0.0 Pa·s in orange juice with tapioca starch or with hydroxypropyl distarch (Yang & Lin, 2021) to 47.0 Pa·s in thickened gazpacho (Ibañez et al., 2019). While the range was wide, it should be considered the first was intended for dysphagic elderly and the latter for people with CP associated with OD. Garin et al. (2014) analyzed thickened beverages for the elderly and obtained values between 0.68 and 3.03 Pa·s, a range closer than obtained by Yang and Lin (2021).

Rotational viscometer allows information of the analyzed foods to be obtained, distinguishing samples measured according to type and amount of thickener, food matrix, or temperature (Adeleye & Rachal, 2007). But this technique needs to be complemented with others such as VFS (Yang & Lin, 2021) or BET to make more complete characterizations or classifications (Ibañez et al., 2019). It is a reliable method, but it is limited to products that are as homogeneous as possible. When this criterion is not met, the results are difficult to interpret (Tashiro et al., 2010). However, it is a more appropriate method than others, such as BCT or LST, to characterize thickened liquids (Germain et al., 2006; Lund et al., 2013). In addition, the suitability of TMFs can be established by taking as a reference a standardized value for viscosity, in the style of the Korean industrial standard (Lee et al., 2021).

Unlike rotational viscometers that estimate stationary viscosity, disc, parallel plate, and cone-plate rheometers measure dynamic parameters such as AV, consistency index, loss modulus, and storage modulus (Zargaraan et al., 2014). The foods evaluated with these methods were fluid foods, purees, liquids with and without thickeners, and semisolid foods (Table 2).

In the case of disc rheometers, a wide range of viscosities was reported. From practically 0.0 Pa·s in tomato gel to 1.5×10^3 Pa·s in *timbal* bread, both foods elaborated and characterized at 0.1 s^{-1} by Stading (2021). Thus, more studies are needed to establish the safe range of viscosities for TMFs for OD. This method has been used to evaluate the impact on the texture of the thickener type added and its concentration. For example, in pea creams, storage modulus (G'), loss modulus (G''), and AV were used to compare the behavior of the gels obtained with 10 thickeners (Talens et al., 2021). In *rendang* chicken paste, an increase in consistency index and in yield stress was found when the concentration increased (10%, 20%, and 30%) with the addition of five commercial thickeners (Abu Zarim et al., 2018).

Parallel plate and cone-plate rheometers provided more discrete viscosity ranges (Table 2). With the parallel plate rheometer, the range of values was from 0.01 Pa·s (at 41.9 s^{-1}) in an infant nutritional supplement (Creech et al., 2019) to 27.8 Pa·s (at 50 s^{-1}) in thickened orange juice. This range was greater when cone-plate geometry rheometers were used. In this case, the minimum value was 0.02×10^{-5} Pa·s (at 10 s^{1}) in commercial gelled water (Casanovas et al., 2011). The maximum value of 8.75 Pa·s (at 5 s^{1}) in choco-paste with biscuits was obtained by Claes et al. (2011). These authors pointed out the cone-plate method was not suitable for heterogeneous products or with suspended particles since greater errors are generated in the data. Even with these limitations, rheometers are effective in improving the technological processes of TMFs. For example, the optimal 3D printing conditions were established with the help of a parallel plates rheometer using a shear rate sweep of 0.001–100 s^{-1} (Pant et al., 2021).

TABLE 2 Summary of methods to characterize food texture for oropharyngeal dysphagia by rheometric devices: Shear Rheology Test, Surface Tension Test, Line Spread Test, Bostwick Consistometer Test, and IDDSI Syringe Test

Method	Sample geometry	Test parameters ranges	Foodstuffs analyzed	Results	Findings	Reference
Rotational rheology	Inside a container as a cup Sample (ml): 10–600	Spindle: according to the sample viscosity Shear rate (s^{-1}): 0.1–100 T (°C): 20–25 t (s): 40–240	Liquids, pureed, and semisolid foods normal or thickened.	Viscosity at 50 s^{-1} (Pa·s): 0.0–47.0	More sensitivity than other methods as Bostwick and LST. Method shall be complemented with other instrumental and sensory methods to classify the food textures. Method proposed in some countries to determine the food suitability for OD.	Adeleye & Rachal, 2007; Bagheri et al., 2014; Garcia et al., 2005; Garcia & Chambers, 2019; Garin et al., 2014; Germain et al., 2006; Ibañez et al., 2019; Lee et al., 2021; Lund et al., 2013; Nicosia & Robbins, 2007; Stahlman et al., 2001; Tashiro et al., 2010; Yang & Lin, 2021
Disc rheology	Not applicable	Plate (mm): 20–49.9 Gap (mm): 0.5–2.0 Shear rate (s^{-1}): 0.01–1000 T (°C): 4–75 t (s): 300–1092 Torsion par (μNm): 0.01–10,000 Spectrum (rad/s): 0.063–125.66 Strain (%): 0.01–100	Gel, purees, liquid, and thickened foods. Meat pastes and regular food as yogurts.	Apparent viscosity (Pa·s): ≈0.0 to >1500.0 Consistency coefficient (Pa·s^n): 14.0–273.47 G' (Pa): 0–88,900 G'' (Pa): 1.78–563.3	Good correlations with "easy to swallow", but unrelated with IDDSI parameters. Need to complement with other instrumental methods to whole characterization of TMFs for OD. Need for clinical trials to confirm the rheological parameters to get safe food for OD.	Abu Zarim et al., 2018; Ben Tobin et al., 2020; Choichuedee et al., 2018; Dick et al., 2020; Kim & Yoo, 2018; Patel et al., 2020; Sharma et al., 2020; Stading, 2021; Talens et al., 2021; Villiers et al., 2019; Zargaraan et al., 2014
Parallel plates	Unknown	Plate (mm): 20–50 Gap (mm): 0.5–3.0 Shear rate (s^{-1}): 0.001–1000 T (°C): 8–55 t (s): 15–600 Torsion par (μNm): Unknown Spectrum (rad/s): 0.063–94.2 Strain (%): 0.001–100	Desserts, gels, liquids, purees, and semisolid foods with and without thickeners.	Apparent viscosity (Pa·s): 0.01–27.8 Consistency coefficient (Pa·s^n): 0.05–361.07 G' (Pa): 0.11–3124.2 G'' (Pa): 0.06–563.3	The viscoelastic properties are useful as quality method in food industry. Rheometers detect more changes in the samples consistencies than flow tests (IDDSI). Need for studies with dysphagic patients to confirm the foods safety for dysphagia. Good correlations with sensory analysis. It is better for high viscosities than other methods as LST. It is a complex method that only can be used by experts.	Cho & Yoo, 2015; Cho et al., 2012; Creech et al., 2019; Kim et al., 2014a, 2014b; Kim & Yoo, 2015; Mackley et al., 2013; Pant et al., 2021; Park & Yoo, 2020; Payne et al., 2011; Prinz et al., 2006; Pure et al., 2021; Sharma et al., 2017; Štreimikytė et al., 2020; Syahariza & Yong, 2017; Zargaraan et al., 2013

(Continues)

TABLE 2 (Continued)

Method	Sample geometry	Test parameters ranges	Foodstuffs analyzed	Results	Findings	Reference
Cone-plate	Unknown	Cone (mm): 20–60 Gap (mm): 50.8 (μm) to 1 Shear rate (s^{-1}): 0–1000 T (°C): 0–60 t (s): 200–3600 Torsion par (μNm): 0.01–100 (Pa) Spectrum (rad/s): 0.01–100 Strain (%): 0.5–1.0 Angle (°): 2–4	Desserts, gels, liquids, purees, and semisolid foods with and without thickeners.	Apparent viscosity (Pa·s): 0.02×10^{-5} to 8.75 Consistency coefficient (Pa·s^n): 0.02–34.76 G' (Pa): 7.29–20,400 G'' (Pa): 97.9–2820	Not appropriate for home foods with unique characteristics. It is necessary to be the rheology parameters equal to lingual shear rate. The method helps with the standardized elaboration of foods for dysphagia. It makes classifications by textures and rheological characteristics. With heterogeneous particles in food, the present method produces more errors. Good correlations with sensory analysis. But it is necessary to confirm the food safety by in vivo methods.	Casanovas et al., 2011; Claes et al., 2011; Eleya & Gunasekaran, 2007; Kim et al., 2017; Moret-Tatay et al., 2015; Moritaka, 2012; Sano et al., 2015; Sopade et al., 2007; Sopade, Halley, Cichero, Ward, Hui, et al., 2008; Sopade, Halley, Cichero, Ward, Liu, et al., 2008; Steele et al., 2003; Vieira et al., 2020; Wendin et al., 2010
Line Spread Test	Cylindrical geometry Sample (ml): 20–200	Cylinder (Ø × h, mm): 20 × 20 to 65 × 45 Concentric rings interval (cm): 0.25–1.00 Dispersion time (s): 20–120 T (°C): 10–70 Surface material: Plexiglas, glass, and plastic	Liquid foods, purees, and triturated foods and thickened drinks.	Spread (mm): 1.5–22.2	Easy to use by untrained career. Objective, fast, and cheap method. Only for liquid or thickened liquids. Need to standardize and detail the initial point to measure the spread (the middle of the bullseye or the limit of the cylinder). Other methods as viscometers are appropriates to characterize fluids.	Abu Zarim et al., 2018; Adeleye & Rachal, 2007; Budke et al., 2008; Ettinger et al., 2014; Garcia et al., 2020; Kim et al., 2014a; Lund et al., 2013; Mann & Wong, 1996; Matsuo et al., 2021; Merino et al., 2020; Nicosia & Robbins, 2007; Paik et al., 2004; Rieder er al. et al., 2020; Watanabe et al., 2017

(Continues)

TABLE 2 (Continued)

Method	Sample geometry	Test parameters ranges	Foodstuffs analyzed	Results	Findings	Reference
Bostwick Consistometer Test	Cube compartment ($h \times l \times w$, cm) 3.8 × 5.0 × 5.0 to 4.0 × 5.0 × 5.0	Sample (ml): 75–100 T (°C): 8–35 t (s): 30–60 Interval, precision (cm): 0.25–0.50	Liquids and thickened liquids.	Consistency (cm): 5.0–22.2 (only data with results in cm)	Methods is less accurate than viscometers or rheometers but more than IDDSI syringe method. Methods are not appropriate for consistencies beyond 212 kPa. Good classification of fluids.	Côté et al., 2019; Germain et al., 2006; Milczarek & Mccarthy, 2006; Steele et al., 2014
IDDSI syringe test	Syringe geometry: IDDSI syringe – 60 ml tip	T (°C): 8–30 t (s): 10 s	Liquids and thickened liquids and purees.	Flow (ml): 0.0–10.0	IDDSI initiative does not standardize the test temperature and units. Easy to use for inexperienced users. Flow speed is measure easier with 60 ml syringes than 10 ml. Different fluids can be characterized by the IDDSI method. Samples with particles in suspension could obstruct the syringe tip.	Côté et al., 2019; Creech et al., 2019; Garcia et al., 2020; Hron & Rosen, 2020; Maieves & Teixeira, 2021; Rush et al., 2021; van der Stelt et al., 2020; Weston & Clarke, 2020

Rheometers can be complemented with other instrumental or sensory techniques to be able to perform a better characterization or classification of food for OD. An example of this is the case of the rotational rheometer used by Ibañez et al. (2019) at two shear rates (50 and 100 s^{-1}) in combination with BET to generate a three-level classification for TMFs oriented to the OD associated with CP. Similarly, rheometric analysis (shear rate range of 1–100 s^{-1}, frequency sweeps over the range of 0.1–10 Hz, and strain of 0.01-300%) complemented with sensory profile analysis has made it possible to improve the characterization of thickened broccoli soup (Baert et al., 2021). As for the analyses by parallel plate rheometers, complemented with TPA they can effectively describe the behavior of thickeners based on pureed carrots (Sharma et al., 2017). In addition, correlations have been detected between the parameters of these tests and some organoleptic attributes as mouth-coating and perception of residues in mouth (Ben Tobin et al., 2020; Kim et al., 2017), which can be useful in establishing the safety of food. Nevertheless, further tests are needed to confirm these relationships (Kim et al., 2017) and resolve the discrepancies arising from their comparison with in vivo models of bolus characterization (Patel et al., 2020).

The efficacy of the method was evaluated through a work in which the suitability of the food was confirmed by speech therapists. It could not be evaluated by comparison with VFS because none of the chosen articles performed this method of safety measurement, such as the research performed by Ibañez et al. (2019). Twelve TMFs for OD associated with CP were evaluated and three levels of consistency were established for these products by these authors. The first level reached 7.64 Pa·s, the second at 23.98 Pa·s, and the third up to 46.97 Pa·s, all at 50 s^{-1}. These values are suitable for dishes intended for OD associated with CP. It is a method commonly used in food research and technology for its ability to differentiate fluids by their viscosity, viscoelasticity, and pseudoplasticity characteristics (Vieira et al., 2020) depending on, among other factors, the food matrix or thickener used (Hron & Rosen, 2020). For these reasons, this method performs a correct evaluation and description of the bolus (Stading, 2021). Even so, use in the clinical setting is uncommon due to its complexity and need for trained assessors (Payne et al., 2011).

Research with methods such as the Extensional Rheology Test (Table S6) and Surface Tension Test (Table S7) applied in foods for OD were scarce. These methods mimic the behavior of fluid food in the esophageal phase of swallowing (Ekberg et al., 2009) and have been established as methods that should be complementary to the "shear rate" parameter to evaluate the safety of OD-oriented foods. It is a precise and fast technique since the pistons travel at the end gap of 4.6 mm at a shear rate of 150 mm/s (Hadde et al., 2020). The Surface Tension Test is useful to evaluate the functional properties of some thickeners (Bagheri et al., 2014). It also allows the assessment of the cohesiveness of TMFs, a critical parameter to establish their safety since it conditions the flow rate of food in the oral and pharyngeal phase and determines the fragmentation, extensibility, and elastic limit of the products (Nishinari et al., 2019).

3.1.3 | Analysis by other devices

Line Spread Test

Of the 111 publications about the LST initially identified, 12 met the inclusion criteria. Two additional publications were added after subsequent searches. A total of 14 LST publications were included in the present systemic review (Table S8). All focused on the consistency of thickened liquids, with the exception of one in commercial purees.

The first application of the LST was the evaluation of apple sauce consistency (Grawemeyer & Pfund, 1943). Mann and Wong (1996) proposed LST as a tool for estimating the consistency of OD-oriented beverages and foods. Like the methods mentioned above, the range of consistencies was wide, from a spread of 1.0 cm in samples of meat pastes, crushed potato, or honey (Paik et al., 2004) to 22.2 cm in unthickened mushroom cream (Mann & Wong, 1996). Some authors have pointed out products with spreads smaller than 3 cm are not suitable for OD (Ettinger et al., 2014). Therefore, this range of consistencies should be compared with studies based on clinical diagnostic methods to verify the safety of TMFs.

LST can be used in preliminary tests before resorting to more complex instrumental methods to predict the viscosity of fluid foods intended for a dysphagia diet (Kim et al., 2014a). Its use is discouraged in the field of research or quality control of the food industry because its results are inaccurate and less reproducible than viscometer or rheometer methods (Adeleye & Rachal, 2007; Lund et al., 2013). However, it is a method frequently used in the clinical setting due to its simplicity, speed, low cost, and lack of need for training (Budke et al., 2008; Gosa & Dodrill, 2017; Lund et al., 2013; Nicosia & Robbins, 2007).

Bostwick Consistometer Test

The BCT is an empirical method that has traditionally been used in the food industry to evaluate the consistency of fruit purees, including tomatoes. Of the 88 publications about BCT initially identified, three met the inclusion criteria. An additional publication was added after subsequent searches. A total of four articles were included in the present systematic review (Table S9).

