RHEOLOGICAL, TEXTURAL, AND SENSORY EVALUATION OF TEXTURE-MODIFIED RICE PORRIDGE FOR PATIENTS WITH DYSPHAGIA

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2019

RHEOLOGICAL, TEXTURAL, AND SENSORY EVALUATION OF TEXTURE-MODIFIED RICE PORRIDGE FOR PATIENTS WITH DYSPHAGIA

by

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

August 2019

ACKNOWLEDGEMENT

I want to take this opportunity to express my profound gratitude and sincere regards to my main supervisor, Dr. Syahariza Zainul Abidin for her patient, encouragement, and support. Her guidance helped me throughout this research and writing of this thesis. I would also like to extend my gratitude to my co-supervisors, Dr. Norazatul Hanim Mohd. Rozalli and Dr. Norsila Abdul Wahab provided their advice and expertise in making this research a success.

I gratefully acknowledge the support provided by Malayan Sugar Manufacturing (MSM) Malaysia Holdings Berhad and Kuok Foundation for awarding me the fellowship to pursue this Master Degree. It would not have been possible without financial support from them. My sincere thanks also go to staff and patients in Hospital USM, Kelantan that allowing me to conduct the sensory evaluation test. I want to give special thanks to a speech-language pathologist (Mr. Izzat Ismail) for his supervision and students from USM Speech Pathology programme for their assistance throughout the sensory data collection process. To all lecturers and laboratory assistants from the School of Industrial Technology, thank you for helping me in accomplishing my research.

I truly appreciate to have a great supporter and motivator, Rumaisa Nordin, to help me went through all the tough time and listen to me when I needed someone to talk. Not forgetting to my fellow friends, Syuzeliana, Yong Yi, Sook Yee, Nuraihan, Syazana, and the rest from the postgraduate room for their continuous help and moral support during the entire course of this research. Last but not least, I would like to dedicate my heartiest appreciation to my family members for their blessings, love, understanding, and motivation who made my research success.

TABLE OF CONTENTS

CHAPTER 4 - CHARACTERIZATION OF INSTANT RICE PORRIDGE: PHYSICOCHEMICAL, RHEOLOGICAL, AND TEXTURAL ANALYSES

LIST OF TABLES

Page

LIST OF FIGURES

LIST OF SYMBOLS

G’	Elastic modulus
G”	Viscous modulus
δ	Phase angle
σ	Shear stress
$\dot{\gamma}$	Shear rate
K	Consistency index
n	Flow behavior index
σ_{oc}	Casson yield stress
$\tan \delta$	Loss tangent

LIST OF ABBREVIATIONS

BVA	Brabender Viscoamylograph
FDA	Food and Drug Administration
FEES	Fiberoptic Endoscopic Evaluation of Swallowing
IDDSI	International Dysphagia Diet Standardization Initiative
LST	Line Spread Test
LVR	Linear Viscoelastic Region
NDD	National Dysphagia Diet
PCA	Principal Component Analysis
RVA	Rapid Visco Analyzer
SAOS	Small Amplitude Oscillatory Shear
SD	Standard Deviation
TPA	Texture Profile Analysis
VAS	Visual Analog Scale
VFSS	Videofluoroscopic Swallowing Study

PENILAIAN REOLOGI, TEKSTUR, DAN SENSORI TERHADAP PRODUK BUBUR NASI TERUBAH SUAI TEKSTUR UNTUK PESAKIT DISFAGIA

ABSTRAK

Disfagia ditakrifkan sebagai kesukaran atau ketidakupayaan menelan makanan atau cecair. Makanan puri merupakan salah satu kategori makanan yang terubah suai tekstur dan selalu digunakan untuk pengurusan disfagia. Pesakit disfagia boleh mendapat manfaat daripada prekripsi diet ini kerana ia hanya memerlukan penyediaan dan manipulasi oral yang minima. Setakat ini, hanya beberapa kajian mengkhusus kepada reologi makanan puri berbanding minuman yang telah dipekatkan untuk pesakit disfagia. Pemekat komersial ditambah semasa penyediaan makanan puri bagi mendapatkan konsistensi makanan yang diperlukan supaya risiko tercekik dapat dikurangkan. Bagaimanapun, kos yang tinggi dan ketersediaan yang terhad bagi pemekat komersial menjadi beban kepada segelintir pesakit. Oleh itu, kajian dijalankan untuk menilai kesan penambahan kanji (ubi kayu dan sagu) dan gam (xantan dan guar) menggunakan kepekatan yang berbeza (1, 2, dan 3% berdasarkan jumlah berat **ingredien**) terhadap ciri-ciri reologi dan tekstur puri bubur nasi. Sampel puri bubur nasi dengan penambahan 1% gam dan 2% kanji menghampiri kelikatan sampel rujukan (bubur nasi komersial untuk pesakit disfagia). **Semua sampel puri dengan kelikatan yang sama menunjukkan ciri reologi dan tekstur yang berbeza. Selepas pemilihan kepekatan yang sesuai bagi setiap bahan pemekat (1% gam dan 2% kanji), sampel puri bubur nasi dikeringkan dengan menggunakan pengering udara panas (80 ℃ selama 3 jam) untuk menghasilkan bubur nasi segera.** Produk yang dihasilkan **dianalisa untuk sifat fizikokimia, pempesan, reologi serta tekstur.** Selain itu, **kajian dijalankan ke atas kesan enzim amilase**

<u>dari air liur terhadap kelikatan bubur nasi segera yang telah dibancuh semula.</u> Kajian ini mendapati bahawa setiap pemekat mempunyai kesan sinergis yang tersendiri terhadap bubur nasi segera. Bubur nasi segera yang mengandungi gam menunjukkan ciri-ciri seperti kuasa pembengkakan, kelarutan, kelikatan puncak, *breakdown*, dan rintangan terhadap enzim amilase dari air liur yang lebih tinggi tetapi lebih rendah bagi ketumpatan pukal, suhu pempesan, dan kepejalan berbanding dengan bubur nasi segera yang mengandungi kanji. Penilaian sensori bagi bubur nasi segera telah dijalankan di kalangan pesakit disfagia (n=20). Analisis statistik menunjukkan penerimaan keseluruhan sampel bubur nasi adalah berkadar negatif terhadap kelekatan dan keupayaan menelan. Keseluruhannya, kajian ini berjaya menghasilkan bubur nasi segera yang sesuai digunakan di kalangan pesakit disfagia dan penerimaan dibuktikan melalui penilaian sensori. Gam xantan menunjukkan potensi yang tinggi untuk digunakan sebagai bahan pemekat bagi bubur nasi segera. Kejayaan terhadap penggunaan gam xantan ke dalam bubur nasi segera mampu menggantikan pemekat komersial di pasaran dan mengurangkan beban kewangan pesakit.

