Textural Complexity and its Influence on Satiation

Insights from a Gel–Based Model Study

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Abstract

Background

Textural complexity was defined as ‘the number and intensity of texture sensations, as well as their interactions and contrasts’. Satiation is the termination of eating, often accompanied by feelings of contentment.

This thesis aimed to study the effects of textural complexity on satiation. The hypothesis was that more texturally complex food gels would lead to greater satiation. Oral processing time was recorded to study if more texturally complex food Gels had a longer mastication period. Liking was accessed to study if textural complexity had an impact on preference.

Small bead-like particles and discs were used to attain textural complexity in the food gel. Bead-shaped particles of Kappa Carrageenan, were known to produce gritty, beady, and lumpy sensations. Agar discs were associated with perceptions of hardness, chewiness and elasticity. Put together, the Gels had a smooth outer orange colour body with a soft jelly-like appearance, like that of a dessert.

Although the hypothesis ‘that more texturally complex food Gels lead to greater satiation’ was not supported, the definition of textural complexity was.

Objective

The primary goal of this research was to study the impact of varying textural complexities on satiation, using Gel–based model foods.

Design

The satiation test design was a randomised cross-over blind trial based on a preload of the model foods followed by an ad-libitum intake based on a two-course meal. Thirty participants with a healthy body mass index (BMI) were recruited. Three variants of model food Gels (low complexity: A, medium complexity: B, and high complexity: C) were developed to
create textural complexity differing only in mechanical properties. The study ensured that the macronutrient content and flavour of the Gels were controlled and kept consistent across all three Gel complexities to maintain uniformity, and liking was assessed. The amount of a two-course *ad-libitum* meal (pasta in tomato basil sauce and cake) consumed, and appetite ratings were used to measure satiation. Oral processing time for the gels was also recorded.

**Conclusion**

Overall, the results confirmed no significant impact on satiation (*p* > 0.05), but revealed that there was a significant difference in textural complexity between the three variants of the Gels (*p* < 0.05). A significant difference in liking between the Gels (*p* < 0.05) was noticed. Lastly, highest complexity of Gel needed the most oral processing time, and the lowest complexity of Gel required the least oral processing time.
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Table of Contents

Abstract ........................................................................................................................................... ii

Acknowledgements ....................................................................................................................... iv

Table of Contents .......................................................................................................................... vii

List of Tables .................................................................................................................................. xii

List of Figures .............................................................................................................................. xiii

Abbreviations ............................................................................................................................... xiv

Chapter 1: Introduction .................................................................................................................. 1

1.1 Why Understanding Food Texture Matters? ...................................................................... 1

1.2 Satiation and Satiety ............................................................................................................ 2

1.2.1 Satiety Cascade .............................................................................................................. 2

1.3 Previous Research and Gaps ............................................................................................... 3

1.4 Considering Complexity and Preference ........................................................................... 3

1.5 Implications and Significance ............................................................................................. 4

1.6 Purpose of the Current Study ............................................................................................ 6

1.7 Main Research Questions .................................................................................................... 6

1.8 Hypothesis ............................................................................................................................ 6

1.9 Structure of Thesis ............................................................................................................... 7

Chapter 2: Literature Review ....................................................................................................... 8

2.1 Texture: Definitions and Explanations ................................................................................ 8

2.1.1 Food Texture ................................................................................................................ 8
TEXTURE AND SATIATION

2.1.2 Texture Perception...........................................................................................................9
2.1.3 Textural Complexity........................................................................................................10
2.1.4 Sensory Complexity........................................................................................................12

2.2 Design and Measurements .................................................................................................13
2.2.1 Designing Textural Complexity.........................................................................................13
2.2.2 Measuring Textural Complexity.........................................................................................13

2.3 Manipulating Textural Complexity in Food .................................................................19

2.4 Satiation ............................................................................................................................21
2.4.1 Relationship between Textural Complexity and Satiation............................................21

2.5 Effect of Textural Complexity on Satiation ......................................................................24
2.5.1 Solid Foods ....................................................................................................................25
2.5.2 Liquid Food .....................................................................................................................26
2.5.3 Semi-Solid Foods ..........................................................................................................28
2.5.4 Solid and Liquid Foods ..................................................................................................29
2.5.5 Liquid and Semi-Solid Foods .........................................................................................30
2.5.6 Liquid and Soft Solid Foods ..........................................................................................32
2.5.7 Liquid, Pureed, and Chunky Foods ................................................................................32
2.5.8 Semi-Solid, Pureed, and Chucky Foods .........................................................................32
2.5.9 Solid, Liquid, and Pureed Foods ....................................................................................33

2.6 Effect of Pleasantness on Satiation ....................................................................................34
2.6.1 Liquid and Semi-Solid Foods .........................................................................................34

2.7 Effect of Oral Processing Time (OPT) on Satiation .........................................................36
2.7.1 Liquid Foods ..................................................................................................................36
2.7.2 Semi-Solid Foods ...........................................................................................................37
2.7.3 Solid Foods ................................................................. 37

2.8 Highlights from Past Literature ............................................. 38

Chapter 3: Methods..................................................................... 41

3.1 Demographic Overview – Age, Gender, and Body Mass Index (BMI) .......... 41
  3.1.1 Participants........................................................................ 41

3.2 Apparatus: Gels and Ad-Libitum Meals ........................................ 41
  3.2.1 Creation of Gels ................................................................ 41
  3.2.2 Materials used for Gels ....................................................... 43
  3.2.3 Ad-Libitum Meals................................................................. 54
  3.2.4 Materials used for Ad-Libitum Meals................................. 54

3.3 Procedure ............................................................................. 55
  3.3.1 COVID-19 Sanitisation and General Safety Procedures ................. 55
  3.3.2 Experimental Design........................................................... 55
  3.3.3 Scales used for Testing and Analysis...................................... 59

Chapter 4: Results..................................................................... 62

4.1 Textural Complexity ................................................................. 62

4.2 Oral Processing Time............................................................... 64

4.3 Appetite Ratings................................................................. 65

4.4 Liking Ratings...................................................................... 71

4.5 Linear Mixed Effects Regression Model (LMERM).............................. 73
  4.5.1 Consumption Analysis....................................................... 73
  4.5.2 Textural Complexity Analysis ........................................... 74
  4.5.3 Liking Analysis................................................................. 75
Chapter 5: Discussion

5.1 Key Findings

5.2 Textural Complexity

5.3 Liking

5.4 Appetite and Food Consumption

5.5 Oral Processing Time (OPT)

5.6 Food Diary

5.7 Comparison to Other Studies

5.8 Limitations

5.9 Future Research

5.10 Summary and Conclusion

References

Appendix A1: Participant Information Sheet

Appendix A2: Consent Form

Appendix B1: Demographics

Appendix B2: Appetite Questionnaire – Before Gel Consumption

Appendix B3: Appetite Questionnaire – After Gel Consumption

Appendix B4: Appetite Questionnaire – After Ad- Libitum (Pasta) Consumption

Appendix B5: Appetite Questionnaire - After Ad- Libitum (Cake) Consumption

Appendix B6: Food Diary

Appendix C1: Oral Processing Time
Appendix D1: Qualitative Data for Dinner Time .................................................................143

Appendix E1: Qualitative Data for Textural Complexity .....................................................145
List of Tables

Chapter 3: Methods, Materials, and Procedure

Table 1: Ingredients Used to Make the Three Different Complexities of Gels

Table 2: Ingredients used to make Kc particles.

Table 3: Ingredients used to make Agar disk.

Table 4: Ingredients used to Develop the Pectin Base solution

Chapter 4 Results

Table 5: Combined appetite ratings for trial 1 and 2

Table 6: Illustrates the Consumption Analysis for ad-libitum meals

Table 7: Illustrates the Textural Complexity Analysis

Appendices

Table D1: Qualitative data for dinner eaten by participants post testing.

Table E1: Illustrates the qualitative data for textural complexity.
List of Figures

Chapter 3: Methods, Materials, and Procedure

Figure 1: Ingredients and Equipments used to set the Gels used for Testing

Figure 2: The Figures show (part 1) The Kc Bead Particles Production Stages.

Figure 3: The Images Below Show the Disc Making Procedure.

Figure 4: The Images below show the Pectin Base, the Solution Formulating the Gel Body.

Figure 5: The Gel Making Assembly and Demoulding Process

Figure 6: The Image Shows the Gels De-moulded and served To Participants for Testing.

Figure 7: The Images Below Show The Ad – Libitum Meals Served to the Participants Post The Gels.

Chapter 4 Results

Figure 8: Combined Textural Complexity Data for Trial 1 and Trial 2

Figure 9: Oral Processing Time for Trials 1 And 2

Figure 10: Comparative Analysis of Appetite Ratings Across Two Trials and the Aggregated Results.

Figure 11: Appetite Ratings Across Two Trials and the Aggregated Results of Both

Figure 12: Liking Ratings Across Two Trials and the Aggregated Results Of Both.
Abbreviations

OPT – Oral Processing Time
BMI – Body Mass Index
VAS - Visual Analogue Scale
Kc - Kappa carrageenan
KCL - Potassium Chloride
PEC HM - High-Methyl Pectin
Sod Al – Sodium Alginate
GDL - Glucono Delta lactone
LBG – Locust Bean Gum
H₂O - Water
UoA – University of Auckland
Chapter 1: Introduction

Many people indulge in eating processed foods and sugary drinks, which can easily lead to overeating and becoming overweight. Managing food intake and portions is vital to maintaining a healthy lifestyle. Feeling full (satiation) and staying full (satiety) significantly control eating habits. Creating foods that promote longer satiety could help prevent overeating and obesity. Studies have consistently highlighted the positive correlation between food form and satiation. The impact of food texture on feelings of fullness has been explored to some extent.

1.1 Why Understanding Food Texture Matters?

Research shows that the texture and structure of food play a role in food consumption (Forde & Bolhuis, 2022). Foods that promote the feeling of fullness might lead to eating less, either by reducing hunger between meals (Chambers et al., 2015) or prolonging the gap between meals (Lasschuijt et al., 2017). Studies indicate that foods with varied textures can decrease food consumption (Larsen et al., 2016a; Tang et al., 2016). The rising global obesity crisis, which poses a notable health threat to humanity, underscores the importance of this finding (Rolls, 2009; Sarma et al., 2021; Tremmel et al., 2017).

Many everyday foods have multiple textures - like a chocolate bar with nuts and caramel, soup with vegetables and noodles, or multigrain bread. Consumers value these foods for their mix of textures and flavours. The reason was that they provided sensory experiences orally and have a mix of novel flavours. (Hyde & Witherly, 1993; Szczesniak & Kahn, 1984). Studies show that a food item's enjoyment was often enhanced by its ability to provide a variety of sensations (Lévy et al., 2006; Mielby et al., 2012; Palczak et al., 2019b). Nevertheless, Berlyne (1971) identified that the appreciation of a stimulus was subject to an
inverted U-shaped relationship with its complexity, whereby appreciation increases with complexity to a certain optimal level, beyond which further complexity results in decreased appreciation. Overall, sensory complexity was a crucial factor in food preferences and choices (Lévy et al., 2006; Mielby et al., 2012; Palczak et al., 2019b. Researchers are realising the importance of these sensory qualities in food and beverages. Studies have considered considering the importance of consumer perception and product development (Köster, 2009). Nevertheless, understanding how people sense different food textures was not transparent. More textures in a portion of food sometimes make it more complex (Bitnes et al., 2009). The perception of a food's complexity depends on the eater's surroundings and experiences (Berlyne, 1970; Palczak et al., 2019b).

1.2 Satiation and Satiety

Central to eating behaviour is the concept of satiation, which brings an end to eating, usually followed by a sensation of contentment. Subsequently, satiety was characterised as the lingering feeling of fullness after a meal until hunger resurfaces. The dynamic interplay between textural complexity and satiation remains an area yet to be thoroughly explored (Benelam, 2009). According to Ni et al. (2022), satiation refers to the feeling of being full that determines the end of a meal and influences the quantity of food and energy consumed in one sitting. Alternatively, satiety, the post-meal sensation of fullness, obstructs eating between meals and controls how often eating occurs.

1.2.1 Satiety Cascade

Around 25 years ago, Blundell, Rogers, and Hill proposed the 'Satiety Cascade' to assess how food impacts satiation and satiety in 1987. The 'Satiety Cascade' describes various behavioural, cognitive, and physiological episodes after food consumption, decreasing hunger between meals. Since then, the satiety cascade has been modified and reviewed several times (Blundell et al., 2013). This process allows for adequate energy distribution and regulation of
body weight (Belisle, 2008). The physiological systems that control hunger and the sensation of an urge to eat can be associated with physical phenomena such as the stomach feeling empty. These systems were linked to associations between peripheral physiology and metabolism, closely related to various brain functions and processes. For instance, when consuming food, the gut releases hormones like ghrelin and leptin that communicate with the brain to indicate satiety or hunger (Blundell et al., 1987; Blundell et al., 2013; Belisle, 2008). Ghrelin typically signals to the brain that the stomach has become empty and increases appetite, while leptin signals satiety and reduces hunger (Näslund et al., 2013).

1.3 Previous Research and Gaps

Previous research has investigated factors that may impact satiation (Bolhuis et al., 2014; Zijlstra et al., 2010; Smit et al., 2011). These were macronutrient composition, the proportions of proteins, fats, and carbohydrates in a meal, and meal sequencing, which relates to the order in which a meal was consumed, for instance, having a salad before the main course. However, textural complexity, especially when isolated from other sensory modalities such as visual and olfactory cues, has yet to be thoroughly researched (Tang et al., 2017; Bitnes et al., 2009; Cain & Drexler, 1974). Gel-based model foods, due to their malleability and uniformity, have recently been used to study nuances of texture without the confounding influence of varied flavours and nutrient content (Flood-Obbagy & Rolls, 2009; Hogenkamp et al., 2012; DiMeglio et al., 2000; Stull et al., 2008; Viskaal-van Dongen et al., 2011). However, gaps remain even with these initial explorations, especially concerning diverse populations, broader textural ranges, and the long-term effects of textural diets.

1.4 Considering Complexity and Preference

Psychological and social factors were crucial in food choice and preference (Köster, 2009). While much research presupposes that food choices were primarily logical, evidence also suggests that sensory factors play an essential role in decision-making, preferences and
liking when selecting a food item. (Tuorila, 2007; Haddad et al., 2007). Intriguingly, most decision-making processes, even beyond food, might be less consciously rational and more intuitively driven (Kahneman, 2003; Köster, 2009). Psychological theories suggest that human behaviours and preferences stem from an inclination towards optimal stimulation (Hebb, 1949). Berlyne (1971) integrated this perspective into his arousal theory, explaining that a stimulus appeal hinges on its cognitive stimulation capacity. However, too much or too little stimulation can perceive a stimulus as unsettling or dull.

Berlyne (1960) noted that a stimulus arousal potential was influenced by various properties, such as psychological, which involves how a stimulus was perceived and interpreted; ecological features, which refers to biological properties such as hunger; and collative properties, which include a collation of how novel or familiar a stimulus was when compared to previously encountered experiences. However, its detailed measurement, especially complexity, has been sporadically explored in food-related studies (Palczak et al., 2019b). Berlyne (1971) discovered that appreciation for a stimulus follows an inverted U-curve concerning its complexity: appreciation increases with complexity up to an optimal point, after which it diminishes. Previous theories and studies have tested and observed this phenomenon, noting its possible transiency and alteration with repeated exposure (Dember et al., 1957).

**1.5 Implications and Significance**

Today, obesity has become a significant health concern and challenge to human beings (Rolls, 2009). Understanding food intake has considerably improved by learning that the brain and gut hormones maintain energy homeostasis through a neural pathway. The hypothalamus is the crucial region in the brain that integrates many peripheral signals which modulate food intake and energy expenditure (Suzuki et al., 2012). Graff et al. (2010) found that foods consumed quickly offer brief sensory exposure, thereby limiting cognitive cues
that cause satiation, resulting in higher food consumption. Tremblay and Arguin (2013) highlight that in a traditional sense, satiety was the psycho-biological mechanism that inhibits hunger after the ingestion of a food or beverage. Classical theories imply that metabolism and nutrient intake influence satiety and appetite control (Tremblay & Arguin, 2013). Therefore, satiety should be well connected with hunger and satiation; however, the obesity epidemic suggests otherwise. (Tremblay & Arguin, 2013). A preventative factor to consider could be focusing on the properties of food, such as portion sizes and energy density. Increasing the intake of water-rich foods such as fruits and vegetables allows people to eat a satisfying portion of their meals while decreasing energy intake and thereby controlling hunger (Rolls, 2009).

