EVALUATION ON THE EFFECT OF SAGO/IOTA-CARRAGEENAN MICROGELS THICKENERS ON RHEOLOGY, TEXTURE AND SENSORY OF PUREED CARROT AS DYSPHAGIA DIET

NORRAZATIN HAIDA BINTI ROZMAN

UNIVERSITI SAINS MALAYSIA

2024

EVALUATION ON THE EFFECT OF SAGO/IOTA-CARRAGEENAN MICROGELS THICKENERS ON RHEOLOGY, TEXTURE AND SENSORY OF PUREED CARROT AS DYSPHAGIA DIET

by

NORRAZATIN HAIDA BINTI ROZMAN

Thesis submitted in fulfilment of the requirements for the degree of Master of Science

July 2024

ACKNOWLEDGEMENT

I would like to take this opportunity to express my profound gratitude and sincere regards to my supervisor, Dr. Syahariza Zainul Abidin for her encouragement and support. Her guidance helped me throughout this research and the writing of this thesis. Thank you to all of the lecturers and lab assistants at the School of Industrial Technology for assisting me with my studies. A note of gratitude is also sent to all staffs and students in School of Industrial Technology, School of Pharmaceutical Science, School of Educational Studies, School of Humanities and School of Chemical Science, Universiti Sains Malaysia, Pulau Pinang, permitting me to conduct the sensory evaluation test. I would like to thank Syazana Sulaiman for her supervision and support during the entire sensory data collection procedure. Not to mention the other members of the postgraduate room and my friends, who have provided unwavering support throughout this research project. Finally, but just as importantly, I want to express my sincere gratitude to my family for their support, encouragement, love, and understanding—all of which contributed to the success of my research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

σ_{oc}	Casson yield stress
R	Coefficient Of Determination
K	Consistency index
n	Flow behaviour index
G"	Loss modulus
tan δ	Loss tangent
δ	Phase angle
$\dot{\gamma}$	Shear rate
σ	Shear stress
G'	Storage modulus
τ_0	Yield stress

LIST OF ABBREVIATIONS

CI	Commercial iota-carrageenan
CT	Commercial Thickener
FDA	Food and Drug Administration
FEES	Fibreoptic Endoscopic Evaluation of Swallowing
IDDSI	International Dysphagia Diet Standardization Initiative
LST	Line Spread Test
LVR	Linear Viscoelastic Region
MI	iota-carrageenan Microgels
MS	Sago Microgels
NDD	National Dysphagia Diet
NS	Native Sago
PCA	Principal Component Analysis
SD	Standard Deviation
TM	Texture Modified
TPA	Texture Profile Analysis
TX	Thixer
USM	Universiti Sains Malaysia
VFSS	Videofluoroscopic Swallowing Study

LIST OF APPENDICES

PENILAIAN TERHADAP KESAN PEMEKAT MIKROGEL SAGU/IOTA-KARAGENAN TERHADAP RHEOLOGI, TEKSTUR DAN SIFAT SENSORI TERHADAP PURI LOBAK SEBAGAI PEMAKANAN DISFAGIA

ABSTRAK

Disfagia didefinisikan sebagai kesulitan atau ketidakmampuan menelan makanan dan cecair. Penyediaan tekstur makanan yang diubahsuai yang lembut, enak, dan sihat bagi kumpulan ini merupakan satu cabaran besar bagi industri makanan. Disebabkan oleh rasa tepung yang kuat dari pemekat disfagia berasaskan kanji komersial, kajian untuk menghasilkan mikrogel dari biopolimer makanan lain adalah diperlukan. Objektif kajian ini adalah untuk menghasilkan mikrogel berasaskan kanji sagu dan iota-karagenan sebagai pemekat makanan dalam makanan puri. Dalam Fasa 1, kepekatan iota-karagenan yang berbeza ditambah ke dalam serakan kanji sagu. Mikrogel dibuat menggunakan rawatan ultrasound diikuti oleh proses pengeringan semburan. Pemekat disfagia komersial juga dimasukkan sebagai rujukan. Mikrogel dengan peningkatan kepekatan iota-carrageenan menunjukkan variasi dalam tingkah laku semasa pengukuran rheologi dan tekstur. Ujian rheologi mendapati bahawa mikrogel sagu/iota-karagenan mempamerkan tingkah laku elastik yang dominan, dengan G' > G" dalam julat frekuensi. Analisis profil tekstur (TPA) menunjukkan bahawa sampel dengan 2.0 g kanji sagu dan 2.0 g iota-karagenan, MS50, mempunyai kelebihan berbanding pemekat komersial dari segi kelekatan dan tingkah laku elastik. Penggunaan mikrogel sagu/iota-karagenan sebagai pengubahsuai tekstur dalam makanan yang diubahsuai tekstur seterusnya dikaji dalam Fasa 2. Beberapa kepekatan mikrogel sagu/iota-karagenan dan pemekat komersial ditambah ke dalam puri lobak merah dan sifat teksturnya dikaji. Thixer, sejenis pemekat komersial berasaskan tepung jagung diubahsuai digunakan sebagai sampel rujukan manakala puri lobak merah tanpa penambahan pemekat bertindak sebagai sampel kawalan. Pengukuran rheologi, analisis profil tekstur (TPA), kajian tindakbalas enzim, dan penilaian sensori digunakan untuk menilai sifat puri lobak merah. Mikrogel sagu/iota-karagenan menunjukkan tingkah laku elastik (G'>G") dan berada dalam julat menelan yang selamat (tan δ iaitu 0.11-0.20). Mereka juga mempunyai nilai tegasan alah yang tinggi (36.51-95.11 Pa), yang penting untuk membentuk bolus yang padu, untuk mengurangkan penguraian matriks makanan, sekali gus mengurangkan risiko aspirasi. Diperhatikan bahawa mikrogel sagu/iota-karagenan dengan kepekatan yang lebih tinggi mempunyai G', kekerasan, dan kekenyalan yang lebih tinggi berbanding dengan kepekatan yang lebih rendah. Walaupun mikrogel sagu/iota-karagenan mempunyai struktur gel yang kuat pada keadaan rehat, ia mempunyai kejelekitan yang tinggi apabila dikenakan deformasi besar yang menghalangnya daripada terurai menjadi pecahan semasa menelan. Tiada perubahan yang ketara diperhatikan apabila mikrogel sagu/iota-karagenan bersentuhan dengan air liur, disebabkan oleh ketiadaan ikatan glikosidik α-1,4 dalam struktur karagenan. Dalam Fasa 3, hanya sedikit perbezaan dalam sifat sensori yang dirasai antara mikrogel sagu/iota-karagenan, Thixer, dan sampel kawalan di kalangan panelis, kecuali untuk tekstur keseluruhan. Keputusan menunjukkan bahawa penghasilan mikrogel berasaskan kanji sagu dan iota-karagenan dengan keupayaan memekat makanan berpuri berjaya dihasilkan, berdasarkan penilaian instrumental dan sensori berpotensi untuk digunakan dalam pengurusan diet disfagia.