RHEOLOGICAL, TEXTURAL, AND SENSORY EVALUATION OF TEXTURE-MODIFIED RICE PORRIDGE FOR PATIENTS WITH DYSPHAGIA

ABSTRACT

Dysphagia is defined as the difficulty or inability to swallow food and liquid. Pureed food, a class of texture-modified food is commonly used in dysphagia management. Patients with dysphagia can benefit from this diet prescription because it requires minimal oral preparation and manipulation. To date, only few studies focused on the rheological properties of dysphagia-oriented pureed foods compared to thickened beverages. During the preparation of pureed food, commercially available thickener is usually added to impart desired consistency, which aids in reducing the risk of choking. However, high cost and limited availability **of** commercial thickener are burden for some patients. Therefore, this study was carried out to evaluate the effects of different starches (tapioca and sago) and gums (xanthan and guar) at different concentrations (1, 2, and 3% based on total weight of ingredients) on rheological and textural properties of pureed rice porridge. The thickening of pureed rice porridge with 1% gum and 2% starch produced samples with close apparent viscosity to the reference sample (commercial dysphagia-oriented rice porridge product). All pureed samples with similar viscosity showed variation in behaviors during rheological and textural measurements. **After selection of suitable concentration for each thickener (1% gum and 2% starch), the pureed rice porridge samples were then dried using hot air dryer (80 ℃ for 3 hours) to produce instant rice porridges.** The developed products were tested **for** their **physicochemical, pasting, rheological, and textural properties.** Besides, the effect

of salivary amylase on the viscosity of the reconstituted rice porridge samples was also investigated. This study illustrated that each thickener has its own synergistic effect with instant rice porridge. The instant rice porridge with gums showed higher swelling power, solubility, peak viscosity, breakdown, and higher resistance towards salivary amylase reaction, but lower in bulk density, pasting temperature, and firmness compared to instant rice porridge with **added** starches. Sensory evaluation of instant rice porridge samples was also conducted among patients with dysphagia (n=20). The statistical analyses revealed that overall acceptability of rice porridge samples were negatively correlated with stickiness and swallowing effort. Overall, this study had successfully developed instant rice porridge that suitable for consumption among patients with dysphagia and was proven to be accepted through sensory study. Xanthan gum was shown to have the greatest potential to be used as a thickener in instant rice porridge. The success in incorporation of xanthan gum into instant rice porridge can help to replace existing commercial thickener in the market and reduce patients' financial burden.

CHAPTER 1

INTRODUCTION

1.1 Background and Rationale of Study

Dysphagia can be defined as the difficulty or inability to swallow food and liquid. The prevalence of dysphagia had been reported as about 8% in the general population (Cichero *et al*., 2013). However, it is difficult to determine the overall prevalence of dysphagia in a country because it is often reported as part of other medical conditions for which the patient is being treated (Linn *et al*., 2015). Dysphagia can result from several conditions such as cancer, stroke, neurological disorders, and brain injury (Houjaij *et al*., 2009; Cichero, 2013). **Dysphagia** affects all age groups but it is more common among the elderly population (Bangyeekhan *et al*., 2010). People with dysphagia may also encounter difficulties in controlling saliva, problems in chewing solid foods, and choking or pain during swallowing (Adeleye & Rachal, 2007). Consequently, it leads to complications such as malnutrition and dehydration due to some of the food restrictions (decreased food and fluid intake) and dietary alteration (Andersen *et al*., 2013; Zargaraan *et al*., 2013).

Dysphagia is a symptom of an underlying disease. Often, the disease has to be treated first before dysphagia can be managed successfully. However, as patients need to be fed to maintain their nutritional intake, diet modification is usually prescribed for patients as a compensatory method to manage dysphagia. Diet modification can be classified into thickened liquid and texture-modified food. Texture-modified food is usually prepared by blending, straining to remove lumps, and followed by the addition of thickener to compensate chewing difficulties and to improve patient's safety during swallowing. Pureed food, a class of texture-modified food, is highly recommended for patients with dysphagia, who may also benefit from this diet prescription because it requires minimal oral preparation and manipulation (Zargaraan *et al*., 2013).

To support the people with dysphagia, food industries have started to develop (i) special type of thickener in powder form that can be used to thicken food and liquid and (ii) pre-thickened texture-modified food for convenience. However, the commercial thickener is only available at selected pharmacies and sold at high price. There is also another issue related to the **thickness consistency level during preparation of food using commercial thickener** (Payne *et al*., 2012). Accordingly, the use of pre-thickened texture-modified food has been proposed as an alternative solution for these shortcomings. Nevertheless, the existing pre-thickened texture-modified food is very limited and only available in certain countries **such as Japan and United States**.

Standardization of guidelines and terminologies are necessary to deliver better treatment outcome for patients with dysphagia (Steele *et al*., 2015) and also facilitate the product development from the industry sector (Cichero *et al*., 2007). Several standards have been developed from different countries but each standard varies across countries. The terminology, labels, and the number of levels of modification used are different. The lack of objective measurement regarding the food texture and consistency is a major barrier to the diet management of patients with dysphagia. Only subjective descriptions such as the presence of visible lumps and the ability to form shape are used to classify texture-modified food into different levels. To standardize guidelines of texture-modified food, it becomes essential to understand the major factors or measures which have to be addressed for easy and safe swallowing.

In general, this study was designed to evaluate the suitability of starch and gum as a thickener in pureed rice porridge for patients with dysphagia using rheological, textural, and sensory parameters with the aims to find an alternative for commercial thickener. **<u>The overall experiemnt design for this study was divided into three phases and shown in Figure 1.1.</u>** The pureed rice porridge was selected as a food model in this study. Unlike the normal rice porridge, the pureed rice porridge need to be pureed to a homogenous texture without solid pieces being noticed and followed by the addition of thickening agent to ensure the consistency of the rice porridge is suitable for patients with dysphagia. Rice porridge is comfort food that usually recommended by the doctors for patients. The texture is soft and easily digestible, hence, it is very suitable for those who are just recovering from illnesses or have weak digestion. Rice porridge also can help to increase energy intake as the carbohydrates from the rice can serve as a good energy source.