Oral processing time was another crucial factor to consider. Miquel-Kergoat et al. (2015) suggest that prolonged mastication (i.e., processing food in the mouth) may decrease self-reported hunger and appetite, possibly due to alterations in the gut hormones. Still, more research is needed in these areas. Larsen et al. (2016) identified an increased number of textures perceived while chewing a solid food triggered the satiation response faster than when chewing less texturally complex food. In other words, greater sensory stimulation per bite could be an answer to enhance satiation and decrease food intake. The implications of understanding food texture's role in satiation extend beyond academic curiosity. For people trying to manage their weight or dietary intake, insights into how textural complexity impacts feelings of fullness could be transformative (Rolls, 2009). Moreover, the food industry can tailor products to support healthier patterns by controlling or modulating textural profiles (Miquel-Kergoat et al., 2015). With the rising global concerns around overconsumption and its associated health ramifications, such insights could have broad societal implications (Larsen et al., 2016; Rolls, 2009; Tremblay et al., 2013).
1.6 Purpose of the Current Study

Given the earlier considerations, this study investigates the relationship between textural complexity and satiation. Using a Gel-based model of foods controlled for size, colour, and flavour, this study aims to understand how variations in texture, when other factors were constant, influence satiation. This research aims to study the direct impact of textural complexity on satiation without interfering with other sensory factors such as visual attributes, liking, and preferences. This understanding holds significance in addressing the rising obesity rates, offering potential strategies to combat overconsumption.

1.7 Main Research Questions

This thesis's primary objective was to study the impact of textural complexity on satiation – from a Gel-based model food perspective. The research study investigates if textural complexity in Gel-based model foods directly influenced satiation. To address this question, researchers developed three complexities of Gels to study their impact on satiation. A two-course ad-libitum meal was served to participants to measure appetite. The second question was to study if there was a measurable difference in chew time among Gel-based foods of varying complexity. If so, how did that relate to perceptions of satiation?

1.8 Hypothesis

This thesis aimed to study the effects of textural complexity on satiation. The hypothesis was that more texturally complex food Gels lead to greater satiation. The primary rationale for this hypothesis was rooted in the mechanics and sensory experiences of eating. Foods with higher textural complexity often require longer oral processing (chewing) and increased oral stimulation (Larsen et al., 2016; Miquel-Kergoat et al., 2015). Consequently, foods with more complex textures might contribute to quicker feelings of fullness, reducing food intake (Suzuki et al., 2012).
1.9 Structure of Thesis

The thesis commences with an introduction, chapter 1, highlighting the importance of understanding food texture and its impact on satiation and satiety. It delves into physiological factors of satiety and previous research, shedding light on some research gaps and outlining the study's significance, objectives, and structure. Chapter 2 is the literature review, exploring core concepts about textural complexity, perception of textural complexity, the biology of satiation, and measuring and designing textural complexity. The chapter continues to illuminate the relationship between texture and satiation, examining empirical evidence on various food forms and texture offering analytical reviews of the impact of textural complexity on satiation and the role of oral processing time. Chapter 3 describes the research methodology, detailing participant demographics, the creation of culinary Gels, and procedural strategies for data collection and analysis. Chapter 4 presents the results, focusing on a detailed analysis of textural complexity score, appetite ratings, and oral processing time. Lastly, chapter 5 discusses findings, comparing them to existing research, addressing limitations, and suggesting avenues for future research, ending in concluding remarks.
Chapter 2: Literature Review

Complexity in food is a multifaceted sensory experience that combines a blend of flavours, textures, aromas, and visual elements to create a layered culinary experience. In texturally complex food, each ingredient contributes its unique profile, interacting with others to produce depth and nuances. This interaction often results in textures that are not immediately identifiable individually but contribute to a richer, more engaging whole. Complexity in food is not just about the number of ingredients but how they are combined, influencing the overall perception of the food item. It challenges the palate, offering a dynamic experience due to its intricacy and balance.

This chapter provides a comprehensive exploration of textural complexity within the context of food, detailing the methods for designing and measuring it and strategies used to manipulate textural complexity. It further delves into the relationship between textural complexity and satiation, and the influence of textural complexity, pleasantness, and the duration of oral processing on the sensation of being satiated. The chapter concludes by summarising current research discussing textural complexity's impact on satiation.

2.1 Texture: Definitions and Explanations

2.1.1 Food Texture

Food texture was the sensory reflection of structural, mechanical, and surface properties detected through vision, hearing, touch, and kinaesthetics (Szczesniak, 2002, p. 215).
Kinaesthetics relates to the feel of food, primarily mouthfeel (Kramer & Twigg, 1960). Texture arises from a food's physical structure and component interactions (James, 2018). Perception of food texture comes from multiple senses and varies based on the food's structure (Hutchings et al., 2012; Santagiuliana et al., 2018a), environmental factors (Zampini & Spence, 2004), and the individual's physiology and experiences (Engelen & Van Der Bilt, 2008; Hutchings et al., 2014). Food texture was essential for quality and consumer preference (Çakır et al., 2012).

### 2.1.2 Texture Perception

The primary gustatory cortex in the brain helps in recognising food texture, but distinguishing texture from taste was challenging (Grabenhorst & Rolls, 2014; Kadohisa et al., 2005; Verhagen et al., 2006). Some brain regions specifically respond to taste, texture, or both (Rolls et al., 2003; Verhagen et al., 2004). In the orbitofrontal cortex (OFC), which plays a role in liking of food, neurons react differently to varying textures, indicating its role in texture sensing (Rolls, 2015; Rolls, 2019, 2020). The oral somatosensory cortex also aids in texture detection. When individuals consumed high-fat foods, the oral somatosensory cortex showed increased interaction with the OFC, a region linked to the reward value of food (Grabenhorst & Rolls, 2014).

During mastication, food texture sensations were perceived through oral sensory receptors and transmitted to the central nervous system via the trigeminal sensory system (Engelen, 2012; Engelen & de Wijk, 2012). This feedback guides adjustments to food handling, with texture perception changing based on how food interacts with mouth organs and saliva. The human body has four types of receptors: touch, temperature, chemicals, and electromagnetic. All of these were present in the mouth except for the electromagnetic ones (Engelen & de Wijk, 2012). The sense of how food feels was not just from one kind of receptor; it mainly comes from touch receptors in the gums, tongue, and palate (Engelen & Van Der Bilt, 2008).
These tactile receptors convey the hard, soft, and crunch textures of the food. Tongue movements and saliva help break down the food and make it easier for these receptors to detect the texture (de Wijk et al., 2003; Engelen et al., 2007). It was challenging to understand which receptors perceive the food texture, given the complexity of distinguishing the texture from factors such as the bite force or the speed of mastication. (Foegeding et al., 2011). However, the ability to feel food in the mouth helps to know its size, shape, and other features (Guinard & Mazzucchelli, 1996). Oral anatomy varies among individuals, leading to potential variations in the perception of textures. Factors like age, gender, and even the ability to taste can affect how perception of food in the mouth (Engelen & Van Der Bilt, 2008; Ketel et al., 2019; Zhou et al., 2021).

2.1.3 Textural Complexity

Only a few studies have researched the textural complexity of food itself (Tang et al., 2017). The present thesis describes textural complexity as ‘the number and intensity of texture sensations, as well as their interactions and contrasts’, adapted from Patterson et al. (2023, p.2). Larsen et al. (2016a) and Zhong (2020) defined it as the many noticeable textures and sensations experienced from the initial bite until swallowing the food. Patterson et al. (2021) noted that the overall textural complexity also rises as the number of perceived textures (such as those felt through mouthfeel, touch, or sight) increases and their uniqueness becomes more pronounced. Tang et al. (2017) stated that grasping the concept of food texture can be a complex process. Individuals perceive and describe it differently, using varied expressions and terminologies. Since this is an emerging concept, researchers have approached and interpreted it differently. The variation in definition comes from the difficulty of studying the concept due to the impact of individual variability (Conner et al., 2017; Taylor et al., 2009; Machado-Oliveira et al., 2020; Weston et al., 2019).
Interestingly, different regions have distinct texture terminologies; for example, while the US and Austria might describe a portion of food as "crisp," Japan might refer to its "hard-soft" nature (Bourne, 2002, p. 5; Hayakawa et al., 2013). Japan boasts over 400 texture descriptors, many being onomatopoeic (Yoshikawa et al., 1970; Hayakawa et al., 2015). Food texture is critical in the perception and identification of different products. Chewing habits change and adapt in response to different food textures. Therefore, oral processing was essential to study because texture affects how long food stays in the mouth, known as oral processing or oral transit time. The length of oral transit time was linked to fullness or satiation (Zijlstra et al., 2008, 2009; Weijzen et al., 2009; de Graaf & Kok, 2010; Zijlstra et al., 2010). Although most studies on this topic have focused on liquids and semi-solid foods (Zijlstra et al., 2007; Wijk wt. al., 2008; Hongenkamp et al., 2011; Tsuchiya et al., 2006), there was also some evidence suggesting that the texture of solid foods may have a similar effect on satiation (Hogenkamp et al., 2011).

Previous studies often used foods with a single, uniform texture to make it easier to study chewing (Tang et al., 2016; Forde et al., 2013). Prior studies suggest that varying textures in food affect chew time and perception of food, which could ultimately impact satiation, regardless of oral processing time. For instance, a study found that adding sucrose to different layers of gelled food enhanced perceived sweetness (Holm et al., 2009; Mosca et al., 2010). Chewing for longer and experiencing intense sensory signals were linked to feeling fuller (Blundell et al., 2010; Bolhuis et al., 2011). Instrumental measurements and sensory analysis to quantify food texture have improved over time (Oraguzie et al., 2009; Zdunek et al., 2010a, b). Texture assessment was complex and depends on food properties, structure, individual perception, and how it has broken down in the mouth (Bitnes et al., 2009; Cain & Drexler, 1974; Wilkinson et al., 2000).
2.1.4 Sensory Complexity

Sensory complexity, as described by Paulsen et al. (2012), refers to feeling and sensing various tastes and flavours all at once when studying how sauces play a role in sensory perceptions of meals. Mielby et al. (2013) described it as energy spent using cognitive functions such as noticing how pleasant the food appeared visually and liking the tactile sensations felt in a mouthful. Sensory complexity, consisting of taste, texture, and odour, was challenging to define and measure (Palczak et al., 2019b). While physical complexity was contingent on the number of product components (Kildegaard et al., 2011; Olabi et al., 2015), perceived complexity comprises both stimulus and individual perception. Increasing components does not necessarily augment perceived complexity, as interactions between components can enhance or mask sensations (Bitnes et al., 2009; Cain & Drexler, 1974). The wine industry's usage of "complexity" was often vague. Although wine has a multitude of organic and inorganic constituents, making it objectively complex (Thorngate, 1997), this does not equate to perceived complexity.

Palczak et al. (2019b) classified definitions of perceived complexity into sensory, cognitive, and emotional categories. Sensory complexity relates to the number and progression of perceived sensations (Bitnes et al., 2009; Lévy et al., 2006; Paulsen et al., 2015). Participants' definitions of complexity generally align with this sensory perspective (Palczak et al., 2019a). Specifically, Palczak et al. (2019a) outlined six criteria for sensory complexity, with the perception of many sensations and textures as commonly chosen ones. Cognitive definitions pertain to component identification, with complex mixtures making component recognition difficult (Lévy et al., 2006; Meillon et al., 2010). Mielby et al. (2012) linked complexity to the effort to discern mixture components. Emotionally, complexity was associated with surprise or unexpected sensations (Reverdy et al., 2010; Palczak et al., 2020). Berlyne (1960) viewed complexity as a product of physical attributes and individual
experiences, emphasising the diversity and interplay of stimulus units (Berlyne, 1967).

Jellinek and Köster (1979) provided a four-part definition for aroma complexity, underscoring the dynamic progression of sensations as a critical factor (Larsen et al., 2015; Palczak et al., 2019b). Nakao et al. (2013) found that uneven aroma distribution led to higher perceived intensity and longer oral transit time (Nakao et al., 2013).

2.2 Design and Measurements

2.2.1 Designing Textural Complexity

Researchers created food models to study the effects of different textures on taste and post-eating feelings. They can manipulate these models to achieve different textures using gelatin or other ingredients (Guinard & Mazzucchelli, 1996; Kohyama, 2020; Meullenet et al., 1998). Some studies have focused on changing the hardness, size, or amount of a single component in the food model (Aguayo-Mendoza et al., 2020; Aguayo-Mendoza et al., 2021; Santagiuliana et al., 2020; Santagiuliana et al., 2018a; Santagiuliana et al., 2019a; Shewan et al., 2020; Stribitcaia et al., 2020b). Some researchers have started to add more components to their food models to make them even more complex, and they found that having more textures could make people feel full faster (Larsen et al., 2016; Tang et al., 2016). However, these studies often needed to consider how much people liked the taste of these foods and how that might have affected their results (Patterson et al., 2021).

2.2.2 Measuring Textural Complexity

Measuring and assessing texture involves both subjective sensory evaluations and objective instrumental measurements, which were necessary (Bourne, 2002). The approach to measuring firmness varies depending on the food, such as using viscosity for soft foods or applying pressure for firmer ones. Similarly, researchers determine the perceived viscosities of different foods under various shear stresses and strains. Humans also adjust their food consumption based on perceived texture (Szczesniak & Bourne, 1969; Shama & Sherman,
1973). Bridging the data gap between objective and subjective methods requires examining physical changes in food during consumption (Nishinari & Fang, 2018). Physiological measurements can link instrument readings with sensory assessments. Instruments with built-in sensors can objectively record data during consumption, measuring force, pressure, movement, and muscle activity (Wilkinson et al., 2000; Bourne, 2002; Koç et al.,; Kohyama, 2015). Bourne (1975) noted that rheology-based instrumental measurements only capture some physical properties felt in the mouth, such as size changes, moisture, temperature, and surface roughness.

Tribological measurements were associated with mouthfeel (Chen, 2009; Chen & Stokes, 2012; Stokes et al., 2013). Depending on the food thickness during oral processing, different properties like firmness, creaminess, or astringency predominate. Both rheology and tribology can study these properties at different stages of oral processing (Stokes et al., 2013). Three studies have delved into the intricacies of textural complexity using two distinct sets of samples. Larsen et al. (2016b) examined how gel samples of medium and high textural complexity were broken down orally compared to a more consistent, homogenous sample. The findings indicated that the overall complexity of the sample did not drastically alter the duration of oral processing or the chewing speed. However, the samples with high textural complexity exhibited a unique breakdown pattern, disintegrating into a greater number and size of particles during the initial stages of oral processing.

Further exploring this realm, Tang et al. (2017) performed puncture experiments on five gelatine-agar blends, each with different textural attributes. They then mapped out the deformation in relation to the load applied. The data revealed that as the structural intricacy of the samples varied, so did the observed patterns in the resultant puncture graphs. The low-complexity samples yielded a straightforward curve. In contrast, the curves for the more
intricate samples were characterised by a range of pronounced peaks, suggesting disparities in the mechanical interactions within the samples.

**2.2.3 Sensory Measurements.** Sensory evaluations delve into psychophysics, exploring the transformation of physical stimuli into psychological experiences. In the context of food, it assesses how humans perceive specific characteristics like the crunch of a chip or the smoothness of pudding. Friedman (1963) and Brandt et al. (1963) introduced a classification system for texture attributes such as hardness, chewiness, and viscosity that was widely accepted. While the methodology by Szczesniak and colleagues primarily emphasises touch, it also considers visual and auditory attributes (Brandt et al., 1963; Szczesniak, 2002; Bourne, 2002). Although evaluations were not limited to touch, the in-mouth experience was crucial in texture assessments. Techniques such as Quantitative Descriptive Analysis (QDA) and the Check-all-that-apply (CATA) approach were employed (Stone et al., 2004; Lazo et al., 2016).

It was also noteworthy that as food transitions from hand to mouth, the perception of its texture changes (Chen, 2009; Nishinari & Fang, 2018).

Sensory evaluations of diverse samples involved combinations of descriptive, discrimination, and temporal methods, using either trained sensory panels (Shewan et al., 2020) or untrained participants (Santagiuliana et al., 2018a; Stribiţcaia et al., 2021).

Santagiuliana et al. (2018a) employed the Rate-All-That-Apply (RATA) method to assess samples with beads of different sizes and stress levels. Notably, bead size influenced the sensory attributes chosen, while the stress level affected their perceived intensity. For example, samples with smaller beads felt grittier. Conversely, Stribiţcaia et al. (2020) had participants evaluate bead-layered gels against homogenous ones for texture. They found that while the layered texture was detectable, bead size was not. Santagiuliana et al. (2018b) had participants continuously rate sample heterogeneity during chewing.
Results showed that differences in fracture stress determined the detection of heterogeneity. Meanwhile, Aguayo-Mendoza et al. (2021) used the temporal dominance of sensations to compare cheeses. This method focuses on the most dominant sensation at a time, with results indicating varied dominance patterns depending on the sample's consistency. Lastly, some studies delved into oral processing behaviour, like those by Aguayo-Mendoza et al. (2021) and Devzeaux de Lavergne et al. (2016). These used tools like video recording or electromyography to understand chewing patterns, revealing that harder gels led to prolonged chewing. Larsen et al. (2015) evaluated three samples: homogeneous, medium, and high complexity. Their approach used descriptive evaluation and an adapted texture profiling method with 20 participants not explicitly trained. Seven texture characteristics showed higher intensity scores for the high complexity sample than its counterparts.