EVALUATION ON THE EFFECT OF SAGO/IOTA-CARRAGEENAN MICROGELS THICKENERS ON RHEOLOGY, TEXTURE AND SENSORY ON PUREED CARROT AS DYSPHAGIA DIET

ABSTRACT

The inability or difficulty to swallow food and liquids is known as dysphagia. Providing soft, palatable and healthy texture modified foods for these group of people, is a major challenge for the food industry. Due to strong starchy flavour imparted from commercial starch-based dysphagia thickener, a study to develop microgels from other food biopolymers are needed. The objective of this study was to develop sago starch and iota-carrageenan based microgels with a functionality as food thickeners in pureed food. In Phase 1, different concentrations of iota-carrageenan were added into sago starch dispersion. Microgels were fabricated using ultrasound treatment followed by spray drying process. A commercial dysphagia thickener that normally used at medical institutions and nursing homes was also included as a reference. Microgels exhibiting varying concentrations of iota-carrageenan demonstrated distinct behaviours in rheological and textural assessments. According to rheological tests, sago/iota-carrageenan microgels showed a predominant elastic tendency, with $G' > G''$ in the frequency range. According to texture profile analysis (TPA), the sample containing 2.0 g of sago starch and 2.0 g of iota-carrageenan, MS50, exhibited excellent adhesiveness and elastic behaviour compared to a commercial thickener. The usage of sago/iota-carrageenan microgels in texture-modified food as texture modifier was further investigated in Phase 2. Different sago/iota-carrageenan microgel concentrations and a commercial thickener were added to pureed carrots, and the textural properties were examined. Thixer, a commercial thickener made of modified corn starch, was used as a reference sample, while pureed carrot without the addition of thickener acts as a control

group. Rheological measurements, TPA, enzyme reaction study and sensory analysis were employed to characterize the thickened pureed. Sago/iota-carrageenan microgels showed elastic behaviour (G′>G″) and were within the safe-swallowable range (tan δ of 0.11–0.20). They also exhibit a high yield stress value (36.51-95.11 Pa), which is important to form a cohesive bolus to minimize the disintegration of food matrices, hence minimizing the risk of aspiration. It was observed that sago/iota-carrageenan microgels at higher concentrations had a higher G', hardness and gumminess than lower sago/iota-carrageenan microgels concentrations. Sago/iota-carrageenan microgels possessed a strong gel structure when they were at rest, but when they underwent significant deformation, they exhibited great cohesiveness, which prevented them from breaking up into pieces when swallowed. No big changes were observed when sago/iota-carrageenan microgels encounters saliva, due to absence of the particular α-1,4 glycosidic bond in the carrageenan structure. In Phase 3, only small differences were perceived by the sensory panellists for pureed carrot with sago/iota-carrageenan microgels, Thixer and control sample properties, except for overall texture. The results indicated that the sago starch and iota-carrageenan-based microgels with food thickening capabilities for pureed food were successfully developed based on the instrumental and sensory evaluation and could potentially be used for dysphagia diet management.

CHAPTER 1

INTRODUCTION

1.1 Background and Rationale of Study

The term dysphagia refers to difficulties in swallowing (Ala'A *et al.,* 2015). The community prevalence of dysphagia ranges between 2% and 20% of the worldwide population (Adkins *et al.,* 2020). Stroke, traumatic brain injury, progressive neurological disease, and head and neck cancer are well-known causes of swallowing difficulties (Jardine *et al.,* 2018). Although dysphagia affects people of all ages, it is most prevalent in the elderly (Jardine *et al.,* 2018). Some issues, such as loss of muscle mass, changes of the cervical spine, dental problems, and decreased saliva production affect swallowing function. As a result, the risk of dysphagia increases with age and the natural ageing processes (Rajati et al., 2022). People with swallowing difficulties are at risk of choking, aspiration, malnutrition, pneumonia, and constipation (Roy *et al.,* 2007; Chadwick & Jolliffe, 2009).

A way to reduce these risks is by modifying food texture and liquid thickness without compromising nutritional quality to ensure patients can meet their nutritional requirements (Cichero *et al.,* 2017). For example, studies on bolus rheology by Ishihara *et al.* (2011) suggest that bolus viscoelasticity balance is important to ease swallowing. Other researchers recommended that food texture for dysphagia diets be soft, smooth, moist, elastic, and easy to swallow (Yoshioka *et al.,* 2016; Miles *et al.,* 2020). Handling viscous food components will involve more studies on their rheological parameters. However, a general understanding of the parameters defining texture-modified (TM) food for dysphagia patients worldwide is generally lacking.

To ensure moisture in texture-modified foods, additional fluids are often incorporated. Therefore, thickening agents are usually added to control the textural and rheological properties of various food products (Clegg, 1995; Imeson, 2009). A thickened diet is the common strategy to manage food intake of dysphagia patients. The most prevalent commercial thickeners available in the markets for medical management of such patients are starch-based thickeners such as modified corn starch (Cichero, 2013; Dewar & Joyce, 2006; Garcia *et al.,* 2008; Ilhamto, 2012). This might be as a result of its low cost, broad availability, and spreadability.

Several issues related to the utilization of this starch-based thickener have been reported. First, Lotong *et al*. (2003) reported that the starch-based thickeners imparted a starchy flavour and off-flavours, which can reduce the acceptability of thickened drinks and foods. This flavour can be a deterrent for individuals with dysphagia. Moreover, starch-based thickeners have been found to increase post-deglutition residue, which raises the risk of aspiration after swallowing in dysphagia patients (Rofes *et al.,* 2014). The presence of excess residue in the oral cavity and throat can lead to complications and compromise the safety of swallowing. Lastly, the action of salivary amylase on starch appears to decrease the viscosity of thickened foods and, therefore, is potentially considered an unsafe option (Martínez *et al.,* 2019; Vieira *et al.,* 2020). For these reasons, mixing of starch with non-starch hydrocolloid gels has gained considerable interest recently as edible thickeners because of their superior stability than modified starches.

Generally, microgels are composed of polymeric material, with a typical size of below 100 μm. Microgels which possess complex structures and functionalities are often used as thickening agents, emulsifiers, or steric stabilizers (Dickinson, 2015). These microgels find increasing use across industries, including food, where they serve as texture modifiers in liquid meals like milk and juices or incorporated as ingredients in finished goods (Norton *et al.*, 2006; Shewan & Stokes, 2013; Ellis & Jacquier, 2009). Various hydrocolloids, such as carrageenan, gelatin, and pectin, have been explored for microgel production (Ellis & Jacquier, 2009; Farrugia & Groves, 1999; Mironov *et al.*, 2013). Microgels exhibit viscoelasticity, crucial for rheological control in food systems, with parameters like yield stress and storage/loss moduli defining their behaviour (Lucey, 2002; Norton *et al.*, 2010). These microgels offer an alternative to achieve desired rheological properties without unwanted elastic characteristics, making them valuable in various food applications (Stokes, 2011). Their potential extends to pharmaceutical use, in which the microgel may facilitate safer drug administration for dysphagia patients (Mahdi *et al.*, 2014). Microgels also hold promise in revolutionizing dysphagia management and enhancing the sensory properties of dysphagia-oriented foods and medications with further research and development (Joye & McClements, 2014).