1.2 Objectives

The specific objectives of this study were as below:

i. To study the rheological and textural properties of pureed rice porridge with the addition of starch (sago and tapioca) and gum (xanthan and guar) as thickener

ii. To evaluate the physicochemical, pasting, rheological, textural properties, and the effect of salivary amylase on the developed instant rice porridge

iii. To study the sensory acceptability of instant rice porridge among patients with dysphagia in Hospital USM, Kelantan

Phase 1: Development of pureed rice porridge using different thickeners

Sample Preparation

Type of thickeners : xanthan gum, guar gum, sago starch, tapioca starch
Levels of addition : 1, 2, and 3% based on total weight of ingredients

↓

Analyses

- Line spread test (LST)
- Rheological measurements (Flow behavior and Oscillatory frequency sweep)
- Textural measurements (Back extrusion test)

Note: only the selected formulations were used in the next phase

Phase 2: Development of instant rice porridge

Sample Preparation

Hot air dryer (80 ℃, 3 h)

↓

Analyses

Powder

- Moisture content and water activity
- Swelling power and solubility
- Bulk density (tapped density)
- Pasting properties

Reconstituted

- Line spread test (preliminary)
- Rheological measurements
- Textural measurements
- Salivary amylase effect

Phase 3: Sensory acceptability of instant rice porridge

Location : Hospital USM, Kelantan
Participants : Adult patients with dysphagia (n=20)
Test : Visual Analog Scale (VAS)
Attributes : Thickness, stickiness, graininess, swallowing effort, overall acceptability

Figure 1.1 Overall experimental design of this study which consisted of three phases and all the analyses conducted.

CHAPTER 2

LITERATURE REVIEW

2.1 Dysphagia

Normal swallowing is a complex action which involved three different phases, namely oral, pharyngeal, and esophageal (Kim & Han, 2005) (Figure 2.1). First, the food is chewed to reduce particle size and mixed with saliva to form a bolus (Houjaij *et al*., 2009). In the second **phase** or pharyngeal phase, the bolus which transferred by the tongue to the back of the throat triggers an involuntary swallowing reflex and passes through pharynx (the canal that connects the mouth with esophagus) (Forster *et al*., 2011). The soft palate also elevates to close the nasopharynx and avoid nasal regurgitations (Germain *et al*., 2006). At the same time, the involuntary closure of the larynx by the epiglottis occurs and breathing stops for a few seconds to prevent food from entering the airway (Bangyeekhan *et al*., 2012). This movement also opens the upper esophageal sphincter and allows the bolus to enter the esophagus. Once the bolus passes through the upper esophageal sphincter, relaxation of pharyngeal structures begins and breathing resumes. The esophageal phase further propels the bolus down the esophagus and directed towards the stomach with the aid of muscular action called peristalsis (Bangyeekhan *et al*., 2010).

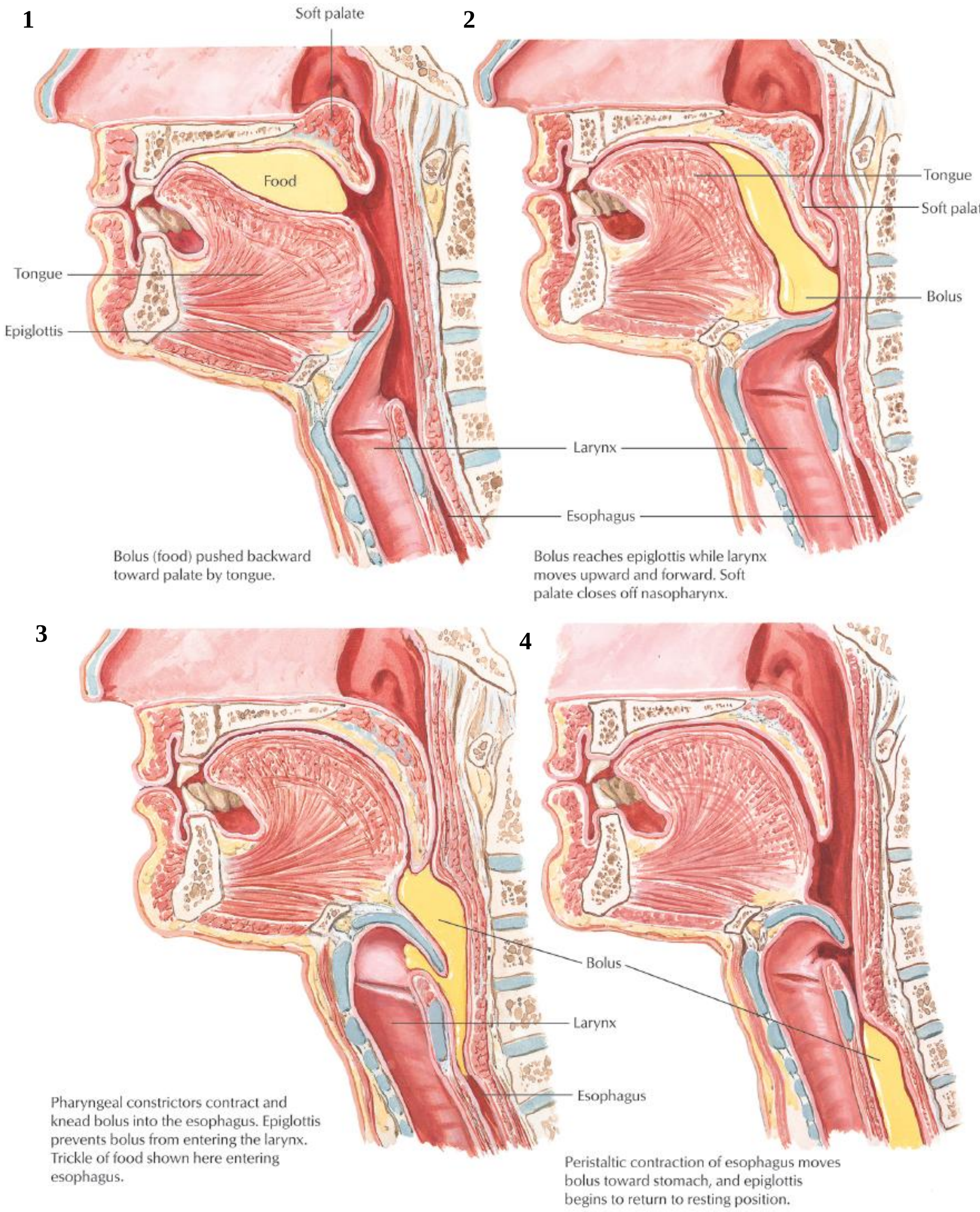
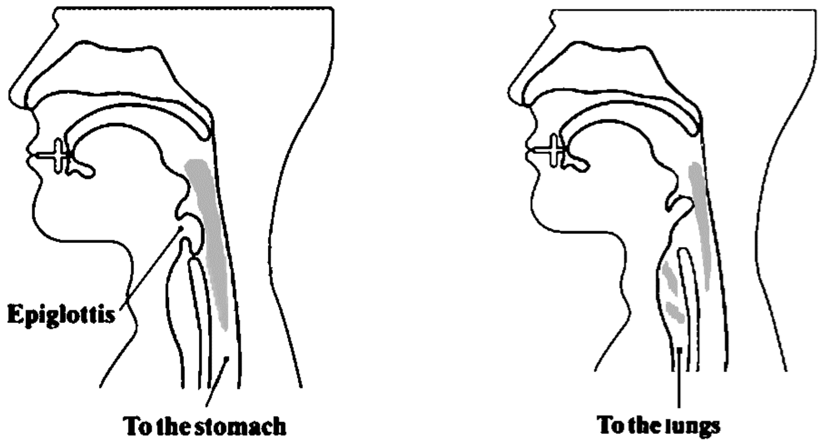