Moreover, as complexity increased from homogeneous to high complexity, there was a notable uptick in the number of highlighted attributes. Similarly, Tang et al. (2017) embarked on a sensory exploration of five different textural complexity (TC) samples. Their methodology hinged on generating texture characteristics, gauging the intensity of 12 texture attributes with 20 participants, and applying the temporal dominance method with 12 participants who needed training for such evaluations. Their findings demonstrated that the generation of texture characteristics was directly proportional to structural intricacy. The texture of the sample with the highest complexity, TC5, was assessed to be particularly strong in attributes such as hardness, crunchiness, crispness, and roughness. Temporal dominance observations supported a consistent growth in complexity from TC1 through TC4, with the frequency of texture attribute changes increasing and more distinct characteristics emerging as dominant. Interestingly, for TC5, the dominant sensations were less, yet many sensations lingered just below the significance threshold, suggesting an underlying complexity.
2.2.4 Instrumental Measurements: Instrumental evaluations rooted in physics and chemistry utilise machinery and tools to discern the physical and chemical attributes of food. Researchers classify texture measurement methodologies into three primary categories: fundamental, empirical, and imitative (Scott-Blair, 1958; Rosenthal, 1999; Bourne, 2002). Methods based on disciplines like rheology provide intricate details but might not always correlate with human texture perceptions (Scott-Blair, 1958; Rosenthal, 1999; Bourne, 2002). Scott-Blair (1958) and Rosenthal (1999) highlighted the value of these fundamental approaches. On the other hand, Bourne (2002) extolled the practicality of empirical techniques, with the Magness-Taylor puncture tester being a prime example. However, the reliability of empirical methods was sometimes questionable. Imitative methods, such as the Texture Profile Analysis (TPA), were tailored to mimic human interaction with food. Initially, TPA employed a texturometer, simulating chewing to uncover characteristics like food hardness. This method often resonates with human sensory feedback, a link that Szczesniak (1968) delved into deeper. Over time, TPA's role in analysing texture alterations during oral processing has grown, as discussed by Shiozawa et al. (1999) and Nishinari et al. (2018).

Acoustic tests also provide texture insights, particularly for crunchy foods. When crunched, these foods produce sounds which can be indicators of texture. These acoustic emissions, a result of the liberation of pent-up elastic potential energy, can be linked to food texture. Drake (1965), Vickers (1976), and Vickers and Bourne (1984) have intensively researched the relationship between these sounds and perceived crispness. The crispness or breakability of food can often be gauged from its auditory feedback during consumption. Contemporary research has incorporated acoustic detectors and texture analysers, as demonstrated by studies from Chen et al. (2005) and Taniwaki and Kohyama (2012), to understand the relationship between emitted sounds and exerted force in crispy edibles. The
puncture test, by Tang et al. (2017), was quintessential for understanding textural intricacies. A cylindrical probe was used, which journeys through the food sample, noting various layers or components. The resultant curve can shed light on texture layers, depth, and complexity.

Rheology, which revolves around the deformation and flow of substances, correlates with the human sensation of food texture during mastication. Initially defined by Bingham (1930) and later honed for food-specific applications by experts such as White (1970), rheology remains pivotal in texture analysis. Visual elements combined with flavours offer a holistic understanding of food's viscoelastic properties. Although microscopic and spectroscopic analysis was standard in scientific domains, human perceptions typically draw from a confluence of visuals, taste, and aroma, especially during oral consumption. This intertwining of sensory experiences and flavour release, as detailed by Kohyama (2015) and Verhaegen and Engelen (2006), significantly impacts overall perception of food texture and nature. In a comprehensive exploration of physical properties, several research endeavours incorporated particles, spheres, or cube-like inclusions into gels or genuine foods. The primary focus of these studies was to evaluate their mechanical characteristics. Preliminary research by Aguayo-Mendoza et al. (2021) and Shewan et al. (2020) investigated the fracture attributes of these inclusions and their encompassing matrix. Follow-up studies delved into the combined gel sample's fracture traits, rheological tendencies, and tribological features. Some mechanical tests, like those conducted by Santagiuliiana et al. (2018a) and Tang et al. (2017), deduced nuanced variations. In an exhaustive study, Stribițcaia et al. (2020) analysed diverse gels containing calcium alginate beads embedded in a κ-carrageenan matrix. The gels unveiled insights into the bolli's viscosity and tribological properties. Interestingly, the bead size did not affect the multi-layered gels' rheological behaviours or the resulting bolli, but it did influence their lubricative properties.
2.3 Manipulating Textural Complexity in Food

To effectively manipulate textural complexity and understand its impact on both satiation and satiety, knowledge of both the physical and perceptual aspects of texture was required. There was not a direct correlation between the two. While more textural elements lead to greater complexity, the perceived intricacy hinges on how identifiable each component was and how these components relate or even clash when mixed (Kroeze, 1990; Schifferstein, 1992). Perceived complexity was not just about the sum of its parts (Bitnes et al., 2009).

Additionally, examining the impact of introducing textural attributes to food was complex, as these attributes often bring about sensory characteristics beyond mere texture. For instance, Marcano et al. (2015) aimed to boost the complexity of cheese pies by introducing visible particles such as wheat bran, ground coconut, flaxseeds, and oatmeal. The visible particles altered the pies' texture and influenced their flavour, appearance, and appeal. Hence, although one might demonstrate an uptick in overall sensory complexity, pinpointing which aspects—flavour, texture, visual, or aroma—played a role can be elusive. Likewise, determining which physical ingredients influenced perceived complexity (like wheat bran versus ground coconut) was difficult. An accurate texture assessment as a sensory factor demands control over other sensory variables.

Gel-based model foods offer a systematic method to integrate and study multiple texture properties simultaneously while minimising confounding factors in texture perception (Hutchings et al., 2011). One strategy involves utilising proteins, like whey protein, and polysaccharides, like gelatine, agar, and κ-carrageenan to create specific structures. Campbell et al. (2016) argue that mixed gels of proteins and polysaccharides serve as exemplary model foods that mirror the composition and functional characteristics of semi-solid and soft-solid foods. When these molecules merge, they can exhibit solubility, phase separation, or complexation, giving rise to various structures and textures (Tolstoguzov, 1986). By adding
colourants, flavourings, sugar, and salt, these gels can more closely resemble commonplace commercial foods like dairy items and candies.

Some studies have examined textural variation by introducing a single physical element with differences in polysaccharide levels, firmness, dimension, and count, typically using spherical or cubical polysaccharide particles in gel chunks (Aguayo-Mendoza et al., 2021; Santagiuliana et al., 2020; Santagiuliana et al., 2018a; Santagiuliana et al., 2019a; Santagiuliana et al., 2019b; Shewan et al., 2020; Stribiţcaia et al., 2020). In contrast, specific investigations modified the core matrix where this element was embedded (Hutchings et al., 2011; Laguna & Sarkar, 2016). Additional research has explored textural differences using dual-layered gels (Devezeaux de Lavergne et al., 2016; Santagiuliana et al., 2018b). Santagiuliana et al. (2018b) directly assessed noticeable variation in dual-layer, agar, κ-carrageenan, and gelatin gels with rigid and supple layers with differing stress points. The outcomes of these variations on observed textural differences and sensory characteristics (Santagiuliana et al., 2018a; Shewan et al., 2020; Stribiţcaia et al., 2020), likability factors (Santagiuliana et al., 2019c), oral dynamics (Aguayo-Mendoza et al., 2021; Shewan et al., 2020), and recognition (Petersson et al., 2013; Santagiuliana et al., 2019b) have been scrutinised. Studies exploring perceived variation described it as a "noticeable texture difference during chewing, signifying a sample has both soft and hard segments" (Santagiuliana et al., 2018a, p. 206). While these food samples were undeniably varied, they possess two distinct elements: an external matrix and inclusion, or regarding beads, a set of consistent additions. The design of textural heterogeneity was advanced by Tang et al. (2017), Larsen et al. (2015), and Larsen et al. (2016b). These researchers illustrated a favourable link between the intricacy of texture and feelings of fullness (Larsen et al., 2016a; Tang et al., 2016). Using gel-based foods, they crafted items with varying textural complexities, ranging from three to five stages. These researchers employed layering
techniques with gel disks and integrated sunflower and poppy seeds to enhance the physical texture. It was the inclusion of these elements that amplified the textural depth rather than the potency or prominence of individual textural features. The perception of textural complexity was not the primary focus. However, it was inferred from mechanical and sensory evaluations, such as the count and strength of chosen attributes.

2.4 Satiation

In this thesis, the concept of textural complexity was defined as the number and intensity of texture sensations and their interactions and contrasts (Patterson et al., 2023, p.2). The subsequent sections of the literature review explore the implications of varying food forms and viscosities on satiation, emphasising that distinct oral textural experiences arise from changes in food form. This transformation in food form inherently leads to a modification in its texture, which aligns with the previously discussed manipulation of food texture and the definition of textural complexity.

2.4.1 Relationship between Textural Complexity and Satiation

A direct connection exists between the central nervous system and the gastrointestinal tract. Communication between the two was crucial in managing appetite and regulating energy balances. These links often decide how much food was needed, maintain metabolism, and regulate satiation (Berthoud, 2008; Camilleri, 2015; Harrold et al., 2012; Sanders et al., 2012). Some studies (Berthoud, 2008; Camilleri, 2015; Harrold et al., 2012; Ni et al., 2022) have suggested that gut hormones such as ghrelin, leptin, and peptides rise and fall before and during eating episodes to signal the onset of hunger and satiation. Gut hormones affect both the hypothalamus and the brain stem. Suggesting that hormones do influence feelings of fullness. However, delving deep into this subject was beyond this study's scope.

The body's cephalic phase responses (CPRs) were physiological reactions to sensory cues that prepare the digestive system for incoming nutrients (Zafra et al., 2006). These CPRs play
a role in feeling full and encompassing processes like salivation and the release of hormones such as cholecystokinin (CCK) and glucagon-like peptide 1 (GLP-1) (Smeets et al., 2010). Consuming foods with low textural complexity too quickly might not provide enough sensory feedback, implying that the brain signals responsible for feeling satisfied might not activate in time. Food intake was influenced by three main signals: satiety signals, signals related to body fat, and central effectors (Woods, 2004). Satiation relates to how the stomach adjusts to food, but the stomach does not detect food types well. Instead, feelings of fullness (satiety) were tied to signals from other parts of the digestive system (Camilleri, 2015). According to Finlayson & Blundell's (2012) version of the satiety cascade, appetite control was affected by four main signals: sensory, cognitive, pre-absorptive, and post-absorptive. Their model suggests that the manner in which individuals think and feel about food influences consumption. It also says that post-meal feelings combine various signals processed in the brain regions responsible for managing hunger, like the hypothalamus and cortico-limbic structures (Berthoud, 2007).

Most of the food eaten daily was not just a single texture but a mixture of many different textures. For example, consider a chocolate bar containing nuts and caramel or yoghurt mixed with fruit chunks. These foods were often more enjoyable than food with a single texture because of the diversity of textures felt in the mouth. (Emorine et al., 2014; Mosca et al., 2012). Like in art, complexity and novelty can make things more exciting (Berlyne, 1971). Some researchers believe this applies to food, too, suggesting that the perfect mix of textures could make a food item even more desirable (Lévy et al., 2006; Palczak et al., 2020). Food with a mix of textures might increases feelings of fullness quicker, resulting in more prolonged satiation (Hogenkamp et al., 2011; Krop et al., 2019; Larsen et al., 2016; Marcano et al., 2015; Stribitcaia et al., 2020a; Stribitcaia et al., 2021; Tang et al., 2016; Tarrega et al., 2016). Hetherington et al., 2013). Eating foods with complex textures can make people feel
full because of increased oral stimulation (Raynor & Epstein, 2000). This could be especially helpful for people trying to eat healthier because feeling satisfied could stop them from snacking too much (Chambers et al., 2015). Tasting and chewing food leads to greater satiation than introducing the same food directly into the stomach without tasting (French & Cecil, 2001). Wijlens et al. (2012) found that tasting food (oro-sensory exposure) alone can help reduce food intake. Chewing longer and taking smaller bites increase taste exposure. It signals the brain about incoming calories and decreases food consumption (Lasschuijt et al., 2020). Prolonged food tasting might desensitise the taste buds, reducing consumption (Campbell et al., 2017; Mars et al., 2009; van den Boer et al., 2017). Eating quickly and chewing less can lead to eating more and gaining weight (Li et al., 2011; Ohkuma et al., 2015).

Numerous research have investigated the modification of food textures and its influence on mastication duration. This entails modifications like thickening a beverage (Mars et al., 2009) or changing the consistency of solid food items (Bolhuis et al., 2014; Hogenkamp, 2014). Such changes can blur the relationship between texture and the duration of chewing in relation to satiety. It remains to be clarified whether texture alone, independent of chewing duration or eating speed, influences feelings of fullness (James, 2018). In examining the impact of texture on satiety, it was important to factor in chew time, consumption rate, taste, and caloric value. However, applying this in practical settings can be challenging. For example, adding visible particles to cheese pies changed their taste, look, and probably how much people liked them (Marcano et al., 2015). In this example, it would be difficult to pinpoint what specific change led to the increased perception of complexity, given the potential impact on the amount eaten and the need to understand how food texture impacts satiation. Therefore, it was essential to know more about texture complexity in food (Santagiuliana et al., 2018b).
Sensory-specific satiety (SSS) refers to the idea that the more you eat a particular food, the less appealing it becomes compared to foods you have not eaten recently (Rolls et al., 1981a). Foods with distinct textures can strengthen this feeling, enhancing the sensation of fullness promptly or reducing the inclination to consume further and enhancing the sensation of fullness promptly or reducing the inclination to consume further. (Guinard & Brun, 1998; Smeets & Westerterp-Plantenga, 2006). However, foods with various tastes and textures might reduce this fullness feeling. Simply put a meal with much variety can make one eat more (Pliner et al., 1980; Rolls et al., 1981b; Rolls et al., 1983). Thus, if a food exhibits a variety of flavours and sensations, it may induce satiety slowly. Regarding hunger, repeated sensory exposure can lead to a quicker onset of satiety or fullness when consuming the same food item, thereby reducing the overall amount ingested. Conversely, introducing a variety of sensory experiences within a meal through differing tastes, textures, or flavours can delay the onset of satiety, leading to increased consumption. Fundamentally, when the gustatory receptors experience a diverse range of sensations, the inclination to persist in consumption may increase, resulting in diminished feelings of fullness or satiation (Berlyne, 1971; Dember et al., 1957).

2.5 Effect of Textural Complexity on Satiation

Food texture and structure play an essential role in satiation responses, as shown by many studies (Forde & Bolhuis, 2022). Foods with the same nutrient content can influence appetite differently due to factors beyond nutrient metabolism. A meta-analysis showed that out of 29 studies on food texture's impact on satiety, 16 confirmed its effect on curbing hunger and enhancing fullness (Stribitcaia et al., 2020a). Almiron-Roig et al. (2013) also found texture's influence on satiation in preload studies, though solid preloads were minimally represented.

In this section, food types differing in viscosity and texture in the form of solids, liquids, semi-solids, soft-solids, semi-liquids, chunky, and puréed foods were experimented with to
test their effects on satiation and satiety. The studies below show how these different textural complexities in food form affect satiation.

2.5.1 Solid Foods

Bolhuis et al. (2014) concluded that changes in food textures could be a helpful tool in weight management. In their study, 50 participants of Chinese nationality were tested who had a BMI of $21 \pm 2\, \text{kg/m}^2$. Participants were between the ages of 20 and 29 years. Results showed that the hard hamburger led to 9% less consumption than the soft one. Similarly, hard rice salad was consumed 17% less compared to soft rice salad. It was noted that the overall oral processing time for hard foods was ~32% lower than that of soft foods.

Likewise, Zijlstra et al. (2010) attempted to study the effect of texture differences on satiation (*ad libitum*) in three pairs of solid foods. The products used for testing were specially developed luncheon meat, meat replacers, and sweets. Each product had a hard and a soft version. All participants fell within the normal weight range (BMI 18.5-25 kg/m²). Results suggested that the mean intake of the foods did not differ significantly. However, it was interesting to note that most participants chose the soft version of the foods compared to the hard. Eating was considerably slower for hard foods vs soft. Liking scores were significantly correlated to *ad libitum* intake and eating rate. The authors concluded that the texture differences in the foods may have been too subtle to notice any significant differences in satiety.

Similarly, Cahayadi et al. (2020) studied the textural effects of snack foods (potato chips) on perceived satiation in males and females. Those with a healthy BMI were chosen to participate: 31 females and 43 males. Two types of potato chips were used for testing; one group remained untreated, and the other group was treated with pulsed electric fields (PEF). This made the treated potato chips harder (i.e., crunchier) than the untreated batch. Chips were randomly picked from a vacuum-packed bag of chips. Participants were served an oat-
based breakfast and were asked to eat until they felt full. Forty-five minutes later, the chips were randomly served, and participants could ask for refills. Despite a textural difference, the chips shared the same hedonic value. Results indicated across sexes a significant difference in perceived satiation ($p = 0.009$) but not in intake. However, analyses for males alone found the PEF-treated chips more satiating and consumed significantly less ($p=0.05$). Results from the t-test on sensory data show that participants found the PEF–treated chips to be significantly crunchier ($p<0.01$). However, there were no significant differences in means for liking and crispiness.