BCT has traditionally been used in the food industry to control the consistency of tomato paste (Marsh et al., 1977). It was subsequently applied in pureed baby foods to establish its consistency (Vercruysse & Steffe, 1989). Using this technique, Germain et al. (2006) characterized the consistency of 30 thickened beverages (juices and nutritional supplements) at 8°C. They found a poor correlation between the consistency measured by BCT and the AV estimated by rotational viscometer. Steele et al. (2014) used BCT to evaluate the consistency of five beverages with xanthan gum-based thickeners at various concentrations (0.50%–0.87%) at room temperature. AV in the range 10–630 s^{-1} was estimated in the same drinks. An indirect relationship was observed between BCT outcomes and AV. The smaller the expansion, the greater the AV. That is, BCT detected the increase in consistency based on the added amount of thickener. Thus, BCT was useful in establishing consistency levels of thickened fluids for subsequent rheological and sensory analysis.

Côté et al. (2019) compared the consistency of four thickened liquids by BCT and the IDDSI Flow Test. The strong correlation between both outputs suggests they measure flow rate in a similar, although not identical, manner. Consequently, the techniques are not interchangeable.

BCT has also been used to assess the impact of extruding on the consistency of a high nutrient-dense weaning food (Chambers IV et al., 2018). This food is aimed at safe swallowing in young children. The technique showed that the extruded food presented a lower consistency because of the gelatinization of starch.

None of the BCT-based studies used clinical methods (direct or surrogate) to assess the safety of OD-oriented TMFs. Therefore, the study of its effectiveness was not possible. Regardless, BCT has been proposed as an ideal method for the clinical setting due to its effectiveness over time, accessibility, and relatively economical cost (Germain et al., 2006). In addition, the use of BCT to measure the consistency of very thick fluids intended for dysphagic people appears to be appropriate in the clinical setting. It could be complemented with IDDSI Syringe Test but never exchanged (Côté et al., 2019).

IDDSI Syringe Test

Of the 81 publications about the IDDSI Syringe Test initially identified, 40 remained after duplication removal. Seven met the inclusion criteria. Four additional publications were added after subsequent searches. A total of 11 publications were included in the present systematic review (Table S10).

The IDDSI Syringe Test was proposed to evaluate food consistency using a syringe of 10 ml and 61.5 mm length. The consistency level is set from the sample volume remaining after 10 s (IDDSI Framework, 2019). In the works included in the present review, the IDDSI Syringe Test was used to characterize liquid and thickened liquid foods (Table 2). The foods obtained a gravity flow range between 0.0 ml for infant formula at level 0 of IDDSI (Brooks et al., 2021; Rush et al., 2021) and 10 ml for infant formula at level 3 of IDDSI and blended regular food (Rush et al., 2021; Weston & Clarke, 2020).

Villiers et al. (2019) used the IDDSI Syringe Test to prepare a nutritious food (porridge with grain maize and soybean) for OD management. The authors established the conditions for modifying texture using two techniques (foaming or straining) so that the food was safe for individuals with swallowing disabilities. Other authors confirmed the ability of this method to discriminate between different beverages such as coffee or milk with commercial thickeners in different concentrations (Garcia et al., 2020). But care must be taken with thick foods or those with particles in suspension since they obstruct the nozzle of the syringe (Maieves & Teixeira, 2021; Weston & Clarke, 2020).

The effectiveness of the IDDSI Syringe Test could not be established as no articles were found in which the test was used simultaneously with a clinical method of food safety assessment or in a surrogate manner by a speech-language therapist. The IDDSI Syringe Test's ability to distinguish between foods with different consistencies and its ease of use in the clinical setting by untrained staff have already been established (Brooks et al., 2021). Furthermore, it is a tool developed by the IDDSI framework to categorize liquid foods. But because no correlations or comparisons with foods for dysphagia have been made, validating the method using quantitative and validated tools is necessary (Côté et al., 2020; Ng et al., 2021).

3.1.4 | Methodological flaws and gaps

The reproducibility of an experimental study is essential in any scientific branch. Repeatability and replicability of a method must be collected in an experimental study for the method to be reproducible by other researchers (Plesser, 2018). In the present systematic review, the level of detail of the experimental conditions was analyzed. It is important to note that the results obtained in the previous sections were reported in different magnitudes. The lack of standardization can lead to errors. Results should therefore be interpreted carefully.

A detailed description of the foods used in a textural characterization study, either by an instrumental method or by a sensory one, is an essential requirement for the method to be reproducible. Therefore, it is necessary to describe the ingredients, the elaborations recipe, and the composition of the TMFs used.

An essential requirement for the comparison and better understanding of the different instrumental and sensory methods is the unification and standardization of the

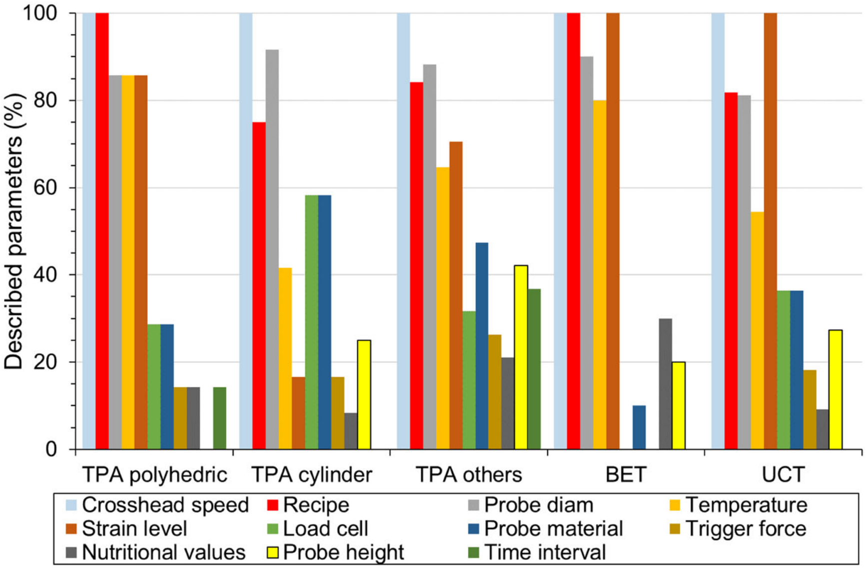

FIGURE 1 Proportion of described parameters in the studies with instrumental methods based in texture analyzer to characterize the OD-oriented foods texture: Texture Profile Analysis (TPA) with 38 references (7 polyhedral, 12 cylinder, and 19 others); Back Extrusion Test (BET) with 15 references; Uniaxial Compression Test (UCT) with 12 references. The time interval parameter does not apply with BET and UCT methods

vocabulary. The definition of the parameters and results in each work must be carried out with a previously defined and standardized vocabulary (Faber et al., 2017). This is achieved with empirical studies such as the trial conducted by these authors for the instrumental parameters as firmness, springiness, and rubberiness. These parameters should be the same for any similar method of texture assessment.

Texture analyzer methods

TPA has been widely used in the analysis of semisolid and solid TMFs. However, some researchers have deviated from the original protocol without considering that the modifications influence the mechanical properties of the food (Rosenthal, 2010). The lack of uniformity in the experimental conditions is shown in Figure 1. This section will assess methodological flaws for some experimental parameters.

Probe to sample diameter ratio (≤1) is a factor that directly influences the firmness values (Friedman et al., 1963). It recognizes the disparity in the dimensions of the used probes and samples. In TPA, probe diameters ranged from 2.5 to 15 mm in polyhedral and cylindrical geometry samples. The diameter was increased to 50 mm in samples with nonspecific height. In BET, these sizes moved between 3.75 and 75 mm with heights not specified. In UCT, the diameters of probes ranged between 1.78 and 75 mm with no known height. In addition, it should be noted the diameter of the probes was described in more than 80% of the chosen works but their height did not exceed 44% for any method.

The materials of the probes for the three texture analyzer methods were primarily aluminum, acrylic, or resin. But, except for TPA with cylindrical samples, less than 50% of the studies described the material. The lubricating qualities of food depend to some extent on the material with which it comes into contact during the test (Joyner et al., 2014). Therefore, the material of the probes must be justified according to the characteristics of the TMF studied.

The crosshead speed was the only parameter described in 100% of the work for all texture analyzer methods. In TPA, it ranged from 1 to 10 mm/s (samples with cylindrical geometries and other geometries) and between 0.42 and 3 mm/s (samples with polyhedral geometry). In BET, these values ranged between 0.05 and 1000 mm/s, and in the UCT between 0.83 and 10 mm/s. Rosenthal (2010) proposed it be greater than 2 mm/s to assimilate to the normal chewing rate (33–66 mm/s). This proposal was based on the logarithmic behavior of the firmness at speeds greater than 2 mm/s. But this should be demonstrated empirically. In addition, dispersion in the firmness data is reduced at high speeds. Tests with speeds of that order are necessary to verify whether they are suitable for OD-oriented TMFs.

Strain level was described in 80% of the studies, reducing to 68% in TPA with samples of other geometries and 18% in TPA with cylindrical geometry. It is related to other experimental parameters and showed significant variations. Important differences in the results were recognized when the strain level was increased from 70% to 80% (Peleg, 2019). This percentage modified the areas of compressions on which firmness and cohesiveness depend, in addition to their derived parameters. Some authors have proposed a 95% strain level for compression to resemble normal human chewing (Nakatsu et al., 2012).

Time interval is the time the probe waits after ascending after the first compression (Bourne, 2002) and is unique to the TPA. It was described in 36.8% of the references for other TPAs. A single work established a time of 10 s for samples with polyhedral geometry (Suebsaen et al., 2019) and none for those with cylindrical geometry. In the case of other geometries, the time moves between 2 and 10 s. Time interval is an important factor since it has a direct relationship with the percentage of compression applied. The longer the time, the more force applied in the first compression dissipates (Rosenthal, 2010). In addition, during this time, the sample partially recovers its initial height, estimated by springiness and expressed in millimeters (Bourne, 2002).

Trigger force and load cell values are parameters that provide information about the detection limits of the TPA method. We did not find any studies in which the variability of the results for TPA according to these parameters was recorded. These are definitions usually made in chemometric studies and should be adopted for physical techniques such as TPA, BET, or UCT.

The temperatures at which the measurements were made showed a wide diversity, with the most frequent being 20–25°C. Exceptionally, serving temperatures between 5 and 60°C were used (Sano et al., 2015). Studies conducted at mouth temperature (37°C) are still scarce and this is a factor that significantly influences the texture parameters of food (Wilkinson et al., 2000).

The firmness of TMFs is traditionally expressed in units of force. However, in the clinical setting the action exerted by the tongue is quantified in pressure units. Only the studies of Igarashi et al. (2002) and Kohyama et al. (2007) expressed firmness in the corresponding units in the case of TPA. For the BET, no study expressed this parameter in units of pressure. For the UCT, Sakamoto et al. (2006) studied the pressure needed to deform samples of burdock roots and enzyme-softened bamboo and Lee et al. (2021) did so similarly in purees with three different consistencies.

Cohesiveness is defined as the ratio of the area of the second and the first compression (Bourne, 2002). Therefore, it is surprising that Stangierski and Kawecka (2019) expressed it in grams without justification. It is important to highlight the relevance of cohesiveness in the characterization of OD since it is one of the parameters that could condition the "point of swallow" (Young et al., 2013). While not certain, cohesiveness is highly correlated with the elastic behavior of the bolus, the speed of the bolus transit, and aspiration risk (Nishinari et al., 2019).

Adhesiveness is expressed as a relationship between force and time or distance. However, in some studies, it was reported as the maximum negative force (Houjaij et al., 2009; Park et al., 2020), distance (Dick et al., 2021a, 2021b), or energy flow (J/m^2 and J/m^3) (Hayashi et al., 2016; Igarashi et al., 2002; Kohyama et al., 2007; Kunimaru et al., 2021; Manda et al., 2019; Nakatsu et al., 2012; Pure et al., 2021; Sano et al., 2015; Umene et al., 2015). This parameter should reach low values in foodstuffs for dysphagic people (Pure et al., 2021).

TPA could be the most appropriate method to measure the textural characteristics of solid foods if the parameters discussed in previous paragraphs are utilized. Bearing in mind that texture analyzer methods emulate swallowing, the probe should resemble the diameter of the pharynx, between 35.5 and 41.1 mm (Inamoto et al., 2015), and tests with probes in this range should be performed. Samples must be the same size and have cylindrical geometry, so the results of different works are reproducible and comparable. In summary, the height of the samples must be normalized and samples with the same diameter as the probe must be used (Friedman et al., 1963). In addition, other experimental parameters should be standardized. For example, the crosshead speed should be set between 33 and 66 mm/s, values similar to those of human swallowing. However, lower speeds should also be tested considering the logarithmic behavior of this parameter (Rosenthal, 2010). Some authors have proposed strain levels of up to 95% for their greater resemblance to chewing (Peleg, 2019). But it has been observed that, from 80% deformation, the results can have important variations (Nakatsu et al., 2012). For these reasons, strain levels of 80% are recommended for measures more like chewing but without problems of variability in the data. Similarly, it is necessary to establish an interval time that allows the sample to recover its initial shape. A time of 10 s is proposed, suitable for this function, and not excessively long. The temperature of the measurement should be standardized, for example, the temperature of the oral cavity (36–37°C). Method parameters such as load cell and trigger force should be noted to establish the method limits.

Because it is also necessary to know the limits of the method to be used, it seems essential to specify the load cell and the trigger force used in the method.

For liquid or semisolid samples, the use of BET as a textural characterization method is recommended. The probe (geometry and materials), the sample, the crosshead speed, and the measurement temperature must be the same as in TPA since it is the way to standardize the processes. As for the results obtained by these techniques, the use of pressure units is recommended, given that tongue strength is quantified with these units in clinical trials.