Sago, derived from the palm species *Metroxylon sagu*, is native to the Southeast Asia region, particularly Malaysia, Indonesia, Papua New Guinea, and the Philippines. In regard to sago production, currently Malaysia is the third largest sago producer in the world after Indonesia and Papua New Guinea which combined produce approximately 94.6 percent of the world production (Istalaksana *et al.*, 2005). In the Southeast Asia region, particularly in countries like Malaysia, Indonesia, Papua New Guinea, and the Philippines, sago starch is commonly used in food applications such as bread, crackers, and biscuits production (Karim *et al.*, 2008). On the other hand, in America and Europe, sago starch is often employed as a thickening agent in the production of soups (Cui & Oates, 1997) and puddings (White *et al.*, 2007). Its ability to enhance the viscosity and texture of these food products makes it a suitable ingredient for achieving the desired consistency and mouthfeel. Further, starch combination with carrageenan, restores the mechanical properties and creates alternative starch based thickening agents with a stable structure (Russ *et al.,* 2016).

Carrageenan, is a sulphated polysaccharide extracted from marine red algae. There are three main types of carrageenans which are kappa-, iota- and lambda-carrageenans. The differences in the textural properties of iota- and kappa- carrageenan gels reflect the differences in their structures: iota- carrageenan gels consist of double helices with little or no aggregation, which renders them flexible and soft. In contrast, kappa-carrageenan gels consist of aggregated helices, these molecules do not gel without any aggregation, the kappa gel being relatively brittle and hard (Stanley, 1990). Carrageenans are applied in food products as stabilizers, thickeners and gelling agents (Dickinson & Pawlowsky, 1997). Carrageenans have also been recently used in dysphagic foods (Tashiro *et al.,* 2010; Hayakawa *et al.,* 2014; Sharma *et al.,* 2019; Suebsaen *et al.,* 2019). According to a research study by Sharma *et al.* (2019), carrageenan may significantly contribute to the viscous and elastic components of pureed carrot formulations that are safe for swallowing. From the three main carrageenans, iota-carrageenan was selected due to the ability to improve the cohesiveness, adhesiveness and springiness properties to the formulation (Al-Baarri *et al.,* 2018).

The use of sago/iota-carrageenan microgels as a thickening agent in dysphagia diets presents a promising solution for addressing the issue of α-amylase resistance with starch-based thickener. Sago starch and iota-carrageenan are known for their high resistance to α-amylase (Pranoto *et al.,* 2013; McKim *et al.,* 2019). Due to their thickening properties, when sago and iota-carrageenan are added to a liquid, they form a gel-like matrix. This gel matrix acts as a physical barrier that surrounds and encapsulates the starch molecules present in the liquid. The sago and iota-carrageenan gel network traps the starch molecules within its structure. This resistance creates a stable network within the food matrix, thus, preserving the thickened consistency of the dysphagia diet even after prolonged oral exposure. Therefore, the risk of premature thinning or degradation of the food bolus can be eliminated (Norton *et al.,* 2006).

The limitations associated with traditional hydrocolloids in rheology control of liquid and pureed foods have led to the exploration of microgels as an alternative solution (Leon *et al.,* 2016). Microgels derived from food-based materials have shown promise in providing rheological control due to their inherent viscoelastic properties (Loewen *et al.,* 2007). Rheological measurements like storage modulus (G') and loss modulus (G"), which stand for the elastic and viscous contributions, respectively, are commonly used to describe the viscoelasticity of microgels. The yield stress (τ0), which establishes the capacity to tolerate deformation and flow resistance, is a further important parameter (Lucey, 2002; Norton *et al.,* 2010; Steffe, 1996; van Vliet, 2014). In industrial settings, it is imperative to effectively manipulate the rheological behaviour of microgel dispersions since the physical characteristics and visual appeal of these goods have a direct bearing on their use and acceptance by consumers (Fischer & Windhab, 2011). This is particularly relevant in the case of dispersed dairy microgels, where the desired texture and sensory properties play a vital role in consumer preference and overall product quality (Lucey, 2002). However, food applications and contributions of food-grade microgels to textural properties of dysphagia diet management are still limited.

People with dysphagia are typically prescribed pureed diets, a class of texture-modified foods (Keller *et al.,* 2012). Choking is a common occurrence in people with dysphagia; pureeing is meant to help with oral manipulation of food and contribute to a swallowable bolus in order to lessen the danger of choking. Foods puréed are semi-solid, velvety, and soft. They undergo mechanical modification, either with or without the inclusion of liquids such milk, juice, gravy, or water, as well as texturizing agents (Keller *et al.,* 2012). When hydrocolloids are introduced to pureed foods, it is possible to observe their behaviour through both sensory and instrumental means. Rheological measures have been used to examine several thickened pureed food matrices, including commercial pureed baby foods, pureed sweet potatoes, fresh/frozen pureed vegetables with cryoprotectants, and pureed and mashed potatoes with single/mixed hydrocolloids (Ahmed & Ramaswamy, 2007; Downey, 2002; Fernández *et al.,* 2008; Truong & Walter, 1994; Álvarez *et al.,* 2013; Álvarez *et al.,* 2012). While hydrocolloids are widely utilized in pureed foods, current understanding of how they affect the textural alterations of these foods is still developing (Ilhamto, 2012). The choice of thickener and suitable texture is crucial in the dysphagia diet since the risk of aspiration varies depending on the type utilized (Leonard *et al.*, 2014).

This research aimed to develop and characterize sago/iota-carrageenan microgels as thickeners and their impact on rheological and functional characteristics on the textural properties of a pureed food matrix. Differences in textures were measured using texture profile analysis (TPA) to get an insight into changes occurring in the samples. At present, viscosity is the parameter considered to be important in the design of dysphagia-oriented food. However, other rheological properties may differ when viscosity is held constant (National Dysphagia Diet Task Force, 2002; Zargaraan *et al.,* 2013). In this work, pureed carrots were prepared since carrot has multiple health benefits, including a good dietary fibre source (Silva Dias, 2014). Thus, adding carrots to their diet may alleviate constipation, which is the most common among those people with dysphagia. Next, pureed carrots were investigated further to see if matrices containing sago/iota-carrageenan microgels may influence sensory attributes that could be important for the product's suitability for dysphagia patients.

1.2 Objectives

1.2.1 General Objectives

To formulate and characterize sago/iota-carrageenan microgels as thickener for texture-modified food that is suitable for people with swallowing problems.

1.2.2 Specific Objectives

1. To evaluate the physicochemical, rheological, and textural properties of sago/iota-carrageenan microgels.
2. To determine the rheological, textural properties and the effect of salivary amylase on pureed carrot with addition of sago/iota-carrageenan microgels as thickener.
3. To determine the sensory acceptability of sago/iota-carrageenan pureed carrot among potential customers in Universiti Sains Malaysia (USM), Pulau Pinang.