Figure 2.1 Normal swallowing mechanism (Garcia & Chambers, 2010)**.**

Swallowing disorder, also called dysphagia can be defined as difficulty in swallowing or moving food and liquid from mouth to stomach. Dysphagia influences the safety and efficacy of swallowing function (Forster *et al*., 2011). Safety usually refers to aspiration or entry of food and liquid into the airways whereas efficacy relates to efficiency and speed of patient when swallowing food and liquid (Andersen *et al*., 2013). For instance in Figure 2.2, there is a danger that thin liquid can flow quickly to the larynx before the epiglottis closes the entrance of airway, leading to aspiration in patients with dysphagia (O'Leary *et al*., 2010). Dysphagia categorization usually based on the point at which the disorder occurs during the swallowing process. In general, dysphagia can be divided into two types: oropharyngeal and esophageal dysphagia (Clavé & Shaker, 2015). Oropharyngeal dysphagia arises when patients cannot initiate a swallow (difficulty in transferring food bolus from mouth to pharynx toward the esophagus) while esophageal dysphagia results from food sticking or feel like it is stuck in the chest (difficulty to move food down the esophagus) (Aslam & Vaezi, 2013).



(a) Normal swallowing **(b) Dysphagia**

Figure 2.2 (a) Normal swallowing - the epiglottis closed to protect airways; (b) Dysphagia - the epiglottis unable to protect airways (Spong, 2015).

2.1.1 Prevalence of Dysphagia

The prevalence of dysphagia had been reported as about 8% of the general population, which is 590 million people worldwide (Cichero *et al*., 2013). According to Bhattacharyya (2014) and Adeleye & Rachal (2007), dysphagia affects up to 15 million adults in the United States and 1 in 25 people in the United States will experience swallowing problem. This swallowing disorder also affects all age groups, but it is more common among the elderly population (Bangyeekhan *et al*., 2010). It is prevalent in between **<u>10-38%</u>** of independent elderly (Garin *et al*., 2014) and 68% of elderly residents in long-term care institutions (Rosenvinge & Starke, 2005). Apart from that, dysphagia also can result from several medical conditions and it affects more than 35% of patients with stroke (Park *et al*., 2014), 52 to 82% of patients with Parkinson's disease (Newman *et al*., 2016), and up to 93% of patients with traumatic brain injury (Andersen *et al*., 2013). To the best of author knowledge, only a few studies have been reported on the prevalence of dysphagia in patients with illnesses in Malaysia. Linn *et al.* (2015) reported that 39 out of 66 patients with head and neck cancer at Hospital Universiti Sains Malaysia from 2001 to 2010 had dysphagia, while 41% based on total 134 patients had dysphagia following acute ischemic stroke in a study conducted by Hamidon *et al.* (2006).

2.1.2 Signs and Symptoms of Dysphagia

In the presence of swallowing disorder, patients may present with a variety of symptoms such as extra effort need to chew or swallow food, a feeling that food is stuck in throat, gurgly sounding voice quality during swallowing, and difficulty in controlling saliva (Adeleye & Rachal, 2007; Kayser-Jones & Pengilly, 1999). Patients with dysphagia may also experience coughing or choking shortly after meals (Aslam & Vaezi, 2013). If this problem left untreated, there is a danger that some people can develop aspiration pneumonia (a lung infection due to the entry of materials like food, liquid, saliva or even stomach content into the airways) (Kayser-Jones & Pengilly, 1999). In addition to aspiration, the impaired swallowing can lead to complications such as malnutrition and dehydration (Andersen *et al*., 2013) due to some of the food restrictions (decreased food and fluid intake) or losing eating pleasure (Zargaraan *et al*., 2013). The negative impact on quality of life and social participation also other consequences of dysphagia (Cichero *et al.*, 2013). Therefore, it is essential to know the symptoms of dysphagia and seek medical advice and treatment immediately if note any of these symptoms.

2.1.3 Management of Dysphagia

It is well established that speech therapists play important roles in the assessment, diagnosis, and management of people with dysphagia. There are numerous rehabilitative and compensatory strategies for the management of dysphagia. The rehabilitative method includes several oral-motor exercises of the lips, tongue, and jaw which intended to improve the efficiency of swallowing function (Forster *et al*., 2011). Besides, compensatory method focus on the implementation of techniques to allow individuals to continue safe swallowing and hence to maintain their nutrition intake (Sura *et al*., 2012). Compensatory strategies mainly include postural adjustments, swallow maneuvers, and diet modification (Aslam & Vaezi, 2013).

Diet modification is one of the most common compensatory methods to manage dysphagia (Andersen *et al*., 2013). Diet modification can be classified into thickened liquid and texture-modified food (Moret-Tatay *et al.*, 2015). In the case of thin liquid, it is known to increase the risk of choking among patients with dysphagia because it flows too quickly and provides insufficient time for the patients to ready to engage airway closure before swallowing (Steele *et al*., 2015). **One of common strategy to slow down the act of swallowing is to manipulate the viscosity of thin liquid by adding thickener (Cho *et al*., 2012). The thickened liquid tends to flow more slowly and thus enhance safe swallowing (Cichero *et al*., 2013).** Likewise, solid food with a coarse texture like meat and rice which require mastication are not well tolerated by the patients with dysphagia and can cause trouble in swallowing

(Layne, 1990). **In order to reduce the risk of choking, the texture of solid food is often altered such that it requires little or no chewing (Cichero *et al*., 2013)**. Therefore, the rationales behind modifying the consistency and texture of foods or drinks are to compensate chewing difficulties and to improve safety during swallowing (Sura *et al*., 2012).

2.2 Texture-Modified Food

In order to help the patients to maintain their nutritional intake, **texture-modified food can be prescribed. However, Keller *et al*. (2012) reported that only 15-30% of long term long term care facilities (nursing homes) and 30-45% hospitals served texture-modified food for people with dysphagia. Texture-modified food is the food that has been modified physically or is a term that refers to food with soft texture or reduced particle size (Aguilera & Park, 2016).** Texture-modified food often includes food that has been minced, mashed, chopped, ground, or pureed. The type of modification is highly depending on the cause and severity of swallowing problem of the patients (Cichero *et al*., 2007). In addition to the type of modification, it is vital to ensure that the food textures are soft, moist, homogenous, not sticky, and do not contain fibrous structures that hard to be broken to allow ease of swallowing (Cichero, 2016). The recommendation on appropriate food texture needs to be done by a speech therapist to each patient based on their screening and clinical assessment (Cichero *et al*., 2013). The process of clinical assessment often started with medical history taking and followed by some non-instrumental measures such as assessing oral motor and vocal function exam and swallowing test using water with different viscosities (Speyer, 2013). Further instrumental measures such as Videofluoroscopic Swallowing Study (VFSS) and Fiberoptic Endoscopic Evaluation of Swallowing (FEES) also can be taken to develop a better overall understanding of a patient's swallowing ability (Cichero *et al.*, 2013).