Rheometer methods

Figure 2a shows the percentages of parameters cited in the work with rotational viscometers. There are important differences in the AV descriptions. In 60% of the studies, the sample size ranged from 10 to 350 ml. It is also important to define the geometry of the sample, a fact provided only by Ibañez et al. (2019). Time was described in 58% of the studies and ranged between 40 and 600 s. However,

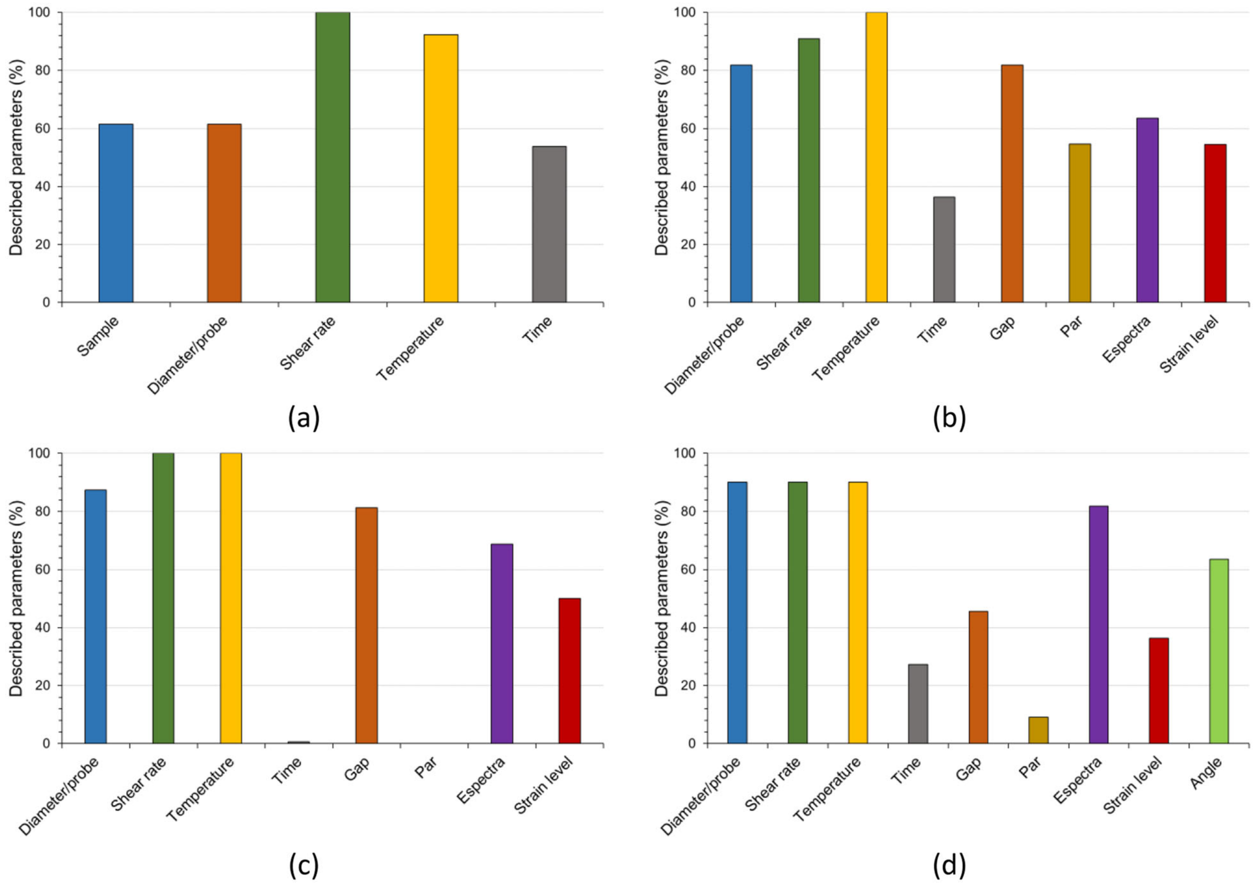

FIGURE 2 Proportion of described parameters in the studies with instrumental methods based in rheometer to characterize the OD-oriented foods texture: (a) Rotational rheology method with 13 references; (b) Disc rheology method with 11 references; (c) Parallel plates' rheology method with 16 references, and (d) Cone-plate rheology method with 13 references

the test time must be identical since non-Newtonian fluids are dependent on this factor (Bourne, 2002). In a study by Germain et al. (2006), the velocity moved in values of 0–100 s^{-1}, as a velocity sweep. These authors were the only ones to describe the totality of the parameters. Temperature (22–25°C) was described in more than 90% of the studies. Exceptionally, temperature tests of 4°C were carried out in desserts such as peach puree at serving temperature (Stahlman et al., 2001).

In the measurements made with the remaining rheometers, a similar behavior was observed in which the sample is at room temperature. The only exception was in the works in which oral temperature or serving temperature was used. Flow rate sweeps were performed, from close to 0 s^{-1} (Casanovas et al., 2011) to maximums of 2000 s^{-1} (Moritaka, 2012), and frequencies from almost 0 to 20 Hz (Stading, 2021). The diameters of the plates, conical and parallel (whether smooth or rough), varied between 20 and 60 mm. Strain level was applied to the sample by a sweep between 0.1 and 2%, reaching up to 1000% (Zargaraan et al., 2013, 2014). As for the execution time of the test, there were few studies that detail this. When done, it was to describe the temperature or "shear rate" sweeps.

Of all the parameters described, only the temperature for the disc and parallel plate rheometers and the shear rate for parallel plates were described in 100% of the chosen articles (Figure 2b–d). Others such as torque were described as 0% in the case of parallel plates.

The shear rate recommended by the National Dysphagia Diet Task Force (50 s^{-1}) has been questioned by several authors and they propose a value commensurate with the speed of human swallowing. This value should be based on clinical trials. Following these guidelines, TMFs design would require rheological approaches (Gallegos et al., 2021). It would also be advisable to standardize the temperature of the tests since they varied between 20 and 25°C. This interval could involve changes in rheological parameters.

Based on the previous information, a series of parameters are proposed to properly perform the rheometric methods. Rheometers seem more appropriate than rotational viscometers as they provide more information through dynamic parameters. Like rotational viscometers, they

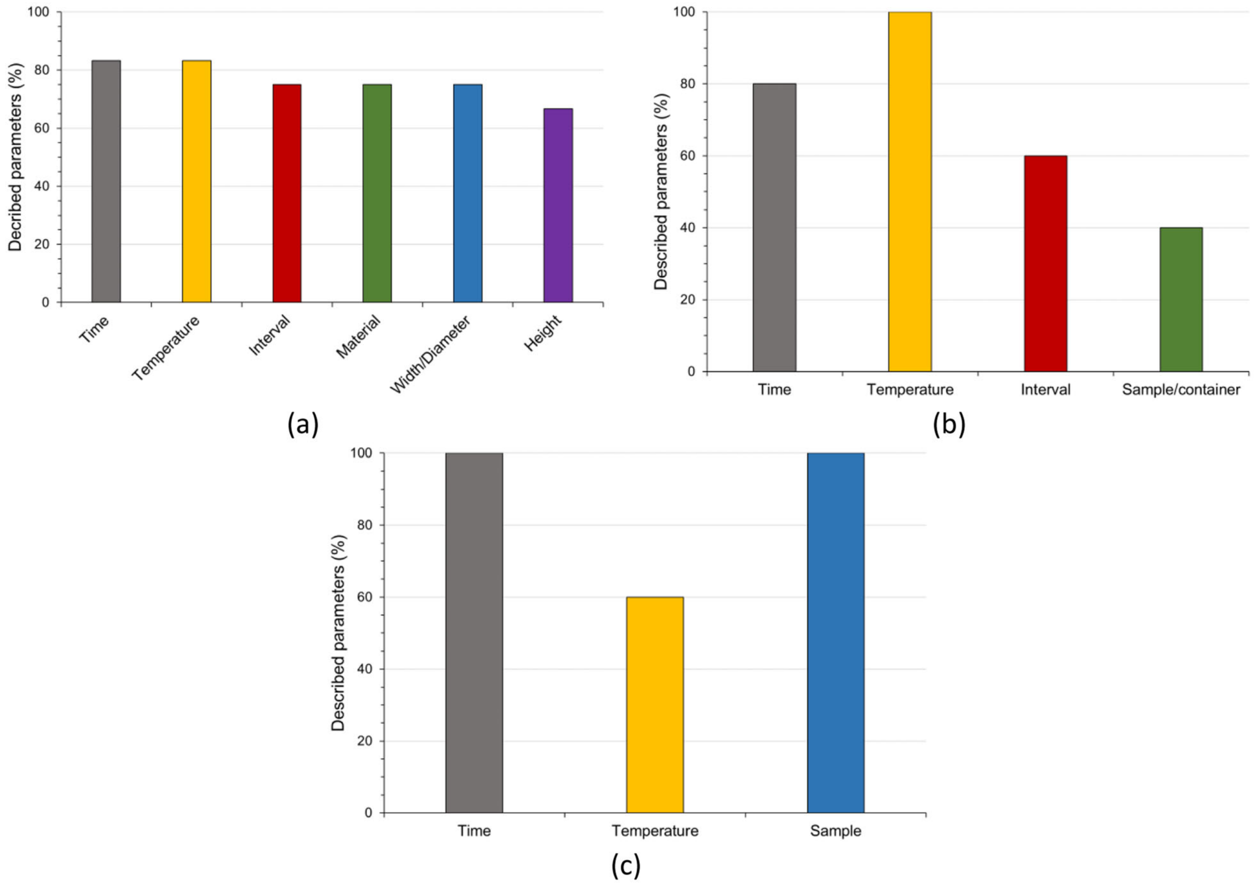

FIGURE 3 Proportion of described parameters in the studies with instrumental methods based in the consistency to characterize the OD-oriented foods: (a) Line Spread Test (LST) with 14 references; (b) Bostwick Consistometer Test with 4 references, and (c) IDDSI Syringe Test with 11 references

allow estimation of the AV by selecting a certain shear rate. Based on the studies included in this review, shear rate sweeps between 0.1 and 1000 s^{-1} and frequency between 1 and 10 Hz are proposed. For the same reason, plates and cones of 40 mm in diameter and a gap of 0.5 mm are recommended. In addition, the grades of the cone used and the strain level should be specified where necessary (2% is recommended). As in the case of texture analyzer methods, the measurement temperature should be the oral temperature (36–37°C).

Other devices

Figure 3 shows the lack of parameters description of the articles included in this review. None of the parameters were described in 100% for the LST-based works. The parameters with the highest percentage of description were time and temperature (80%) and the lowest cylinder height (68%). In the BCT method, temperature was described 100% of the time, while the sample container was only described in 40% of the work. In the IDDSI Syringe Test, time and temperature were described 100% of the time, while temperature, not defined by IDDSI framework, was described in 60% of the included jobs.

The absence of standardization of the LST method can be seen in the results collected in Table 2. Although the most common sample quantity for trials was 50 ml, 20 ml (Matsuo et al., 2021) to 68.7 ml (Budke et al., 2008; Lund et al., 2013) have been used. The usual diameter of the sample-holder cylinder was 5 cm, but 3 cm was also used (Matsuo et al., 2021). The circles typically had separations of 0.5 cm, but 0.25 and 1 cm were also used (Nicosia & Robbins, 2007). The dispersion time experienced few variations, the most common being 60 s. The materials through which the food flows have a direct impact on the behavior of the fluid that lubricates them (Joyner et al., 2014). In the works included, the materials were plexiglass, glass, and plastic (without specifying type). As for the temperature of the analyses, the temperature ranged from 6.9 to 70°C.

Similarly, studies using the BCT method presented certain methodological inconsistencies. Volumes ranged from 75 to 100 ml. These results were dependent on compartment size. There were two options for test time, 30 and 60 s.

Obviously, the longer the time, the greater the expansion. It is known that viscosity depends on the measurement time (Bourne, 2002). As in previous methods, a lack of agreement was observed in the temperature of the test (8–60°C). The importance of temperature in the texture and physical properties of food has already been indicated in previous sections.

The IDDSI syringe method involves standardized parameters with the exception of temperature. Consequently, temperature varied among the included studies. The IDDSI syringe method is effective for discriminating between different consistencies of Newtonian and non-Newtonian fluids (Matsuyama et al., 2020). Other nozzles geometries and alternative experimental conditions have been investigated. The results are comparable with other methods, such as BCT and LST, if the conditions established in the IDDSI method are observed (Hanson et al., 2019). Côté et al. (2020) reported the lack of validation of this method according to the "funnel post-humus." This study highlighted the lack of documentation of the metrological qualities of the method, whose rationale appear only in one article (Cichero, 2019). In addition, the IDDSI syringe method has a number of limitations. Nondysphagic people perceived sensory differences in fluids of the same IDDSI level. By contrast, the same AV generates different IDDSI levels, and the same level is associated with different apparent viscosities (Machado et al., 2019). These differences result in risk for people with dysphagia.

The three methods discussed in this section seem the best suited for the clinical setting because they are economical as well as quick and easy to interpret. Of these, LST would be ideal because it is cheaper and correlates acceptably with viscosity and organoleptic attributes. In this case, the use of sheets with concentric circles with intervals of 5 mm is recommended and the amount of sample to fill the sample-holder cylinder (Ø, 50 mm; h, 30 mm) should be about 60 ml. Additionally, similar to the other methods, the tests should be carried out at the temperature of the oral cavity.

3.2 | Sensory methods

3.2.1 | Descriptive methods

Of the 523 articles about descriptive sensory methods initially identified, 21 met the inclusion criteria. Eight additional publications were added after subsequent searches. The final number of publications included in the present systematic review was 29 (Table S11).

Most of the included publications were based on descriptive sensory analysis, highlighting QDA® (Baert et al., 2021; Mann & Wong, 1996; Wendin et al., 2010). Other methods such as Free Choice Profiling (Baert et al., 2021), Projective Mapping (Field et al., 2017), and CATA (Merino et al., 2021) were used to select descriptors for a posterior descriptive analysis or to characterize the TMFs. Also, other methods such as the Temporal Dominance Sensations (TDS) and Temporal Check-All-That-Apply (TCATA) (Sharma & Duizer, 2019) begin to be used for the characterization of food for dysphagia during the complete swallowing process. An ideal method to describe TMF texture is the Texture Profile Method. This method was developed by Brandt et al. (1963) for the exclusive characterization of food texture and has specific standard (ISO, 11036:2020). These authors established the attributes and perceptions of texture based on the mechanical or geometric characteristics of three different phases, the first bite, the chewing process, and residual (after chewing).

For the present systematic review, descriptive sensory analysis methods have been differentiated according to the type of assessor (trained or untrained). Table 3 summaries the characteristics of the studies according to the type of assessors, used descriptors, and methodological procedure.

Through trained assessors, it has been possible to discern between thickened drinks with different thickeners (Matta et al., 2006). The attributes of melting, ease of swallowing, or creaminess served to differentiate between drinks with and without starches and in different quantities (Wendin et al., 2010). Using the attributes of denseness, smoothness, cohesiveness, and oily mouth coating, it was possible to evaluate the behavior of thickening agents in different pureed carrots (Sharma et al., 2017) and 3D printed carrots (Strother et al., 2020). Sensory analysis results with trained assessors showed high correlations with AV instrumental results (Chambers IV et al., 2018; Conti-Silva et al., 2018). However, some authors concluded that sensory analysis cannot be replaced by instrumental analyses such as TPA since they did not record sufficiently strong correlations between sensory cohesiveness and springiness and their instrumental counterparts (Pematilleke et al., 2022). In addition, trained assessors were able to perceive the increase in the intensities of texture attributes and ease of swallowing with the addition of thickeners to thickened purees, milk, or juices and vegetable drinks (Chambers et al., 2017; Kim et al., 2017; Stahlman et al., 2001). The variability of the results collected and evaluated after the analysis should be considered since there are cases with a high dispersion of the data (Chambers et al., 2017; Ettinger et al., 2014) that can lead to errors in the conclusions drawn from them.

