DEVELOPMENT OF TEXTURE MODIFIED PUMPKIN PORRIDGE FOR DYSPHAGIA DIET: THE EFFECTS OF FISH GELATIN-MICROBIAL TRANSGLUTAMINASE GEL MICROPARTICLES ON THE RHEOLOGICAL AND SENSORY CHARACTERISTICS

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by

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
CT	Commercial thickener
CuFS	Cued facial scale
DLS	Dynamic light scattering
FGMT	Fish gelatin-microbial transglutaminase
GERD	Gastro-oesophageal reflux disease
HPP	High pressure processing
IDDSI	International Dysphagia Diet Standardization Initiatives
LST	Line spread test
LVR	Linear viscoelastic region
mTGA	Microbial transglutaminase enzymes
PPIc	Pea protein isolates
rpm	Revolutions per minutes
SD	Standard deviation
SLP	Speech language pathologist
SPSS	Statistical Package for the Social Sciences
TMF	Texture modified food
TPA	Texture Profile Analysis
UES	Upper oesophageal sphincter

LIST OF SYMBOLS

%	Percentage
°C	Degree celcius
w/w	Weight per weight
w/v	Weight per volume
n	Number of samples
mm/s @ mms^{-1}	Millimeter per second
mm	Millimeter
µm	Micrometer
cm	Centimetre
G’	Elastic modulus
G”	Viscous modulus
tan δ	Loss tangent
p	Probability level
g	Gram
n	Flow behaviour index
K	Consistency index
R^2	The square of correlation
r	Correlation coefficient
σ_{oc}	Casson yield stress
Pa	Pascal
Pa.s	Pascal second

LIST OF APPENDICES

PEMBANGUNAN BUBUR LABU YANG DIUBAHSUAI TEKSTUR UNTUK DIET DISPHAGIA: KESAN GEL MIKROPARTIKEL DARIPADA GELATIN IKAN-MIKROB TRANSGLUTAMINASE TERHADAP CIRI REOLOGI DAN DERIA

ABSTRAK

Disfagia adalah keadaan yang memberi kesan kepada semua peringkat umur, terutamanya orang tua dan mereka yang mempunyai penyakit seperti kanser, strok, dan demensia. Ia boleh mengurangkan pengambilan makanan dan membawa kepada kekurangan nutrisi. Untuk menguruskan disfagia, makanan yang diubahsuai tekstur disediakan menggunakan pemekat seperti kanji dan gam, tetapi ini boleh meninggalkan rasa kesan yang kuat atau menyebabkan ketidakselesaan perut. Oleh itu, dalam Fasa 1 kajian ini, gel mikrozarah telah dibangunkan daripada gelatin ikan dan enzim transglutaminase mikrob (mTGA) sebagai pemekat yang berpotensi untuk makanan yang diubahsuai tekstur. Gel mikrozarah, antara 18μm hingga 1445μm, menunjukkan ciri-ciri bolus yang selamat untuk ditelan dengan kelekatan rendah dan kepaduan tinggi, menunjukkan potensi gel mikrozarah dengan 0.7% mTGA sebagai pemekat yang sesuai untuk pengubahsuaian tekstur. Analisis reologi menunjukkan bahawa sampel dengan 0.7% mTGA mempunyai sifat gel yang lemah dengan kelakuan lebih kenyal berbanding kelakuan likat. Di samping itu, kepekatan gula meningkatkan kekerasan dan kepaduan sambil mengurangkan kelekatan, menjadikannya sebagai makanan yang mudah ditelan. Dalam Fasa 2, kesan gel mikrozarah pada tekstur bubur labu, sifat reologi, dan tindak balas enzim amilase telah dianalisis. Penggunaan 2% gel mikrozarah gelatin ikan-mikrobial transglutaminase (FGMT) ikan menunjukkan tekstur, kelikatan, dan kelakuan aliran yang sama kepada

sampel yang ditambah dengan pemekat komersial. Keanjalan bubur adalah dominan, dengan rintangan yang lebih tinggi terhadap tindak balas amilase, menunjukkan sifat menelan selamat. Sampel terbaik dengan gel mikrozarah FGMT 2% telah diteruskan dengan ujian penilaian deria dalam Fasa 3, bersama-sama dengan sampel kawalan (tanpa pemekat) dan sampel ditambah dengan pemekat komersial. Bubur diubah suai tekstur dengan gel mikrozarah FGMT 2% mendapat markah tertinggi dalam rupa, penerimaan keseluruhan, kemudahan menelan, rasa dan niat membeli, sambil mempunyai sisa dan rasa kesan yang paling rendah. Secara keseluruhannya, gel mikrozarah yang dibangunkan telah berjaya dimasukkan ke dalam bubur labu dan mempamerkan sifat mudah ditelan dan menunjukkan ciri yang serupa dengan sampel yang disediakan dengan pemekat komersial. Keputusan menunjukkan potensi besar gel mikrozarah daripada gelatin ikan dan mTGA untuk digunakan sebagai pemekat alternatif untuk makanan yang diubahsuai tekstur.

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ABSTRACT

Dysphagia is a condition affecting people of all ages, particularly the elderly and those with diseases like cancer, stroke, and dementia. It can reduce food intake and lead to nutritional deficiencies. To manage dysphagia, texture-modified food is prepared using thickeners like starch and gum, but these can leave a strong aftertaste or cause stomach discomfort. Therefore, in Phase 1 of this study, gel microparticles were developed from fish gelatin and microbial transglutaminase enzyme (TGA) as a potential thickener for texture-modified foods. The gel microparticles, ranging from 18µm to 1445µm, showed safe swallowing bolus properties with low adhesiveness and high cohesiveness, demonstrating the potential of gel microparticles with 0.7% mTGA as a suitable thickener for texture modification. The rheological analysis showed that the sample with 0.7% mTGA has weak gel properties with more elastic behaviour than viscous behaviour. In addition, sugar concentration increases hardness and cohesiveness while decreasing adhesiveness, making it as easy-to-swallow foods. In Phase 2, the effects of gel microparticles on pumpkin porridge's texture, rheological properties, and amylase enzyme response were analysed. The use of 2% fish gelatin-microbial transglutaminase (FGMT) gel microparticles showed similar texture, viscosity, and flow behaviour to the samples added with commercial thickeners. The elasticity of the porridge was dominant, with a higher resistance to the amylase reaction, indicating safe swallowing properties. The best samples with 2% FGMT gel