Pureed food, a class of texture-modified food, which is mechanically altered to become soft, homogenous, and smooth in texture is highly recommended to be used in dysphagia management (Cichero, 2016). Pureed food is usually prepared by blending and followed by straining to remove lumps. Patients with dysphagia can benefit from this diet prescription because it requires minimal oral preparation and manipulation (Zargaraan *et al.*, 2013). **In contrast to pureed food, more chewing effort is required for minced food due to its larger particle size (Keller *et al*., 2012). Also, the formation of cohesive bolus will become difficult in minced food because the food is being cut into small pieces, which may lead to the risk of choking (Nishinari *et al*., 2016).** Besides, thickener is also often added during the preparation of pureed food to achieve the desired consistency. According to Hanson *et al.* (2012), food with increased viscosity can help to prolong oral transit time which means individuals will have more time to prepare food bolus before swallowing, resulting in safer swallowing.

Overall, texture-modified food is usually used not only to improve swallowing safety but also help to provide nutrient intake among patient with dysphagia. However, much like a medical prescription, texture-modified food needs to meet certain standards and guarantee a safe texture during preparation to ensure patient safety and to deliver better treatment outcomes (Steele *et al.*, 2015).

2.2.1 Existing Standards of Texture-Modified Food

In Malaysia, there is still no standard for the diet management of patients with dysphagia. In contrast, several standards have been developed from different countries such as Japan, Australia, Ireland, United Kingdom, and United States of America to classify dysphagia diet. However, each standard varies across countries. The terminology, labels, and the number of levels of modification used are different. In a review of Penman & Thomson (1998), they found that there was a huge variety in the degree of modification and many different texture descriptors used covering the years from 1981 to 1996. Meanwhile, 40 different names used to label texture-modified foods were identified by an American task force, as mentioned by Cichero *et al*. (2007). The same authors also reported that multiple labels of texture-modified food not only causing confusion among caregivers, health professionals, and researchers, it also can bring adverse effects to the patient and even death may be an outcome. For example, two patients with dysphagia in England were reported to have died which attributed to the delivery of inappropriate food textures ("Patients choked on hospital soft food," 2018).

Table 2.1 listed the classification of texture-modified food from different world region (Cichero *et al*., 2013). It is apparent that texture-modified foods are commonly classified into three to five levels, without the inclusion of regular food (food without modification). The most widely used terminologies are soft food, minced food, as well as pureed food. Only for United Kingdom, the grading of pureed food is different from other countries where pureed food is divided into two levels: Texture B (thin) and Texture C (thick). Apart from that, the size of particles also became one of the properties that took into consideration by some countries when naming different food textures. In Australia, the recommended particle size of soft food (Texture A) is 1.5 cm whereas 0.5 cm for minced or moist food (Texture B).

In 2012, the lack of international standardized terminology and descriptors for dysphagia diet was lead to the formation of International Dysphagia Diet

Standardization Initiative (IDDSI) (Steele *et al*., 2015). IDDSI consists of a group of volunteers from different professions around the world, namely medicine, speech therapy, nursing, dietician, and food technology. The outcomes of the international standardized terminology aim to improve patient safety, as well as to reduce miscommunication between manufacturer, consumer, and professional sectors (Cichero *et al*., 2017). IDDSI framework was introduced, which categorizes the dysphagia diet into eight levels where drinks are measured from Level 0 to 4 while foods are measured from Level 3 to 7 (Figure 2.3). Pureed food is classified under Level 4.

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		

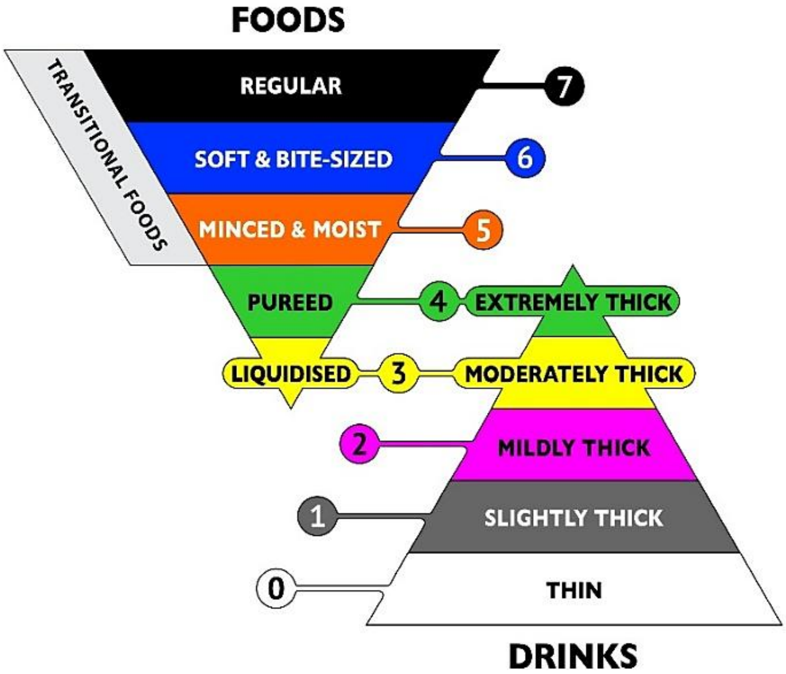


Figure 2.3 Classification of dysphagia diets into eight levels according to **International Dysphagia Diet Standardization Initiative** (IDDSI) framework (IDDSI, 2017).

However, there are limitations of IDDSI framework. The lack of objective measurements for texture-modified food is one of the drawbacks of the framework. The characteristics of food for each level are subjective, relying on descriptions such as the presence of a visible lump, ability to form shape, ability to eat with spoon or fork, and requirement of chewing. The food testing methods also have been based on subjective methods such as (i) fork pressure test (applying a fork to the food sample to observe its behavior when pressure is applied), (ii) fork drip test (assessing whether the food sample flow through the prongs of a fork), and (iii) spoon tilt test (to determine the stickiness and cohesiveness of food sample). These testing methods can cause inherent variability due to the different levels of force applied by the individual (Cichero *et al.*, 2017). Therefore, the classification and descriptions of texture-modified foods depend highly on visual assessment instead of instrumental measures.