With untrained assessors, it has been possible to establish the swallowing point of biscuit bowling (Young et al., 2016a) or to design five dishes suitable for OD associated with CP (Merino et al., 2020). In addition, as with trained

TABLE 3 Summary of methods to characterize the texture of dysphagia-oriented foods by sensory analysis techniques

Method	Panel characteristics	Descriptors	Procedure	Foodstuffs analyzed	Findings	Reference
Descriptive analysis	Type: trained assessors Size: 5–21 Age (years): 19/40 to 50/65 Gender ratio (% F): 52.9–100 Training for the study (h): 2–24	Texture: 3–12 Most used texture parameters (repetitions): Firmness (11), adhesiveness (8), viscosity (7), particles (6), and cohesiveness (5) Less used parameters but important (repetitions): Easy to swallow (4), smoothness (4), oily mouth coating (4), and residue (3) Others: 0 (3) to 26	Scale (points/cm): 5–15 Order: Randomized, Williams Latin Squares and incomplete blocks Replications: 2–4 Container: Plastic opaque or transparent cups, foam cups, ceramic plates, and Styrofoam bowls Samples: 4–32 Sample's amount (g): 5–90 Sample T (°C): 4–75 Sample codification: Three-digit random number Analysis instruction: Amounts and ways to measure the samples Statistical analysis: ANOVA, Principal Components Analysis (PCA), and Multiple Correspondence Analysis (MCA). Environmental conditions: Individual booths and room temperature in most of the cases	Thickened liquid foods and purees, meat, and fish gels and fruit gels.	Sensory analysis has high correlations with instrumental analysis as TPA, LST, or rheology tests and its results could improve complemented with physicochemical analysis. Samples with different thickeners are easily identified. Three to five attributes could be a good number of descriptors to characterize food for OD. Less number of attributes do not provide information enough and more than five to six attributes could be too complex, and tiredness could appear. With the appropriate number of organoleptic attributes, the sensory analysis could have similar discrimination capacity than BET or other instrumental analysis.	Baert et al., 2021; Chambers et al., 2017; Chambers IV et al., 2018; Conti-Silva et al., 2018; Ettinger et al., 2014; Field et al., 2017; Kim et al., 2017; Liu et al., 2020; Lotong et al., 2003; Matta et al., 2006; Patel et al., 2020; Pematilleke et al., 2022; Sharma et al., 2017; Stahlman et al., 2001; Stangierski & Kawecka, 2019; Strother et al., 2020; van der Stelt et al., 2020; Wendin et al., 2010

(Continues)

TABLE 3 (Continued)

Method	Panel characteristics	Descriptors	Procedure	Foodstuffs analyzed	Findings	Reference
	Type: untrained assessors Size: 5–70 Age (years): 20/25 to 65/87 Gender ratio (% F): 8.3–100.0 Training for the analysis (h): 1–15	Texture: 1–8 Most used texture parameters (repetitions): Easy to swallow (7), residues (4), hard/firm (4), and adhesiveness (4) Less used parameters but important (repetitions): Smoothness (3) and fluidity (1) Others: 0 (6) to 22	Scale (points/cm): 4–15 Order: Randomized and Williams Latin Squares Replications: 0–10 Container: Opaque and transparent cups and paper plates. Sample's amount (g): 3.8–50 Sample *T* (°C): Room to 65 Sample codification: Randomly and three-digit numbers Analysis instruction: Amounts and ways to measure the samples Statistical analysis: ANOVA, PCA, and MCA Environmental conditions: Individual booths at room temperature	Semisolid food, thickened beverages as milk, or fruit juices, commercial purees for dysphagia, and normal food have turkey or bread and biscuits with texture modified and nonmodified.	Strong relationship with instrumental analysis as LST, rheology, or BET. Opportunity to measure the point of swallow and the dominate perceptions along the swallowing process time. Saliva can influence the impaired assessor perceptions. Useful to stablish the textural properties of OD-oriented food. Impaired people are not a suitable assessor to characterize the food properties, but they are adequate to assess the "ease of swallowing" or "sample suitability." Correlations between instrumental and sensory analysis could be useful to elaborate suitability food for OD. Novel methods as CATA or flash profile are practical to generate attributes without trained assessors.	Ben Tobin et al., 2020; Mann & Wong, 1996; Merino et al., 2020, 2021; Moritaka, 2012; Olaru et al., 2021; Suebsaen et al., 2019; Tokifuji et al., 2013; Vandenberghe-Descamps et al., 2017; Xie et al., 2021; Yamaguchi et al., 2019; Young et al., 2016b

(Continues)

TABLE 3 (Continued)

Method	Panel characteristics	Descriptors	Procedure	Foodstuffs analyzed	Findings	Reference
IDDSI fork and spoon	Type: untrained assessors Size: 68 college students (correctly defined only in one reference) Gender ratio (%F): 86.8 (only one reference) Age (years): 18/24 (only one reference)	–	Sample presentation (number): 12–21 (15 mm cubes; 36°C) Environmental conditions: Unknown	Regular and commercial food (hard and semisolid), 3D and normal pastes, home blend food, and pediatric formulas.	Saliva can influence the tests responses. The IDDSI general protocol for transitional products was not capable to correctly evaluate the samples because the changes are not captured in the swallowing physiology. IDDSI levels and viscosity not shown coherent relations. Tests for levels 4–7 are qualitative. Consensus about the correlations between IDDSI tests and TPA does not exist. IDDSI tests are not capable to evaluate some samples (lumps, stickie, and both). IDDSI methods are not enough to classify some foods with characteristics or particular ingredients. It is possible to complement with instrumental analysis to help the manufacturers to elaborate standardized and safe products for dysphagia. Spoon tilt test evaluates adhesiveness and cohesiveness of food. Good agreement between training assessors.	Barewal et al., 2020; Dick et al., 2020, 2021a, 2021b; Hron & Rosen, 2020; Pant et al., 2021; Park et al., 2020; Pematilleke et al., 2021; Rule et al., 2020; Trček Kavčič et al., 2020; Xie et al., 2021

assessors, it has been possible to evaluate the impact of the different thickeners on TMFs. Suebsaen et al. (2019) were able to detect the effects of gelatin (harder than agar-agar and carrageenan), agar-agar, and carrageenan (higher facility of chewing and swallowing scores than gelatin) in banana gel samples. In addition, Yamaguchi et al. (2019) observed the addition of thickeners increased the ease of swallowing carrot puree.

The sensory analysis results obtained by untrained assessors presented positive correlations (r = 0.90–0.96) with the results of the LST in cases of soups and fruit juices (Mann & Wong, 1996) and correspondences between organoleptic attributes and firmness and maximum force of the BET in TMFs for the dysphagia associated with CP (Merino et al., 2020).

The effectiveness of sensory methods was evaluated considering studies based on diagnostic tests or tests performed by speech therapists to establish the aptitude of TMFs. The first of the methods was carried out by Tokifuji et al. (2013). These authors evaluated pork gels treated at high temperatures and were able to select the experimental conditions to obtain a product suitable for OD. Sensory analysis established these samples had high intensities of smoothness, softness, swallowing ease, mashing by tongue ease (intensities greater than 1 in a (−2, +2) scale), and medium values of elasticity and residue in the oral cavity (between 0 and 1). Similarly, Merino et al. (2020) developed five TMFs for OD associated with CP whose suitability was established by five speech therapists and which were accepted by people with OD associated with CP. These authors concluded that products suitable for dysphagia should have low firmness intensities (between 1 and 2 in a 1- to 5-point scale), medium-high in cohesiveness (3–4.5/5), high fluidity (4–5/5), and very low residue and stickiness (1–1.5/5). The five TMFs were also evaluated with a panel of untrained assessors using the CATA method (Merino et al., 2021).

The present findings demonstrate the ability of descriptive sensory analyses to assess the textural characteristics of foods suitable for OD. However, these methods are expensive to execute over time, especially those that require training and follow-up of trained assessors. In addition, the methods used to establish the effectiveness of sensory techniques to characterize foods suitable for OD have been very specific to the studies in question. For example, adequate references of the different characteristics of the texture that delimit the appropriate range for food for OD would be needed. For these reasons, descriptive sensory analysis is a reliable method to industrially produce products for OD with the appropriate texture characteristics, but with the need for new tests to improve the effectiveness of sensory methods. In the clinical setting, sensory testing requires time that is not available.

3.2.2 | IDDSI sensory method

Ninety-four publications about the IDDSI sensory method were initially identified. Of these, nine met the inclusion criteria. Two additional publications were added after subsequent searches. The final number of publications included in the present systematic review was 11 (Table S12).

IDDSI sensory method is composed of two tests, one by a spoon and the other a fork. The spoon tilt test was used to determine the adhesiveness and cohesiveness of food. The amount of sample remaining after turning the spoon sideways was evaluated. The fork pressure test was used for assessment of food hardness. Pressure applied to the food sample is quantified by assessment of the pressure needed to make the thumb nail noticeably blanch to white (IDDSI Framework, 2019). The first study in TMFs that was different than simple models was carried out by Barewal et al. (2020). The authors evaluated the texture of carrot cookies from different sources and with different formulations. A panel of trained assessors in the IDDSI method applied a positive pressure fork test, discerning between cookies with different consistency levels when they should be the same. The other 10 works perform similar tests for the texture study of regular foods and solid and semisolid commercial food, pastas, and home-made and pediatric formulas.

The tests proposed in the IDDSI method have been used to characterize different products. In the IDDSI framework, eight levels of texture (levels 0–4 for drinks and levels 3–7 for foods) are defined. Dick et al. (2020) evaluated the ability to print pork pastes with levels 6 and 7. Trček Kavčič et al. (2020) conducted a study training two assessors in the IDDSI method and confirmed the ease of use of these tests. These same authors tested the ability of the two assessors to classify samples of vegetable, meat, and mixed purees of different textures. The degree of coincidence between assessors was 226 out of 230. For their part, Dick et al. (2021b) correctly classified five samples of 3D veal pasta at level 4 of IDDSI, pureed extremely thick. But they had difficulty to characterize sticky textures, lumpy, or both. Rule et al. (2020) had difficulty classifying 231 commercial foods of different consistencies into IDDSI levels using the Fork Drip and Spoon Tilt Tests with a panel of 68 university students (untrained assessors). They obtained a task performance accuracy of 66.7% ± 12.1%, a very low proportion, and a high deviation. These tests were therefore ineffective. The results obtained by Hron and Rosen (2020) with different commercial and home-made products for infants and pediatric patients were difficult to interpret. The products were tested using the Fork Drip Test and rheometric analysis. Foods that were cataloged in different IDDSI groups had very similar viscosities. These results reveal the need for instrumental food measures for OD to obtain objective and coherent results, thus helping to ensure food safety for dysphagic people.

The efficacy of the IDDSI method could not be evaluated using relationships with clinical test or assessment by speech therapist. However, the Fork Drip and Spoon Tilt tests are quick and useful for characterizing and establishing IDDSI levels for OD-oriented foods (Trček Kavčič et al., 2020). Although some authors point out it is an adequate method in the clinical setting to evaluate foods with consistency higher than level 4 (Barewal et al., 2020; Dick et al., 2020), others note there is insufficient evidence to recommend the IDDSI methods for assessing foods oriented to frail older people (Côté et al., 2020).

3.2.3 | Methodological flaws and gaps

Each of the experimental parameters must be described for a valid sensory analysis. In the case of descriptive sensory analysis and especially QDA®, the selection, training, and monitoring of assessors are required (e.g., by the ISO 8586:2012 standard [ISO, 2012]). The performance and analytical capacity by the panel members should also be indicated (e.g., by the ISO 11132:2021 standard [ISO, 2021]). In most of the works, a training of "familiarization" with the samples or the method of analysis was mentioned that does not ensure the reliability of the method. Figure 4a shows the percentage of works that have described each of the experimental parameters. Previous training was noted in 76.5% of the studies. Only two studies reported the assessors training citing the standard, but these did not describe the method (Stangierski & Kawecka, 2019; Wendin et al., 2010).

Studies based on trained assessors defined parameters 39.2% more than those based on untrained assessors. Exceptions were the panel description, instructions to assessors, and Remain Operative Details (ROD) at 0%–40%. The order of the samples and the statistical treatment were the ones with the highest rate of description (94.1%). For the presentation of the samples, "random order" is insufficient. It must conform to an experimental design such as Williams Latin squares or others that ensure a balanced order sample presentation. In this way, the analysis is more sensitive and errors such as positional bias, contrast and convergence errors, carryover, and first sample are avoided (Kemp et al., 2018). In addition, replicas of a design or blocks give robustness to the analysis (Piggott et al., 1998)

As for the description of the panel, according to Faraldo-García et al. (2012) while gender does not influence the responses, the age of assessors does. This aspect should be considered when recruiting assessors, as a small age range may imply bias.

The definition and evaluation of texture attributes can be described according to a specific standard (ISO 11036:2020 [ISO, 2020]). The number and type of attributes are difficult to establish in the experimental design. Due to the lack of standardization, this information has not been collected in Figure 4a. These attributes must be adequate, not opposed, and unequivocally defined (Kemp et al., 2018).

When the number of attributes was high, scores with very extreme values and great dispersion in the data were observed (Chambers et al., 2017; Chambers IV et al., 2018). Although these authors used 10 texture attributes, five were enough to differentiate the samples. When the number of attributes was reduced, the method was ineffective. Conti-Silva et al. (2018) used a texture attribute and a mouthfeel attribute to evaluate desserts such as yogurt or *petit-suisse*. The authors concluded that sensory analysis has a less discriminative power than BET or rheometric methods. This capacity could increase with a higher number of attributes. It seems that a number of five to six attributes is adequate to describe the texture of TMFs.

Rapid methods of sensory characterization have certain similarities in design to conventional descriptive analysis. The CATA method has been developed to avoid the training and control of classical methods. Trained assessors are not necessary, and gender does not have a bias effect on the results. However, the number of assessors needed is higher. It has been shown with less than 80 assessors the CATA method provided robust results when working with samples with large differences. However, caution is needed when samples with smaller differences or complex organoleptic characteristics are analyzed because sensory spaces become less stable (Ares et al., 2014). In addition, the number of attributes that each assessor can value is greater (Kemp et al., 2018). This method is based on the selection of certain descriptors within a long list of words. It has been observed in lists with more than 30 attributes, fatigue begins to appear in assessors (Jaeger et al., 2015). Finally, in this rapid method of characterization, the order of the samples is recommended to be balanced and correctly designed to avoid bias (Ares et al., 2015).

The TDS and TCATA methods are presented as alternatives for which an expert panel is not necessary. In addition, these methods allow for the evaluation of oral processing until swallowing in relation to the characteristics of food for dysphagic people throughout (Sharma & Duizer, 2019; Young et al., 2013). For example, it has been found that the swallowing point of cookies by healthy individuals is 21 s (Young et al., 2016a), but this determination does

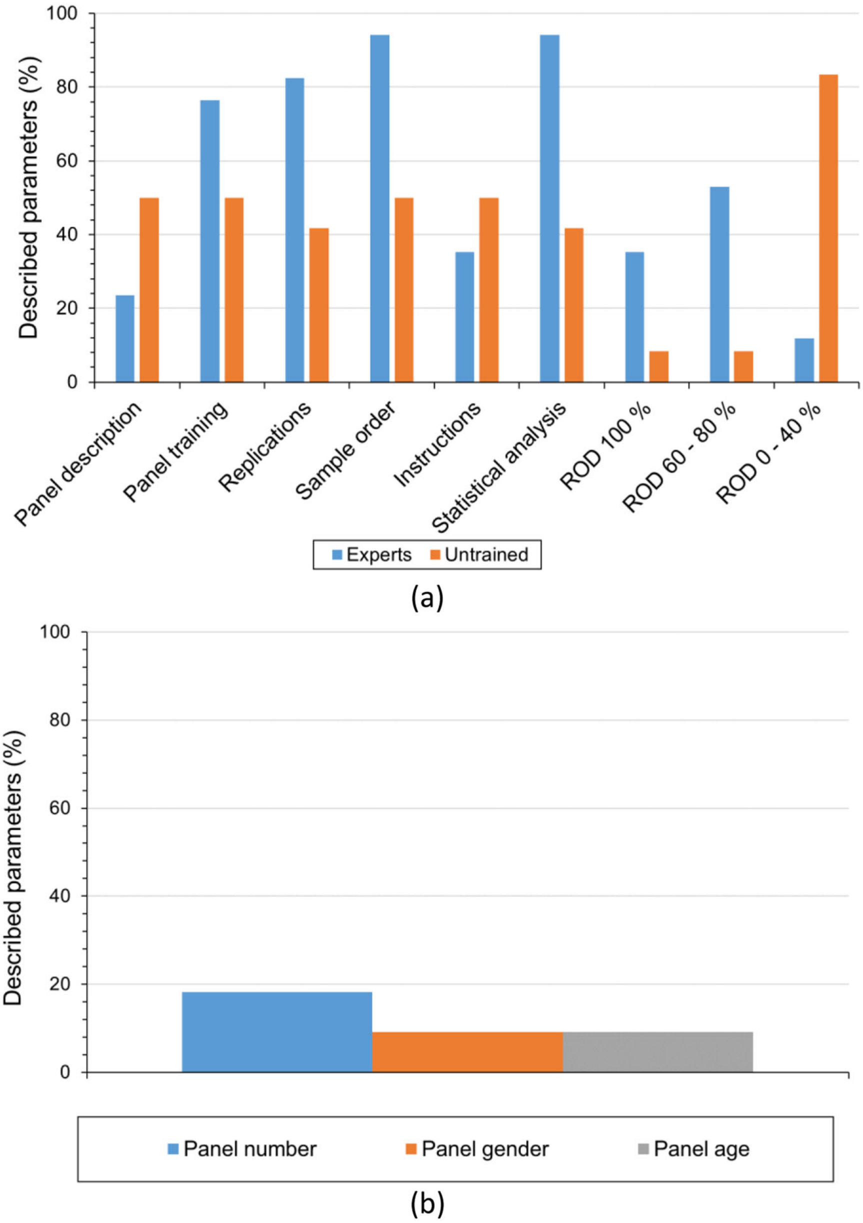

FIGURE 4 Proportion of described parameters in the studies with sensory analysis methods to characterize the OD-oriented foods: (a) Descriptive analysis with experts or with untrained assessor with 29 references (17 for experts and 12 for untrained assessors) and (b) IDDSI fork and spoon tests with 11 references. In (a) section: panel description included the number and the assessor profile; ROD "remain operative details" (percentage of included studies that explained a certain ratio of these details) and encompass the definition of sample size, amount, temperature, and codification and the container information (five parameters)

not account for the "cohesiveness" attribute (Young et al., 2013). The TDS and TCATA have been shown to demonstrate correlations with instrumental analyses, including rheology and tribology. Sharma et al. (2021) report that studying the temporal succession of dominance of different organoleptic attributes during the swallowing process facilitates a more robust characterization and differentiation between samples. This could be very useful for assessing the suitability of food for dysphagia. However, as Young et al. (2013) indicate, additional research is needed in this area to ensure the effectiveness of these methods in foods for dysphagia.