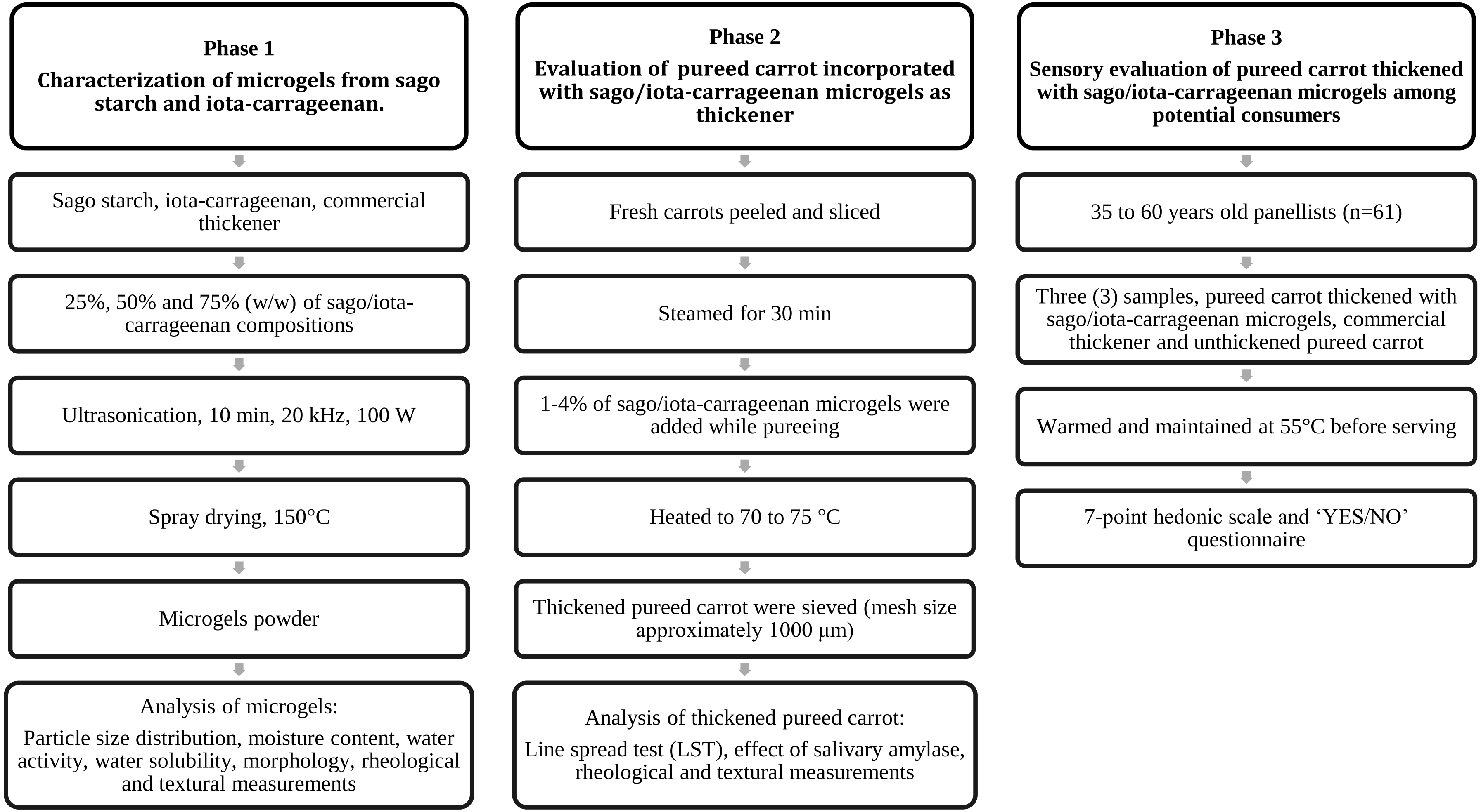

Figure 1.1 Overall experimental design

CHAPTER 2

LITERATURE REVIEW

2.1 Dysphagia

Oral, pharyngeal, and esophageal phases are all involved in normal swallowing (Kim & Han, 2005) (Figure 2.1). A bolus is created during the oral phase by combining food particles with saliva after they have been chewed into smaller pieces (Houjaij *et al.,* 2009). As seen in Figure 2.1(a), the pharyngeal phase involves moving the bolus from the mouth to the back of the throat. An involuntary swallowing response causes the bolus to pass via the pharynx, which is the canal that connects the mouth to the esophagus (Forster *et al.*, 2011). In order to close the nasopharynx and prevent nasal regurgitation, the soft palate lifts during this stage, as shown in Figure 2.1(b) (Germain *et al.,* 2006). When the epiglottis concurrently closes the larynx to prevent food from entering the airway, breathing pauses for a brief period (Figure 2.1(c)) (Bangyeekhan *et al.,* 2012). The bolus can pass into the esophagus when the upper esophageal sphincter opens. The pharyngeal structures relax as the bolus gets through the upper esophageal sphincter, allowing regular breathing to resume. In the esophageal phase (Figure 2.1(d)), the bolus is propelled down the esophagus through muscular contractions known as peristalsis. This propels the bolus towards the stomach, ensuring its efficient passage (Bangyeekhan *et al.*, 2010).

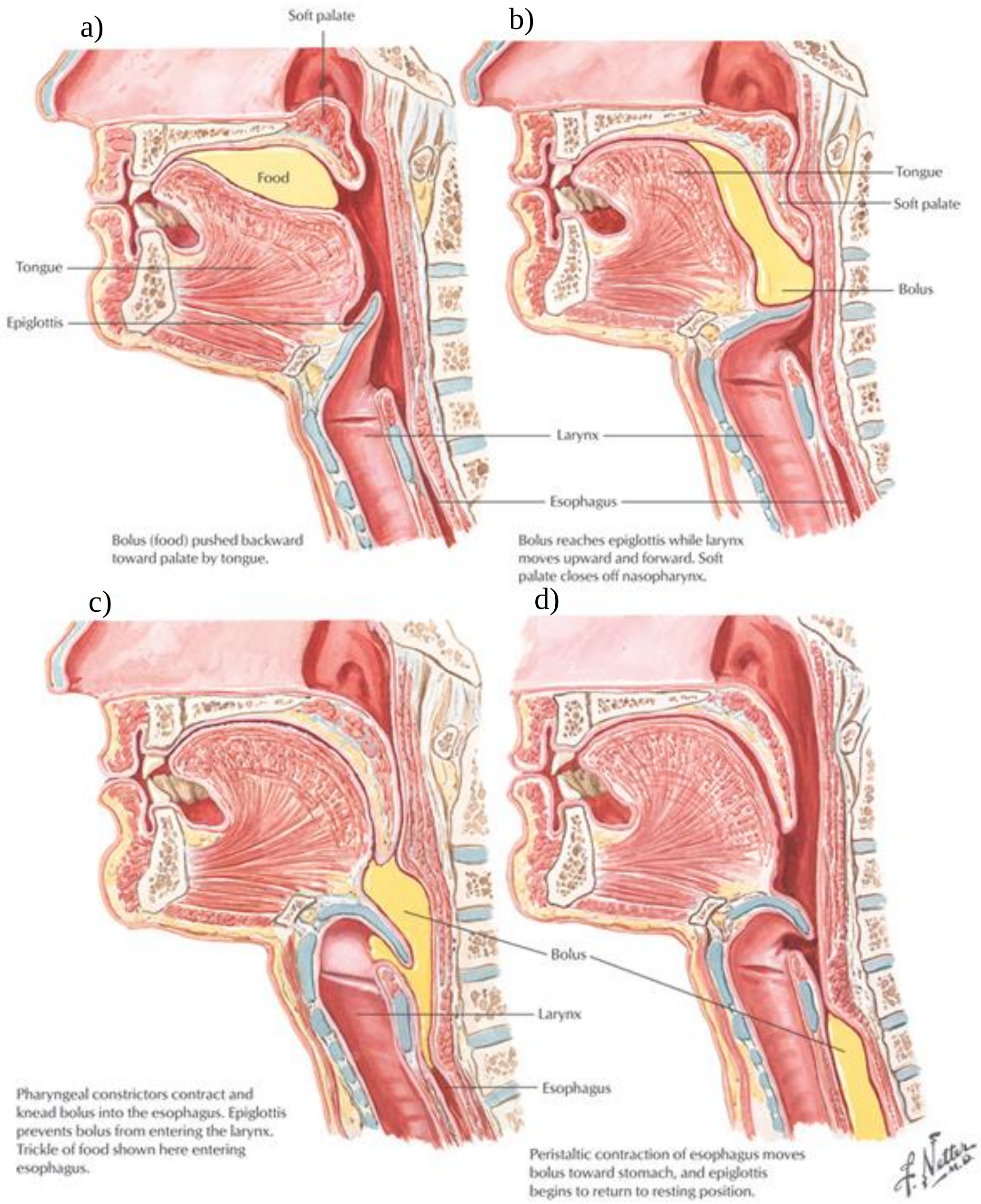

Figure 2.1 Normal swallowing mechanisms (Garcia & Chambers, 2010).