Using pureed food as an example, the characteristics and testing methods in IDDSI framework were listed in Table 2.2.

Table 2.2 Characteristics of pureed food (Level 4) according to IDDSI framework (International Dysphagia Diet Standardization Initiative, 2017)

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 molded • 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

2.3 Thickening Agent

Starch and gum have been widely used as an ingredient in food due to their thickening purpose. Food industries also rely heavily on these ingredients because they can give products certain desired taste, texture, and mouthfeel (Chen & Ramaswamy, 1999). The food industries have created some choices to support people with dysphagia. These choices can be categorized into two main groups: (1) powdered thickeners that can be added to food or liquid and (2) pre-thickened products (Zargaraan *et al*., 2013). **There are still limited choices of dysphagia-oriented food in the market especially in Malaysia.** For instance, there is only one company (Simply Puree) in United Kingdom that producing a range of texture-modified foods with different levels (Texture B, C, D, and E).

Both thickener and pre-thickened product for the management of dysphagia use polysaccharides as thickening agent, which generally consisting of modified starch or gum (Payne *et al*., 2012). These polysaccharides have been used in texture modification because **of their** ability to absorb water, causing an increase in viscosity.

As mentioned by Clavé *et al*. (2006), the increase in food viscosity can help to increase the safety of swallow in patients with dysphagia, but it also may impair the efficacy of swallow if the residues are increasing in the mouth (or throat). Hence, it is vital to understand the effect of thickeners on the swallowing process in patients with dysphagia. According to Saha & Bhattacharya (2010), the effects of thickening agent depend largely on the type and concentration used and the food model in which it is used. There are still multiple sources of starch or gum that have not been properly tested for their characteristics and suitability in thickening foods for dysphagia needs. The data comparing the effects of starch and gum on safe swallowing and acceptability of patients with dysphagia are also limited in pureed food.

2.3.1 Starch

Starch is the major reserve polysaccharide in plants which composed of two polymers: amylose and amylopectin (Figure 2.4). Amylose is a linear chain of glucose units that linked together by α-1,4 glycosidic bonds which make up about 15 to 30% of starch (Srichuwong *et al*., 2005). Amylopectin, the dominant component (70 to 85%), has the same basic structure as amylose, but it is larger and heavily branched with α-1,6 glycosidic bonds (Jobling, 2004). These two components form the alternate layer of amorphous and crystalline in starch granule. The botanical origins for producing starches can be divided into cereal (maize, rice, and wheat), tuber (potato), root (cassava), legume (mung bean and green pea), and stem of palm (sago) (Karim *et al*., 2008). More than 80% of the starch production in the world market come from maize and is mostly produced in USA (Waterschoot *et al*., 2015a). Wheat and potato starches are mainly produced in Europe (Jobling, 2004). In Asia, cassava (or tapioca) and sago starch are mainly produced (Jobling, 2004; Singhal *et al*., 2008).

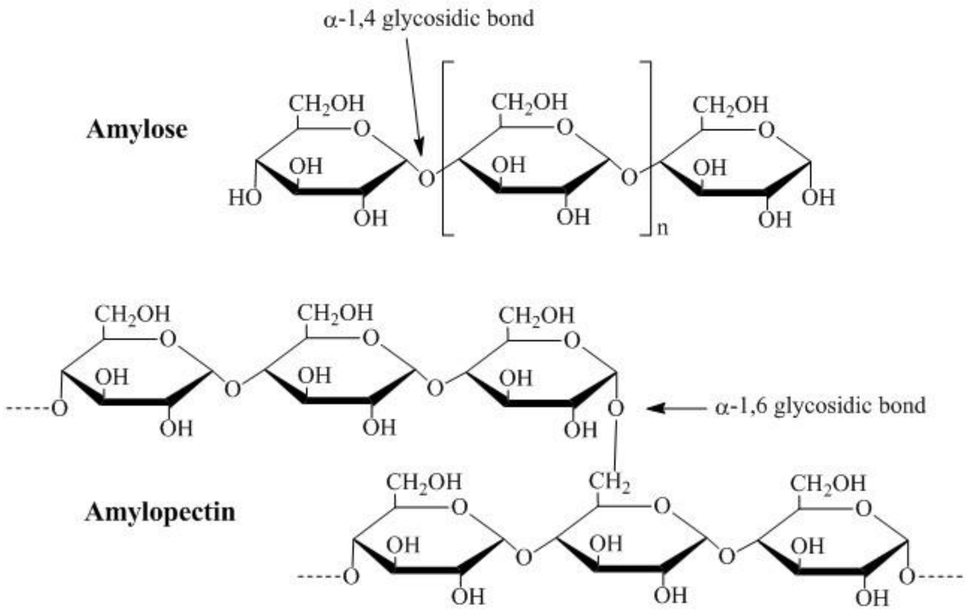


Figure 2.4 Primary structure of amylose and amylopectin in starch (Sanyang *et al*., 2018)

2.3.1(a) Physicochemical Properties of Starch

The composition and structure of starch granules vary between different botanical sources and variability providing starches of diverse properties and functionalities (Table 2.3).

Table 2.3 Morphological and physicochemical properties of starches from different botanical sources (Karim *et al*., 2008; Murphy, 2000; Waterschoot *et al*., 2015a)

Properties	**Sources of starch**			
	Rice	**Tapioca**	**Sago**	**Maize**
Granular shape	Polygonal	Oval, truncated	Oval, truncated	Round, polygonal
Granular size (µm)	3-8	4-35	15-65	5-30
Amylose content (%)	4-29	17-20	24-31	23-28
Gelatinization temperature (°C)	68-78	62-73	69-74	62-72
Cooked properties	Opaque gel	Clear cohesive, tendency to gel	Opaque gel	Opaque gel

Gelatinization is a phase transition of the starch granules from an ordered state to disordered state, which usually achieved by heating starch with sufficient water (Altay & Gunasekaran, 2006). The gelatinization temperature of most starches is in the range between 60 to 80 ℃ (Copeland *et al*., 2009). During gelatinization, the starch granules absorb water and start to swell. The initial swelling takes place in the amorphous regions of the granules and causes destabilization in the crystalline regions (Hsu *et al*., 2000). The crystalline regions irreversibly disrupted as evidenced by a loss of birefringence (Palav & Seetharaman, 2006). Then, the amylose slowly leaches out from the swollen granules increase the viscosity of the solution.