RODs are mentioned separately because they encompass all the methods of sensory analysis chosen for this review. ROD values between 0%–40% indicate insufficient description of parameters such as the number of samples or their quantity, the temperature of the samples, or the sample container. This parameter appears 83.3% in untrained assessors' studies compared to 11.8% in trained assessors' studies (Figure 4a). ROD 60%–80%, which indicates a more detailed description of the test parameters, reaches up to 8.3% in untrained assessors and 52.9% in trained assessors and ROD 100% remains at the same percentage in untrained assessors and decreases to 35.3% in trained assessors. All these operational details are necessary. For example, as corroborated by certain authors (Pematilleke et al., 2022), the number of samples depends on the experimental design and randomization previously described, and temperature has an important effect on texture.

For the IDDSI Fork Drip and Spoon Tilt tests, only the parameters of "panel size," "gender," and "age" have been selected since the rest of the parameters to carry them out are described in the IDDSI regulations and only the two covered are necessary. A fourth parameter, "sample presentation," has been removed from the graph to avoid misunderstandings since it has a description of 0%. As explained in previous paragraphs, it is necessary to detail and make a correct design in the order of the samples when a sensory analysis is going to be carried out. An incorrect order can cause biases in the response of the assessors. None of the three parameters achieved a 20% of description in the included works. For this reason, it is difficult to draw conclusions about this method. Authors who have received some previous training before evaluating the products have found it to be a very simple and effective method, but it has some limitations (Barewal et al., 2020; Trček Kavčič et al., 2020).

Fork and spoon tests are subjective when used in level 3 foods. Barbon and Steele (2018) considered IDDSI spoon tilt and fork drip tests subjective and insufficient to characterize flow features of extremely thick liquids. The fork drip test evaluates parameters as viscosity and yield stress, but the results are qualitative and inaccurate (Hadde et al., 2016). Manufacturers therefore cannot follow these guidelines to make suitable and standardized products for dysphagia or to release instructions that guarantee consumer safety. Pant et al. (2021) described the spoon tilt and fork pressure tests as qualitative assessments apt to evaluate a food and estimate its suitability for a dysphagic diet.

The intention of this review is to stress the subjectivity of the IDDSI methods and the need for a more objective approach that allows comparison between works. A more objective approach could help the dysphagia food industry base its products on easy-to-interpret objective numerical levels. This would improve the suitability of food and thus the safety of dysphagic people. This could be achieved through simple changes to current methods such as the addition of an Iowa Oral Performance Instrument (IOPI) in pressure fork/spoon tests. This would give numerical values to this test, making it easily classifiable and comparable.

This review will formulate a series of recommendations to carry out the correct textural characterization of TMFs for OD. It is necessary to keep in mind these recommendations are the result of this research, and it will be necessary to carry out tests to check whether or not they are effective in each type of food, age group, condition, and so forth.

Sensory analysis is necessary to understand the suitability of food for dysphagia and different methods are proposed to carry out a correct characterization of TMFs. QDA® is recommended when possible in large food industry companies or research centers. The number of assessors must be adequate, and their training and efficiency must be controlled over time using the criteria established by the ISO 8586:2012 standard (ISO, 2012) and the specific standard for QDA® panels.

When only the evaluation of the texture profile is required, the use of the ISO 11036:2020 standard (ISO, 2020) is recommended. When time or trained assessors are not available, the use of qualitative descriptive analysis methods such as the CATA or the flash profile could be an option. These methods require a larger number of assessors but are effective, robust, and faster than QDA® or TPA in characterizing the texture of TMFs. Although it is a reliable method and has great potential in industry, it is necessary to emphasize they do not perform quantitative profiles of the samples, and therefore other methods would be necessary (Alexi et al., 2018).

4 | CONCLUSIONS

There is enough evidence about the relevance of texture in beverage and food design for the management of OD. It is evident these products (thickened liquids and textured foods) are complex matrices from a physical and sensory point of view. The complexity of the texture increases as the number of ingredients for its elaboration increases and different physical and organoleptic characteristics are manifested during the swallowing process of the bolus.

Among the instrumental methods established as more suitable for the industrial setting due to their ease of handling, versatility, and speed of analysis are TPA or UCT for solid and homogeneous foods and BET for semisolids and liquids with large particle size. LST was selected as the most suitable method for the clinical setting. It is simple, fast, and does not require a high initial outlay or training of staff. Dynamic and static viscosity methods need a significant initial outlay and training of staff. Their complexity makes them more effective methods for the research setting than for the food and clinical industry setting. Rheometers are more efficient than rotational viscometers to evaluate the characteristics of the dysphagia food.

Given the importance of proper sensory characterization of TMFs, the recommendation to use techniques such as the QDA® is the first choice because it can provide the most accurate descriptions and quantifications of product attributes. However, the large investment in time and resources this method requires can make it difficult to use in many circumstances. In these cases, CATA is faster and more versatile and adaptable method that, when properly implemented, has proven its robustness as a descriptive method. On the other hand, it is important to highlight the unique information that dynamic methods can provide on a naturally dynamic process such as the perception of the characteristics of a food during consumption.

Finally, and for these instrumental and sensory techniques to be useful, it is necessary to reach an international consensus and agree on practical guidelines through the participation of experts from different fields (speech therapists, physicians, food scientists, and industrialists).

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AUTHOR CONTRIBUTIONS

F.C. Ibañez was responsible for conceptualizing and designing the systematic review. F.C. Ibañez and G. Merino individually performed the database search and the collection of references. M.J. Beriain supervised the screening for the instrumental studies. M.R. Marín-Arroyo supervised the screening for the sensory studies. F.C. Ibañez and G. Merino drafted the manuscript. All authors edited the manuscript. All authors read and approved the final version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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REFERENCES

Abu Zarim, N., Zainul Abidin, S., & Ariffin, F. (2018). Rheological studies on the effect of different thickeners in texture-modified chicken *rendang* for individuals with dysphagia. *Journal of Food Science and Technology*, *55*(11), 4522–4529. https://doi.org/10.1007/s13197-018-3386-5

Adeleye, B., & Rachal, C. (2007). Comparison of the rheological properties of ready-to-serve and powdered instant food–thickened beverages at different temperatures for dysphagic patients. *Journal of the American Dietetic Association*, *107*(7), 1176–1182. https://doi.org/10.1016/j.jada.2007.04.011

Alexi, N., Nanou, E., Lazo, O., Guerrero, L., Grigorakis, K., & Byrne, D. V. (2018). Check-All-That-Apply (CATA) with semi-trained assessors: Sensory profiles closer to descriptive analysis or consumer elicited data? *Food Quality and Preference*, *64*, 11–20. https://doi.org/10.1016/j.foodqual.2017.10.009

Alsanei, W. A., Chen, J., & Ding, R. (2015). Food oral breaking and the determining role of tongue muscle strength. *Food Research International*, *67*, 331–337. https://doi.org/10.1016/j.foodres.2014.11.039

Arakawa, I., Igarashi, K., Imamura, Y., Müller, F., Abou-Ayash, S., & Schimmel, M. (2021). Variability in tongue pressure among elderly and young healthy cohorts: A systematic review and meta-analysis. *Journal of Oral Rehabilitation*, *48*(4), 430–448. https://doi.org/10.1111/joor.13076

Ares, G., Reis, F., Oliveira, D., Antúnez, L., Vidal, L., Giménez, A., Chheang, S. L., Hunter, D. C., Kam, K., Roigard, C. M., Paisley, A. G., Beresford, M. K., Jin, D., & Jaeger, S. R. (2015). Recommendations for use of balanced presentation order of terms in CATA questions. *Food Quality and Preference*, *46*, 137–141. https://doi.org/10.1016/j.foodqual.2015.07.012

Ares, G., Tárrega, A., Izquierdo, L., & Jaeger, S. R. (2014). Investigation of the number of consumers necessary to obtain stable sample and descriptor configurations from check-all-that-apply (CATA) questions. *Food Quality and Preference*, *31*, 135–141. https://doi.org/10.1016/j.foodqual.2013.08.012

Baert, F., Vlaemynck, G., Beeckman, A., Van Weyenberg, S., & Matthys, C. (2021). Dysphagia management in Parkinson's disease: Comparison of the effect of thickening agents on taste, aroma, and texture. *Journal of Food Science*, *86*(3), 1039–1047. https://doi.org/10.1111/1750-3841.15595

Bagheri, L., Mousavi, M. E., & Madadlou, A. (2014). Stability and rheological properties of suspended pulp particles containing orange juice stabilized. *Journal of Dispersion Science and Technology*, *35*(9), 1222–1229. https://doi.org/10.1080/01932691.2013.834422

Bakke, M. (2006). Bite force and occlusion. *Seminars in Orthodontics*, *12*(2), 120–126. https://doi.org/10.1053/j.sodo.2006.01.005

Barbon, C. E. A., & Steele, C. M. (2018). Thickened liquids for dysphagia management: A current review of the measurement of liquid flow. *Current Physical Medicine and Rehabilitation Reports*, *6*(4), 220–226. https://doi.org/10.1007/s40141-018-0197-6

Barewal, R., Shune, S., Ball, J., & Kosty, D. (2020). A comparison of behavior of transitional-state foods under varying oral conditions. *Dysphagia*, *36*, 316–324. https://doi.org/10.1007/s00455-020-10135-w

Ben Tobin, A., Mihnea, M., Hildenbrand, M., Miljkovic, A., Garrido-Bañuelos, G., Xanthakis, E., & Lopez-Sanchez, P. (2020). Bolus rheology and ease of swallowing of particulated semi-solid foods as evaluated by an elderly panel. *Food & Function*, *11*(10), 8648–8658. https://doi.org/10.1039/D0FO01728K

Bourne, M. C. (2002). *Food texture and viscosity* (2nd ed.). Academic Press. https://www.sciencedirect.com/book/9780121190620/food-texture-and-viscosity

Brandt, M. A., Skinner, E. Z., & Coleman, J. A. (1963). Texture profile method. *Journal of Food Science*, *28*(4), 404–409. https://doi.org/10.1111/j.1365-2621.1963.tb00218.x

Brooks, L., Liao, J., Ford, J., Harmon, S., & Breedveld, V. (2021). Thickened liquids using pureed foods for children with dysphagia: IDDSI and rheology measurements. *Dysphagia*, 1–13. https://doi.org/10.1007/s00455-021-10308-1

Budke, J., Garcia, J. M., & Chambers, E. (2008). Comparisons of thickened beverages using line spread measurements. *Journal of the American Dietetic Association*, *108*(9), 1532–1535. https://doi.org/10.1016/j.jada.2008.06.434

Casanovas, A., Hernández, M. J., Martí-Bonmatí, E., & Dolz, M. (2011). Cluster classification of dysphagia-oriented products considering flow, thixotropy and oscillatory testing. *Food Hydrocolloids*, *25*(5), 851–859. https://doi.org/10.1016/j.foodhyd.2010.07.029

Chambers, E., Jenkins, A., & Garcia, J. M. (2017). Sensory texture analysis of thickened liquids during ingestion. *Journal of Texture Studies*, *48*(6), 518–529. https://doi.org/10.1111/jtxs.12265

Chambers, E., IV, Maughan, C., Padmanabhan, N., Alavi, S., & Adedji, A. (2018). Sensory analysis of 20% solids fortified blended porridge. *British Food Journal*, *121*(2), 633–641. https://doi.org/10.1108/BFJ-05-2018-0280

Chen, H., Zhang, M., & Rao, Z. (2021). Effect of ultrasound-assisted thawing on gelling and 3D printing properties of silver carp surimi. *Food Research International*, *145*, 110405. https://doi.org/10.1016/j.foodres.2021.110405

Chen, J., & Stokes, J. R. (2012). Rheology and tribology: Two distinctive regimes of food texture sensation. *Trends in Food Science & Technology*, *25*(1), 4–12. https://doi.org/10.1016/j.tifs.2011.11.006

Chen, W., Hadde, E. K., & Chen, J. (2021). Development of a ball back extrusion technique for texture analysis of fluid food. *Journal of Texture Studies*, *52*(4), 461–469. https://doi.org/10.1111/jtxs.12613

Chen, Y., Zhang, M., & Phuhongsung, P. (2021). 3D printing of protein-based composite fruit and vegetable gel system. *LWT - Food Science and Technology*, *141*, 1–8. https://doi.org/10.1016/j.lwt.2021.110978

Cho, H. M., & Yoo, B. (2015). Rheological characteristics of cold thickened beverages containing xanthan gum–based food thickeners used for dysphagia diets. *Journal of the Academy of Nutrition and Dietetics*, *115*(1), 106–111. https://doi.org/10.1016/j.jand.2014.08.028

Cho, H. M., Yoo, W., & Yoo, B. (2012). Steady and dynamic rheological properties of thickened beverages used for dysphagia diets. *Food Science and Biotechnology*, *21*(6), 1775–1779. https://doi.org/10.1007/s10068-012-0237-4

Choichuedee, P., Suttisansanee, U., Hudthagosol, C., & Sanporkha, P. (2018). Sweet sticky rice puree diet for elderly with dysphagia. *Walailak Journal of Science and Technology*, *17*(1), 47–54. https://doi.org/10.48048/wjst.2020.4038

Cichero, J., Nicholson, T., & Dodrill, P. (2011). Liquid barium is not representative of infant formula: Characterisation of rheological and material properties. *Dysphagia*, *26*, 264–271. https://doi.org/10.1007/s00455-010-9303-3

Cichero, J. A. Y. (2019). Evaluating chewing function: Expanding the dysphagia field using food oral processing and the IDDSI framework. *Journal of Texture Studies*, *51*, 56–66. https://doi.org/10.1111/jtxs.12462

Claes, J. E., De Messchalck, L., Huysmans, V., Van Eyck, H., Schittecat, S., Pastuer, M., & Moldenaers, P. (2011). Rheological study of breakfast replacing recipes used in the treatment of dysphagia. *Journal of Texture Studies*, *43*, 142–152. https://doi.org/10.1111/j.1745-4603.2011.00324.x