microparticles was proceeded with sensory evaluation test in Phase 3, together with . control sample (without thickener) and sample added with commercial thickener. Texture modified porridge with 2% FGMT gel microparticles scored highest in appearance, overall acceptability, ease of swallowing, taste, and buying intention, while having the lowest residual and aftertaste. Overall, the developed gel microparticles were successfully incorporated into the pumpkin porridge and exhibit easy swallowing properties and showed similar characteristics to the samples prepared with commercial thickeners. The results indicate the huge potential of gel microparticles from fish gelatin and mTGA to be used as alternative thickener for texture modified foods.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Dysphagia is a swallowing disorder which affects the transfer of solid or liquid food, often occurring from the oral cavity downwards (Cartagena *et al*., 2024). Dysphagia caused complications during the bolus transition, particularly in the upper digestive tract (Sukkar *et al*., 2018). Dysphagia can lead to choking, blocking airways, and lung infections. Dysphagia can affect all age groups, however it is more common among the elderly, as they are already using their swallowing function to the maximum capacity, leading to loss of mastication muscle strength and loss of muscle strength in the neck area (Rothenberg and Wendin, 2015). From literature, 5% to 10% of elderly in Malaysia has been reported to be affected by dysphagia (Md Mizan Asrori and Yi Ying, 2022).

Dysphagia, particularly among the elderly, is closely linked to choking death as individuals in this category are exposed to a high risk of choking on their food during consumption (Feola *et al*., 2023; Kramarow *et al*., 2014). Choking death is defined as death caused by suffocation or insufficient oxygen due to choking by food (Kramarow *et al*., 2014). Food with sticky and adhesive textures should be avoided as these textures could leave residues in the oropharynx that could be aspirated after swallowing and contribute to choking death (Cartagena *et al*., 2024). This texture can be found in some traditional foods like mochi or 'dodol'.

Dysphagia often results in malnutrition due to lower food intake and choking or aspiration due to the unsuitable food texture. Hence, diet modifications are suggested to manage dysphagia diets (Gallego *et al*., 2022; Abu Zarim *et al*., 2018).

Foods with a soft texture, smaller particles, and thickened liquids, known as texture modified food (TMF), are often prepared for those with dysphagia (Aguilera and Park, 2016). There are various ways to prepare TMF, such as conventional processes (softening of traditional foods), the addition of commercial thickeners, and the use of biopolymer particles and gel microparticles (Aguilera and Park, 2016).

Various standards for TMF are used in different countries such as Japan, Australia, the United Kingdom, and the United States (Cichero *et al.*, 2013). In order to standardise terminology and definitions for TMF and thickened liquids that are applicable to all age groups, care settings, and cultures, a community of researchers from around the world launched an initiative known as International Dysphagia Diet Standardization Initiatives (IDDSI) (Cichero *et al.*, 2017). Under IDDSI, foods and drinks are categorised by precise definitions and methods to measure and specify each level. However, the IDDSI standard is still lacking in terms of the quantitative measurements on the TMF properties.

The use of thickening agents such as starches and gums are often associated with issues, such as thickening over time, giving a starchy aftertaste, giving a laxative effect, and flavour suppression (Cichero, 2015). All these disadvantages might lower meal and nutrient intake. To overcome these issues, an alternative thickener using gel microparticles is proposed in this study. Gel microparticles are defined as soft, stable, and small particles produced from biopolymers such as hydrocolloids and protein, and the structure can be turned within a wide range of sizes, shapes, and textural properties (Aguilera and Park, 2016; Leon *et al.*, 2016). Its fragile structure may give strong flavour intensities released during the breakdown in the mouth and deliver nutrients and bioactive compounds during digestion (Leon *et al.*, 2018). The soft texture of the gel microparticles can provide food with a soft texture (Aguilera and Park, 2016). Gel microparticles can also swell in the solvent, increasing viscosity or gel-like consistency in food (Stokes, 2012).

The vast literature on gel microparticles that has recently emerged largely supports their use as encapsulating agents and delivery systems (Aguilera and Park, 2016). Besides, gel microparticles are also being used as rheology control agent in the personal care products and cosmetics. However, its usage in the food industry is yet to be fully realised and studied (Kaneda, 2021; Shewan and Stokes, 2013). Thus, the potential of using gel microparticles as the food thickener in TMF is worth to explore.

In this study, gel microparticles were prepared from fish gelatin cross-linked with microbial transglutaminase (mTGA) enzymes, through chemical gelation and homogenization technique. The developed gel microparticles, labelled as fish gelatin-microbial transglutaminase (FGMT) gel microparticles, were incorporated into the chosen food model, specifically pumpkin porridge and were characterized using rheological test, textural analysis and amylase enzyme reaction. Texture modified pumpkin porridge with the addition of gel microparticles were then tested for sensory analysis, to evaluate its acceptability among potential consumers. The study is divided into three phases and shown in Figure 1.1.

1.2 Problem Statement and Rationale of the Study

Commercial thickeners are often used during the preparation of texture modified food, to control the viscosity of the end products, before being served to those suffering dysphagia. However, commercial thickeners may have certain drawbacks and disadvantages. Starch-based thickeners may thicken over time and give a starchy flavour or aftertaste to food making it less favourable to consumers (Cichero, 2013).

Meanwhile, gums-based thickeners may cause laxatives, resulting in abdominal discomfort (Cichero, 2013). In addition, certain thickeners such as alginate and agar, will produce products with syneresis problems, in which the liquid will pose as choking hazards to people with dysphagia (Wangtueai *et al*., 2010). Besides, flavour suppression associated with some thickeners may provide little to no motivation for individuals with swallowing difficulties to drink and eat (Cichero, 2013).