Marcano et al. (2015), in their study, experimented to see if adding complexity to food would yield higher expectations of satiation capacity. Various 'visible' food texture ingredients were added to cheese pies to create an 'appearance' of texture and enhance the cheese pie's textural complexity. Six variations were made by adding particples such as wheat bran, ground coconut, flaxseeds, oat flakes, and addition of dairy cream to manipulate texture and appearance. Lastly, there was the basic cheese pie. Results showed that harder pies, resistant to penetration and of higher complexity, showed higher expectations of satiating capacity. Pies that were perceived as more complex were also perceived to be more satiating. The significantly softer and deformable sample scored lower on expected satiating capacity.

### 2.5.2 Liquid Food

Vuksan et al. (2009) aimed to assess food intake and appetite regarding liquid viscosity. Three liquid preloads, each containing 5g of either a high (novel viscous polysaccharide; NVP), medium (glucomannan; GLM), or low (cellulose; CE) viscosity fibre, were used. Participants consumed one strawberry-flavoured preload 90 minutes before the ad-libitum pizza meal. Thirty-one healthy-weight adolescents (BMI 22.2 ± 3.7 kg/m$^2$) between the ages of 15 and 18 were selected. Results concluded that pizza intake was significantly lower
after consumption of the high viscosity fibre preload drink (NVP) compared to the medium (GLM) and low viscosity fibre preload drink (CE). A 38g and 35g reduction in pizza intake eventually led to an 85kcal and 78kcal caloric difference in food consumption, respectively. However, no significant differences were found in pizza consumption between medium (GLM) and low (CE) viscosity fibre preload drinks. No significant differences were found in 24-hour food intake after consumption of the different preloads.

McCrickerd et al. (2014) manipulated drink viscosity to see if they influenced expected satiety and food intake. Forty-eight participants (24 female) with a healthy BMI (22.5 kg/m²) between 18 and 52 years participated in the study. They consumed an iso-energetic drink in four sensory contexts: thin and low creamy, thin and high creamy, thick and low creamy, and thick and high creamy. Results indicated that males consumed the same amount of food irrespective of sensory context; however, females consumed less of the thick drink. Overall, increasing the perceived thickness by subtly increasing viscosity led to less consumption but generated the same expectations of satiation. Another interesting finding was that the creamy flavour did not affect intake, but the thicker drinks were associated with perceived creaminess.

In a previous paper, McCrickerd et al. (2012) examined if subtle changes in the flavour and texture of a drink would enhance expected satiety. Participants were divided into two groups to rate a fruit yoghurt drink based on its different textures and viscosities. Results showed that subtle manipulations in textures and the creamy flavour of a drink could suppress hunger despite its energy content; this was not in line with the research mentioned above. While a thicker consistency enhanced expected satiety to a greater extent than the creamy flavour in beverages.

Taking the thickness of a drink into consideration, Bertenshaw et al. (2013) studied the increasing effects of protein on satiety to determine if it was protein alone or its sensory
properties that increased satiety. Three high drink preloads and one low energy (LE) preload were developed to distinguish its nutritive characteristics from the sensory characteristics. Two of the higher energy drinks had 44% of energy from protein. One had the sensory attributes of a juice drink (HP – low sensory protein), and the other was thicker and creamier (HP + high sensory protein). The high carbohydrate preload was matched in thickness and creaminess to HP+ drink (HC+ high sensory carbohydrate). Results indicated that though protein did increase satiety, sensory cues of creaminess and thickness played an important role. The satiety ratings were similar for protein- and carbohydrate-based drinks (matched in thickness and creaminess). Even though protein was usually more satiating than carbohydrates, it was not the case here, although more research was needed to confirm these findings. In contrast, results indicated a significant difference in satiety ratings for drinks that matched protein content but differed in thickness and creaminess.

2.5.3 Semi-Solid Foods

Zhu et al. (2013) conducted a study exploring the correlation between the viscosity of semi-solid foods and its potential implications for appetite regulation. The test preload meal consisted of chocolate pudding that had two versions. The first was a standard version (SV), and the second was a high viscosity (HV) version achieved by adding guar gum to the pudding. The study showed a significant effect of viscosity on hunger ($p = 0.019$). Hunger ratings were lower, and fullness ratings were higher when participants consumed the HV version of the pudding. Desire to eat was also significantly lower ($P<0.001$) after consuming the HV version of the chocolate pudding. Overall, the data suggested that increasing the viscosity of the semi-solid chocolate pudding resulted in a slower eating rate, reduced hunger, desire to eat, and increased fullness compared to the SV version.
2.5.4 Solid and Liquid Foods

DiMeglio et al. (2000) found in their study of liquid vs solid carbohydrates that liquid energy-yielding drinks elicit positive energy balance, whereas comparable carbohydrates elicit precise dietary compensation. Their study raised some essential ideas when considering liquid vs. solid foods and their impacts on satiation and food intake. Of interest were some questions they posed: Did cognitive influences contribute to the findings in their paper? Since solid foods have higher energy content, did participants naturally consume less?

Stull et al. (2008), in their study experimenting with liquid vs. solid meal replacements, found that, on average, participants consumed 13.4 % more ad–libitum (oatmeal) after liquid meal replacements vs. solid meal replacements. Subjects were required to fast overnight and consume either a beverage (liquid) or a bar (solid) as their test meals. Participants reported that hunger and desire to eat were higher ($P = 0.04$) ($P = 0.15$) after liquid meal replacement consumption.

Similarly, Leidy et al. (2010), in their paper studying 'food form and portion size affects postprandial appetite sensation and hormonal responses in healthy, non-obese, older adults, found the following. The test meals presented to the participants were meal-replacement shakes (beverages) or meal-replacement nutrition bars (solid); these were matched in energy and macronutrient content. However, it was important to note that these meals did not have dietary fibre in either solid or liquid form. As expected, older adults experienced greater hunger, desire to eat, and lesser satiety after consuming the beverage compared to the solid meal replacement. One reason could be the fluctuation in hormonal levels (ghrelin and insulin) after consuming beverages. Lastly, results also showed that portion size influenced the appetite of older adults. Smaller portions created a greater desire to eat and higher hunger levels than larger quantities.
Compared to liquid-based foods like apple juice or sauce, consuming solid or semi-solid foods such as an whole apple has demonstrated a greater effect on suppressing appetite, as indicated by appetite scores (Flood-Obbagy & Rolls, 2009; Hogenkamp et al., 2012; Viskaal-van Dongen et al., 2011). Hogenkamp et al. (2012) attributed these outcomes to the early activation of the satiety cascade via cognitive and sensory signals. Similarly, DiMeglio and Mattes (2000) discovered that when given a liquid food as a preload compared to an equivalent calorie solid food preload, the liquid option resulted in a notably reduced energy consumption.

2.5.5 Liquid and Semi-Solid Foods

Zilstra et al. (2007) studied the effect of viscosity on ad libitum food intake. Two situations were used to test 108 participants. The other was a laboratory setting where 49 non-restrained participants were tested. Participants in the real-life setting consumed a chocolate-flavoured liquid, semi-liquid, and semi-solid milk-based product similar in energy content. In comparison, participants in the laboratory received the liquid or semi-solid product. Results showed that overall, the consumption of liquids was 30% higher than semi-liquid and semi-solid products. For participants in the laboratory, even when eating, effort was removed using a peristaltic pump. Though it felt unnatural for participants, consumption of liquids was significantly higher than that of semi-solid food. If eating had not been controlled, consumption of liquids would have been like that of the real-life setting.

Likewise, a study by Wijk et al. (2008) attempted to study 'the effects of food viscosity on bite-size, bite effort and food intake'. A chocolate-flavoured dairy drink in liquid and semi-solid forms was examined by dividing participants into two groups. The first group consumed 47% more of the liquid to reach the same satiation level as the semi-solid form of food. This was done by taking larger bite sizes throughout the 15 minutes. For the second group, bite effort was eliminated as a peristaltic pump was used, and oral processing time was
standardised. Results showed that participants consumed equal amounts of semi-solids and liquids to reach the same degree of satiation. Finally, it was concluded that semi-solid foods resulted in smaller bite sizes and lower intake when compared to liquid foods. Albeit, these differences disappeared when bite effort was eliminated.

Hongenkamp et al. (2011) argued that texture and not flavour determines expected satiation in dairy products. Products used were commercially available yoghurts and custards, lemon and meringue–flavoured custards with different textures, and chocolate milk and chocolate custard consumed with a spoon or straw. Three independent experiments were conducted to test their hypothesis. Experiment one showed that thickness, creaminess, and sweetness intensity were positively correlated with expected satiation, whereas freshness and sourness were negatively correlated. In experiment two, Thick and mealy mouthfeel, thickness, jelly textures, visual imagery, and smell intensity were positively related to expected satiation. However, the sweetness was negatively correlated. In experiment three, custard products were expected to be more satiating than milk products. \( p < 0.0001 \). Overall, an increase in thickness showed increased expected satiation, while flavour and means of consumption did not affect expected satiation.

Tsuchiya et al. (2006) compared the satiating power of semi-solid and liquid yoghurts with fruit beverages and dairy fruit drinks. The products used were a fruit beverage made of peach syrup and water, another beverage that was a milk–based peach and apricot drink, a semi-solid peach yoghurt containing peach pieces, and the same yoghurt homogenised to a liquid form. Results found low-fat yoghurts, whether drinkable or consumed with a spoon, had a greater satiating effect than fruit-based beverages and dairy fruit drinks. However, it did not reduce food or energy intake at the next meal.
2.5.6 **Liquid and Soft Solid Foods**

Juvonen et al. (2013) studied the structural modification of milk protein-based model foods and its effects on postprandial intestinal peptide release, and fullness concluded that increasing firmness of dairy proteinaceous foods and modifying protein-based food structure could eventually lead to optimising postprandial glucose and insulin concentration resulting in higher levels of fullness. Eight healthy male participants consumed test products of equivalent energy and volume. These products contained either whey protein (Wh, a low-viscosity liquid), casein (Cas, a high-viscosity liquid), or casein protein cross-linked with transglutaminase (Cas-TG, a rigid gel). Results indicated that although the liquids (Cas and Wh) initially lowered postprandial glucose levels, the feeling of fullness was stronger after consuming the rigid gel than after drinking high-viscosity and low-viscosity liquids.

2.5.7 **Liquid, Pureed, and Chunky Foods**

Flood et al. (2007) explored if consuming soup in different forms before a meal could reduce energy intake. Results indicated that soup could enhance satiety when consumed in various forms. This study tested soups as a preload in the form of broth and vegetables served separately, chunky vegetable soup, chunky–pureed vegetable soup, and pureed vegetable soup. Sixty participants between the ages of 18 and 45 years were selected. These participants had a BMI between 18 – 40 kg/m² and scored <40 on the Zung questionnaire and <20 on the EAT -26 questionnaire. Data showed that participants reduced energy intake by 20% when the soup was consumed. Hunger ratings were also significantly lower ($p = 0.001$) when the preload was consumed than when participants did not consume the preload meal (soups). However, the texture of the preload food (soups) did not affect meal intake.

2.5.8 **Semi-Solid, Pureed, and Chucky Foods**

Brunstrom et al. (2009) stated that the ‘extent to which food was expected to deliver satiation was called expected satiation’. Tarrenga et al. (2016) in their study explored the
relationship between two texture variations in yoghurts and their expected satiation capacity (ESC). One variation had three types of pineapple particles: fresh pineapple purée (+PP samples), small cubes of fresh pineapple (+PF samples), and small cubes of lyophilised pineapple (+LP samples). The other texture created a variation in yoghurt viscosity: yoghurt thickened with starch (high viscosity HVY samples) and yoghurt without starch (low viscosity LVY samples). Eight samples were made: two plain yoghurts without added fruits (HVY and LVY) and each yoghurt base with added fruits. These were: (LVY +PP), (LVY+PF), (LVY + LP), (HVP+PP), (HVY+PF), (HVY+LP). The study found that ESC and acceptability were closely related; therefore, samples that were not liked as much scored lower on expected satiation. Ninety-eight participants (61 Females and 37 males) between 18 and 62 years participated in the study. ANOVA results showed that the highest ESC values were found for samples (HVY+LP and HVY+PP), and the lowest values were found for samples (LVY+PP and HVP+PP). To further investigate the results, a Penalty Analysis approach was used. Data indicated that the thick and creamy texture attributes positively impacted the mean ESC value across all participants. McCrickerd et al. (2012) study found thicker drinks to be more filling and suppress hunger for longer. However, the Tarrenga et al. (2016) study found that texture differences were not associated with differences in energy content.

2.5.9 Solid, Liquid, and Pureed Foods

Flood-Obbagy et al. (2009) tested how consuming different forms of apple preloads before a meal influences satiety and energy intake. The fruit was served in its original form (apple), a pureed form (applesauce), and a liquid form (apple juice with fibre) and (apple juice without fibre). Results indicated that consuming apples reduced energy intake at lunch by 15% ($p < 0.0001$) compared to applesauce, apple juice (both forms), and the control group, where no preload was served. Consuming applesauce ($p < 0.01$) and both juices ($p <$
0.05) also decreased energy compared to the control group. However, eating the whole fruit increased satiety more than the applesauce and apple juice, even when naturally occurring fibre was added to the apple juice. Fullness ratings were also significantly ($p < 0.0001$) greater after consuming preloads compared to the control group, but it was more after consuming the fruit (apple) in its original form.

Haber et al. (1977) found similar results in their paper focusing on dietary fibre and its effects on satiety. They found that apples in their original form were more satisfying than puree, and the puree was more satisfying than juice. Results further showed that the fruit in its original form was more satisfying due to its fibre and carbohydrate content. Also, more chews provided more satiety than the other forms, such as puree and juice. They increased electrical activity in the hypothalamic satiety centre during ingesting and swallowing the food.

2.6 Effect of Pleasantness on Satiation

The definition of palatability has been debated in the past. The main reason was that all the various purposes and perspectives used to describe the notion of palatability make sense on some level (Ramirez, 1990). Eating was pleasurable, and neurotransmitters or peptides often mediate the brain's sensory pleasure response to food. (Drewnowski 1997). Sensory characteristics of food were often important decision-making reasons why people choose to eat something (Cardello, 1994). The food flavour has a significant impact when deciding what to eat; this was closely linked to positive or negative experiences with food (Wijk et al., 2004). The studies below reflect on how the pleasantness of the food taste and palatability affect satiation.

2.6.1 Liquid and Semi-Solid Foods

Nazlin (1999), in their study, experimented with different textures of a dairy mousse dessert. Visual properties of the dessert were manipulated to enhance the perception of
creamy textures. Previous studies, state that perceived thickness was associated with creaminess, which led to higher levels of liking (McCrickerd et al., 2014).

Bolhuis et al. (2010) explored the significance of sensory attributes of food on satiation, discovering that the duration of orosensory exposure influenced satiation during trials involving creamy tomato soup. Their research indicated that extended orosensory exposure consistently resulted in a reduced consumption of food (Bolhuis et al., 2011). The primary aim was to assess the effects of orosensory exposure duration on food intake. An additional objective examined the influence of bite size on satiation. In the experimental design, 55 participants of healthy weight partook in the consumption of creamy tomato soup with varying levels of salt (low-salt [LS] and high-salt [HS]) across different orosensory exposure times (extended and brief) as well as in a free intake condition, with the soup delivered through a pump mechanism. The findings revealed that both an increased duration of orosensory exposure and greater saltiness led to a decrease in food intake. Notably, however, it was the orosensory experience that had a more pronounced effect on limiting intake than the intensity of the saltiness

2.6.2 Solid Foods

Zandstra et al. (2000) found that ‘with repeated exposure, the desire to eat, fullness and intake of less preferred food can increase over time.’ They studied the effects of pleasantness on ad-libitum food intake, liking, and appetite over five consecutive days. The food served was sandwiches as a lunch meal, made with bread perceived as low, medium, or high in pleasantness. This was done by manipulating the sodium chloride levels. Results found that over time, consumption of less preferred food, desire to eat, and satiety can increase. It was noted that consumption and desire to eat the most preferred sandwich remained constant throughout the five days, concluding that pleasantness did affect satiation.
2.7 Effect of Oral Processing Time (OPT) on Satiation

Mastication involves breaking down food into smaller particles, blending it with saliva, and warming it to near body temperature, preparing it for its journey to the stomach, where most digestion occurs. (Bourne. 2004). Sethupathy et al. (2020) stated that chewing and breaking down food was a complicated process with many detailed stages. The main reason mastication was a critical factor when studying satiation was because it was an orosensory process that provides gratification (pleasure), the release of flavour, temperature adjustment before swallowing, and blous preparation (food mixed with saliva) (Bourne, 2004). However, to date, no ideal techniques have been developed to study these complex sensory aspects of oral processing and texture perception processes. (Sethupathy et al., 2020).