Pasting is usually related to the development of viscosity which also involving granular swelling, leaching of molecular components from the granules, and total disruption of the granules (BeMiller, 2011). Brabender Viscoamylograph (BVA) and Rapid Visco Analyzer (RVA) are usually used to evaluate the pasting properties of starch (Hagenimana & Ding, 2005) When the heating continues, more and more amylose molecules, as well as amylopectin, are leached out from the granules. The maximum viscosity (called peak viscosity) is achieved when the granules are fully swollen (Considine et al., 2011). The **maximum viscosity** is then followed by a decrease in viscosity due to the breakdown of granules and the dispersion of starch molecules in the solution (Waterschoot *et al*., 2015b). Several factors are affecting the rate and extent of swelling and breakdown **of the starch** such as the type of starch, composition of starch (for example the presence of protein and lipid), temperature, and shear force (Debet & Gidley, 2007). In general, the higher the amylose content, the lower the peak viscosity (Copeland *et al*., 2009). During the cooling phase, the solubilized starch polymers begin to re-associate in an ordered structure. Thiis process is called retrogradation. Then, the viscosity increased due to the formation of gel which held together by intermolecular interactions involving amylose and amylopectin molecules and known as final viscosity (Fu *et al*., 2015).

2.3.1(b) Applications of Starch in Foods

Starch is one of the most commonly used thickening agents in food. According to Copeland *et al*. (2009), approximately 60 million tons of starches are extracted annually worldwide from various botanical origins, and 60% are used in foods. This is because starch is considered as a natural ingredient. It is also cheap, abundant, and easily available in the market (Chantaro *et al*., 2013). According to Saha & Bhattacharya (2010), the use of starch at low concentration (2 to 5%) also possibly does not contribute any remarkable taste to food. Hence, starch has been added into many foods like sauce, soup, cream-based product, and dessert (Srichuwong *et al*., 2012). For instance, tapioca starch which essentially **<u>contribute minimal flavor</u>** to the food system is commonly used in pudding, fish crackers, soup, and baked goods (Otegbayo *et al*., 2013). Besides, tapioca starch has been widely used in baby food as a thickener because it can provide the desired texture and stability, as well as its low flavor contribution (BeMiller & Whistler, 2009). Native tapioca starch also usually forms a clear and smooth texture when cooked (Russ *et al*., 2016). In addition, sago starch which is one of the native starches has been used in food for many years mainly for the production of vermicelli, bread, and biscuit (Ahmad *et al*., 1999). The properties of sago starch are it is easy to gelatinize, exhibit high viscosity, and low in gel syneresis (Maaruf *et al*., 2001). Due to these reasons, sago starch also has been used in jellies, puddings, and soups in Southeast Asia (Karim *et al*., 2008).

However, the use of native starch in industrial applications is limited because of its low solubility in water and low resistance towards processing conditions that involve heat, shear, and acid (Sun & Yoo, 2015). Several attempts had been carried out by researchers to improve the functional properties of starch. First, starch is subjected to physical or chemical modification to obtain the desired properties such as quick dispersion in cold or hot food and higher resistance towards the processing conditions (Ashogbon & Akintayo, 2014). **Secondly**, with the drive towards more natural food system, mixing of starches or mixing **of** starch and gum is another way to improve the functional properties of native starch without modification (Arocas *et al*., 2009; Waterschoot *et al*., 2015b). Sun & Yoo (2015) reported that the blend of rice starch with tapioca starch resulted in higher gel strength and better freeze-thaw stability. Additionally, the quality of noodles which made by blending of potato starch and rice starch was shown to improve in transparency and slipperiness (Sandhu *et al*., 2010). The blends of oat, potato, and corn starch with xanthan gum also were tested in strawberry sauce and found that the sensory and texture properties of the sauce were stable for three months.

2.3.2 Gum

Gum, also known as hydrocolloid, is categorized based on its source (botanical, animal, seaweed, microbial, and synthetic) or chemical structure (glucan, protein, xylan, galactomannan, and many others) (Li & Nie, 2016). **According to Li & Nie (2016), as in 2013, the food hydrocolloid market is growing significantly and is projected to reach $8.8 billion by 2018 with North America as the largest consumer for food hydrocolloid.** The main reason for the extensive use of gum as food additives is due to the presence of many hydroxyl groups in the structure that can increase their ability to bind with water.

Xanthan gum is a non-linear anionic microbial polysaccharide that produced by *Xanthomonas campestris* (Ahmed & Ramaswamy, 2004). The primary structure of xanthan gum composed of two glucose units, two mannose units, and one glucuronic acid (Figure 2.5). Its main chain consists of β-D-glucose units linked at the 1- and 4-

positions, which is the same as in cellulose (García-Ochoa *et al*., 2000). Trisaccharide side chain which composed of a D-glucuronic acid unit between two D-mannose units is attached to every second glucose residue of the main chain. Xanthan gum is accepted as a safe food additive under United States Food and Drug Administration (FDA) without any specific quantity limitations and also designated by European Union as E415 (Lopes *et al*., 2015). Xanthan gum has been commonly used as thickening agent and stabilizer in a wide variety of foods such as frozen foods, bakery products, juice, powder beverages, yogurt, sauces, and gravies (Lopes *et al*., 2015). The advantages of xanthan gum as thickener include high viscosity at low concentration, high shear-thinning behavior, and stable towards pH, temperature, and enzyme (Demirci *et al*., 2014). The stability of xanthan gum can be explained through its conformation in solution where the side chain wraps around the main chain to protect the labile linkages from adverse conditions (Sworn, 2000).