Previous studies have shown that gel microparticles have the potential to be used as a thickener in texture modified foods, due to its unique characteristics that maintain the food structure and ability to improve the swallowing process (Leon *et al*., 2016, 2018, 2019). However, to date, no effort on developing gel microparticles from fish gelatin was carried out. Furthermore, it is crucial to study the interaction between the developed gel microparticles and food system. Knowing the effect of gel microparticles in food system would ensure the safety of consumers, particularly those people with swallowing difficulties (Xu *et al*., 2023).

In addition, mostly dysphagia-oriented foods are evaluated through qualitative measurements such as description-based method (naked eyes observation) and utensil test methods (spoon tilt test and fork drip test) (www.iddsi.org, IDDSI Framework Testing Methods). Therefore, the use of rheological and textural analysis could fill the gap by providing the insight on the development of quantitative measurements in developing the texture modified food for dysphagia (Yong *et al*., 2023).

1.3 Research Objectives

The general objective this research was to develop gel microparticles using fish gelatin and mTGA enzyme as a thickener for texture-modified food.

The specific objectives were as follows:

i. To characterise the textural and rheological properties of fish gelatin and mTGA (FGMT) gel microparticles.

ii. To evaluate the rheological properties, textural characteristics, and the effects of amylase enzyme on the texture modified pumpkin porridge with incorporation of FGMT gel microparticles.

iii. To evaluate the sensory acceptability of the texture modified pumpkin porridge with incorporation of FGMT gel microparticles among potential consumers.

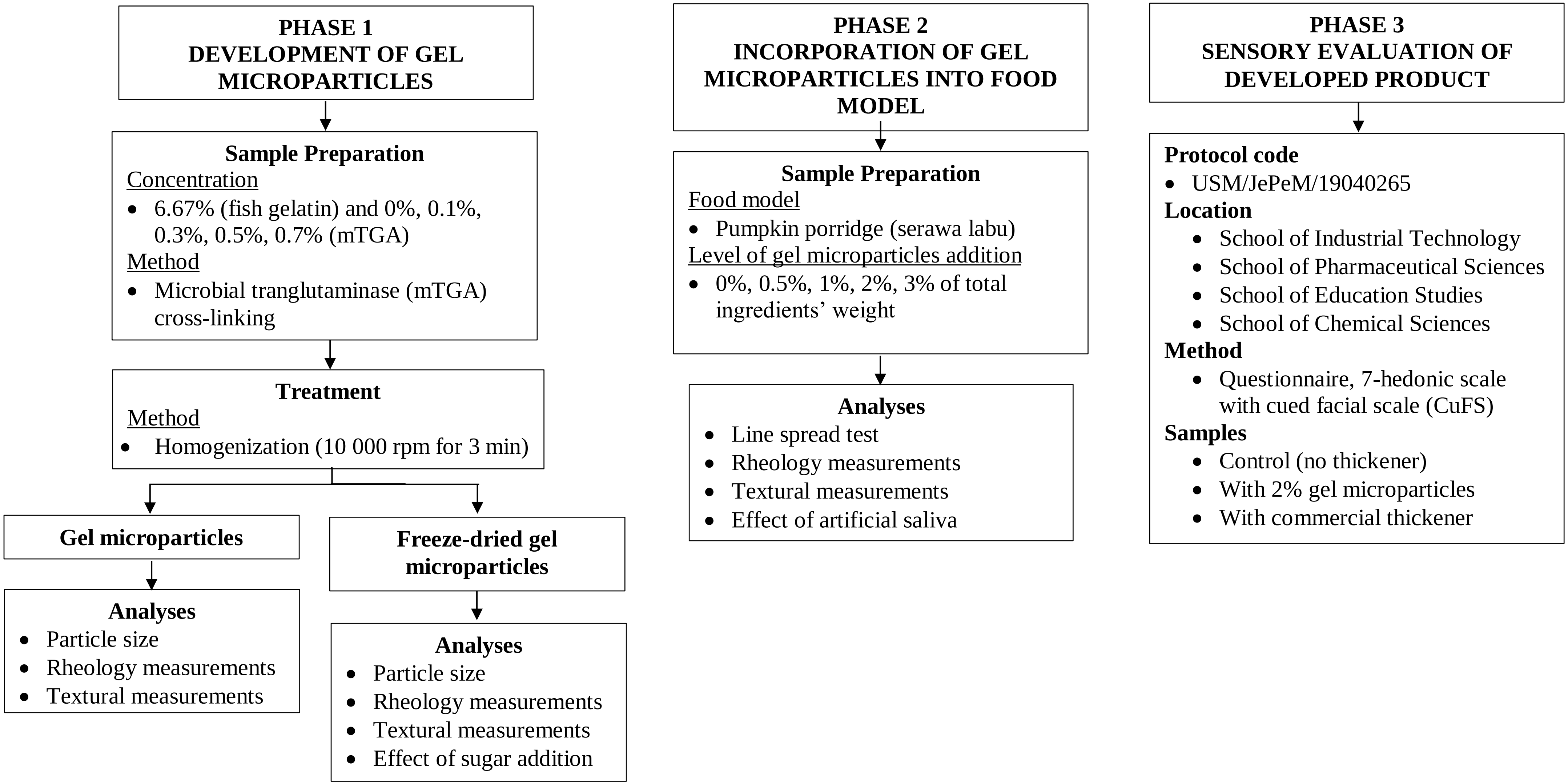

Figure 1.1 Overall experimental work

CHAPTER 2

LITERATURE REVIEW

2.1 Process of swallowing

The swallowing process is divided into three main phases: (1) the oral phase (oral preparatory, A, and oral transit phases, B); (2) the pharyngeal phase, C; and (3) the oesophageal phase, D. Figure 2.1 shows the illustrated normal swallowing process for each stage involved (McKean *et al*., 2017). The first phase, the oral phase, is further divided into the preparatory and transport phases (Khan *et al*., 2014).