Tyle (1993) found that factors such as the size, shape, and hardness of edible particles present in food play a role in the perception of textural complexity and palatability. Four flavoured suspensions (garnet–grape flavour, garnet–raspberry cherry flavour, micronised polyethene raspberry cherry flavour, and mica–raspberry cherry flavour) and a control were used to evaluate if shape and size played a role in texture perception. Results showed that as size increases, hard garnet and mica particles were viewed as grittier. The trend was reversed for soft polyethene particles. However, no effect of increasing the thickness of particles played a part in textural perception. Overall, data showed that grittiness and smoothness were influenced by particle size.

2.7.1 Liquid Foods

Weijzen et al. (2009) studied how to sip size affects sensory-specific satiation using orangeade. Participants consumed no energy and regular energy drinks by taking large and small sips. Overall, as expected, it was observed that small sip sizes due to the increased duration and longer orosensory exposure could decrease the intake of drinks. Moreover, it was also noticed that low orosensory exposure, in other words, consuming larger sip sizes,
led to a higher intake of energy-containing orangeade, suggesting that consumption of sweet drinks may be triggered more by reward value and inhibited by satiation.

**2.7.2 Semi-Solid Foods**

Zijlstra et al. (2009a) found that eating food in smaller bites, which offers more oral sensory experience, paired with longer oral processing time, vastly reduces food consumption. Participants consumed a chocolate-flavored custard through a tube connected to a peristaltic pump. Results showed that significantly more custard was consumed when oral processing time was 3 seconds rather than 9 seconds ($P = 0.008$).

**2.7.3 Solid Foods**

Smit et al. (2011) found that prolonged chewing reduces food intake and leads to weight loss. Their premise was based on the idea that obese people may exhibit a different eating style (bite size, injection rate, number of chews, chewing speed) than those with normal weight. The experiment required participants to consume cooked pasta and pesto at specific rates. There, they concluded that higher chewing counts per mouthful could reduce energy intake despite faster chewing and longer meal duration, but more research is needed to investigate the data thoroughly.

When the duration of mastication increases, the food stays in their mouth longer, enhancing fullness, especially with harder foods (Lasschuijt et al., 2021). It was crucial that the food feels notably harder to notice these effects. New research shows that tiny tweaks in how a portion of food was put together do not change chew time and rate (Forde & Bolhuis, 2022). Also, making a portion of food much harder can make it less enjoyable, which was hard to do in practice (Forde & Bolhuis, 2022). Nevertheless, when the taste was kept the same, Lasschuijt et al. (2017) found that people ate significantly less of a hard gel than a soft one, even when the energy content was the same.
2.8 Highlights from Past Literature

The studies described above have shown some common trends and patterns. Harder foods compared to softer foods in solid form have shown that longer oral processing time and longer orosensory exposure increase satiation and decrease energy intake (Bolhuis et al., 2014; Zijlstra et al., 2010; Smit et al., 2011). It was important to note here that though texture does have some impact on satiation, subtle textures in foods often show no significant difference in satiation and energy intake, whereas more obviously visible textures have demonstrated significant differences in satiation and perceived satiation (Zijlstra et al., 2010; Cahayadi et al., 2020; Marcano et al., 2015). The viscosity of food also seemed to play a role in satiation; thicker and more fibrous food products appeared to have a more significant effect on satiation and expected satiation compared to the less thick and fibrous forms as described in the studies above (Vuskan et al., 2008; McCrickerd, 2014, 2012; Zhu et al., 2012; Zilstra et al., 2007; Hongenkamp et al., 2011). Thicker foods can help people feel less hungry than thinner foods (Mattes & Rothacker, 2001; Solah et al., 2010; Yeomans et al., 2014; Yeomans et al., 2016). It was also noted that foods that were in solid or semi-solid forms have generally been more desirable and filling compared to liquid foods or beverages (Tsuchiya et al., 2006; Wijk et al., 2008; Zijlstra et al., 2007; Juvonen et al., 2011).

Yeomans et al. (2014) discovered that after people ate thick foods many times, it stopped making them feel full. When it comes to dairy, Zijlstra et al. (2008) found that as food got thicker, people chose to eat less of it. Other researchers found the same (de Wijk et al., 2008; Mars et al., 2009). Still, another study did not see any change in how much people ate or their stomach hormones, even though semi-solid foods made them feel fuller than liquid foods (Zijlstra et al., 2009b). Likewise, it was found that foods consumed in their original solid form were more satiation and filling compared to either juiced (with or without fibre) or pureed form (Flood–Obbagy et al., 2009; Haber et al., 1977). On the contrary, Flood et al.
(2007) found that consuming preload meals such as soup in various forms did enhance satiety and reduced energy intake. However, the texture of the soup did not affect food consumption. Bite size and higher duration oro-sensory exposure were two important aspects when considering satiation. As mentioned previously, foods that were easier to swallow need less oral processing time and were not as satiating as foods that take longer to chew (McCrikerd et al., 2015; Bourne, 2004; Sethupathy et al., 2020; Zijlstra et al., 2009). Lastly, research suggests that people generally enjoy eating food with various layers of textures (Emorine et al., 2014; Mosca et al., 2012; Berlyne, 1971). Some research suggests that a mix of textures like nuts in chocolates or fruit pieces in yoghurt could make the food more desirable and increase the feeling of fullness sooner (Lévy et al., 2006; Palczak et al., 2020; Hogenkamp et al., 2011; Krop et al., 2019; Larsen et al., 2016; Marcano et al., 2015; Strībitcaia et al., 2020a; Strībitcaia et al., 2021; Tang et al., 2016; Tarrega et al., 2016). Some research shows that the addition of solid or semi-solid textural components can affect satiation. Tarrega et al. (2016) observed that incorporating freeze-dried pineapple pieces into yoghurts extended the time taken for consumption. Which subsequently enhanced the anticipated satiating effect and decreased subsequent food and energy intake. Likewise, when peach gel segments were added to yoghurts, Aguayo-Mendoza et al. (2020) noted a transformation in associated eating habits; it resulted in a two-fold increase in consumption time and chewing frequency, as well as a reduction in eating speed by as much as 60%. In a comparison study, Mosca et al. (2019) established that yoghurts with smaller yet more numerous granola bits, as opposed to those with larger, scarcer pieces, prompted a slower eating pace and reduced ad libitum food intake despite being energy-matched.

Aguayo-Mendoza et al. (2021) validated a similar effect in solid foods. When bell-pepper gel segments differing in fracture stress and density were integrated into hard/non-sticky and soft/sticky processed cream cheese textures, a rise in consumption duration and a decline in
eating speed were observed. Conversely, modifying the cheese texture from a soft to a hard matrix reduced the time of consumption and accelerated the eating rate. Additionally, Laguna and Sarkar (2016) determined a positive correlation between oral processing duration and the number of chews, with the strength of a modelled food matrix and the degree of inconsistency related to the size of calcium alginate beads. Limited research has explored how changing textural complexity impacts food consumption, hunger control, and anticipated fullness. Nonetheless, notable outcomes have been documented (Larsen et al., 2016a; Marcano et al., 2015; Tang et al., 2016). Studying this may provide helpful insights to resolve the obesity pandemic and help people maintain their body weight as well as aid in weight loss (Chambers et al., 2015; Hetherington et al., 2013).
This chapter outlines the demographic overview, apparatus used, and procedure of the experiment. It describes the developmental process of creating textural complexity in food Gels and the materials involved in Gel preparation. It further describes materials used to prepare the *ad-libitum* meals. Lastly the chapter details the scales used to capture the results of and participant responses for the experiment.

### 3.1 Demographic Overview – Age, Gender, and Body Mass Index (BMI)

#### 3.1.1 Participants

This study involved 30 (23 females and seven males) New Zealand residents aged 18-45, primarily University of Auckland (UoA) students and one staff member, with an average age of 31.5 years. Conducted in UoA's Food Science/Sensory Psychology Lab, the study included healthy participants with BMIs of 18-25 kg/m². The gender imbalance, with most participants being female, limited comparative analysis between males and females. Exclusions applied to smokers and individuals with certain health conditions. Participants received a $20 Countdown voucher per session. The study, approved by the University of Auckland Human Participants Ethics Committee until 05.08.2025 (reference number 023323), has further details in Appendices A1 and B1.

### 3.2 Apparatus: Gels and *Ad - Libitum* Meals

#### 3.2.1 Creation of Gels

Gels of varying complexities—low, medium, and high—were developed to investigate the influence of textural complexity on satiation. The food Gels were orange in colour and had a citrus orange flavouring. These food Gels were standardised in size, flavour, and nutritional constituents—the foundational layer of each Gel matrix incorporated beads and a disc. The
entire structure was consolidated using a solution composed of pectin and alginate, culminating in the formation of the comprehensive Gel matrix. Put together, the Gels had a smooth outer orange colour body with a soft jelly-like appearance, like that of a dessert.

The employed layers consisted of agar-based disks and Kappa carrageenan (Kc) – based particulates (beads). Table 1 delineates the hydrocolloid concentrations found within the insert Gels and the nutritional constituents of the samples employed for sensory evaluation.

Developing textures- to attain distinct mechanical properties, small bead-like particles and discs were used to create unique texture experiences orally (Patterson et al., 2023).

Beads- small bead-shaped Kc particles, about 0.8 mm wide, were known to produce a gritty feeling, while medium-sized beads, around 2 mm, feel beady, and large beads, about 4 mm across, create a lumpy sensation (Santagiuliana et al., 2018a). In addition, Kc concentrations of 1%, 2%, and 4% show clear differences in the force needed to break them when punctured. As the desired yield stress (measured in kilopascals, kPa) increases, so does the perceived chewiness and hardness of the material (Santagiuliana et al., 2018a).

Disc- Agar discs were associated with perceptions of hardness, chewiness and elasticity. Characterised as a brittle and firm Gel, agar's attributes were cited by Sharma and Bhattacharya (2014). Agar exhibits enhanced elastic characteristics when augmented with locust bean and xanthan gums (Myhrvold et al., 2011). Amplified concentrations of these hydrocolloids potentially heighten perceptions of chewiness and elasticity. The disc configuration was employed for the agar insert, potentially correlating to sensations of lumpiness and contrast (Patterson et al., 2021). A disc's enhanced yield stress (kPa) might be more straightforwardly associated with amplified hardness (Patterson et al., 2021; Tang et al., 2016) instead of beads or other diminutive configurations. Consequently, lower agar concentrations, relative to Kappa carrageenan, were utilised.
### Table 1

*Ingredients Used to Make the Three Different Complexities of Gels*

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Gels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Kc particles (w/w%)</td>
<td>1</td>
</tr>
<tr>
<td>Agar disc (w/w%)</td>
<td>0.3</td>
</tr>
<tr>
<td>Kc (kPa)</td>
<td>25</td>
</tr>
<tr>
<td>Agar (kPa)</td>
<td>20</td>
</tr>
<tr>
<td>Sample weight (g)</td>
<td>4</td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>6.8</td>
</tr>
<tr>
<td>Protein (g/sample)</td>
<td>&lt;0.0</td>
</tr>
<tr>
<td>Fat (g/sample)</td>
<td>&lt;0.0</td>
</tr>
<tr>
<td>Carbohydrates (g/sample)</td>
<td>1.60</td>
</tr>
<tr>
<td>-Sugars (g/sample)</td>
<td>1.1</td>
</tr>
<tr>
<td>Dietary fiber (g/sample)</td>
<td>0.7</td>
</tr>
</tbody>
</table>

*Note.* The table describes the composition (w/w%) of the agar disc and Kc particles and the nutritional content of each sample (6g) in kcal or grams per sample. The letters in the sample codes denote the target yield stress of Kc and agar (low, medium, high; l, m, h).

#### 3.2.2 Materials used for Gels

**3.2.2.1 Ingredients and Equipment.** The ingredients used for the samples were sucrose (Countdown, Auckland, New Zealand), glucose syrup (PatisFrance, France), high-methyl pectin (classic CF 201, Hawkins Watts, Auckland, New Zealand) (PEC HM), 91%
sodium alginate (Protanal DP1780, Hawkins Watts, Auckland, New Zealand), orange infuse extract (Hawkins Watts, Auckland, New Zealand), red colouring (Dr Oetker Queen, Australia), yellow colouring (Dr Oetker Queen, Australia), titanium dioxide (TiO2; Chefmaster, CA, USA), slow release glucono delta lactone (GDL; E575, Jungbunzlauer, Basel, Switzerland), citric acid (Hansells Food Group Ltd, Auckland, New Zealand), distilled water (Pure Dew Water Limited, Auckland, New Zealand), κ-carrageenan (Gelcarin GP 911, Hawkins Watts, Auckland, New Zealand), potassium chloride (KCL; Sigma-Aldrich, Darmstadt, Germany), agar (Type 8925, Hawkins Watts, Auckland, New Zealand), locust bean gum (LBG) (type A-200, Hawkins Watts, Auckland, New Zealand), and xanthan gum (Novaxan 80, Hawkins Watts, Auckland, New Zealand). Referring to Figure 1, panel (A) depicts a plastic mould used to establish and set the Gels. Panel (B) displays the syringe used to inject the solution precisely into the mould, and panel (C) shows the dry ingredients used. Some other types of equipment used were a mixer (nutribullet), a magnetic stirrer (CORNING), a measuring scale (JADEVER SKY – 600 Precision Balance), and a water bath (ASL NZ – Acorn Scientific Ltd).

Figure 1

Ingredients and Equipments used to Set the Gels used for Testing.

A          B          C

Note. The moulds shown in panel (A) serve as the apparatus for the Gel setting, while the syringe shown in panel (B) introduces the solution into the mould. Panel (C) shows the ingredients used in the Gel making.
3.2.2.2 Kappa Carrageenan (Kc) Particles. Kc solutions: In a clean glass beaker, as shown (refer to figure 2) in panel (A), Kc, white sugar, and potassium chloride (KCl) were weighed to precision. These ingredients were added to a separate container containing distilled water (H\textsubscript{2}O), as shown in panel (B). To get the orange colour, red and yellow food colourings (FC) were added to the same container, respectively. The container was then emptied into a Schott bottle and placed on a magnetic stirrer, as seen in panel (C). The dry ingredients of the first container were slowly poured into the Schott bottle. This solution was allowed to stir for 10 minutes and then placed in the water bath at 85°C for 30 minutes. It was ensured that the solution had minimal to no air bubbles. If air bubbles did form, a knife was used to deflate them before the solution was placed in the water bath, as seen in panel (D).

Development of Kc bead particles: The beads were prepared using an emulsification method adapted from Santagiuliana et al. (2018a). The hot Kc solution (85 °C) was emulsified in hot sunflower oil using a ratio of 2:3. In a saucepan, sunflower oil was heated to 95°C – 105°C. Simultaneously, a 1 L Schott bottle (sitting in a plastic bag) with a large magnetic stir bar was placed on the magnetic stirrer at level 4, 4.5, and 6.5 respectively for each complexity as seen in panel (E) and (F). Once the sunflower oil was heated, 120 Ls was slowly poured into the Schott bottle using a plastic funnel. Following that, 80L of the Kc solution was poured slowly in one stream into the same bottle using a plastic funnel. This process then facilitated the emulsification, and it was stirred using a magnetic stirrer for 25 minutes, as depicted in the panel (G). Precaution was taken that the magnetic stirrer was constantly stirring the solution; it was carefully adjusted if needed. After the 25 minutes of stirring, ice chips were poured into the plastic bag in which the Schott bottle was placed, ensuring the stirring remained undisturbed, as seen in panel (H). The emulsion was then allowed to cool down to around 18°C for the low complexity Kc
particles and to approximately 20°C for medium and high complexity Kc particles. Once cooled, the emulsion was poured through a 2 mm sieve into a 1 mm sieve, collecting any discarded Gel And oil in a tray as seen in panel (I). The waste was carefully discarded into a bin, and the particles were washed with the KCL solution, which was 0.075 % KCL in (w/w) distilled H₂O. The particles were washed three times with a 0.075% KCL solution and dried on absorbing paper at room temperature under a fan for 30 minutes. The beads were then stored at 4°C in the refrigerator until they had to be used, as seen in panel (J).

Table 3.3.1 details the ingredients used to make the kc particles.
Figure 2

The Figures Show (Part 1) The Kc Bead Particles Production Stages.