Normal swallowing occurs smoothly and effortlessly, without any significant symptoms or difficulties. In contrast, dysphagia refers to the difficulty or discomfort experienced during any phase of swallowing, including oral, pharyngeal, or esophageal stages. The effectiveness and safety of swallowing function are impacted by dysphagia (Forster *et al.,* 2011). Aspiration or the entrance of food or liquid into the airways is usually referred to as safety, whereas efficacy is concerned with the patient's effectiveness and speed when swallowing food and liquid (Andersen *et al.*, 2013).

According to O'Leary *et al.* (2010), aspiration is more likely in individuals with dysphagia when thin liquids reach the larynx rapidly before the epiglottis closes the airway's entrance. This can be observed in Figure 2.2(b). Dysphagia is usually classified according to the stage of swallowing at which the condition first appears. Oropharyngeal and esophageal dysphagia are the two major categories into which dysphagia can be classified (Kim & Kahrilas, 2019). The two are significantly different in that esophageal dysphagia is usually associated with esophageal disease, whereas oropharyngeal dysphagia is frequently one of several symptoms of neuromuscular conditions such as Parkinson's disease, multiple sclerosis, stroke, amyotrophic lateral sclerosis, or dementia (Kim & Kahrilas, 2019). Aslam & Vaezi (2013) state that oropharyngeal dysphagia is brought on by patients' inability to initiate a swallow, while esophageal dysphagia is caused by food sticking or feeling as though it is lodged in the chest (difficulty in transporting food bolus from mouth to pharynx toward the esophagus).

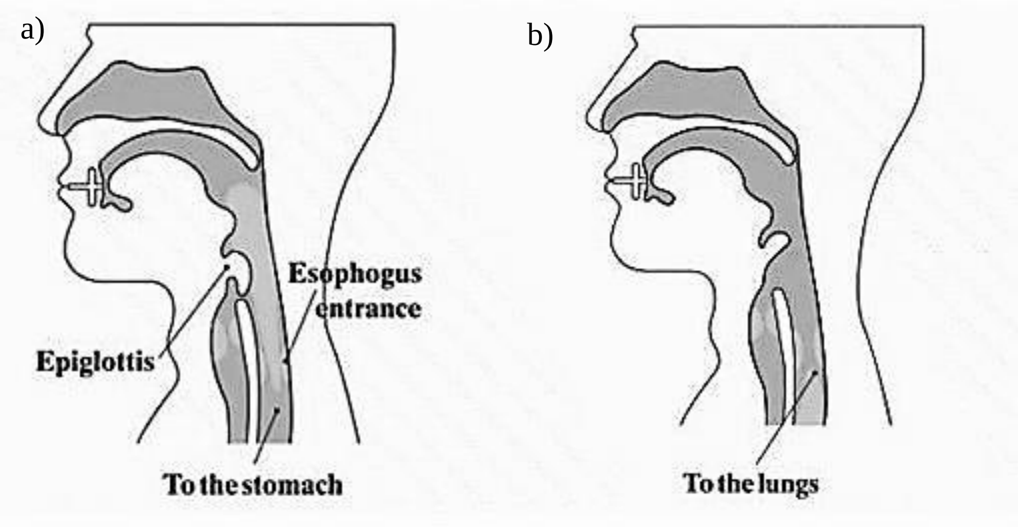

Figure 2.2 (a) Normal swallowing – the epiglottis closed to protect airways; (b) Dysphagia – epiglottis unable to protect airways (Spong, 2020).

2.1.1 Occurrence of Dysphagia

International data reported the prevalence of dysphagia in the general populations ranges between 2% and 20% (Adkins *et al.,* 2020). Dysphagia is a frequently observed complication among stroke patients, with prevalence rates ranging from 8.1% to 80%, as reported by Takizawa *et al*. (2016). A recent meta-analysis conducted by Hien *et al.* (2022) revealed that dysphagia progressed with time in 35% of Parkinson's disease patients. All age groups are impacted by this swallowing issue, however older individuals are more likely to suffer from it (Kertscher *et al.*, 2015). As far as the author is aware, not many studies have been released regarding the occurrence of dysphagia among Malaysian patients suffering from various illnesses. Husmeela *et al*. (2021) reported that 43.3% based on total 240 patients from Hospital Kuala Lumpur and the National Cancer Institute had dysphagia. On the other hand, among the 406 patients who attended the Speech Therapy clinic at Queen Elizabeth Hospital in Kota Kinabalu, Sabah, 139 patients (34.2%) were diagnosed with dysphagia (Muniandy *et al.,* 2021). Out of these 139 patients with dysphagia, the highest proportion falls within the age groups of 41 to 60 (43.2%) and above 60 (42.2%).

2.1.2 Signs and Symptoms of Dysphagia

Dysphagia can cause less serious conditions like difficulty controlling saliva, feeling like food is stuck in the throat, extra effort needed to chew or swallow, and gurgly voice quality during swallowing (Adeleye & Rachal, 2007; Kayser-Jones & Pengilly, 1999) to more serious conditions and illnesses. Shortly after eating, patients with dysphagia may also cough or choke (Aslam & Vaezi, 2013). Aspiration pneumonia, a lung infection caused by foreign objects getting into the airways such as food, liquid, saliva, or even stomach contents, can happen to some people if this issue is not treated (Kayser-Jones & Pengilly, 1999). Other than aspiration, the inability to swallow may be caused by certain dietary constraints (lower food and fluid consumption) or a loss of enjoyment in eating (Andersen *et al.*, 2013; Zargaraan *et al.*, 2013). These implications include malnutrition and dehydration. Other implications of dysphagia include a poor influence on social involvement and quality of life (Cichero *et al.*, 2013). Consequently, it is critical to understand the signs of dysphagia and to seek prompt medical attention if note any of these symptoms.

2.2 Management of Dysphagia

Numerous compensatory and rehabilitation strategies can be used to address dysphagia. As part of the rehabilitation process, there are several oral-motor exercises for the lips, tongue, and jaw that are designed to improve the efficiency of swallowing (Forster *et al.*, 2011). Furthermore, compensatory strategies focus on using techniques that allow individuals to keep swallowing safely and, consequently, to keep up their nutritional intake (Sura *et al.*, 2012). According to Aslam & Vaezi (2013), the three primary compensating strategies are dietary modifications, postural corrections, and swallowing motions.