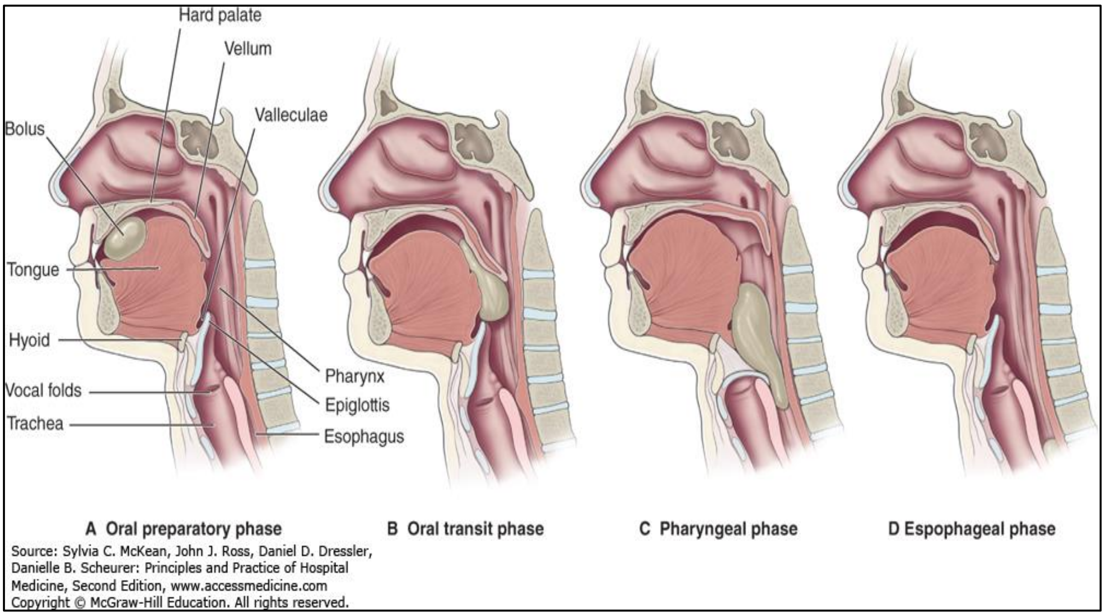

Figure 2.1 Illustration of normal swallowing process (McKean *et al*., 2017)

The first phase is to prepare food components before they are transferred into the pharynx (Aslam and Vaezi, 2013). The oral preparatory phase occurs when food is introduced into the mouth, chewed, and mixed with saliva. At this point, a food bolus is formed. Liquids are sipped or sucked into the mouth during this phase. The oral transit phase happens when the food bolus is sealed between the roof of the mouth and the tongue (Sasegbon and Hamdy, 2017). The tongue moves the bolus in a wave motion into the back of the throat (Furness, 2012).

The pharyngeal phase initiates when the soft palate elevates and the tongue moves back to contact the pharyngeal wall (Panara *et al*., 2020). The epiglottis tilts down and back to guide the food bolus past the airway (Khan *et al*., 2014). Vocal folds come together to protect the airway as the muscles of the pharynx contract. Lastly, the upper oesophageal sphincter relaxes and opens, and the bolus moves into the oesophagus (Aslam and Vaezi, 2013). This phase approximately occurs in less than 1.0 to 1.5 seconds, depending on the bolus viscosity, as higher viscosity might increase the duration (Aslam and Vaezi, 2013).

Lastly, the oesophagal phase starts when a wave contraction moves the bolus through the oesophagus (Panara *et al*., 2020). The lower oesophagus sphincter then relaxes to open so the bolus can move into the stomach (Khan *et al*., 2014). In addition, the bolus commonly takes approximately 8 to 10 seconds to pass through the oesophagus into the stomach (Furness, 2012).

2.2 Dysphagia

Dysphagia is a swallowing difficulty caused by or influenced by certain conditions or diseases. It mainly affects swallowing and transferring saliva, solid, or liquid food from the oral area into the downward area or the stomach (Cartagena *et al*., 2024). Dysphagia can be classified into three groups which are oral, oesophageal, and oropharyngeal (Munialo *et al*., 2020). Oral dysphagia occurs in the mouth where trouble chewing or difficulties moving food across the mouth are present, while oesophageal dysphagia develops in the oesophagus when food stops (Munialo *et al*., 2020). Meanwhile, oropharyngeal dysphagia is associated with difficulty transferring food to the back of the mouth and beginning the swallowing process (Munialo *et al*., 2020).

Figure 2.2 generally explains dysphagia, where the food bolus enters the airways instead of the oesophagus, which leads to the stomach. This will then cause aspiration or blockage of the airways. This happens when the epiglottis has an abnormality and cannot close properly by the time the food bolus arrives (Sasegbon and Hamdy, 2017).

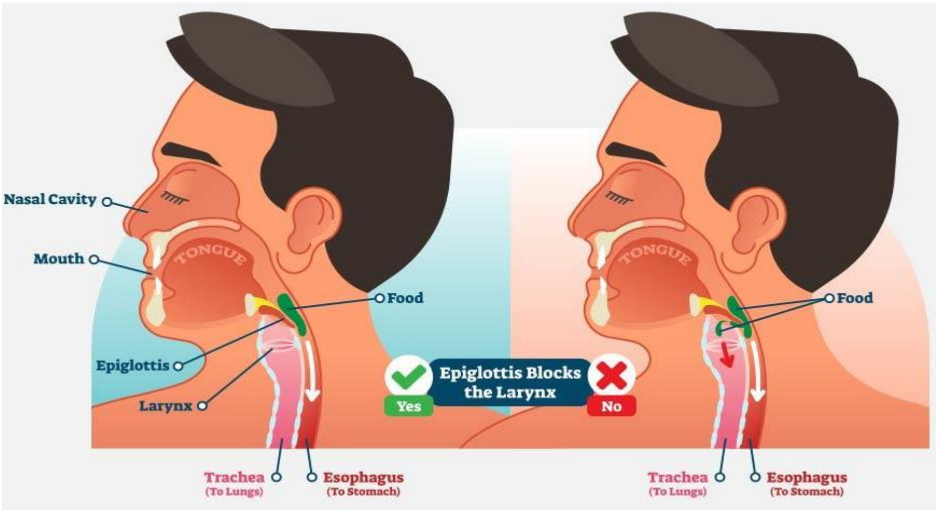

Figure 2.2 Normal swallowing and dysphagia (Munialo *et al*., 2020)

The symptoms of dysphagia may vary, including pain during swallowing, choking, drooling, or parched mouth or throat clearing during or after meals (Khan *et al*., 2014). In most cases, dysphagia will lead to more serious consequences, such as choking, followed by aspiration or the bolus entering and blocking the airways to the lungs (Cichero, 2015). This will then cause pneumonia or a lung infection, which may worsen the health of people with dysphagia (Wang *et al*., 2023). Food intake and nutritional absorption may be limited by dysphagia, which is seen as a swallowing condition in which food does not flow easily down the oesophagus from the oral cavity to the stomach. (Sukkar *et al*., 2018; Wang *et al*., 2023).