(A) (B) (C) (D) (E)

(F) (G) (H) (I)

(J)

Note. Panel (A) depicts the dry ingredients being weighed on a scale, (B) demonstrates the dry ingredients being added to water, (C) shows the mixture allowed to stir on the magnetic stirrer and (D) shows the solution placed in the water bath scientific Ltd.) along with the knife used to deflate any air bubbles. Panel (E) and (F) show the Schott bottle on the magnetic stirrer placed in a plastic bag. Panel (G) shows the emulsification process, (H) shows the cooling down process, (I) show the solution being put through a sieve and beads being collected. Image (J) shows the beads added to the plastic mould.
Table 2

*Ingredients Used to Make Kc Particles.*

<table>
<thead>
<tr>
<th>% (w/w)</th>
<th>Kc (g)</th>
<th>Sugar (g)</th>
<th>KCl (g)</th>
<th>H_2O (mL)</th>
<th>Red (g) (FC)</th>
<th>Yellow (g) (FC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kc_1</td>
<td>1</td>
<td>5</td>
<td>0.75</td>
<td>93.125</td>
<td>0.25 (1 drop)</td>
<td>0.1 (4 drops)</td>
</tr>
<tr>
<td>Kc_2</td>
<td>2</td>
<td>5</td>
<td>0.75</td>
<td>92.125</td>
<td>0.25 (1 drop)</td>
<td>0.1 (4 drops)</td>
</tr>
<tr>
<td>Kc_3</td>
<td>4</td>
<td>5</td>
<td>0.75</td>
<td>90.125</td>
<td>0.25 (1 drop)</td>
<td>0.1 (4 drops)</td>
</tr>
</tbody>
</table>

*Note.* The measurements listed above were used to develop the low, medium, and high complexity of Kc bead particles to develop the Gel's inner parts.

### 3.2.2.3 Agar Disk.

Table 3 details the ingredients used to make the agar disks. Agar, LBG, xanthan, and white sugar were carefully measured in a clean glass container, as seen in (figure 3) panel (A). To get the orange colour, distilled water (H_2O) and red and yellow food colourings were added in another clean glass container, respectively, as seen in panel (B). The container was then emptied into a Schott bottle and placed on a magnetic stirrer, and the dry ingredients of the first container were slowly poured into the Schott bottle, as seen in panel (C). This solution was allowed to stir for 10 minutes to make discs for Gel A and B and 30 minutes for Gel C, then placed in the water bath at 85°C as seen in panel (D). It was ensured that the solution had minimal air bubbles and that all dry ingredients were fully dissolved. After approximately 3 to 4 hours, the solution was removed from the water bath, stirred manually, and placed in 0.5-L flat plastic containers. Once completely cooled, a stainless steel cutter was used to cut out the disks, as seen in panel (E). For A3, the solution was manually flattened as its consistency was thick, and discs were manually trimmed from the edges to maintain height uniformity. The disks were then placed in the plastic moulds on top of the Kc beads, as seen in panel (F).
Figure 3

The Images Below Show the Disc Making Procedure.

Note. Panel (A) show dry ingredients being measured. The next step shows the water solution added to the magnetic stirrer (B/C). The dry ingredients (A) were added to the same bottle on the stirrer (C). The solution was placed in the water bath (D). Once cooled, the steel cutter was used to cut discs (E) and placed them in the plastic moulds (F).
Table 3

Ingredients used to Make Agar Disk.

<table>
<thead>
<tr>
<th>% (w/w)</th>
<th>Agar (g)</th>
<th>LBG (g)</th>
<th>Xanthan (g)</th>
<th>Sugar (g)</th>
<th>H₂O (L)</th>
<th>Red (g) (FC)</th>
<th>Yellow (g) (FC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.3</td>
<td>0.3</td>
<td>0.15</td>
<td>0.2</td>
<td>5</td>
<td>94.225</td>
<td>0.25 (1 drop)</td>
<td>0.1 (4 drops)</td>
</tr>
<tr>
<td>A3</td>
<td>3</td>
<td>0.45</td>
<td>0.6</td>
<td>5</td>
<td>90.525</td>
<td>0.25 (1 drop)</td>
<td>0.1 (4 drops)</td>
</tr>
</tbody>
</table>

Note. The measurements listed above were used to develop the low, medium, and high complexity of Agar disks to develop the Gel's inner parts.

3.2.2.4 Pectin Base. The preparation method was adapted from de Avelar and Efraim's (2020) cold-set alginate/pectin gelation process. A cold-set process was desirable to reduce interaction between the pectin outer matrix and the inserts during gelation. Table 4 details the ingredients used to make the pectin base. In an electric Nutri Bullet blender, 204.6 grams of glucose, 170.4L of H₂O, and 193.8 grams of white sugar were accurately measured. The blender jar was added to the water bath at 85°C for approximately 45 minutes until the glucose and sugar entirely dissolved. In a separate clean glass container, 6.39 grams of Sod Al and 5.80 grams of PEC HM were precisely measured and poured into the blender jar. To get the orange colour and flavouring, 26 drops of orange food flavourings, 26 drops of yellow food colouring, six drops of red food colouring, and two drops of white food colouring were added to the mixer jar with a dropper. The ingredients in the mixer jar were mixed thoroughly in the electric motor. Using a funnel, the solution was slowly and carefully poured into a 1L Schott bottle, put in the water bath at 85°C for 8 hours, and then stored at 4°C in the refrigerator as seen in (figure 4) panel (A). Before use, the solution was removed from the fridge and placed in the water bath for approximately 3 hours. The solution was allowed to cool to room temperature, and the upper layer of forth
and air bubbles was carefully removed. Once cooled, a clean glass container measured 290.4 grams of the solution. In a separate container, 9 grams of Glucono delta-lactone (GDL) and 0.6 grams of citric acid were precisely measured and added to the solution, as seen in panel (B). This base was then used to hold the Gel ingredients in the mould.

**Figure 4**

_The Images below show the Pectin Base, the Solution Formulating The Gel Body._

(A) ![Panel (A) shows the pectic solution blended and placed in the water bath.](image)

(B) ![Panel (B) shows the solution out of the water bath after 8 hours, ready to use, with the dry ingredients thoroughly mixed.](image)

*Note. Panel (A) shows the pectic solution blended and placed in the water bath. Panel (B) shows the solution out of the water bath after 8 hours, ready to use, with the dry ingredients thoroughly mixed.*
Table 4

Ingredients used to Develop the Pectin Base Solution

<table>
<thead>
<tr>
<th>% (w/w)</th>
<th>Glucose (g)</th>
<th>H2O (l)</th>
<th>Sugar (g)</th>
<th>Sod Al (g)</th>
<th>PEC HM (g)</th>
<th>Orange (FC)</th>
<th>Red (FC)</th>
<th>Yellow (FC)</th>
<th>White (FC)</th>
<th>GDL (g)</th>
<th>Citric Acid (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pectin base</td>
<td>204.6</td>
<td>170.4</td>
<td>193.8</td>
<td>6.39</td>
<td>5.80</td>
<td>26</td>
<td>6</td>
<td>26</td>
<td>2</td>
<td>9</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Note. The measurements and ingredients listed above were used to develop the Pectin base to hold the Gel body together in the plastic moulds.

3.2.2.5 Sample Assembly. In black plastic moulds (Figure 5) panel (A), 0.6 grams of Kc₁, Kc₂, and Kc₄ particles were added to the mould cavity, as shown in panel (B). The agar disks A.3, and A3 (C) were also placed in those cavities. The researcher used markings on the moulds to distinguish between the Gels' low, medium, and high complexities. The base solution was poured into the mould's cavity with a syringe (D) until it was ¾ full (E). A stainless stirrer was used to mix the Kc particles, agar discs, and base solution and allowed to sit for 20 minutes. The syringe was used again to fill the mould's cavity with the base solution. This ensured that all the inserts of the Gels were covered entirely (F), making all Gels look uniform. The moulds were placed in airtight plastic containers and set for 24 hours in the refrigerator. To de-mould, a teaspoon was used to scoop out the Gels and used for testing, as seen in panel (G). Increasing sample volume and dimensions was recommended to ensure accurate instrumental testing for heterogeneous samples (Ramírez et al., 2010). This was particularly advantageous for semi-soft matrices like pectin. Consistent geometric shapes, such as 40x20 mm cylindrical
moulds, aid in engineering stress calculation. Please refer to Patterson et al. (2023), as sensory characterisation was part of a larger project.

**Figure 5**

*The Gel Making Assembly and Demoulding Process*

(A) ![Image (A)](image1)
(B) ![Image (B)](image2)
(C) ![Image (C)](image3)
(D) ![Image (D)](image4)
(E) ![Image (E)](image5)
(F) ![Image (F)](image6)
(G) ![Image (G)](image7)

*Note.* Image (A) shows the plastic mould, panel (B) shows the Kc bead particles added to the mould cavities, panel (C) shows the agar disks added to the mould cavities, panel (D) (E) shows the Pectic base solution added to the mould cavities to hold in place the inserts and form the Gel body. Image (F) shows the Gels set in the mould cavities, and panel (G) show the Gel de-moulded and plated.
3.2.3 Ad-Libitum Meals

Participants were served pasta in tomato basil sauce and plain chocolate cake. This meal was served after participants had consumed the Gels. The general instruction was to eat until feeling full with refills were permitted. Once participants were done eating, the leftover food was weighed to calculate food consumption. This was done each session to finally measure and compare consumptions within and across the two trials and between each Gel complexity.

3.2.4 Materials used for Ad-Libitum Meals

3.2.4.1 Ingredients for Pasta. The meal consisted of penne-style pasta from the brand (Barilla) and tomato basil sauce from the brand (Jamie Oliver). When these brands were out of stock, a substitute from La Molisana was used for the pasta, and the brand Barilla was used for the tomato basil sauce. Ingredients of the tomato basil sauce included Tomato and basil Pasta Sauce Ingredients: Tomatoes (66%) (Contains Acidity Regulator: Citric Acid), Tomato Concentrate (15%), Carrots, Water, Onions, Extra Virgin Olive Oil, Basil (1.2%), Salt. All pasta items were purchased from Countdown in Hamilton, New Zealand.

3.2.4.2 Ingredients for Cake. Ingredients for the plain chocolate cake included flour, cocoa powder, eggs, sugar, and dairy products. All cakes were prepared and purchased from the New World Bakery in Te Rapa, Hamilton, New Zealand.

3.2.4.3 Preparation Process. In a saucepan, one L of water was boiled for every 500g of uncooked pasta in a 7.2L saucepan. In the boiling water, 40g of salt was added and allowed to simmer for 1 minute, and then the uncooked pasta was added to the pan. The pasta was allowed to cook for 11 minutes and then strained. The sauce was heated for 6 minutes in the emptied saucepan, and then the strained pasta was added to the same pan and mixed thoroughly before serving. The pasta was served at approximately 57°C, within
an hour of being cooked. The plain chocolate sponge cake was bought every day of
testing, fresh, from the bakery and served at room temperature.

3.3 Procedure

3.3.1 COVID-19 Sanitisation and General Safety Procedures

All equipment and utensils were sanitised before and after use to ensure optimal
hygiene standards. Before and after participant use, medical-grade sprays were used to
thoroughly clean all surfaces, including tables, chairs, and stationery. A handwashing
station with soap and sanitiser was readily available to all participants. The researcher
ensured their hair was appropriately secured and tied back while preparing food and Gels.
Gloves were worn while mixing ingredients, and hands were thoroughly washed and
sanitised after each step to prevent contamination. A clean lab coat, mask, and gloves were
worn during each testing session. All participants wore masks until they began eating.

3.3.2 Experimental Design

The satiation test design was a randomised cross-over blind trial based on a preload of
the model food Gels followed by an ad libitum intake based on a two-course meal.
Participants fasted three hours before the test meal, drinking water only. The testing was
done at lunchtime, in three slots between 11:00 a.m. and 11:50 a.m., 12:00 p.m. – 12:50
p.m., and 1 p.m. – 1:50 p.m. This allowed participants to choose their preferred slots, eat
breakfast in the morning, and then refrain from eating until the testing time.

Participants were emailed an information sheet (Appendix A1) and also had one
available in the testing room. A maximum of two participants were allowed in the sensory
laboratory. At first, participants filled out their consent form (Appendix A2), demographic
details, BMI, and checked the experiment criteria (Appendix B1). Participants then
completed an appetite questionnaire by marking responses on 10 cm line scales (Appendix
B2 – Q1). The appetite scale used was the Visual Analog Scale (VAS), described in detail
in section (3.7.2). The data derived from the appetite questionnaire was used as an indicator to measure satiation.

They were given a set portion of 6 Gel pieces of either low, medium or high complexity. The Gels weighed 36 grams in total (6x6 = 36g). Participants underwent two trials, each involving three different Gel complexities. In the first trial, they tasted all three complexities, with the time between each complexity tasting being exactly one week at the same time. They then proceeded to the second trial. They tasted the same three complexities again, with the time between each complexity tasting being exactly one week at the same time. This means every participant tasted each complexity twice, once in each trial.

All three Gel complexities were presented in both trials in a randomised order. The test food was consumed within 10 minutes, and one glass (250 mL) of water was provided, as seen in (figure 6) panel (A). Oral Processing Time (OPT) for each piece of Gel was also measured using a stopwatch, and participants were requested to rate the Gel based on liking and textural complexity. Lastly, participants were given a food diary to record their food within three hours and after three hours. The food diary and OPT are described in more detail under (Sections 3.7.3 and 3.7.4).
Figure 6

The Image Shows the Gels De-moulded and served To Participants for Testing.

(A)

Note. Panel A shows the Gels plated ready to serve to the participant. A 250 mL glass of water was present for the participant to cleanse their palate between each Gel sample. The numbers on the spoons serve to randomise the order of the Gel samples in each trial. This helps reduce any potential bias or sequence effects in their responses to the samples.

Participants were then given an appetite questionnaire (Appendix B3 - Q2) after finishing the test meal and were allowed 20 minutes to complete the questionnaire. At this point (figure 7), the meal's first (pre-weighed) course (620.5g) was served, consisting of pasta in tomato basil sauce, as seen in panel (B). This was consumed ad libitum, with refills allowed. Participants could stop eating or decline a refill at any time. After eating, the participants complete an appetite questionnaire (Appendix B 4 - Q3). This was filled out within 20 minutes of finishing the meal's first course. A second (pre-weighed) course (178.4g) was served and consumed ad libitum with refills allowed. This was a plain chocolate sponge cake, as seen in panel (C). Participants can stop eating at any time or decline a refill. After eating, the participant was given an appetite questionnaire (Appendix B 5 - Q4). During the course of
the experiment the participants were provided with a 250 mL glass of water and they were allowed to ask for refills. Water intake was not measured.

**Figure 7**

The Images Below Show The *Ad-Libitum* Meals Served to the Participants Post The Gels.

(B)  
(C)

*Note.* Panel (B) shows pasta in tomato basil served with a 250 mL glass of water. Once the participants were finished eating the pasta, they were served a chocolate sponge cake with a 250 mL glass of water, as seen in panel (C).

Participants left the room with a post-meal questionnaire, a basic food diary that they fill out for any food consumed within 3 hours of testing, and then fill a post-meal and an appetite questionnaire (Appendix B 6 - Q5), which participants fill out 3 hours after testing. Participants were also asked to record the time they ate their next main meal (e.g., dinner). This was to collect the time of the main meal as it will likely be consumed more than 3 hours after participants left the test location. Participants were given three options to either email, message or record manually the time of dinner in their food diaries in order for the researcher to keep a record of their dinner time.
3.3.3 Scales used for Testing and Analysis

3.3.3.1 The Body Mass Index. The BMI measures body fat based on height and weight. It was usually used as a screening scale to identify individuals at risk for health problems such as obesity associated with excess body fat. BMI was calculated by dividing weight (in kilograms) by height (in meters) squared. The acquired result was then compared to standard BMI category ranges to determine whether a person was underweight, normal weight, overweight, or obese. The range between 18 – and 25 was considered a healthy score, 25.5 – and 29.5 was considered overweight, and anything above the score of 30 and below the score of 18 was considered obese and underweight, respectively.

Reliability and Validity: BMI is still commonly used as a screening tool for obesity and is generally considered a reliable measure of body fat in population studies (Di Angelantonio et al., 2016). However, BMI may not be as accurate in predicting health risks associated with cardiovascular disease and diabetes (Browning et al., 2010).

3.3.3.2 The Visual Analog Scale. The VAS was commonly used in studies to measure conscious change in appetite. (Dubé et al., 2013; Flint et al., 2000; Rumbold et al., 2013). The scale was used to measure evaluations of sensory attributes, including hunger, liking, and textural complexity. It allowed participants to express their opinions and preferences using a continuous and unstructured rating scale. The VAS was a continuous 10 cm line that ranged from 0 to 10, with 0 representing the absence of hunger and 10 expressing the maximum desire to eat. During testing, participants were asked to mark a point on the line corresponding to their appetite level. For example, participants were asked to rate their current hunger level when they first came in, after eating the plate of Gels (6 pieces), and after each ad libitum meal (pasta and cake). They did this by marking a point on the line that best represented their hunger level, with 0 representing no hunger and 10 representing
extreme hunger. Regarding liking and textural complexity, the participants were asked to rate their level of liking. They perceived the textural complexity of the samples based on two endpoints of the VAS, which represent extreme opposites of the evaluated attribute. Please refer to (Appendix B1-6) for the detailed questionnaire.