Conti-Silva, A. C., Ichiba, A. K. T., Silveira, A. L., Albano, K. M., & Nicoletti, V. R. (2018). Viscosity of liquid and semisolid materials: Establishing correlations between instrumental analyses and sensory characteristics. *Journal of Texture Studies*, *49*, 569–577. https://doi.org/10.1111/jtxs.12358

Côté, C., Germain, I., Dufresne, T., & Gagnon, C. (2019). Comparison of two methods to categorize thickened liquids for dysphagia management in a clinical care setting context: The Bostwick consistometer and the IDDSI Flow Test. Are we talking about the same concept? *Journal of Texture Studies*, *50*(2), 95–103. https://doi.org/10.1111/jtxs.12377

Côté, C., Giroux, A., Villeneuve-Rhéaume, A., Gagnon, C., & Germain, I. (2020). Is IDDSI an evidence-based framework? A relevant question for the frail older population. *Geriatrics*, *5*(4), 82. https://doi.org/10.3390/geriatrics5040082

Creech, T. N., Bailey-Van Kuren, M., Sparks, J., Becker, S. B., Kou, R. S. N., Wnek, O. C., & Scarborough, D. R. (2019). A comparison of measurements of a pediatric supplement. *Dysphagia*, *34*(2), 257–268. https://doi.org/10.1007/s00455-018-9931-6

Crow, H. C., & Ship, J. A. (1996). Tongue strength and endurance in different aged individuals. *The Journals of Gerontology: Series A*, *51A*(5), M247–M250. https://doi.org/10.1093/gerona/51A.5.M247

Dick, A., Bhandari, B., Dong, X., & Prakash, S. (2020). Feasibility study of hydrocolloid incorporated 3D printed pork as dysphagia food. *Food Hydrocolloids*, *107*, 1–11. https://doi.org/10.1016/j.foodhyd.2020.105940

Dick, A., Bhandari, B., & Prakash, S. (2019). Post-processing feasibility of composite-layer 3D printed beef. *Meat Science*, *153*, 9–18. https://doi.org/10.1016/j.meatsci.2019.02.024

Dick, A., Bhandari, B., & Prakash, S. (2021a). Printability and textural assessment of modified-texture cooked beef pastes for dysphagia patients. *Future Foods*, *3*, 100006. https://doi.org/10.1016/j.fufo.2020.100006

Dick, A., Bhandari, B., & Prakash, S. (2021b). Effect of reheating method on the post-processing characterisation of 3D printed meat products for dysphagia patients. *LWT – Food Science and Technology*, *150*, 111915. https://doi.org/10.1016/j.lwt.2021.111915

Ekberg, O., Bülow, M., Ekman, S., Hall, G., Stading, M., & Wendin, K. (2009). Effect of barium sulfate contrast medium on rheology and sensory texture attributes in a model food. *Acta Radiologica*, *50*(2), 131–138. https://doi.org/10.1080/02841850802555638

Eleya, M. M. O., & Gunasekaran, S. (2007). Rheology of barium sulfate suspensions and pre-thickened beverages used in diagnosis and treatment of dysphagia. *Applied Rheology*, *17*(3), 1–8. https://doi.org/10.1515/arh-2007-0008

Ettinger, L., Keller, H. H., & Duizer, L. M. (2014). Characterizing commercial pureed foods: Sensory, nutritional, and textural analysis. *Journal of Nutrition in Gerontology and Geriatrics*, *33*(3), 179–197. https://doi.org/10.1080/21551197.2014.927304

Faber, T. J., Jaishankar, A., & McKinley, G. H. (2017). Describing the firmness, springiness and rubberiness of food gels using fractional calculus. Part I: Theoretical framework. *Food Hydrocolloids*, *62*, 311–324. https://doi.org/10.1016/j.foodhyd.2016.05.041

Faraldo-García, A., Santos-Pérez, S., Crujeiras-Casais, R., Labella-Caballero, T., & Soto-Varela, A. (2012). Influence of age and gender in the sensory analysis of balance control. *European Archives of Oto-Rhino-Laryngology*, *269*(2), 673–677. https://doi.org/10.1007/s00405-011-1707-7

Field, K. M., Duncan, A. M., Keller, H. H., Stark, K. D., & Duizer, L. M. (2017). Effect of micronutrient powder addition on sensory properties of foods for older adults. *Journal of Food Science*, *82*(10), 2448–2455. https://doi.org/10.1111/1750-3841.13849

Friedman, H. H., Whitney, J. E., & Szczesniak, A. S. (1963). The texturometer—A new instrument for objective texture measurement. *Journal of Food Science*, *28*(4), 390–396. https://doi.org/10.1111/j.1365-2621.1963.tb00216.x

Gallegos, C., Turcanu, M., Assegehegn, G., & Brito-de la Fuente, E. (2021). Rheological issues on oropharyngeal dysphagia. *Dysphagia*, https://doi.org/10.1007/s00455-021-10337-w

Garcia, J. M., & Chambers, E. (2019). Incremental adjustments to amount of thickening agent in beverages: Implications for clinical practitioners who oversee nutrition care involving thickened liquids. *Foods*, *8*(2), 74. https://doi.org/10.3390/foods8020074

Garcia, J. M., Chambers, E., & Noll, K. S. (2020). Gravity flow test comparisons for mildly thick consistency. *Journal of Texture Studies*, *51*(2), 308–313. https://doi.org/10.1111/jtxs.12491

Garcia, J. M., Iv, E. C., Matta, Z., & Clark, M. (2005). Viscosity measurements of nectar- and honey-thick liquids: Product, liquid, and time comparisons. *Dysphagia*, *20*, 325–335. https://doi.org/10.1007/s00455-005-0034-9

Garin, N., Pourcq, J. T. D., Martın-Venegas, R., Cardona, D., Gich, I., & Mangues, M. A. (2014). Viscosity differences between thickened beverages suitable for elderly patients with dysphagia. *Dysphagia*, *29*(4), 483–488. https://doi.org/10.1007/s00455-014-9533-x

Germain, I., Dufresne, T., & Gray-Donald, K. (2006). A novel dysphagia diet improves the nutrient intake of institutionalized elders. *Journal of the American Dietetic Association*, *106*(10), 1614–1623. https://doi.org/10.1016/j.jada.2006.07.008

Gosa, M. M., & Dodrill, P. (2017). Effect of time and temperature on thickened infant formula. *Nutrition in Clinical Practice*, *32*(2), 238–244. https://doi.org/10.1177/0884533616662991

Grawemeyer, E. A., & Pfund, M. C. (1943). Line-spread as an objective test for consistency. *Journal of Food Science*, *8*(2), 105–108. https://doi.org/10.1111/j.1365-2621.1943.tb16550.x

Groher, M. E., Crary, M. A., Carnaby (Mann), G., Vickers, Z., & Aguilar, C. (2006). The impact of rheologically controlled materials on the identification of airway compromise on the clinical and videofluoroscopic swallowing examinations. *Dysphagia*, *21*(4), 218–225. https://doi.org/10.1007/s00455-006-9046-3

Guénard-Lampron, V., Masson, M., & Blumenthal, D. (2021). Critical review of sensory texture descriptors: From pureed to transitional foods for dysphagia patients. *Journal of Texture Studies*, *52*(5-6), 665–678. https://doi.org/10.1111/jtxs.12604

Guo, Q., Ye, A., Lad, M., Dalgleish, D., & Singh, H. (2013). The breakdown properties of heat-set whey protein emulsion gels in the human mouth. *Food Hydrocolloids*, *33*(2), 215–224. https://doi.org/10.1016/j.foodhyd.2013.03.008

Guo, T., Xue, S., Zou, Y., Han, M., Xu, X., & Zhou, G. (2017). Effect of sodium chloride on the properties of ready-to-eat pressure-induced gel-type chicken meat products. *Journal of Food Process Engineering*, *40*(1), e12299. https://doi.org/10.1111/jfpe.12299

Hadde, E. K., & Chen, J. (2021). Texture and texture assessment of thickened fluids and texture-modified food for dysphagia management. *Journal of Texture Studies*, *52*(1), 4–15. https://doi.org/10.1111/jtxs.12567

Hadde, E. K., Nicholson, T. M., & Cichero, J. A. Y. (2020). Evaluation of thickened fluids used in dysphagia management using extensional rheology. *Dysphagia*, *35*(2), 242–252. https://doi.org/10.1007/s00455-019-10012-1

Hanson, B., Steele, C. M., Lam, P., & Cichero, J. A. Y. (2019). Fluid testing methods recommended by IDDSI. *Dysphagia*, *34*(5), 716–717. https://doi.org/10.1007/s00455-018-9957-9

Hasegawa, Y., Sugahara, K., Fukuoka, T., Saito, S., Sakuramoto, A., Horii, N., Sano, S., Hasegawa, K., Nakao, Y., Nanto, T., Kadoi, K., Moridera, K., Noguchi, K., Domen, K., & Kishimoto, H. (2017). Change in tongue pressure in patients with head and neck cancer after surgical resection. *Odontology*, *105*(4), 494–503. https://doi.org/10.1007/s10266-016-0291-0

Hayashi, M., Kato, K., Umene, S., & Masunaga, H. (2016). A method for softening beans with coats. *International Food Research Journal*, *23*(6), 534–2539.

Hirota, N., Konaka, K., Ono, T., Tamine, K., Kondo, J., Hori, K., Yoshimuta, Y., Maeda, Y., Sakoda, S., & Naritomi, H. (2010). Reduced tongue pressure against the hard palate on the paralyzed side during swallowing predicts dysphagia in patients with acute stroke. *Stroke; A Journal of Cerebral Circulation*, *41*(12), 2982–2984. https://doi.org/10.1161/STROKEAHA.110.594960

Houjaij, N., Dufresne, T., Lachance, N., & Ramaswamy, H. S. (2009). Textural characterization of pureed cakes prepared for the therapeutic treatment of dysphagic patients. *International Journal of Food Properties*, *12*(1), 45–54. https://doi.org/10.1080/10942910802312157

Hron, B., & Rosen, R. (2020). Viscosity of commercial food-based formulas and home-prepared blenderized feeds. *Journal of Pediatric Gastroenterology and Nutrition*, *70*(6), e124. https://doi.org/10.1097/MPG.0000000000002657

Ibañez, F. C., Gómez, I., Merino, G., & Beriain, M. J. (2019). Textural characteristics of safe dishes for dysphagic patients: A multivariate analysis approach. *International Journal of Food Properties*, *22*(1), 593–606. https://doi.org/10.1080/10942912.2019.1597881

IDDSI. (2019). *IDDSI Framework Testing Methods 2.0*. https://iddsi.org/IDDSI/media/images/Testing_Methods_IDDSI_Framework_Final_31_July2019.pdf

Igarashi, A., Arai, E., Watanabe, R., Miyaoka, Y., Tazawa, T., Hirano, H., Nomura, S., & Yamada, Y. (2002). Comparison of physical properties of agar, low gel strength agar and gelatin, as supplementary food for people with swallowing difficulty. *Journal of Texture Studies*, *33*(4), 285–295. https://doi.org/10.1111/j.1745-4603.2002.tb01350.x

Iida, Y., Katsumata, A., & Fujishita, M. (2011). Videofluorographic evaluation of mastication and swallowing of Japanese udon noodles and white rice. *Dysphagia*, *26*(3), 246–249. https://doi.org/10.1007/s00455-010-9295-z

Inamoto, Y., Saitoh, E., Okada, S., Kagaya, H., Shibata, S., Baba, M., Onogi, K., Hashimoto, S., Katada, K., Wattanapan, P., & Palmer, J. B. (2015). Anatomy of the larynx and pharynx: Effects of age, gender and height revealed by multidetector computed tomography. *Journal of Oral Rehabilitation*, *42*(9), 670–677. https://doi.org/10.1111/joor.12298

International Organization for Standardization (ISO). (2012). *Sensory analysis—General guidelines for the selection, training and monitoring of selected assessors and expert sensory assessors (8586:2012)*. Author.

International Organization for Standardization (ISO). (2020). *Sensory analysis—Methodology—Texture profile (11036:2020)*. Author.

International Organization for Standardization (ISO). (2021). *Sensory analysis—Methodology—Guidelines for the measurement of the performance of a quantitative descriptive sensory panel (11132:2021)*. Author.

Jaeger, S. R., Beresford, M. K., Paisley, A. G., Antúnez, L., Vidal, L., Cadena, R. S., Giménez, A., & Ares, G. (2015). Check-all-that-apply (CATA) questions for sensory product characterization by consumers: Investigations into the number of terms used in CATA questions. *Food Quality and Preference*, *42*, 154–164. https://doi.org/10.1016/j.foodqual.2015.02.003

Jeong, S., Kim, H., & Lee, S. (2021). Rheology-based classification of foods for the elderly by machine learning analysis. *Applied Sciences*, *11*(5), 2262. https://doi.org/10.3390/app11052262

Joyner, H. S., Pernell, C. W., & Daubert, C. R. (2014). Beyond surface selection: The impact of different methodologies on tribological measurements. *Journal of Food Engineering*, *134*, 45–58. https://doi.org/10.1016/j.jfoodeng.2014.03.003

Karsten Hadde, E., Ann Yvette Cichero, J., & Michael Nicholson, T. (2016). Viscosity of thickened fluids that relate to the Australian national standards. *International Journal of Speech-Language Pathology*, *18*(4), 402–410. https://doi.org/10.3109/17549507.2015.1081289

Kemp, S. E., Hort, J., & Hollowood, T. (2018). *Descriptive analysis in sensory evaluation* (1st ed.). John Wiley & Sons Ltd.