2.2.1 Prevalence of dysphagia

To date, most dysphagia cases are often reported together with diseases. Most patients diagnosed with Parkinson's disease and multiple sclerosis showed dysphagia symptoms (Kalf *et al*., 2012). Apart from that, the prevalence of this symptom has been associated with neurological diseases such as dementia, stroke, traumatic brain injury (TBI), degenerative disorders (Parkinson's, Alzheimer's and Motor neuron diseases), cancer (head and neck cancer, and brain tumours), and other health conditions such as chronic obstructive pulmonary disease, burns, and infectious diseases (Cichero, 2015; Rothenberg and Wendin, 2015). According to Rothenberg and Wendin (2015), approximately 50% of acute stroke patients had dysphagia symptoms or swallowing difficulties at the onset of the illness. According to previous studies, dysphagia was common among head and neck cancer patients, with rates ranging from 40% to 60%(Hussain *et al*., 2021). Ko *et al.* (2015) found that 7.3% of gastro-oesophageal reflux disease (GERD) patients at the University Hospital of Kuala Lumpur (UHKL) and 41% of patients who had acute ischemic strokes at the Hospital Universiti Kebangsaan Malaysia (HUKM) experienced dysphagia.

Dysphagia has also been reported in infants and elderly groups. Infants with weak muscles and strength related to swallowing food are more likely to develop dysphagia (Raheem *et al*., 2021). Elderly individuals are at risk for dysphagia due to excessive swallowing function, muscle weakness, and connective tissue elasticity (Khan *et al*., 2014; Rothenberg and Wendin, 2015; Sura *et al*., 2012). This leads to longer food preparation times and slower material transit. Additionally, changes in salivary production and increased tongue connective tissue also contribute to swallowing difficulties (Khan *et al*., 2014). According to Khan *et al*. (2014), approximately 50% of all residents in nursing homes experience swallowing difficulties. Cichero (2015) reported that the incidence of this symptom is approximately 0.35% to 6.7% in acute care hospitals. In the literature, it is reported that 5% to 10% of the elderly population is affected by dysphagia (Md Mizan Asrori and Yi Ying, 2022).

2.2.2 Dysphagia management

Dysphagia management in hospitals and skilled nursing facilities requires a multidisciplinary team approach, including doctors, physiotherapists, nurses, and dietitians (Yong Xinyi *et al*., 2018). In general, there are three types of dysphagia treatment strategies: behavioural, medical, and surgical, with behavioural treatment being the easiest treatment (Zargaraan *et al*., 2013).

Treatment for oropharyngeal dysphagia typically starts with behavioural intervention, which may involve postural adjustments to affect bolus flow, dietary modification by increasing sensory input to speed up and improve the safety of the swallowing, using swallow manoeuvres to change airway closure voluntarily, opening the upper oesophageal sphincter, and applying pressure while swallowing (Aslam and Vaezi, 2013; Sura *et al*., 2012; Zargaraan *et al*., 2013). Behavioural interventions also include strengthening exercises to enhance tongue and lip movement and exercise programmes to increase the range of motion of the oral tongue, hyoid, and larynx. Several surgical techniques have been proposed to treat swallowing issues (Logemann, 2007). Results are again somewhat unpredictable. Typically, surgical procedures are introduced after unsuccessful attempts at behavioural therapy.

One of the main behavioural treatments is dietary modification, which involves altering the rheologic qualities of foods and liquids (Speyer, 2019). The use of commercial thickening agents for liquids or the blending of solid foods are two examples of how to change the consistency of foods in order to control flow rates and transport speed (Selvanderan *et al*., 2021; Zargaraan *et al*., 2013). This method may aid with bolus adjustment and management during swallowing (Speyer, 2019). A pureed diet is used to make up for chewing difficulties brought on by weakness, poor dentition, or a dry mouth that makes bolus formation difficult (Wilkinson *et al*., 2021).

Dysphagia diet management ensures the safety and efficiency of swallowing food (Cartagena *et al*., 2024; Cichero, 2015). Swallowing safety refers to the ability to process food orally and then propel food, liquids, saliva, or oral medicines to the stomach while at the same time avoiding the airway. On the other hand, swallowing efficiency means timely food preparation and swallowing and sufficient food intake. This diet management is crucial for individuals with dysphagia, which is often associated with inadequate caloric intake as the swallowing difficulties make them eat or drink less. Texture modified foods (TMF), is an approach that is commonly used by therapists to manage dysphagia diet as TMF may provide certain textures such as soft, moist may help increase food intake (Cartagena *et al*., 2024; Speyer, 2019). Dysphagia diet management should ensure that TMF food is nutritious and easy to swallow (Raheem *et al*., 2021).

Different countries use different standards and terminology to describe TMF. Table 2.1 displays a variety of dysphagia diet standards in various countries worldwide (Cichero *et al*., 2013). For instance, food standards in Australia are divided into 4 levels, whereas 6 levels are used in Japan. Additionally, every country uses unique terminology. For example, Japan categorises their TMF using the term “level,” while others, like the United Kingdom, Australia, and Ireland, categorise their TMF using the term “texture”. There is no standardisation in the categories of foods for dysphagia diets, with each country using a different category and terminology. Therefore, standardization of the categories and terminologies is required.