3.3.3.3 Oral Processing Time, Liking, and Textural Complexity. Before consuming the Gel samples, participants were provided written and verbal instructions to record their oral processing time. Participants were instructed to place the Gel in their mouths. At this point, the researcher would begin timing with a stopwatch. Participants indicated their readiness to swallow the Gel sample by raising their hands, allowing the researcher to stop the stopwatch and record the time. Participants were given a 250 mL glass of water to cleanse their palate between samples. Following each oral processing time measurement, participants rated each Gel sample on the VAS, assessing both their level of liking and the perceived textural complexity of the Gel piece. Participants were asked to provide comments regarding the basis of their ratings following the completion of the VAS assessment. Please refer to (Appendix C 1) to see the detailed questionnaire. In this study, liking was defined as something that was favourable and produces a positive attitude. Textural complexity was defined as ‘the number and intensity of texture sensations, as well as their interactions and contrasts’, adapted from Patterson et al. (2023, p.2).

3.3.3.4 The Food Diary. The food diary was used to record the participants' foods and beverages within three hours of testing. Each participant was given a blank food diary after each session to fill out and bring in the next time over six testing sessions. The food diary detailed the type and quantity of each food item and beverage consumed. It also included the dinner time for those participants who recorded it in the diary. Others conveyed it to the researcher electronically. In addition, the diary also had information
about hunger and fullness levels on a VAS after three hours of testing. Please refer to (Appendix B 5 - Q6).
Chapter 4: Results

This thesis aimed to analyse the effects of textural complexity on satiation. The hypothesis was that more texturally complex food Gels lead to greater satiation. The satiation test design was a randomised cross-over blind Trial based on a preload of the model food Gels followed by a two-course *ad libitum* meal. Data was collected using BMI measurements, and the visual analogue scale (VAS) was used to collect data on appetite, textural complexity, oral processing time, liking, and appetite after three hours which was part of the food diary. Participants also recorded the food or beverages they consumed within three hours of test completion on their food diary. A total of 30 participants were tested for this experimental study. The results showed a significant difference in textural complexity between the Gels (p < 0.05). Although, the textural complexity did not have a significant effect on appetite (p > 0.05). Oral processing time was measured to see if more texturally complex Gels had a longer mastication period. The data revealed that more texturally complex food Gels did have a longer mastication period. The liking results showed that Gel A was most preferred, followed by Gel B, and Gel C was least preferred.

This chapter is structured to explore the data collected in relation to textual complexity, liking, oral processing time, appetite ratings and food consumption for each complexity of Gel, namely low, medium, and high.

4.1 Textural Complexity

Textural complexity was measured on the VAS to record the participants' perceptions of the textural complexity of each Gel piece within every session. As expected, the data revealed that Gel C (designed as the highest complexity) was considered the most complex Gel. This data validates its inherent merit and corroborates the prior findings of Patterson et al. (2023).
The data presented in Figure 8 offers a comprehensive analysis of the Gel specimens under consideration. The mean values indicate that Gel C, with a score of 6.72, was superior, followed by Gel B at 4.67 and Gel A, with the lowest value of 3.77. Cumulatively, the metrics indicate that Gel A exhibits the lowest central tendencies while simultaneously displaying the broadest data range. This indicates a distinct bifurcation in the participants' interpretation of Gel A's textural complexities. Contrarily, Gel C consistently presents the most pronounced textural complexity, as its central and upper quartile metrics underscored.

A qualitative assessment of textural complexity, based participants’ responses is described in Appendix E1. Participants commonly described Gel A as ‘smooth’ (149 responses), with other responses varying from 'soft' (89 responses) to a small number of participants (2) describing it as chewy. Gel B was most frequently rated as ‘grainy’ (106 responses), with other participant responses ranging from 'gritty' (49 responses) to 'soft' (2 responses) and 'chewy' (1 response). Similarly, Gel C scored a high number of responses referring to it as ‘hard’ (177 responses), with a broad range of other participants (49) describing it as 'chewy' and also 'spongy' (4 responses). Analysis of the quantitative and qualitative responses showed that participants exhibited similar ranges of subjectivity regarding the textural complexity of all three Gels. Participants most commonly attributed a lower textural complexity score with 'smooth’ and progressively a higher textural complexity with increasing levels of ‘hardness’.
**Figure 8**

*Combined Textural Complexity Data for Trial 1 and Trial 2*

![Combined Textural Complexity Data for Trial 1 and Trial 2](image)

Note. An increase in textural complexity from Gel A to Gel C.

**4.2 Oral Processing Time**

Oral processing time was recorded to study if more texturally complex food Gels took longer to chew. The data was in line with the expectation, and more texturally complex food Gels recorded a higher oral processing time. Oral processing time was recorded for each Gel piece within every session. The stopwatch started when participants put the Gel in their mouths and was stopped immediately before they could swallow the bolus.

The data in Figure 9 illustrates the oral processing time analysis of Gel A, B, and C and shows significant variations in participants' responses. The mean score of 7.93 for Gel C suggests a generally higher oral processing time than Gel B (6.48) and Gel A (5.79).
Figure 9

Oral Processing Time for Trials 1 And 2

Note: An increase in oral processing time from Gel A to Gel C.

4.3 Appetite Ratings

Appetite levels were recorded a total of four times during the test session. Participants were asked to rate their hunger levels on the VAS. The first was before participants began eating the Gels, the second was after finishing all six pieces of Gels, the third was after eating the pasta, and the fourth was after eating the cake. Once testing was complete, participants were given a food diary and asked to record their appetite levels three hours after their test session. Appetite levels were recorded to study the impact of the food Gels of varying complexity on appetite levels.

Combined results (Trial 1 and 2) show that participants who consumed Gel B had slightly higher appetite levels, followed by those who consumed Gels C and A. A universal decline in hunger was observed after consuming Gels and subsequent ad-libitum meals. However, hunger levels after three hours varied, with the highest increase noted in Gel B consumers despite its initial satiating effect. In Trial 1, Gel B was the most effective in reducing hunger post-consumption. However, after three hours, Gels B and A led to higher hunger levels compared to Gel C. Data showed that participants reported the greatest satiety with Gel C.
Trial 2 results indicated that participants consuming Gel B experienced the highest initial hunger but the most significant satiation post-*ad-libitum* intake. Contrastingly, participants who started with Gel C felt more satiated three hours post-consumption than those who began with Gel A. Despite initial satiety, Gel A had the highest hunger levels after three hours. Overall, Gel B demonstrated the most immediate satiating effect, while Gel C appeared to offer more extended satiety.

Qualitative data from food diaries confirmed meal consistency and minimal variation in dinner times across all Trials and Gel types; this is described in Appendix D1.

**Figure 10**

*Comparative Analysis of Appetite Ratings Across Two Trials and the Aggregated Results.*

A
Note. The figure illustrates pre- and post-consumption hunger ratings immediately after ingesting the Gels and ad libitum meals and three hours later.
Table 5

Combined Appetite Ratings for Trials 1 And 2

<table>
<thead>
<tr>
<th>Trials</th>
<th>Before Gel</th>
<th>After Gel</th>
<th>After Pasta</th>
<th>After Cake</th>
<th>After 3 hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gel A</td>
<td>6.36</td>
<td>5.81</td>
<td>2.18</td>
<td>0.65</td>
<td>3.87</td>
</tr>
<tr>
<td>Gel B</td>
<td>6.25</td>
<td>5.74</td>
<td>1.94</td>
<td>0.81</td>
<td>3.98</td>
</tr>
<tr>
<td>Gel C</td>
<td>6.51</td>
<td>5.67</td>
<td>2.15</td>
<td>0.81</td>
<td>3.62</td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gel A</td>
<td>6.51</td>
<td>5.91</td>
<td>3.01</td>
<td>1.11</td>
<td>4.10</td>
</tr>
<tr>
<td>Gel B</td>
<td>6.96</td>
<td>6.26</td>
<td>2.44</td>
<td>0.62</td>
<td>4.08</td>
</tr>
<tr>
<td>Gel C</td>
<td>6.51</td>
<td>5.88</td>
<td>2.29</td>
<td>0.65</td>
<td>3.66</td>
</tr>
<tr>
<td>Combined</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gel A</td>
<td>6.44</td>
<td>5.86</td>
<td>2.59</td>
<td>0.88</td>
<td>3.99</td>
</tr>
<tr>
<td>Gel B</td>
<td>6.61</td>
<td>6.00</td>
<td>2.19</td>
<td>0.71</td>
<td>4.03</td>
</tr>
<tr>
<td>Gel C</td>
<td>6.51</td>
<td>5.78</td>
<td>2.22</td>
<td>0.73</td>
<td>3.64</td>
</tr>
</tbody>
</table>

Note. The table illustrates pre- and post-consumption hunger ratings immediately after ingesting the Gels and ad libitum meals and three hours later.

The combined analysis of two Trials revealed that the mean change in appetite scores observed was 0.58, 0.61, and 0.73, respectively. The highest and lowest changes in appetite recorded were 3.10 and -1.60 for Gel A, 3.20 and -1.70 for Gel B, and 4.30 and -1.50 for Gel C. Four extreme outliers were reported, suggesting unique responses or other influences. Gel C prompted the greatest average appetite change, albeit with minor differences among the Gels.
Trial 1 recorded average appetite changes of 0.55, 0.51, and 0.84 following Gels A, B, and C consumption. The extremities observed in appetite scores were 3.00 and -1.60 for Gel A, 2.00 and -1.70 for Gel B, and 4.30 and -1.10 for Gel C. A handful of outliers demonstrating extreme changes were again seen. Gel C again had the highest average appetite change and the broadest range.

On the contrary, Trial 2 results showed slightly higher average appetite changes, with Gels A, B, and C eliciting changes of 0.60, 0.70, and 0.63, respectively. The extremities were 3.10 and -1.60 for Gel A, 2.70 and -1.20 for Gel B, and 3.50 and -1.50 for Gel C. In this Trial, Gel B prompted the greatest average appetite change. Only one significant outlier was seen. While the differences in average appetite changes between Gels were modest, Gel C led to the most considerable change in the combined analysis and Trial 1.

In contrast, Gel B led in Trial 2. Outliers in each analysis indicated individual or variable responses to the Gels. These findings underscore the complex influences on appetite ratings and highlight the potential differential effects of these three Gels.
Figure 11

*Appetite Ratings Across Two Trials and the Aggregated Results of Both*

A

![Box plot for Trial 1 - Gels]

B

![Box plot for Trial 2 - Gels]

C

![Box plot for Combined T1 & T2 - Gels]

*Note.* The box plots illustrate appetite ratings immediately after ingesting the three complexities of Gels.
4.4 Liking Ratings

Liking was recorded on the VAS for each Gel piece within every session. This was done to assess how much participants liked the model food Gels and to know which complexity of Gel was most and least liked.

Gel A emerged as the favoured Gel in both Trials, evidencing the highest average liking scores (Trial 1: 5.79, Trial 2: 6.28) and median liking scores (Trial 1: 5.76, Trial 2: 6.43). Nonetheless, the wide liking score ranges (Trial 1: 0.78-10.00, Trial 2: 1.60-9.93) underscore a notable variability in participant responses. In contrast, Gel C consistently registered the lowest liking scores across both Trials, indicating a general disfavour despite exhibiting the broadest score range in Trial 2 (0.35-9.68), signifying higher response variability and potential polarisation. Interestingly, Gel B had an incongruity between its high central tendency liking scores and low liking score outliers (1.05 and 0.32) in Trial 2, demonstrating a diverse range of participant preferences. Notably, the quartile liking scores revealed higher dispersion for Gel B, showcasing an elevated upper quartile liking score in Trial 2 (8.23). At the same time, Gel C perpetually showed the lowest lower quartile liking scores, suggesting a marked disapproval from the bottom 25% of scorers.

The data suggest a generalised preference for Gel A, albeit with pronounced response variability. Conversely, despite occasional high liking scores, Gel C was the least preferred, indicating a polarised response. Gel B displayed complexity, with high overall approval, disrupted by low-scoring outliers. The subjective nature of liking was hence underscored in these Trials.
Figure 12

Liking Ratings Across Two Trials and the Aggregated Results Of Both.

A

B

C

Note. The box plots illustrate liking ratings immediately after ingesting the three complexities of Gels, which were low (A), medium (B), and high (C).
4.5 Linear Mixed Effects Regression Model (LMERM)

4.5.1 Consumption Analysis

The LMERM analysis was conducted to investigate whether textural complexity in food Gels significantly impacted participants' mean ad-libitum consumption.

Participants who consumed Gel C had a mean food consumption statistically lower than Gel A. However, there was no statistically significant difference in mean food consumption between Gel B and Gel A. Specifically, the intercept (i.e., the mean food consumption when Gel A was consumed) was estimated to be 434.32 gms. The coefficient for Gel B (-10.84) indicates that the mean food consumption for participants who consumed Gel B was expected to be 10.84 gms lower than those who consumed Gel A, but this difference was not statistically significant. The coefficient for Gel C (-19.21) indicates that the mean food consumption for participants who consumed Gel C was expected to be 19.21 gms lower than those who consumed Gel A, and this difference was statistically significant at the conventional threshold of alpha = 0.05.

The variance in participants' random intercepts was significantly larger than the residual variance, signifying pronounced differences in food consumption among them. In the fixed effects section, the intercept denotes the expected food intake for Gel A, while coefficients for Gels B and C indicate the intake difference when using these Gels compared to Gel A. The coefficient for Gel B was negative yet insignificant, and the same holds for Gel C. There was a negative correlation of -0.24 between the fixed effects, suggesting those who eat less with Gel B likely consume even less with Gel C. The t-values and corresponding p-values determine statistical significance. For Gel B, the t-value was -0.72, and its p-value exceeds 0.05, deeming it insignificant. Likewise, Gel C's t-value was -1.28, with a p-value greater than 0.05, confirming its insignificance.
Table 6

Illustrates the Consumption Analysis for Ad-Libitum meals

<table>
<thead>
<tr>
<th>Gel</th>
<th>df</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - B</td>
<td>177</td>
<td>-0.72</td>
<td>&gt; 0.05</td>
</tr>
<tr>
<td>A - C</td>
<td>177</td>
<td>-1.28</td>
<td>&gt; 0.05</td>
</tr>
</tbody>
</table>

Note. The values for LMERM for consumption analysis of ad-libitum meals consumed after Gels.

4.5.2 Textural Complexity Analysis

The LMERM analysis was conducted to investigate whether the food Gels had a significant difference in textural complexity.

The variance of the random intercepts for the participants was 2.08, and the residual variance was 3.91. The fixed effects section shows the estimated coefficients (Estimate), standard errors (Std. Error), and t-values (t-value) for the fixed effects of the model. The intercept represents the expected value of the dependent variable when Gel was at its reference level (Gel A). The coefficients for Gel B and Gel C represent the expected difference in the dependent variable when comparing Gel B and Gel C to Gel A. The fixed effects were negatively correlated, with a correlation coefficient of -0.26. This means that participants with a higher value on Gel B were expected to have a lower value on Gel C. Based on the provided output, the intercept (Gel A) was estimated at 3.77 with a standard error of 0.28 and a t-value of 13.31.

This indicates that, on average, when participants were in the Gel A condition, the estimated value of the dependent variable (textural complexity) was significantly different from zero. The coefficient for Gel B was estimated to be 0.90 with a standard error of 0.15 and a t-value of 6.11. This suggests that, compared to Gel A, participants in the Gel B
condition have a significantly higher estimated dependent variable value. The coefficient for Gel C was estimated to be 2.96, with a standard error of 0.15 and a t-value of 20.06. This indicates that, compared to Gel A, participants in the Gel C condition have a significantly higher estimated value of the dependent variable. Gel B and Gel C have statistically significant effects on the dependent variable, with Gel C having a more prominent effect (higher estimated coefficient and t-value) than Gel B.

Table 7

Illustrates the Textural Complexity Analysis

<table>
<thead>
<tr>
<th>Gel</th>
<th>df</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-B</td>
<td>1077</td>
<td>6.11</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>A-C</td>
<td>1077</td>
<td>20.06</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>

Note. The values for LMERM for the textural complexity score of the Gels.

4.5.3 Liking Analysis

The LMERM analysis was conducted to investigate whether there was a significant difference in liking between the three complexities of the model food Gels.

The standard deviation for the intercept was 2.13, indicating substantial variability in the average liking score across different participants. The residual standard deviation was 1.61, representing the variability in liking scores not accounted for by the Gel or the variability among participants. The intercept represents all participants' estimated average liking score for the reference category (Gel A). Its estimated value was 6.04. The coefficients for Gel B and Gel C represent the average change in the liking score when shifting from the reference Gel A to Gel B or Gel C, respectively. The effect of Gel B was not statistically significant (p = 0.31). The estimate of -0.12 suggests a slight decrease in the liking score for Gel B compared to Gel A, but this was not statistically significant. The effect of Gel C was
statistically significant (p < 0.05). The estimate of -1.25 indicates that, on average, participants rate Gel C about 1.25 points lower than Gel A. Based on this model, there was strong evidence that participants rate Gel C lower than Gel A, but there was no significant difference in ratings between Gel A and Gel B. Additionally, there was substantial variability among the participants in their average liking scores.