Kim, C.-Y., & Yoo, B. (2018). Rheological characterization of thickened protein-based beverages under different food thickeners and setting times. *Journal of Texture Studies*, *49*(3), 293–299. https://doi.org/10.1111/jtxs.12332

Kim, D.-S., & Joo, N. (2020). Texture characteristics of horse meat for the elderly based on the enzyme treatment. *Food Science of Animal Resources*, *40*(1), 74–86. https://doi.org/10.5851/kosfa.2019.e86

Kim, H., Hwang, H.-I., Song, K.-W., & Lee, J. (2017). Sensory and rheological characteristics of thickened liquids differing concentrations of a xanthan gum-based thickener. *Journal of Texture Studies*, *48*(6), 571–585. https://doi.org/10.1111/jtxs.12268

Kim, S.-G., & Yoo, B. (2015). Viscosity of dysphagia-oriented cold-thickened beverages: Effect of setting time at refrigeration temperature. *International Journal of Language & Communication Disorders*, *50*(3), 397–402. https://doi.org/10.1111/1460-6984.12141

Kim, S.-G., Yoo, W., & Yoo, B. (2014a). Relationship between apparent viscosity and line-spread test measurement of thickened fruit juices prepared with a xanthan gum-based thickener. *Preventive Nutrition and Food Science*, *19*(3), 242–245. https://doi.org/10.3746/pnf.2014.19.3.242

Kim, S.-G., Yoo, W., & Yoo, B. (2014b). Effect of thickener type on the rheological properties of hot thickened soups suitable for elderly people with swallowing difficulty. *Preventive Nutrition and Food Science*, *19*(4), 358–362. https://doi.org/10.3746/pnf.2014.19.4.358

Kohyama, K., Sawada, H., Nonaka, M., Kobori, C., Hayakawa, F., & Sasaki, T. (2007). Textural evaluation of rice cake by chewing and swallowing measurements on human subjects. *Bioscience, Biotechnology, and Biochemistry*, *71*(2), 358–365. https://doi.org/10.1271/bbb.60276

Kunimaru, W., Ito, S., Motohashi, R., & Arai, E. (2021). Ease of swallowing potato paste in people with dysphagia: Effect of potato variety. *International Journal of Food Properties*, *24*(1), 615–626. https://doi.org/10.1080/10942912.2021.1908353

Kwak, S., Choo, Y. J., Choi, K. T., & Chang, M. C. (2021). Safety and efficacy of specially designed texture-modified foods for patients with dysphagia due to brain disorders: A prospective study. *Healthcare*, *9*(6), 728. https://doi.org/10.3390/healthcare9060728

Lee, C. G., Shim, Y. Y., Reaney, M. J. T., & Chang, H.-J. (2021). Food puree for seniors: The effects of xanflax as a new thickener on physicochemical and antioxidant properties. *Foods*, *10*(5), 1100. https://doi.org/10.3390/foods10051100

Lee, J. H., Kim, H.-S., Yun, D. H., Chon, J., Han, Y. J., Yoo, S. D., Kim, D. H., Lee, S. A., Joo, H. I., Park, J., Kim, J. C., & Soh, Y. (2016). The relationship between tongue pressure and oral dysphagia in stroke patients. *Annals of Rehabilitation Medicine*, *40*(4), 620. https://doi.org/10.5535/arm.2016.40.4.620

Leon, A. M., Aguilera, J. M., & Park, D. J. (2019). Mechanical, rheological and structural properties of fiber-containing microgels based on whey protein and alginate. *Carbohydrate Polymers*, *207*, 571–579. https://doi.org/10.1016/j.carbpol.2018.11.094

Leon, A. M., Medina, W. T., Park, D. J., & Aguilera, J. M. (2016). Mechanical properties of whey protein/Na alginate gel microparticles. *Journal of Food Engineering*, *188*, 1–7. https://doi.org/10.1016/j.jfoodeng.2016.05.005

Liu, J., Pedersen, H. L., Knarreborg, L., Ipsen, R., & Bredie, W. L. P. (2020). Stabilization of directly acidified protein drinks by single and mixed hydrocolloids—Combining particle size, rheology, tribology, and sensory data. *Food Science & Nutrition*, *8*(12), 6433–6444. https://doi.org/10.1002/fsn3.1933

Lotong, V., Chun, S. S., Chambers, E. I., & Garcia, J. M. (2003). Texture and flavor characteristics of beverages containing commercial thickening agents for dysphagia diets. *Journal of Food Science*, *68*(4), 1537–1541. https://doi.org/10.1111/j.1365-2621.2003.tb09680.x

Lund, A. M., Garcia, J. M., & Chambers, E. (2013). Line spread as a visual clinical tool for thickened liquids. *American Journal of Speech-Language Pathology*, *22*(3), 566–571. https://doi.org/10.1044/1058-0360(2013/12-0044)

Machado, A. S., Lenz, D., de Souza, R. d. S., Eugênio, R. M., de Andrade, T. U., Pereira, T. C., & Endringer, D. C. (2019). Lack of standardization in commercial thickeners used in the management of dysphagia. *Annals of Nutrition and Metabolism*, *75*(4), 246–251. https://doi.org/10.1159/000504334

Mackley, M. R., Tock, C., Anthony, R., Butler, S. A., Chapman, G., & Vadillo, D. C. (2013). The rheology and processing behavior of starch and gum-based dysphagia thickeners. *Journal of Rheology*, *57*(6), 1533–1553. https://doi.org/10.1122/1.4820494

Maieves, H. A., & Teixeira, G. L. (2021). Assessment of tomato-based thick fluid diet for patients with dysphagia using a simple and cheap test. *Journal of Texture Studies*, *52*(5-6), 647–655. https://doi.org/10.1111/jtxs.12617

Manda, Y., Kodama, N., Maeda, N., & Minagi, S. (2019). Effect of food properties and chewing condition on the electromyographic activity of the posterior tongue. *Journal of Oral Rehabilitation*, *46*(6), 511–517. https://doi.org/10.1111/joor.12774

Mann, L. L., & Wong, K. (1996). Development of an objective method for assessing viscosity of formulated foods and beverages for the dysphagic diet. *Journal of the American Dietetic Association*, *96*(6), 585–588. https://doi.org/10.1016/S0002-8223(96)00160-5

Marsh, G. L., Buhlert, J., & Leonard, S. (1977). Effect of degree of concentration and of heat treatment on consistency of tomato pastes after dilution. *Journal of Food Processing and Preservation*, *1*(4), 340–346. https://doi.org/10.1111/j.1745-4549.1977.tb00335.x

Matsuo, T., Sasaki, H., Tomita, T., & Sadzuka, Y. (2021). Comparison of the effects on tablet disintegration of solvents used to dissolve food thickeners. *Journal of Texture Studies*, *52*, 380–388. https://doi.org/10.1111/jtxs.12589

Matsuyama, S., Nakauma, M., Funami, T., Yamagata, Y., & Kayashita, J. (2020). The influence of syringe geometry on the International Dysphagia Diet Standardisation Initiative flow test. *International Journal of Food Science & Technology*, *55*(8), 2962–2969. https://doi.org/10.1111/ijfs.14559

Matsuyama, S., Nakauma, M., Funami, T., Hori, K., & Ono, T. (2021). Human physiological responses during swallowing of gel-type foods and its correlation with textural perception. *Food Hydrocolloids*, *111*, 106353. https://doi.org/10.1016/j.foodhyd.2020.106353

Matta, Z., Chambers, E., Garcia, J. M., & Helverson, J. M. (2006). Sensory characteristics of beverages prepared with commercial thickeners used for dysphagia diets. *Journal of the American Dietetic Association*, *106*(7), 1049–1054. https://doi.org/10.1016/j.jada.2006.04.022

Merino, G., Gómez, I., Marín-Arroyo, M. R., Beriain, M. J., & Ibañez, F. C. (2020). Methodology for design of suitable dishes for dysphagic people. *Innovative Food Science & Emerging Technologies*, *64*, 102383. https://doi.org/10.1016/j.ifset.2020.102383

Merino, G., Marín-Arroyo, M. R., Beriain, M. J., & Ibañez, F. C. (2021). Dishes adapted to dysphagia: Sensory characteristics and their relationship to hedonic acceptance. *Foods*, *10*(2), 480. https://doi.org/10.3390/foods10020480

Milczarek, R. R., & Mccarthy, K. L. (2006). Relationship between the Bostwick measurement and fluid properties. *Journal of Texture Studies*, *37*(6), 640–654. https://doi.org/10.1111/j.1745-4603.2006.00075.x

Miller, J. L., & Watkin, K. L. (1996). The influence of bolus volume and viscosity on anterior lingual force during the oral stage of swallowing. *Dysphagia*, *11*(2), 117–124. https://doi.org/10.1007/BF00417901

Minagi, Y., Ono, T., Hori, K., Fujiwara, S., Tokuda, Y., Murakami, K., Maeda, Y., Sakoda, S., Yokoe, M., Mihara, M., & Mochizuki, H. (2018). Relationships between dysphagia and tongue pressure during swallowing in Parkinson's disease patients. *Journal of Oral Rehabilitation*, *45*(6), 459–466. https://doi.org/10.1111/joor.12626

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., & Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews*, *4*(1), 1–9. https://doi.org/10.1186/2046-4053-4-1

Momosaki, R., Abo, M., & Kobayashi, K. (2013). Swallowing analysis for semisolid food texture in poststroke dysphagic patients. *Journal of Stroke and Cerebrovascular Diseases*, *22*(3), 267–270. https://doi.org/10.1016/j.jstrokecerebrovasdis.2011.08.009

Moret-Tatay, A., Rodríguez-García, J., Martí-Bonmatí, E., Hernando, I., & Hernández, M. J. (2015). Commercial thickeners used by patients with dysphagia: Rheological and structural behaviour in different food matrices. *Food Hydrocolloids*, *51*, 318–326. https://doi.org/10.1016/j.foodhyd.2015.05.019

Moritaka, H. (2012). Relation between the rheological properties and the swallowing characteristics of vegetable juices fortified with carrot puree. *Bioscience, Biotechnology, and Biochemistry*, *76*(3), 429–435. https://doi.org/10.1271/bbb.110576

Mortimore, I. L., Fiddes, P., Stephens, S., & Douglas, N. J. (1999). Tongue protrusion force and fatiguability in male and female subjects. *European Respiratory Journal*, *14*(1), 191–195. https://doi.org/10.1034/j.1399-3003.1999.14a32.x

Nakatsu, S., Kohyama, K., Watanabe, Y., Shibata, K., Sakamoto, K., & Shimoda, M. (2012). Mechanical properties of softened foodstuffs processed by freeze–thaw infusion of macerating enzyme. *Innovative Food Science & Emerging Technologies*, *16*, 267–276. https://doi.org/10.1016/j.ifset.2012.07.010

Ng, V., Bogaardt, H., Tzannes, G., Collins, S., & Docking, K. (2021). Thickened formulas used for infants with dysphagia: Influence of time and temperature. *Dysphagia*, https://doi.org/10.1007/s00455-021-10353-w

Nicosia, M. A., & Robbins, J. (2007). The usefulness of the line spread test as a measure of liquid consistency. *Dysphagia*, *22*(4), 306–311. https://doi.org/10.1007/s00455-007-9086-3

Nishinari, K., Turcanu, M., Nakauma, M., & Fang, Y. (2019). Role of fluid cohesiveness in safe swallowing. *Npj Science of Food*, *3*(1), 1–13. https://doi.org/10.1038/s41538-019-0038-8

Okita, A., Takahashi, K., Itakura, M., Horio, A., Yamamoto, R., Nakamura, Y., & Osako, K. (2021). A novel soft surimi gel with functionality prepared using alcalase for people suffering from dysphagia. *Food Chemistry*, *344*, 128641. https://doi.org/10.1016/j.foodchem.2020.128641

Olaru, L. D., Nistor, O.-V., Andronoiu, D. G., Ghinea, I. O., Barbu, V., & Botez, E. (2021). Effect of added hydrocolloids on ready-to-eat courgette (*Cucurbita pepo*) puree ohmically treated. *Journal of Food Science and Technology*, *59*, 388–396. https://doi.org/10.1007/s13197-021-05025-4

Osorio, F. A., & Steffe, J. F. (1987). Back extrusion of power law fluids. *Journal of Texture Studies*, *18*, 43–63. https://doi.org/10.1111/j.1745-4603.1987.tb00569.x

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, *372*, n71. https://doi.org/10.1136/bmj.n71

Paik, N.-J., Han, T. R., Park, J. W., Lee, E. K., Park, M. S., & Hwang, I.-K. (2004). Categorization of dysphagia diets with the line spread test. *Archives of Physical Medicine and Rehabilitation*, *85*(5), 857–861. https://doi.org/10.1016/j.apmr.2003.08.079

Palinkas, M., Nassar, M. S. P., Cecílio, F. A., Siéssere, S., Semprini, M., Machado-de-Sousa, J. P., Hallak, J. E. C., & Regalo, S. C. H. (2010). Age and gender influence on maximal bite force and masticatory muscles thickness. *Archives of Oral Biology*, *55*(10), 797–802. https://doi.org/10.1016/j.archoralbio.2010.06.016

Pant, A., Lee, A. Y., Karyappa, R., Lee, C. P., An, J., Hashimoto, M., Tan, U.-X., Wong, G., Chua, C. K., & Zhang, Y. (2021). 3D food printing of fresh vegetables using food hydrocolloids for dysphagic patients. *Food Hydrocolloids*, *114*, 106546. https://doi.org/10.1016/j.foodhyd.2020.106546

Park, H. S., Kim, D.-K., Lee, S. Y., & Park, K.-H. (2017). The effect of aging on mastication and swallowing parameters according to the hardness change of solid food. *Journal of Texture Studies*, *48*(5), 362–369. https://doi.org/10.1111/jtxs.12249

Park, J., & Yoo, B. (2020). Particle agglomeration of gum mixture thickeners used for dysphagia diets. *Journal of Food Engineering*, *279*, 109958. https://doi.org/10.1016/j.jfoodeng.2020.109958

Park, J.-W., Lee, S., Yoo, B., & Nam, K. (2020). Effects of texture properties of semi-solid food on the sensory test for pharyngeal swallowing effort in the older adults. *BMC Geriatrics*, *20*(1), 493. https://doi.org/10.1186/s12877-020-01890-4

Park, S.-O., Kim, W.-K., Park, D.-J., & Lee, S.-J. (2017). Effect of blanching time on the quality characteristics of elderly-friendly *kkakdugi*. *Food Science and Biotechnology*, *26*(2), 419–425. https://doi.org/10.1007/s10068-017-0057-7

Patel, S., McAuley, W. J., Cook, M. T., Sun, Y., Hamdy, S., & Liu, F. (2020). The swallowing characteristics of thickeners, jellies and yoghurt observed using an in vitro model. *Dysphagia*, *35*(4), 685–695. https://doi.org/10.1007/s00455-019-10074-1

Payne, C., Methven, L., Fairfield, C., & Bell, A. (2011). Consistently inconsistent: Commercially available starch-based dysphagia products. *Dysphagia*, *26*(1), 27–33. https://doi.org/10.1007/s00455-009-9263-7

Peleg, M. (2019). The instrumental texture profile analysis revisited. *Journal of Texture Studies*, *50*(5), 362–368. https://doi.org/10.1111/jtxs.12392

Pematilleke, N., Kaur, M., Adhikari, B., & Torley, P. J. (2022). Relationship between instrumental and sensory texture profile of beef semitendinosus muscles with different textures. *Journal of Texture Studies*, *53*, 232–241. https://doi.org/10.1111/jtxs.12623

Pematilleke, N., Kaur, M., Rai Wai, C. T., Adhikari, B., & Torley, P. J. (2021). Effect of the addition of hydrocolloids on beef texture: Targeted to the needs of people with dysphagia. *Food Hydrocolloids*, *113*, 106413. https://doi.org/10.1016/j.foodhyd.2020.106413

Piggott, J. R., Simpson, S. J., & Williams, S. A. R. (1998). Sensory analysis. *International Journal of Food Science & Technology*, *33*(1), 7–12. https://doi.org/10.1046/j.1365-2621.1998.00154.x

Plesser, H. E. (2018). Reproducibility vs. replicability: A brief history of a confused terminology. *Frontiers in Neuroinformatics*, *1*, 76. https://doi.org/10.3389/fninf.2017.00076

Posen, A. L. (1972). The influence of maximum perioral and tongue force on the incisor teeth. *Angle Orthodontist*, *42*(4), 285–309. https://doi.org/10.1043/0003-3219(1972)042⟨0285:TIOMPA⟩2.0.CO;2

Prinz, J. F., Huntjens, L., & de Wijk, R. A. (2006). Instrumental and sensory quantification of oral coatings retained after swallowing semi-solid foods. *Archives of Oral Biology*, *51*(12), 1071–1079. https://doi.org/10.1016/j.archoralbio.2006.05.008

Pure, A. E., Yarmand, M. S., Farhoodi, M., & Adedeji, A. (2021). Microwave treatment to modify textural properties of high protein gel applicable as dysphagia food. *Journal of Texture Studies*, *52*(5-6), 638–646. https://doi.org/10.1111/jtxs.12611

Rieder, A., Franceschinis, E., Santi, M. D., Realdon, N., & Santomaso, A. C. (2020). Reconstitution of food powders granulated with oil-in-water emulsions. *Chemical Engineering & Technology*, *43*(5), 859–868. https://doi.org/10.1002/ceat.201900439

Robinovitch, S. N., Hershler, C., & Romilly, D. P. (1991). A tongue force measurement system for the assessment of oral-phase swallowing disorders. *Archives of Physical Medicine and Rehabilitation*, *72*(1), 38–42. https://doi.org/10.5555/uri:pii:000399939190077V

Rosenthal, A. J. (2010). Texture profile analysis – How important are the parameters? *Journal of Texture Studies*, *41*(5), 672–684. https://doi.org/10.1111/j.1745-4603.2010.00248.x

Rule, D. W., Kelchner, L., Mulkern, A., Couch, S., Silbert, N., & Welden, K. (2020). Implementation strategies for the International Dysphagia Diet Standardisation Initiative (IDDSI), Part I: Quantitative analysis of IDDSI performance among varied participants. *American Journal of Speech-Language Pathology*, *29*(3), 1514–1528. https://doi.org/10.1044/2020_AJSLP-19-00012

Rungraung, N., Trachootham, D., Muangpracha, N., Purttiponthanee, S., & Winuprasith, T. (2020). Textural properties and sensory acceptability of texture-modified pork balls for the elderly. *Asia-Pacific Journal of Science and Technology*, *25*(01), 1–7.