Table 2.1 Dysphagia diet standards for foods from different countries (Cichero *et al.*, 2013)

Country	< normal food					Texture modified food >
United States	Regular	Dysphagia advanced	Dysphagia mechanically altered			
United Kingdom		Texture E – fork mashable dysphagia diet	Texture D – pre-mashed dysphagia diet	Texture C – thick puree dysphagia diet	Texture B – thin puree dysphagia diet	
Australia	Regular	Texture A – soft	Texture B – minced + moist	Texure C – smooth pureed		
Ireland		Texture A – soft	Texture B – minced and moist	Texture C – smooth pureed	Texture D – liquidised	
Japan	Level 5 Normal diet	Level 4 Soft food	Level 3 (dysphagia diet) Paste with meat/fish	Level 2 (dysphagia diet) Jelly food with protein	Level 1 (dysphagia diet) Smooth jelly food with protein, except for meat and fish	Level 0 (test food) Smooth jelly food without protein
Denmark	Normal	Soft		Puree		
Spain	Normal	Easy mastication		Puree		
Netherlands	Normal	Normal with soft meat/fish/chicken	Mashed	Puree		
Brazil	Solid					Soft solid or pureed
Sweden	Regular or cut	Coarse pate	Timbales	Jellied products	High viscosity fluids	Low viscosity fluids

2.2.3 International Dysphagia Diet Standardization Initiative (IDDSI)

Following the discussion of different countries' inconsistent standards, more work is required to achieve standardisation. An international group of researchers has launched an endeavour to provide nomenclature and descriptions for thickened liquids and food with altered textures that apply to all age ranges, care settings, and cultural contexts (Cichero, 2015). The programme is named The International Dysphagia Diet Standardization Initiative (IDDSI).

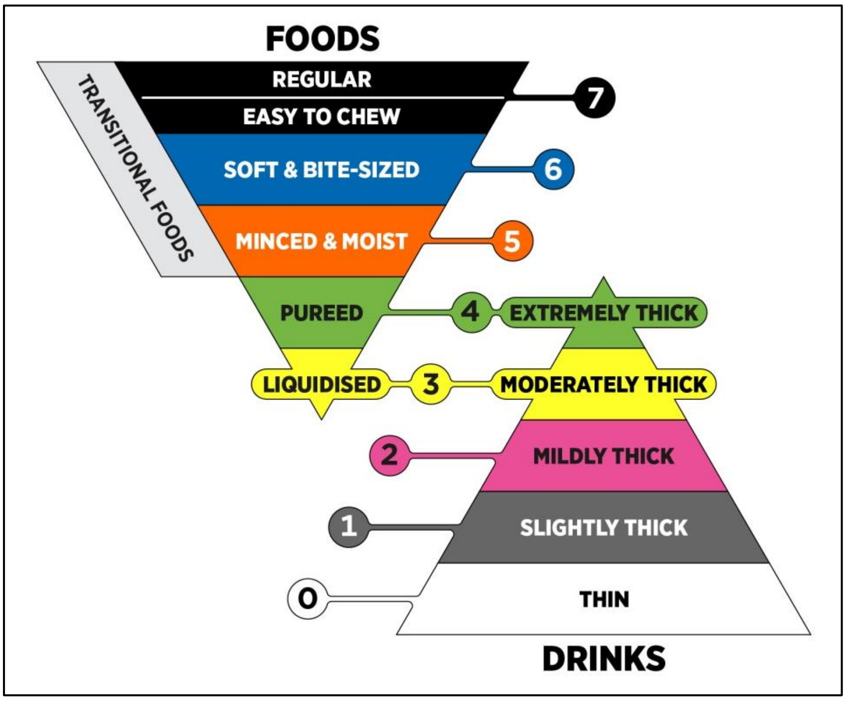

Figure 2.3 IDDSI framework (Cichero *et al*., 2017)

IDDSI has developed a framework for foods and drinks, as shown in Figure 2.3. This framework includes detailed descriptors for all IDDSI levels supported by easy measurement methods that can be used by people with dysphagia, caregivers, clinicians, food service professionals, and industry.

There are eight levels in which drinks are categorized from Level 0 to Level 4 and foods from Level 3 to Level 7. To classify foods or drinks at a specific level, tests such as the syringe flow test and the fork drip or spoon tilt test can be carried out (Cichero *et al*., 2017). For Levels 0 to 3, the syringe flow test, which is based on the flow rate of the liquid, is used. Meanwhile, for Levels 3 and 4, the food can be tested using a fork drip. In addition, the spoon tilt test can also be used to test the stickiness of foods in Levels 4 and 5 (www.iddsi.org, IDDSI Framework Testing Methods). Transitional food (Level 5 to 7) initially has one texture (such as a firm solid), but when moisture (such as saliva or water) is added or when the temperature changes (heating), it transforms into a different texture. For transitional foods in Levels 5 to 7, the texture can be assessed using a fork, chopstick, and between thumb and index finger (www.iddsi.org, IDDSI Framework Testing Methods).

All tests shall comply with the testing methods provided and explained in the IDDSI Framework Testing Methods document. The ability of thick liquids and solid foods (Levels 3 and 4) to pass through the tines or prongs of a fork can be tested. The results can then be compared to the thorough descriptions of each level. The sample's stickiness (adhesiveness) and ability to hold together are assessed using the spoon tilt test (cohesiveness). A cohesive sample should hold its shape on a spoon and plop off easily with minimal food left. A thin film on the spoon after the spoon tilt test is acceptable, but the sample should not be firm or sticky. A scooped mound may spread or slump slightly on a plate. For transitional food, it must be able to break easily with the side of a fork or spoon.

The IDDSI framework, however, has some shortcomings. Even though forks and spoons are inexpensive, accessible, and readily available, however they are not reliable in providing comprehensive data on masticatory behaviour, bolus structure and perceived texture, mechanical and rheological properties throughout the oral processing of foods (Munialo *et al*., 2020). Generally, this framework is lacking in providing quantitative measurements for food whose texture has been altered. Food qualities are subjectively described for each level based on subjective standards like whether a lump is discernible, whether it can be moulded into a specific shape, whether it can be eaten with a spoon or fork, and whether chewing is necessary.