One of the most well-known compensatory strategies for managing dysphagia is diet modifications (Anderson *et al.*, 2013). Diet modifications include things like thickened beverages and texture-modified food (Moret-Tatay *et al.*, 2015). Texture-modified foods aim to lower the danger of choking, while thickened drinks are claimed to lower the risk of aspiration, in order to ensure patient safety. Therefore, it is thought that the use of thickened liquids and texture-modified foods is a vital strategy for dysphagic people who want to ensure a safe oral intake of important nutrients (Atherton *et al.*, 2007).

2.2.1 Thickened liquids

Dysphagia increases the likelihood of consuming inadequate fluids intake. In the research by Streicher *et al.* (2018), 75% of individuals living in nursing homes had symptoms of dehydration. Thin fluid is known to increase the risk of choking in patients with dysphagia because it flows too quickly, leaving patients with insufficient time to prepare to engage airway closure before swallowing (Steele *et al.,* 2015). Controlling the viscosity of a thin liquid by adding thickener is one of the primary strategies to slow down the swallowing process (Cho *et al.,* 2012). Videofluoroscopy studies for pharyngeal transit time revealed that thicker liquids lengthen the swallowing duration (Goldfield *et al.,* 2013; Hanson, 2016; Bingjie *et al.,* 2010). Therefore, the consumption of thickened fluids is indicated to reduce the risk of aspiration, as the thickening promotes a longer duration of oral fluid conduction and allows more time for the closure of the upper airways to occur (Steele *et al.,* 2015).

Total swallowing time increases from liquids to thin pastes to thick pastes. Raut *et al.* (2001) therefore, warned that the ability to swallow thick and viscous substances may be much more hindered for "weak and feeble patients" or those with pharyngeal phase dysfunction because of difficulty generating the tongue and pharyngeal pressures required to move the bolus. Consequently, the use of thickened liquids can contribute to incomplete clearance from the pharynx and a higher risk of aspiration from post swallow residue. As a result, individuals who aspirate very thick liquids frequently experience worse health outcomes, including fatal ones (Logemann *et al.,* 2008).

2.2.2 Texture-modified food

One of the many effective interventions that may be used to help people with dysphagia maintain their nutritional intake is textured-modified (TM) food (Flynn *et al.,* 2018). The phrase "TM food" describes foods with soft textures that have been processed, chopped, pureed, liquidized, or have had their particle size decreased. It also includes thickened liquids (IDDSI, 2020). The sort of modification greatly depends on the cause and severity of the patient's swallowing problem (Cichero *et al.*, 2007). To make swallowing easier, it's critical to make sure that the meal textures are soft, moist, homogenous, non-stick, and free of fibrous structures that are difficult to break (Cichero, 2016). For instance, people with dysphagia find it difficult to tolerate solid foods with coarse surfaces, such as meat and rice, which need mastication and might cause disturbances when swallowing (Layne, 1990). The texture of solid food is frequently changed to minimize the risk of choking, with the ultimate goal of requiring little to no chewing (Cichero *et al.*, 2013). Speech therapists should advise each patient on the proper food texture based on their screening and clinical evaluations (Cichero *et al.*, 2007). Clinical history taking is typically the first step in the assessment process. Other non-instrumental measures include testing vocal and oral motor function and swallowing with various viscosities of water (Speyer, 2013). To gain a more comprehensive understanding of a patient's ability to swallow, additional instrumental measurements, such as the Videofluoroscopic Swallowing Study (VFSS) and Fiberoptic Evaluation of Swallowing (FEES), can be employed (Cichero *et al.*, 2007).

Pureed food, a class of TM food, which is mechanically altered to become soft, homogenous, moist and smooth in texture, is highly recommended to be used in dysphagia management (Cichero, 2016). The literature also states that purees should not "bleed" or leak liquid onto the plate when served; instead, they should be lump-free, smooth, and cohesive enough to maintain their shape on a spoon (Dietitians Association of Australia & Speech Pathology Association of Australia Limited, 2007). Usually, pureed food is made by blending and then filtering to get rid of lumps. This meal plan helps patients who have dysphagia since it requires less oral preparation and manipulation (Zargaraan *et al.,* 2013). A pureed diet does not include solid foods, finely mashed foods, fibrous particles, lumps, seeds, nuts, or textures that are hard, dry, or crumbly (Cichero, 2015). Textures that are sticky or adhesive, like peanut butter, are not included (Cichero, 2015). Furthermore, when puréeing food, thickener is often added to get the desired consistency. Foods with a higher viscosity can aid in prolonging the oral transit time, enabling people to better prepare food boluses before to swallowing and encouraging safer swallowing practices (Hanson *et al.,* 2012). To ensure patient safety and improved treatment outcomes, TM food must, like a medical prescription, comply to specific requirements and guarantee a safe texture throughout preparation (Steele *et al.,* 2015).

Considering the international movement of both patients and healthcare practitioners, the utilization of universally acknowledged terminology for food and beverages offers evident benefits in ensuring the safe and effective distribution of therapeutic products to individuals with swallowing difficulties. Further, it is crucial that the same words, definitions, and quantifiable characteristics are utilised in order for researchers to precisely identify which texture-modified foods or thickened fluids offer dysphagia patients the best therapeutic benefit. To enhance the quality of treatment and patient safety, standardised language and definitions will enable consistent communication across health professionals, care providers, researchers, and industry partners.

2.2.3 Existing Standards of Thickened Liquid and Texture-Modified Food

Presently, there is currently no standardized diet management protocol for patients with dysphagia in Malaysia. However, different nations have created their own classification systems for dysphagia diets, including the United States, the United Kingdom, Australia, Japan, and Ireland. There are national variations in these guidelines concerning terminology, labelling, and the quantity of modification levels that are employed. Significant differences were seen between 1981 and 1996 in the degree of modification and the application of several texture descriptors, according to a review by Penman & Thomson (1998). Cichero *et al.* (2007) discovered 40 distinct labels for texture-modified foods, based on information provided by an American task force. Different labels for texture-modified foods can cause confusion for researchers, healthcare providers, and caregivers. They can also have negative consequences for patients, including deadly consequences. For example, it has been reported that the provision of incorrect food textures resulted in the deaths of two dysphagia patients in England (Laura, 2018).

The classification of TM food from various global areas is shown in Table 2.1 (Cichero *et al.*, 2013). It is clear that, with the exception of conventional food (unmodified), TM foods are typically divided into three to five categories. Soft food, minced food, and pureed food are the most often used terminology. Unlike other nations, the UK distinguishes between two types of pureed food: Texture B, which is thin, and Texture C, which is thick. While naming various food textures, several nations also take particle size into account. In Australia, for instance, 1.5 cm is the acceptable particle size for soft food (Texture A) and 0.5 cm for minced or moist food (Texture B).

Table 2.1 Classification of texture-modified food from selected countries (Cichero *et al.*, 2013).