Rush, O. M., Bolland, A. C., & Gosa, M. M. (2021). Effect of mixing method on resulting thickness of infant formula. *Journal of Texture Studies*, *52*(1), 57–70. https://doi.org/10.1111/jtxs.12566

Sakamoto, K., Shibata, K., & Ishihara, M. (2006). Decreased hardness of dietary fiber-rich foods by the enzyme-infusion method. *Bioscience, Biotechnology, and Biochemistry*, *70*(7), 1564–1570. https://doi.org/10.1271/bbb.50562

Sano, J., Noda, R., Watanabe, S., Aoyama, T., Sato, Y., Kayashita, J., & Muto, N. (2015). Basic evaluation of gelatinous fat to improve properties of nursing care food. *Journal of Oleo Science*, *64*(6), 653–662. https://doi.org/10.5650/jos.ess14279

Schmidt, H. O. S., Komeroski, M. R., Steemburgo, T., & de Oliveira, V. R. (2021). Influence of thickening agents on rheological properties and sensory attributes of dysphagic diet. *Journal of Texture Studies*, *52*(5–6), 587–602. https://doi.org/10.1111/jtxs.12596

Sha, B. F. B., England, S. J., Parisi, R. A., & Strobel, R. J. (2000). Force production of the genioglossus as a function of muscle length in normal humans. *Journal of Applied Physiology*, *88*(5), 1678–1684. https://doi.org/10.1152/jappl.2000.88.5.1678

Sharma, M., & Duizer, L. (2019). Characterizing the dynamic textural properties of hydrocolloids in pureed foods—A comparison between TDS and TCATA. *Foods*, *8*(6), 184. https://doi.org/10.3390/foods8060184

Sharma, M., Kristo, E., Corredig, M., & Duizer, L. (2017). Effect of hydrocolloid type on texture of pureed carrots: Rheological and sensory measures. *Food Hydrocolloids*, *63*, 478–487. https://doi.org/10.1016/j.foodhyd.2016.09.040

Sharma, M., Pico, J., Martinez, M. M., & Duizer, L. (2020). The dynamics of starch hydrolysis and thickness perception during oral processing. *Food Research International*, *134*, 109275. https://doi.org/10.1016/j.foodres.2020.109275

Sharma, M., Pondicherry, K. S., & Duizer, L. (2021). Understanding relations between rheology, tribology, and sensory perception of modified texture foods. *Journal of Texture Studies*, https://doi.org/10.1111/jtxs.12656

Sopade, P. A., Halley, P. J., Cichero, J. A. Y., & Ward, L. C. (2007). Rheological characterisation of food thickeners marketed in Australia in various media for the management of dysphagia. I: Water and cordial. *Journal of Food Engineering*, *79*(1), 69–82. https://doi.org/10.1016/j.jfoodeng.2006.01.045

Sopade, P. A., Halley, P. J., Cichero, J. A. Y., Ward, L. C., Hui, L. S., & Teo, K. H. (2008). Rheological characterisation of food thickeners marketed in Australia in various media for the management of dysphagia. II. Milk as a dispersing medium. *Journal of Food Engineering*, *84*(4), 553–562. https://doi.org/10.1016/j.jfoodeng.2007.06.024

Sopade, P. A., Halley, P. J., Cichero, J. A. Y., Ward, L. C., Liu, J., & Varliveli, S. (2008). Rheological characterization of food thickeners marketed in Australia in various media for the management of dysphagia. III. Fruit juice as a dispersing medium. *Journal of Food Engineering*, *86*(4), 604–615. https://doi.org/10.1016/j.jfoodeng.2007.11.013

Stading, M. (2021). Bolus rheology of texture-modified food – Effect of degree of modification. *Journal of Texture Studies*, *52*(5-6), 540–551. https://doi.org/10.1111/jtxs.12598

Stahlman, L. B., Garcia, J. M., Iv, E. C., Smit, A. B., Hoag, L., & Chambers, H. (2001). Perceptual ratings for pureed and molded peaches for individuals with and without impaired swallowing. *Dysphagia*, *16*, 254–262. https://doi.org/10.1007/s00455-001-0084-6

Stangierski, J., & Kawecka, A. (2019). An evaluation of the mechanical and sensory characteristics of selected foodstuffs for senior citizens. *Acta Scientiarum Polonorum: Technologia Alimentaria*, *18*(3), 305–315. https://doi.org/10.17306/J.AFS.2019.0655

Steele, C. M., James, D. F., Hori, S., Polacco, R. C., & Yee, C. (2014). Oral perceptual discrimination of viscosity differences for non-Newtonian liquids in the nectar- and honey-thick ranges. *Dysphagia*, *29*(3), 355–364. https://doi.org/10.1007/s00455-014-9518-9

Steele, C. M., Van Lieshout, P. lH. H. M., & Goff, D. H. (2003). The rheology of liquids: A comparison of clinicians' subjective impressions and objective measurement. *Dysphagia*, *18*(3), 182–195. https://doi.org/10.1007/s00455-002-0104-1

Štreimikytė, P., Keršienė, M., Eisinaitė, V., Jasutienė, I., Lesauskaitė, V., Damulevičienė, G., Knašienė, J., & Leskauskaitė, D. (2020). Formulating protein-based beverages for the dysphagia diets of the elderly: Viscosity, protein quality, in vitro digestion, and consumers acceptability. *Journal of the Science of Food and Agriculture*, *100*(10), 3895–3901. https://doi.org/10.1002/jsfa.10431

Strother, H., Moss, R., & McSweeney, M. B. (2020). Comparison of 3D printed and moulded carrots produced with gelatin, guar gum and xanthan gum. *Journal of Texture Studies*, *51*, 852–860. https://doi.org/10.1111/jtxs.12545

Suebsaen, K., Suksatit, B., Kanha, N., & Laokuldilok, T. (2019). Instrumental characterization of banana dessert gels for the elderly with dysphagia. *Food Bioscience*, *32*, 100477. https://doi.org/10.1016/j.fbio.2019.100477

Sukkar, S. G., Maggi, N., Travalca Cupillo, B., & Ruggiero, C. (2018). Optimizing texture modified foods for oro-pharyngeal dysphagia: A difficult but possible target? *Frontiers in Nutrition*, *5*, 68. https://doi.org/10.3389/fnut.2018.00068

Suzuki, Y., Hatsushika, K., Masuyama, K., Sakata, O., Tanimoto, M., & Morisawa, M. (2019). Classification of esophageal and bolus movements for evaluation of swallowing function by ultrasound video processing using optical flow and stable extremal region method. *Electronics and Communications in Japan*, *102*(9), 19–26. https://doi.org/10.1002/ecj.12201

Syahariza, Z. A., & Yong, H. Y. (2017). Evaluation of rheological and textural properties of texture-modified rice porridge using tapioca and sago starch as thickener. *Journal of Food Measurement and Characterization*, *11*(4), 1586–1591. https://doi.org/10.1007/s11694-017-9538-x

Talens, P., Castells, M. L., Verdú, S., Barat, J. M., & Grau, R. (2021). Flow, viscoelastic and masticatory properties of tailor made thickened pea cream for people with swallowing problems. *Journal of Food Engineering*, *292*, 110265. https://doi.org/10.1016/j.jfoodeng.2020.110265

Tashiro, A., Hasegawa, A., Kohyama, K., Kumagai, H., & Kumagai, H. (2010). Relationship between the rheological properties of thickener solutions and their velocity through the pharynx as measured by the ultrasonic pulse Doppler method. *Bioscience, Biotechnology, and Biochemistry*, *74*(8), 1598–1605. https://doi.org/10.1271/bbb.100192

Tokifuji, A., Matsushima, Y., Hachisuka, K., & Yoshioka, K. (2013). Texture, sensory and swallowing characteristics of high-pressure-heat-treated pork meat gel as a dysphagia diet. *Meat Science*, *93*(4), 843–848. https://doi.org/10.1016/j.meatsci.2012.11.050

Trček Kavčič, M., Ogrin, M., & Vidmar, G. (2020). Suitability of food in a rehabilitation hospital for patients with neurologic dysphagia. *International Journal of Rehabilitation Research*, *43*(3), 276–279. https://doi.org/10.1097/MRR.0000000000000406

Umene, S., Hayashi, M., Kato, K., & Masunaga, H. (2015). Physical properties of root crops treated with novel softening technology capable of retaining the shape, color, and nutritional value of foods. *Dysphagia*, *30*(2), 105–113. https://doi.org/10.1007/s00455-014-9581-2

Vallons, K. J. R., Helmens, H. J., & Oudhuis, A. A. C. M. (2015). Effect of human saliva on the consistency of thickened drinks for individuals with dysphagia. *International Journal of Language & Communication Disorders*, *50*(2), 165–175. https://doi.org/10.1111/1460-6984.12120

van der Stelt, A. J., Mehring, P., Corbier, C., van Eijnatten, E. J. M., & Withers, C. (2020). A “mouthfeel wheel” terminology for communicating the mouthfeel attributes of medical nutrition products (MNP). *Food Quality and Preference*, *80*, 103822. https://doi.org/10.1016/j.foodqual.2019.103822

Vandenberghe-Descamps, M., Sulmont-Rossé, C., Septier, C., Feron, G., & Labouré, H. (2017). Using food comfortability to compare food’s sensory characteristics expectations of elderly people with or without oral health problems. *Journal of Texture Studies*, *48*(4), 280–287. https://doi.org/10.1111/jtxs.12250

Vercruysse, M. C. M., & Steffe, J. F. (1989). On-line viscometry for pureed baby food: Correlation of Bostwick consistometer readings and apparent viscosity data. *Journal of Food Process Engineering*, *11*(3), 193–202. https://doi.org/10.1111/j.1745-4530.1989.tb00029.x

Vieira, J. M., Oliveira, F. D., Salvaro, D. B., Maffezzolli, G. P., de Mello, J. D. B., Vicente, A. A., & Cunha, R. L. (2020). Rheology and soft tribology of thickened dispersions aiming the development of oropharyngeal dysphagia-oriented products. *Current Research in Food Science*, *3*, 19–29. https://doi.org/10.1016/j.crfs.2020.02.001

Villiers, M., Hanson, B., Moodley, L., & Pillay, M. (2019). The impact of modification techniques on the rheological properties of dysphagia foods and liquids. *Journal of Texture Studies*, *51*, 154–168. https://doi.org/10.1111/jtxs.12476

Waqas, M. Q., Wiklund, J., Altskär, A., Ekberg, O., & Stading, M. (2017). Shear and extensional rheology of commercial thickeners used for dysphagia management. *Journal of Texture Studies*, *48*(6), 507–517. https://doi.org/10.1111/jtxs.12264

Watanabe, E., Yamagata, Y., Kogirima, M., Miyamoto, K., & Kayashita, J. (2017). Development of a simple and objective evaluation method for thickened liquids using funnels. *Journal of Texture Studies*, *48*(3), 198–204. https://doi.org/10.1111/jtxs.12235

Wendin, K., Ekman, S., Bülow, M., Ekberg, O., Johansson, D., Rothenberg, E., & Stading, M. (2010). Objective and quantitative definitions of modified food textures based on sensory and rheological methodology. *Food & Nutrition Research*, *54*, 1–11. https://doi.org/10.3402/fnr.v54i0.5134

Weston, S., & Clarke, T. (2020). Determining viscosity of blenderized formula: A novel approach using the International Dysphagia Diet Standardisation Initiative framework. *Journal of Parenteral and Enteral Nutrition*, *44*(6), 1140–1143. https://doi.org/10.1002/jpen.1788

Wilkinson, C., Dijksterhuis, G. B., & Minekus, M. (2000). From food structure to texture. *Trends in Food Science & Technology*, *11*(12), 442–450. https://doi.org/10.1016/S0924-2244(01)00033-4

Wilson, A., Anukiruthika, T., Moses, J. A., & Anandharamakrishnan, C. (2020). Customized shapes for chicken meat–based products: Feasibility study on 3D-printed nuggets. *Food and Bioprocess Technology*, *13*(11), 1968–1983. https://doi.org/10.1007/s11947-020-02537-3

Xie, Y., Zhao, W., Yu, W., Lin, X., Tao, S., Prakash, S., & Dong, X. (2021). Validating the textural characteristics of soft fish-based paste through International Dysphagia Diet Standardisation Initiative recommended tests. *Journal of Texture Studies*, *52*(2), 240–250. https://doi.org/10.1111/jtxs.12578

Yamaguchi, E., Torisu, T., Tada, H., Tanabe, Y., Kurogi, T., Mikushi, S., & Murata, H. (2019). The influence of thickeners of food on the particle size of boluses: A consideration for swallowing. *Odontology*, *107*(4), 546–554. https://doi.org/10.1007/s10266-019-00429-3

Yang, H., & Lin, Y. (2021). Effect of thermal processing on flow properties and stability of thickened fluid matrices formulated by tapioca starch, hydroxyl distarch phosphate (E-1442), and xanthan gum associating dysphagia-friendly potential. *Polymers*, *13*(1), 162. https://doi.org/10.3390/polym13010162

Youmans, S. R., & Stierwalt, J. A. G. (2006). Measures of tongue function related to normal swallowing. *Dysphagia*, *21*(2), 102–111. https://doi.org/10.1007/s00455-006-9013-z

Young, A. K., Cheong, J. N., Foster, K. D., Hedderley, D. I., Morgenstern, M. P., & James, B. J. (2016a). Exploring the links between texture perception and bolus properties throughout oral processing. Part 1: Breakdown paths. *Journal of Texture Studies*, *47*(6), 461–473. https://doi.org/10.1111/jtxs.12185

Young, A. K., Cheong, J. N., Foster, K. D., Hedderley, D. I., Morgenstern, M. P., & James, B. J. (2016b). Textural characteristics of safe dishes for dysphagic patients. *Journal of Texture Studies*, *47*(6), 474–483.

Young, A. K., Cheong, J. N., Hedderley, D. I., Morgenstern, M. P., & James, B. J. (2013). Understanding the link between bolus properties and perceived texture: Mastication: Physical and sensory bolus properties. *Journal of Texture Studies*, *44*(5), 376–386. https://doi.org/10.1111/jtxs.12025

Zargaraan, A., Omaraee, Y., Rastamanesh, R., Taheri, N., Fadavi, G., Fadaei, M., & Mohammadifar, M. A. (2013). Rheological characterization and cluster classification of Iranian commercial foods, drinks and desserts to recommend for esophageal dysphagia diets. *Iranian Journal of Public Health*, *42*(12), 1446–1456.

Zargaraan, A., Omaraee, Y., Rastmanesh, R., Taheri, N., & Fadavi, G. (2014). Rheological and clustering approach to classify Iranian soft/liquid food products to meet dysphagia diet requirements. *Italian Journal of Food Science*, *26*(3), 243–251.

SUPPORTING INFORMATION

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