Although other countries have already implemented the IDDSI framework for dysphagia patients, Malaysia is still at an early stage phase of the implementation. Until today, the Hospital Diet Manual is used to prepare special diets at government hospitals (Azizan *et al*., 2023). In Malaysia, texture-modified food (TMF) for people with dysphagia has been classified under broad headings such as mixed porridge, mince diet, and blended diet (Azizan *et al*., 2023). However, in 2023, the first 'Premiere Asia IDDSI Conference 2023' was organized by the IDDSI community and took place in Malaysia. According to Malaysia's Dietition Association (MDA), the IDDSI framework can prevent confusion caused by different used terminology globally for thickened liquids and foods or food with altered textures. Hence, the planned conference and establishment of Malaysia's IDDSI new reference group representatives among various stakeholders (food industry players, patients with dysphagia and their carers, health and allied health professionals, and other relevant advocate) could be the beginning of IDDSI related activities in Malaysia.

2.3 Texture-modified food

Texture-modified food (TMF) is a common approach used in managing diets for people with dysphagia. TMF refers to any food that has undergone mechanical alterations, such as changing the consistency of the original food so that it will be easier to consume (Abu Zarim *et al*., 2018). Mechanical alterations may refer to modification processes such as chopping, grinding, mincing, or blending. These are the traditional practices in most dysphagia diet management.

TMF includes foods that are softened by processing, minced, pureed, or liquidized, and liquids that have been thickened to various extents. Foods that are recommended for dysphagia should have soft and moist textures, while sticky, adhesive, and fibrous structures that are difficult to break down should be avoided (Wang *et al.*, 2023). Foods with soft textures are preferred because they can be mixed and disintegrated in the mouth without mastication by the tongue and palate (Ishihara *et al.*, 2013). These textures can produce a coherent bolus while increasing oral transit time (Rothenberg and Wendin, 2015). The puree is one of the best food examples, with smooth, moist, and lump-free properties, sufficient stability to maintain its form on a spoon, and the ability not to fill the liquid onto the plate when it is plated (Cichero, 2015).

In addition, sticky textures should be avoided, as these can cause food particles to build up and accumulate in the oropharynx and result in aspiration after consumption(Cartagena *et al.*, 2024). This is because the skills needed to disintegrate solid foods, mix them with saliva, make them into a cohesive bolus, and finally move them to the posterior of the oral cavity can be complex and challenging for those who suffer from dysphagia (Cichero *et al.*, 2013).

Less pressure is preferable when transporting the bolus posteriorly in dysphagia; this is related to the boluses' cohesiveness, adhesiveness, and hardness (Munialo *et al.*, 2020; Sungsinchai *et al.*, 2019). In the literature, it was suggested that the three primary textural characteristics used in TMF are cohesiveness (the ability to form a bolus in the mouth that is safe to swallow), adhesiveness (i.e., the tendency of particles to adhere at their surfaces), and hardness (the ratio of hard to soft) (Aguilera and Park, 2016). The food shall have high cohesiveness and low adhesiveness with a suitable soft texture to promote food bolus with safe swallowing properties (Munialo *et al*., 2020).

Research shows that when TMF is served to individuals with dysphagia, their oral intake and their body weight increase (Germain *et al*., 2006; Raheem *et al*., 2021). Similarly, Wendin *et al*. (2010) reported that the elderly in a nursing home increased their oral intake when TMF was given to them. These show that TMF is vital and needed to tackle problems that arise due to dysphagia, such as malnutrition.

2.3.1 Production of texture-modified food

Several ways can be used to design texture-modified food (TMF), including mechanical alteration and the addition of thickeners (Aguilera and Park, 2016). Mechanical alteration refers to softening traditional meals such as meats, vegetables, and fruits using methods such as chopping, grinding, blending, and mincing (Raheem *et al*., 2021; Sungsinchai *et al*., 2019). These methods have been used in most hospitals or nursing homes to provide TMF for individuals with swallowing difficulties (Wendin *et al*., 2010). Secondly, the typical commercial thickeners used in TMF are starch- and gum-based (Zargaraan *et al*., 2013).

Thickeners will alter and modify the foods' consistency, making food textures more suitable for consumption by people with dysphagia. Due to the delayed flow of liquid and the additional time for safe swallowing, thicker products like pastes and purees are frequently considered more suitable for patients with dysphagia (Wang *et al*., 2023). However, these commercial thickeners might have some disadvantages, making them less favourable for higher consumption. Therefore, gel microparticles are proposed as alternative thickeners. They are made of proteins or polysaccharides. Since they are used to particularly alter and control the rheology and texture in other industries, they have been suggested to serve the same purposes in food applications to design TMF (Aguilera and Park, 2016; Leon *et al*., 2016; Łętocha *et al*., 2022).

Various attempts at the development of dysphagia-oriented food or TMF were reported in the literature. Cartagena *et al*. (2024) studied the use of several hydrocolloids to modify the texture of desserts. Six formulations of strawberry dessert fortified with protein (calcium caseinate) and fibre (wheat dextrin or inulin) were added with xanthan gum, carboxymethylcellulose, or modified starch to achieve the desired texture and stability. For all formulation, the loss tangent ranged from 0.28 to 0.35, suggesting a weak gel behaviour that is safe for swallowing. It is apparent that the addition of dextrin together with xanthan gum or carboxymethyl cellulose produced a dessert with less prone to structural changes. Meanwhile, the products added with inulin satisfy the rheological requirements for foods safe for dysphagia, although several panelists felt that the product was still unsatisfactory because of its strong gel.

In addition, Wang *et al*. (2023) have developed dysphagia-oriented foods by using basic ingredients including rice starch, whey isolate protein, and perilla seed oil. The effects of sugar, salt, minerals, vitamins, and sugar addition on the texture, flow behaviour and swallowing characteristics were investigated. Based on the result, all samples complies to pureed level 4 in the IDDSI framework. Salt and sugar known to strengthen the intermolecular interaction forces to alter the spatial structure and viscoelasticity of the gel system. This led to a more networked gel pattern, which improved the water-holding capacity, viscosity, storage modulus, chewiness, and swallowability of foods for dysphagia patients. In addition, minerals and vitamins may give a deeper colour to the food bolus, and increase the possibility of aspiration, due to the residues left on the spoon.