Country	**Terminology (least to most modified)**					
Australia	Regular	Texture A Soft (1.5 cm)	Texture B Minced and moist (0.5 cm)	Texture C Smooth pureed		
Ireland		Texture A Soft	Texture B Minced and moist	Texture C Smooth pureed	Texture D Liquidised	
United Kingdom		Texture E Fork mashable (1.5 cm)	Texture D Pre-mashed (0.2 cm)	Texture C Thick puree	Texture B Thin puree	
Japan	Level 5 Normal diet	Level 4 Soft food	Level 3 Paste type	Level 2 Jelly food with rough surface	Level 1 Smooth jelly food with protein, except fish and meat	Level 0 Smooth jelly food without protein
USA	Regular	Dysphagia advanced (< 2.5 cm)	Dysphagia mechanically altered (0.6 cm)	Dysphagia pureed		

The International Dysphagia Diet Standardization Initiative (IDDSI) was founded in 2012 in response to the lack of globally accepted terminology and descriptions for dysphagia diets (Steele *et al.*, 2015). Volunteers from a variety of fields, including as medicine, speech therapy, nursing, dietetics, and food technology, are brought together for this project. Improving patient safety and minimizing misunderstandings between suppliers, customers, and professionals are the goals of creating an international standardized terminology (Cichero *et al.*, 2017). With the introduction of the IDDSI framework, dysphagia diets were categorized into eight levels: Level 0 to 4 for liquids and Level 3 to 7 for foods (Figure 2.3). Food that has been pureed belongs to Level 4 of the IDDSI framework.

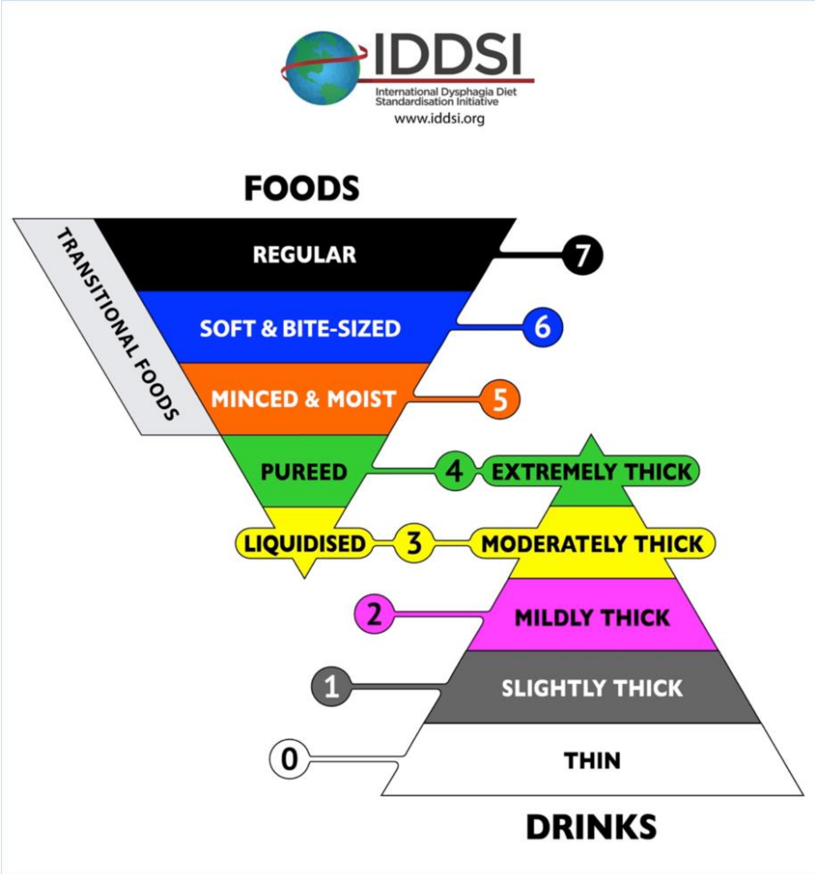

Figure 2.3 Classification of dysphagia diets into eight levels according to International Dysphagia Diet Standardisation Initiative (IDDSI) framework (IDDSI, 2020).

However, there are limitations of IDDSI framework. One of these limitations is the absence of objective measurements for TM food. Food attributes are based on descriptive criteria and are subjective at each level. Yet, the IDDSI framework has certain drawbacks. These requirements can include things like the need to chew, the capacity to form shapes, the existence of lumps, and the capability of using a spoon or fork to eat. The fork pressure test, which involves applying pressure to observe the food's behaviour, the fork drip test, which determines if the food passes through the fork prongs, and the spoon tilt test, which gauges the food's stickiness and cohesiveness, are among the subjective methods used for food testing in the framework. Because people apply different amounts of force, these subjective assessment methods may include basic variability (Cichero *et al.,* 2017). Consequently, visual evaluation, as opposed to instrumental measurements, plays a major role in the IDDSI framework's classification and descriptions of TM foods. For example, Table 2.2 lists the features and procedures for testing that are specified in the IDDSI framework for pureed food.

Table 2.2 Characteristics of pureed food (Level 4) according to IDDSI framework (IDDSI, 2020).

Type of food	Characteristics/ Descriptions
Pureed food	• Usually eaten with a spoon or food • Cannot be drunk from a cup • Cannot be sucked through a straw • Does not require chewing • Can be piped, layered, or moulded • No lumps • Not sticky • Liquid must not separate from solid • Falls off the spoon in a single spoonful when tilted and continues to hold shape on a plate

2.2.4 Line spread test

The IDDSI board has advised employing a syringe flow test as a useful tool for measuring flow when classifying thicker fluids according to levels. However, in recent times, some researchers have looked into how to use the line spread test (LST) to estimate the viscosity of thickened fluids (Mann & Wong, 1996; Adeleye & Rachal, 2007; Nicosia & Robbins, 2007; Budke *et al.*, 2008; Kim *et al.*, 2014). This is because the LST is widely available in healthcare facilities and is a simple, inexpensive method (Mann & Wong, 1996; Kim *et al.*, 2014). For these reasons, the LST approach is frequently applied when determining the viscosity or thickness levels of thickened fluids used to treat dysphagic patients (Kim *et al.*, 2018).

LST was developed to quantify the consistency of fluid like foods (Niscosia & Robbins, 2007). The LST test is an empirical rheology procedure that evaluates the consistency of a standard proportion of thickened product by measuring the sample's travel distance on a level surface following its release from a restricted chamber (Mann & Wong, 1996). It only needs a hollow cylinder, a piece of paper layered and divided into concentric circles, and a flat surface (Figure 2.4). The test sample is placed into the hollow cylinder first, and then the cylinder is raised to allow the sample to spread for a given amount of time (Dahl, 2015). Compared to using a viscometer, this test is easier to use, quicker, and less expensive (Ettinger *et al*. 2014).

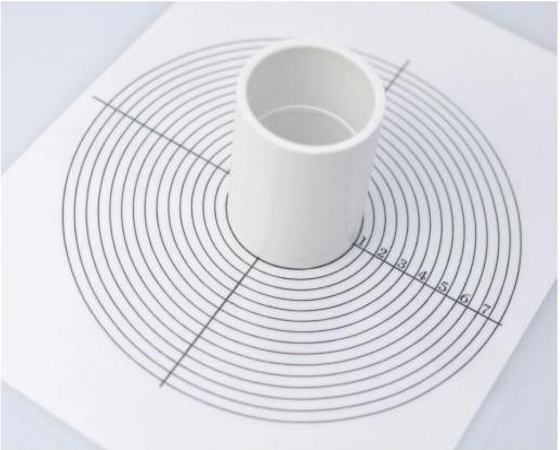

Figure 2.4 Line Spread Test set up

Budke *et al*. (2008) and Paik *et al*. (2004) found strong correlations between line spread measurements and viscosity measurements obtained through viscometers. Nicosia & Robbins (2007) also noted that LST effectively differentiated liquids with distinct consistencies. However, the use of LST in evaluating TM food for individuals with dysphagia has received relatively less attention, and no standardized approach has been established thus far. Paik *et al*. (2004) categorized dysphagia-oriented foods into three levels based on LST and viscosity measurements (using a viscometer), as presented in Table 2.3. Furthermore, Dahl (2015) assessed LST measurements of pureed food alongside visual inspection, considering factors such as thickness and absence of water separation.