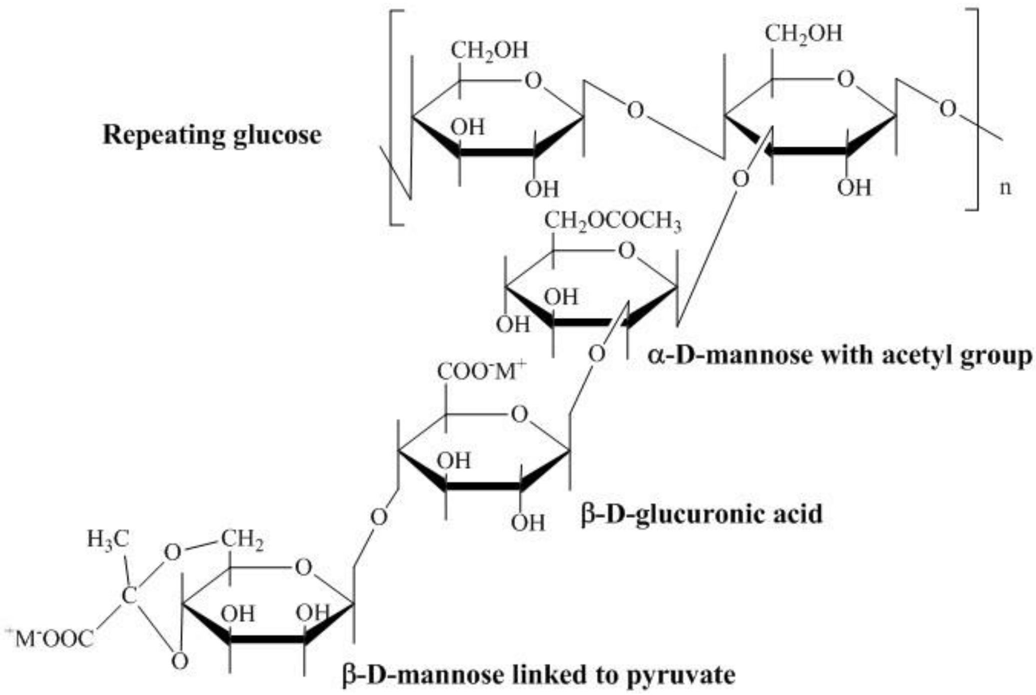


Figure 2.5 Primary structure of xanthan gum (Sworn, 2000)**.**

Guar gum is a natural and non-ionic polysaccharide which extracted from the ground endosperm of guar (Demirci *et al*., 2014). It is a high molecular weight carbohydrate with white to yellowish white (Tripathy & Das, 2013). Guar gum molecules consist of a linear chain of β-1,4-linked mannose units with randomly attached α-1,6-linked galactose units (Figure 2.6) (Mart ń-Alfonso *et al*., 2018). Due to its low cost and ability to produce a highly viscous solution at low concentration, guar gum is widely used as a thickener and stabilizer in foods (Demirci *et al*., 2014). For instance, the incorporation of guar gum in salad dressing, sauce, and canned soup able to improve product stability and appearance (Mudgil *et al*., 2014). The thickening process of guar gum in solution occurs when the galactose side chains interact with water molecules by forming strong hydrogen bonds between them (Tripathy & Das, 2013). Similar to xanthan gum, the FDA has approved guar gum as a food additive (Tripathy & Das, 2013) and designated by the European Union as E412.

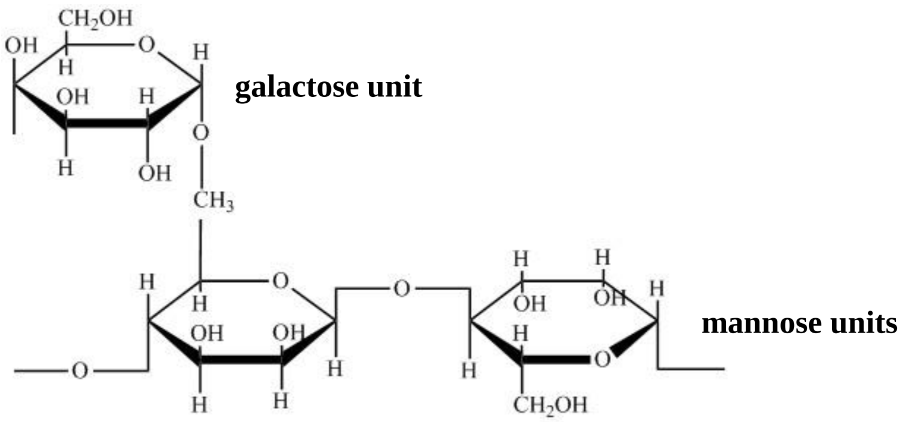


Figure 2.6 Primary structure of guar gum (Tripathy & Das, 2013)**.**

2.3.3 Commercial Thickener for Dysphagia

For diet management of dysphagia, a commercial thickener is usually added into food and drink. However, its availability only limited to selected pharmacies and normally sold at a higher price. At first, the commercial thickeners available in the market are mainly formulated from modified corn starch. Lotong *et al.* (2003) reported that there was an issue closely related to corn starch due to its strong starchy flavor thus reducing the acceptability of the thickened drinks. Garcia *et al.* (2005) also reported that thickened liquid with modified starch was unstable where the viscosity continued to increase over time. It is undesirable because the over-thickened product may increase choking risk in people with dysphagia (Hadde, Nicholson, & Cichero, 2015).

As a result, there has been a shift toward gum-based thickener due to undesirable properties found in the starch-based thickener. Xanthan gum and guar gum are the polysaccharides that typically used in the gum-based thickener. Xanthan gum gained popularity over modified starch in thickened liquid because it possesses a range of desirable properties, such as having a better taste, more stable viscosity over time and less affected by amylase (Vilardell *et al*., 2016). It also eliminates grainy texture and gives smooth texture when compared to starch-based thickener (Cichero, 2013). However, recent review by Cichero (2013) had established that gum reduces the bioavailability of medicine used, which may cause medical complications in critical patients. Gum as non-starch polysaccharides, particularly galactomannan tends to pass through, relatively untouched until the intestines. Since gum only can be digested by the gut microflora, it may cause an issue in patients receiving strong antibiotics that reduce the gut microflora. Unlike gum, starch can be broken down through all phases of digestion, starting from the mouth until further processes in the small intestine where water and nutrients are absorbed (Moret-Tatay *et al*., 2015).

Besides that, a number of studies have found that inconsistencies of thickness level exist when individuals make up their own thickened beverages using a commercial thickener (Adeleye & Rachal, 2007; Steele *et al*., 2003). **This variability** has been reported by Glassburn & Deem (1998) where the clinicians (even experienced speech-language pathologist) in the hospital were not consistent in their ability to thicken liquids. There are several factors that may lead to this variation include the type and temperature of the beverage, thickener brand, and thickening techniques (Pelletier, 1997). Apart from the need of standard guidelines and training to ensure consistent viscosity, Mills (1999) and Zargaraan *et al*. (2013) proposed that the use of pre-thickened foodstuffs is another potential alternative to overcome the shortcomings of commercial thickener.

2.4 Characterization of Pureed Food

The characteristics of pureed food after addition of thickener mostly examined through instrumental measures (rheological and textural analyses). Several testing modes and applications can be carried out by rheometer and textural analyzer to predict the effectiveness of a pureed food for swallowing among patients with dysphagia. This is because the instrumental measurements can be used to determine the structural changes during processing and molecular interactions of foodstuff (Zargaraan *et al*., 2013). Besides, sensory evaluation has been developed as a scientific tool for measuring and analyzing human responses towards a product as perceived through senses of sight, smell, touch, taste, and hearing (Foegeding *et al*., 2011). It also plays an essential role in characterizing pureed food for patients with dysphagia because instrumental methods which often conducted under a controlled condition cannot completely explain the complex texture and sensory attributes of food (Janssen *et al*., 2007). With the combination of instrumental measurements and sensory analyses, it can help to develop safe foods with desired sensory properties and at the same time increase oral and nutrient intake among patients with dysphagia.

2.4.1 Line Spread Test

Line spread test (LST) was developed in the 1940s to measure the consistency of liquid-like foods (Nicosia & Robbins, 2007). LST is an empirical test of rheology