Furthermore, Giura *et al*. (2023) have developed vegetable purees with enhanced lentil protein (carrots, zucchini, extra virgin olive oil, and lentil protein concentrate) for those with dysphagia. The food models were created using either 600 MPa/5 min high-pressure processing (HPP) or 0.8% xanthan gum. Compared to control samples, both types of purees had greater firmness, consistency, and cohesiveness, with gel-like quality (tan δ 0.161–0.222). Products subjected to the HPP treatment show higher G' values and stiffness, especially after the storage period. Conversely, the ones made with xanthan gum had more elasticity, with their cheaper price making them more affordable for consumers.

Aside from that, Xu *et al.* (2023) evaluated the textural and rheological study of pea protein isolate (PPI) treated with ultrasonic treatment (390 W; 20 min) at various sodium chloride (NaCl) concentrations, as a superb meal for dysphagia patients. The result shows that PPI's ordered structure was broken and rearranged by the combination of ultrasonic treatment and NaCl (0–0.6 M) ions which change the textural profile of the material. The rheology analysis's frequency sweep revealed that PPI gels' molecular interactions were enhanced by ultrasonic treatment. The viscosity, wetness, solubility, gelling ability, and rheology performance of PPI are significantly increased by combining ultrasonic and NaCl concentrations. This will greatly extend the application of PPI, particularly for preparation of textural-modified food for those with chewing or swallowing disorders.

2.3.1(a) Commercial thickeners

Thickening agents are often used to modify food texture to improve bolus control. These thickeners bind with water to increase bolus viscosity, slowing the entrance of the bolus during swallowing, which may reduce the risk of aspiration (Zargaraan *et al*., 2013). Starch-based thickeners such as corn starch and potato starch and gum-based thickeners such as xantham gum and guar gum are mostly used in diet management for people with dysphagia. However, both thickeners may have different properties.

Starch-based thickeners may thicken over time, making them unstable (Vilardell *et al*., 2016). Thus, the consistency of food may be thickened over time, making its texture unsuitable for dysphagia (Vilardell *et al*., 2016). During mastication, amylase takes place in the digestion of amylose, the monomers of starch-based thickeners; amylose may be digested, which may lower the consistency of the food bolus (Vilardell *et al*., 2016). This will produce a thin liquid, increasing the risk of choking (Cichero, 2013).

Gum-based thickeners are becoming more favourable and preferable due to the limitations of starch-based thickeners (Cichero, 2013). Gum-based thickeners have a more stable viscosity over time (Vilardell *et al*., 2016). Besides, gum-based thickeners are also more translucent, making them preferable to be added to clear soup (Vilardell *et al*., 2016). However, gum-based thickeners such as xanthan gum were also reported to have laxative effects if consumed in high concentrations (>15g/day) (Daly, 1993). This limitation will cause abdominal discomfort for people with dysphagia.

In addition, all thickening agents demonstrated flavour suppression. For nectar- and honey-thick consistencies, starch-based thickeners were discovered to provide a starch flavour and a gritty texture (Cichero, 2013). While gum-based thickeners generate a higher level of "slickness" than starch-based thickeners, they do not produce gritty textures (Cichero, 2013). Hence, patients may consume less thickened liquids than normal liquids because of poor flavour and poor thirst-quenching ability.

2.4 Gel microparticles

Microgels or gel microparticles are defined as "soft, stable, and small particles whose structure can be turned within a wide range of sizes, shapes, and textural properties" (Zhang *et al*., 2023; Raheem *et al*., 2021; Nicolai, 2016). Microgels may be created artificially for specific uses like texture control and encapsulation (Stokes, 2012). The production of gel microparticles can be done by several methods, such as physical gelation, chemical gelation, emulsion route, atomization route, microparticulate, and coacervation (Raheem *et al*., 2021; Shewan and Stokes, 2013). The basic principles of these technologies are summarised in Table 2.2.

2.4.1 Properties of gel microparticles

Polysaccharides or protein gel microparticles are generally small in size (e.g., sizes from <1 µm to 1000 µm), and they have attractive properties owing to their soft texture and flowability (Zhang *et al*., 2023; Aguilera and Park, 2016; Loewen *et al*., 2017). Gel microparticles are small in size with a higher total surface area, and this will help gel microparticles absorb more nutrients if loaded with additional nutrients, which may increase their nutrient intake (Kaneda, 2021; Shewan and Stokes, 2013). They also can swell in solvents to increase the viscosity of gel-like consistency in food (Stokes, 2012).

Table 2.2 Technologies for the production of gel microparticles (Aguilera and Park, 2016; Shewan and Stokes, 2013)

Technology	Materials	Principle/Claims
Physical gelation	Globular protein solutions	Heat-induced aggregation to form spherical particles
Chemical gelation	Gelatin	Chemical cross-linking by transglutaminase and genipin
Emulsion route	Protein-based o/w emulsions	Lipid droplets (microsphere) trapped inside a protein gel matrix
Atomisation route	Alginate and WPI solutions	Impinging of a spray produced by a high-pressure nozzle with a fog of coagulation phase
Microparticulation	Globular protein or mixed biopolymer solutions	Solutions are heated, mostly under shear.
	Protein and/or polysaccharide gel	Grinding of bulk gels with mechanical instruments.
Coacervation	Biopolymer mix solutions (polysaccharides, protein)	Coacervation uses the principle of difference in ionic forces to cause the polymers to form droplets and drop out of the solution.

According to Leon *et al.* (2018), gel microparticles are fragile particles that will release strong flavour intensities during the mastication of the food and deliver nutrients and bioactive compounds during digestion. When they break down on the tongue, they release a more potent aroma if flavour-filled and have a thin and delicate texture (Kaneda, 2021). Gel microparticles are used as structuring agents to strengthen dispersed phases and as thickeners in soups and sauces (Aguilera and Park, 2016). They can be mixed into purées or blended into thin liquids to alter how their perceived texture and flow behave (Raheem *et al.*, 2021).

2.4.2 Applications of gel microparticles

Gel microparticles have the potential to be applied in various applications. Based on Figure 2.4, these are some of the forms of gel microparticles may attain in texture modified food (TMF): (1) pure gel for rheology of drinks or foods, or they may