Table 2.3 Categorization of dysphagia-oriented foods by LST and viscosity measurements (Paik *et al.*, 2004).

LST (cm)	**Dysphagia-oriented foods**	**Viscosity (Pa·s)**
0 – 1.0	• Thick rice gruel • Crushed potato • Cooked ground vegetable (mixed with 4.5% of thickener) • Cooked ground meat, cooked ground meat (mixed with 4.5% of thickener)	>10
1.1 – 2.9	• Cooked ground vegetable • Thin soup with starch • Cream soup • Thin rice gruel	0.1 – 9.9
3.0 – 3.9	• Thick, fluid type rice	0.01 – 0.09

LST has a couple of limitations that need to be considered. Firstly, the measurement of LST can only be performed at a specific temperature and holding time, as Budke et al. (2008) highlighted. Controlling these critical factors, such as temperature fluctuations and holding time, can be challenging. Secondly, the effectiveness of LST in measuring the distance of spread may be hindered by the increased viscosity of the thickened product. This observation is supported by a study conducted by Ettinger *et al*. (2014) on pureed food, where thick pureed products resulted in indistinguishable readings (0 cm) using LST. This finding aligns with the study by Park *et al*. (2014), who reported similar LST results for thickened products despite variations in their viscosities at higher concentrations.

According to Nicosia & Robbins (2007), using LST can be sufficient as a screening test to distinguish among various thickened products. However, it is not suitable for accurately measuring viscosity. Therefore, additional instrumental analyses are necessary to provide comprehensive information on the rheological and textural characteristics of the thickened product.

2.3 Thickening Agents

During oral manipulation and swallowing, liquid flow is turbulent, forming eddies and vortices (Parkinson & Sherman, 1971). Individuals without swallowing difficulties can effectively manage these factors, guiding the liquids past the airway and into the oesophagus without any issues. However, individuals with dysphagia struggle to control the turbulent and rapid flow of liquids as they pass through the pharynx, resulting in compromised airway protection (Cichero, 2013). A similar situation arises with texture-modified foods. Additional fluids are often incorporated to ensure moisture in texture-modified foods (Cichero, 2015).

Hence, diet modification such as increase in bolus viscosity using thickeners is a compensatory therapeutic strategy against aspirations in dysphagia management. Increased bolus viscosity is linked to decreased mid-term pneumonia episodes (Groher, 1987) and enhanced swallowing safety in dysphagia patients with neurological disorders or ageing by slowing down their flow and providing the individual with enough time to coordinate a safe swallowing action (Clavé *et al.*, 2006; Kuhlemeier *et al.,* 2001; Rofes *et al.,* 2014; Dantas *et al.,* 1990). On the other hand, thickeners' effects on the physiology of the swallow response are not thoroughly known (Clavé *et al.*, 2006; Bhattacharyya *et al.,* 2003), and increasing viscosity may reduce the effectiveness of swallowing by increasing the prevalence of oropharyngeal residue (Clavé *et al.*, 2006). These two important impacts on swallowing and thickened drinks were also noted in a review (Steele *et al.,* 2015). Water-based gelling and thickening agents come in various forms, but the most popular ones are xanthan gum, modified starch, and their mixtures. Additional ingredients include gelatin, locust bean gum, carrageenan, and guar gum (Sopade *et al.,* 2007; Patel *et al.,* 2020).

2.3.1 Starch

Starch is one of the main polysaccharides that can be found in nature besides cellulose and chitin. Starch is a semi-crystalline polysaccharide appearing in nature in the form of granules ranging in size from 1 to 100 μm with polygonal, lenticular or spherical shape. Starch comprises of two major components: amylose and amylopectin (Mbougueng *et al.,* 2012) (Figure 2.5). About 15–30% of starch is composed of amylose, a linear chain of glucose units joined by α-1,4 glycosidic linkages (Srichuwong *et al.,* 2005). The predominant component, amylopectin (70–85%), is bigger and more branched with α-1,6 glycosidic linkages than amylose, but it shares the same basic structure (Jobling, 2004). Cereal (maize, rice, and wheat), tuber (potato), root (cassava), legume (mung bean and green pea), and stem of palm (sago) are the botanical sources of starches (Karim *et al.,* 2008).

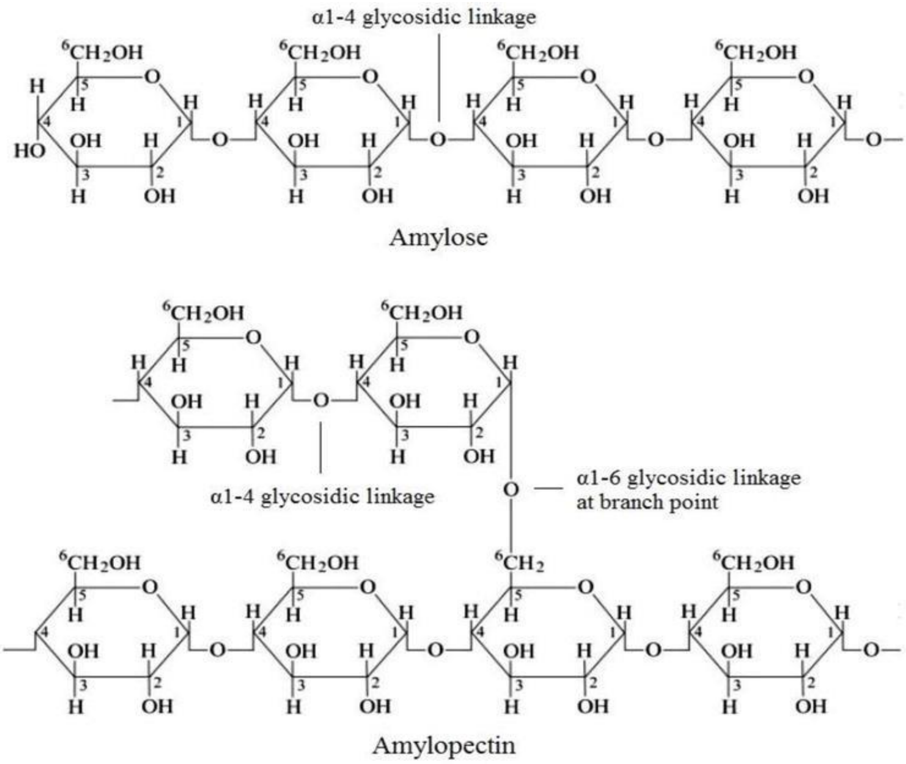

Figure 2.5 Primary structures of amylose and amylopectin in starch (Nawaz *et al.,* 2020).