Table 8
I illustrates the Liking Analysis for Gels

<table>
<thead>
<tr>
<th>Gel</th>
<th>df</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-B</td>
<td>1077</td>
<td>-1.02</td>
<td>&gt; 0.05</td>
</tr>
<tr>
<td>A-C</td>
<td>1077</td>
<td>-10.25</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>

*Note.* The values for LMERM for the liking score of the Gels.

4.6 Summary

Overall, the data revealed that there was a significant difference in textural complexity between the Gels (p < 0.05). Although, it was found that textural complexity did not significantly impact satiation (p > 0.05). Results further revealed a significant difference in liking between the Gels, with Gel A being the most liked and Gel C being the least liked (p < 0.05). Lastly, data showed that the highest-complexity Gel needed the longest oral processing time, and the lowest complexity of Gel required the shortest oral processing time.
Chapter 5: Discussion

This thesis aimed to investigate the effects of textural complexity on satiation. The hypothesis was that more texturally complex food Gels would lead to greater satiation. Consequently, foods with more complex textures might contribute to quicker feelings of fullness, reducing food intake (Suzuki et al., 2012). Discussed below are the key findings of this study. Three variants of Gels, each with a different level of textural complexity, were developed. These were Gel A (low complexity), Gel B (medium complexity), and Gel C (high complexity). During the development phase of these food Gels, great importance was given to maintaining uniformity across various factors, including size, shape, colour, and taste, to ensure that textural differences remained the sole variable under examination. This chapter further delves into summarising the study's key findings, followed by a detailed discussion of the textural complexity data, liking, appetite and consumption data, oral processing time (OPT), and the food diary.

5.1 Key Findings

Gel A was consistently rated as possessing the least textural complexity, with participants commonly characterising its mouthfeel qualities as smooth or soft. Gel B had a higher mean complexity than Gel A but a lower mean complexity than Gel C. Gel B commonly received descriptors such as grainy and gritty. Gel C had the highest ratings for textural complexity and was often described as hard and chewy. The complexity ratings were in line with the expectation: Gel A had the lowest complexity, Gel B had medium complexity, and Gel C had the highest complexity (Appendix E1, Table E1). Gel A was the most liked, followed by Gel B, and Gel C scored the lowest likability score (Figure 12). The difference in appetite ratings between Gels A, B, and C was modest, indicating no significant difference in how the Gels
impacted satiation (Figure 11, Table 6). However, participants who consumed Gel B appeared marginally more satiated than those who consumed Gels A and C (Figure 11).

Gel C recorded the highest OPT scores across all central tendency and dispersion measures, suggesting it requires the longest OPT among the three Gels. Meanwhile, Gel A recorded the lowest scores, indicating it had the shortest OPT. Gel B's performance was intermediate between the two (Figure 9).

5.2 Textural Complexity

The study aimed to explore textural complexity in food Gels by creating three variants: Gel A, Gel B, and Gel C. Participants rated these Gels on the visual analogue scale (VAS) based on the textures they experience in a mouthfeel upon consumption. They were asked to pay attention to the intensity of textures, for example, hardness or softness. Their evaluations of textural complexity are seen in Figure 8. The mean scores for textural complexity across trials demonstrated that Gel A was the smoothest, with the least complexity, scoring between 3.64 and 3.89. Gel B was more complex than Gel A but less complex than Gel C, with scores from 4.54 to 4.79. Gel C was the most complex, with scores ranging from 6.47 to 6.97 (Figure 8).

Despite the structured increase in complexity from Gel A to C, some participants scored Gel A (9.87) higher than Gel C (9.58). This score could be attributed to the variability in understanding textural complexity, which was influenced by cultural, social, and individual differences (Yoshikawa et al., 1970; Hayakawa et al., 2015). Some studies have also found that individual texture perception could vary among cultures (Bourne, 2002; Hayakawa et al., 2013; Yoshikawa et al., 1970; Hayakawa et al., 2015). Cultural and social backgrounds significantly impact texture preferences. The unpredictability of encountering lumps or grittiness in Gels could provoke a negative response, as consistency in food textures is often
TEXTURE AND SATIATION

associated with safety. One study found that people often viewed lumpy or slimy food as a choking hazard. (Szczesniak & Kahn., 1971).

Figure 8 indicates that Gel A had the lowest mean and median scores for textural complexity. Nevertheless, it exhibited the most considerable range of scores varying from 0.38 – 9.87, reflecting a divided opinion on its textural complexity. Overall, Gel C showcased the highest mean complexity score (6.72) of the three Gel variants, making it the most texturally complex. Gel B's wide interquartile range (2.75 – 6.70) suggests greater variability in participants' opinions compared to Gels A and C. These findings demonstrate the challenges of measuring textural perceptions and the important role of cultural and personal experiences in food texture evaluation. This was in line with some past studies that also found it challenging to define textural complexity due to the concept being heavily influenced by individual perceptions and personality factors (Bourne, 2002; Hayakawa et al., 2013; Yoshikawa et al., 1970; Hayakawa et al., 2015). The results, according to the LMERM data, indicated that there was a significant difference (p < 0.05) in complexities between the Gels (seen in Table 7)

5.3 Liking

The participants were asked to rate how much they liked each Gel on the VAS. This was based on their personal preferences. Referring to Figure 12 C, the mean and median scores for Gel C (4.46, 4.68) were significantly lower than those of Gels A (5.79, 5.76) and B (5.68, 5.58), suggesting that it was generally less preferred among the participants. Results show that the liking hierarchy was consistent across two separate trials and the combined data (Figure 12). Regarding Figure 12, Gel A was the most preferred Gel, with average ratings of 5.79 and 6.28 in the first and second trials, respectively, and a combined average rating of 6.04, which suggests textures that appealed most to the participants. A close second was Gel B, which scored 5.68 and 6.15 in the first and second trials, respectively, with a combined
average rating of 5.91. Though not the most favoured, Gel B still maintained a high preference rating, suggesting participants liked its texture. Gel C received the lowest ratings in both trials and the combined data, with average ratings of 4.46, 5.11, and 4.79, respectively. This score suggests it was the least preferred Gel amongst the participants, potentially due to less appealing textures than Gels A and B. The hierarchy of scores across two trials indicates consistency in the participants' liking, implying that these preferences may not be arbitrary but rather influenced by specific characteristics (textures) of the Gels.

Interestingly, according to the LMERM data, the difference in liking between Gel A and B was not statistically significant (p > 0.05) (Table 8). However, there was a significant difference in their textural complexity, as noted (p < 0.05) (Table 7). Further, it was noted that the difference in the liking scores for Gel A and Gel C was statistically significant (p < 0.05) (Table 8), along with there being a statistically significant difference in their textural complexity (p < 0.05) (Table 7). The juxtaposition of these findings indicates that textural complexity may not be the sole determinant of liking.

Some participants disliked Gels A and B in Trial 2 (Figure 12 B). Early studies noted that most people took the texture in food for granted unless specifically asked to observe it or felt that the texture was off (Engelen & Van Der Bilt, 2008; Ketel et al., 2019; Zhou et al., 2021). It was observed that food consumers associated texture with the quality of food. For instance, soggy chips or flat soda were often associated with expired food, whereas crispy lettuce and apples were considered fresh (Szczesniak, 2002). However, looking at the combined liking scores (Figure 12 C), while Gel A and B were generally more favoured than Gel C, the wide range of scores highlights the subjective nature of liking.
5.4 Appetite and Food Consumption

Participants self-reported their appetite ratings on the VAS. This was measured before consumption of Gels, after consumption of Gels, and after the *ad-libitum* meals. With reference to Figure 10 C, the results show that before the Gels were consumed, appetite levels were slightly higher for Gel B (6.61), followed by Gel C (6.51) and Gel A (6.44), respectively. Upon consumption of Gels and subsequent *ad-libitum* meals, a general decline in appetite was observed across all Gel complexities. In this postprandial state, participants who consumed Gel B and subsequent *ad-libitum* meals appeared to be marginally more satiated (0.71) compared to Gels C (0.73) and A (0.88). However, compared to the pre-consumption levels, it was noteworthy that participants who consumed Gel B and subsequent *ad-libitum* meals reported the largest drop in appetite. After the three-hour interim post-consumption, participant hunger levels rose at different rates. Despite being most satiating initially, Gel B consumers reported the highest rise in appetite levels (4.03) compared to those who consumed Gel A (3.99) and Gel C (3.64).

With reference to Figure 11 C, the data also reveals no differences in appetite or *ad-libitum* meal intake. Contrary to the hypothesis, the study found that food textural complexity did not significantly affect how much participants ate or how full they felt. In contrast to the findings of this thesis, Aguayo-Mendoza et al. (2020) and Tarrega et al. (2016) found that the addition of fruit pieces to yoghurt as compared to blending an equivalent amount of fruit pulp and yoghurt resulted in increased satiation and fullness for a longer duration. While the above studies did not precisely measure complexity, it was noted that the change in viscosities did bring a textural difference to food items consumed, as discussed in this thesis.

A study by Griffioen–Roose et al. (2009) investigated whether the sensory properties of food, such as sweet or savory taste, affect how satiated people feel after eating. The research involved healthy-weight adults who consumed rice prepared differently to represent sweet
and savoury flavours. The study measured how much they ate, the speed of eating, the change in how much they enjoyed the rice and their appetite ratings before and after eating. The findings were that the taste did not significantly impact the satiation, as all the measured parameters were similar for sweet and savoury rice. Similarly, this thesis found that textural differences felt orally had little impact on how much food was consumed and did not significantly influence satiation. A link was noticed in both studies, indicating that factors other than the primary sensory properties of food (like taste and texture) might be more influential in determining satiation.

Some oro-sensory studies state that bite size and higher duration of oro-sensory exposure were two important aspects when considering satiation. Food that was easier to swallow needed less oral processing time and was not as satiating as food that took longer to chew (McCrikerd et al., 2015; Bourne, 2004; Sethupathy et al., 2020; Zijlstra et al., 2009).

However, the current data shows that even though Gel A had the least OPT (5.79) and the least textural complexity (3.77) compared to Gel C (7.93, 6.72), there was no effect on the amount of *ad-libitum* consumed. The LMERM results showed no significant difference between the food consumption after Gel A and Gel C (p > 0.05) (Table 6). However, data shows that there was a significant difference in textural complexity between the Gels (p < 0.05) (Table 7).

### 5.5 Oral Processing Time (OPT)

Participants’ OPT for the Gels was recorded from the time they placed the Gel in their mouths, and the timer was stopped just before they were about to swallow the Gels. With reference to Figure 9, Gel A demonstrated the lowest OPT, suggesting it required the least mastication. The recorded OPT average values were 6.02 and 5.56 for Trials 1 and 2, respectively, with a combined score of 5.79. This could be due to the softer texture, leading to quicker oral processing. On the other hand, Gel C exhibited the highest OPT in both trials,
indicating it required the most extensive chewing. The averages for Trials 1 and 2 were 8.25 and 7.61, with a combined OPT score of 7.93. This may be due to a denser texture that requires longer oral processing. Gel B demonstrated intermediate OPT values, 6.98 in trial 1 and 5.98 in trial 2, and a combined score of 6.48. These findings suggest significant differences in oral processing requirements among the three Gel types. Gel C necessitates the most prolonged mastication period, potentially due to its textural complexity.

Conversely, Gel A exhibits a quicker OPT due to its softer texture. Meanwhile, Gel B positions itself in the middle. With reference to Figure 9, Gel A demonstrated the most expansive range (1.53 - 10.44), indicating the highest variation in participants' OPT. Gel B (2.05 - 8.99) and Gel C (2.17 - 12.49) displayed a narrower range of scores, suggesting less variability among the participants OPT.

Regarding the mean and median (Figure 9), Gel C has the highest values, followed by Gel B and Gel A. The mean score of 7.93 for Gel C suggests a generally higher OPT than Gel B (6.48) and Gel A (5.79). Lasschuijt et al. (2021) and Laguna and Sarkar (2016) noted that foods with complex textures took longer to chew compared to less texturally complex foods. Likewise, in this thesis, the data showed that Gel C, the most complex food Gel, recorded the highest OPT score. Meanwhile, Gel A recorded the lowest scores, indicating the shortest OPT. Gel B was intermediate between the two.

5.6 Food Diary

Participants were asked to document their food intake and feelings of hunger within three hours following the test session and any additional eating within that timeframe. They were also tasked with noting down the time they consumed their dinner. Most participants did not exhibit any notable changes in their regular eating patterns after undergoing the test within the immediate three-hour window and beyond. Moreover, the timing of their dinner remained broadly consistent with their regular eating habits as self-reported by the
participants, as seen in Appendix D1. The main goal of having participants record their food intake within three hours was to check if more texturally complex food Gels inhibited hunger for longer. However, no clear trend was noted as per Figure 10 C.

5.7 Comparison to Other Studies

Larsen et al. (2016a) assessed the influence of preloads with low and high textural complexity on feelings of fullness, utilising Gel-based model foods that looked the same. In a study where participants randomly consumed these different preloads, it was discovered that those who ate the preload with higher textural complexity significantly reduced their intake in a subsequent two-course meal served at will.

Meanwhile, Tang et al. (2016) formulated model food samples across three textural complexity levels. Their findings revealed that relative to the sample with the least complexity, the one with the most complexity resulted in a notably decreased food intake during the initial course of a freely consumed meal, though not during the second. Satiety levels reported three hours after the trial were consistent, and there was no discernible difference in the interval until the next meal across different preload scenarios. However, these studies did not fully consider palatability and iso–caloric measurements. Palatability and iso-caloric content generally correlate strongly with the amount of food eaten (Bellisle & Magnen, 1981; Sorensen et al., 2003).

5.8 Limitations

This study was affected by COVID–19; many participants fell ill and had to self-isolate for a week. This was a compulsory governmental procedure in New Zealand. Due to this reason, there was a lack of consistency in testing as people had to fully recover in order to participate again. Another factor was semester breaks that interfered with consistency in testing as some participants left the city to visit their families.
The ratio of females to males was disproportionate for reasons out of the researcher’s control. This study could only be advertised at the University of Auckland (UoA). Therefore, the volunteers were registered based on the interest expressed primarily by students. This disproportionate response from volunteers made a comparison between genders difficult. A potential solution could be to run the study longer to get an equal sample size of males and females. However, this study needed to be completed within the University’s designated deadlines for a Master’s thesis. Another contributing factor could have been the ratio of male to female students who attend UoA. Results from the statistical data show that 57% of students were female and 42% were male, while 1% were of other genders or did not wish to say ("University Demographic Data," n.d.). This study was also primarily advertised to a subsection of students in the School of Psychology, and more female students responded to the advertisement.

The study focused on participants with a BMI ranging from 18 to 25. Many volunteers who wished to participate in the study were turned down due to failing to meet BMI requirements as they fell within the underweight or overweight categories. This was one reason why finding participants suitable for this study took longer. However, selecting participants based on their BMI was one of the inclusion criteria, as the study needed participants who were considered normal weight. The BMI is a widely accepted scale used to measure people who generally fall within the categories of underweight, healthy/normal weight, overweight, and obese. The studies exploring the effect of textural on satiation are sparse (Larsen et al., 2016a; Tang et al., 2016; Patterson et al., 2023); they all use the BMI as an inclusion criterion, therefore making it almost necessary to use the same measurement in order to make it comparable to other literature.

Inclusion criteria for this thesis, apart from BMI requirements, were dental health and the absence of taste impairments. However, many other factors influence texture perception and
satiation and, therefore, the results of this thesis. These factors include participant age, gender, ethnicity, eating habits, as well as factors related to liking and chewing behaviour (Ketel et al., 2019; Zhou et al., 2021; Engelen & Van Der Bilt, 2008; Liu et al., 2022; Devezeaux de Lavergne et al., 2016; Jeltema et al., 2016). However, this limitation cannot be easily addressed and needs to be considered and acknowledged by future research.

As described in Chapter 2 (Section 2.3), Tang et al. (2017) stated that only a few studies have researched the textural complexity of food itself. Grasping the concept of food texture could be a complex process. Individuals perceive and describe texture differently, using varied expressions and terminologies. Since this is an emerging concept, researchers have approached and interpreted it differently (Tang et al., 2017). The variation in definition comes from the difficulty of studying the concept due to the impact of individual variability (Conner et al., 2017; Taylor et al., 2009; Machado-Oliveira et al., 2020; Weston et al., 2019).

Similarly, this study noted that people used different terminologies to describe textural complexity. This subjectivity in descriptions led to difficulties in understanding and differentiating the characteristics of the food Gels the participants considered contributed to a higher or lower textural complexity score. One study found that attitudes toward food texture were further nuanced by learned cultural and social factors (Szczesniak et al., 1971). For example, in this thesis, some participants considered slimy or squishy textures as complex. On the other hand, some people considered hard or lumpy oral sensations as texturally complex (Section 5.2). A possible solution would be to get participants to score the various texture elements in addition to textural complexity. For instance, that would involve separately rating oral sensations such as hardness, chewiness, and sliminess on a VAS, followed by an overall assessment of textural complexity. This would help researchers understand what element of complexity influences satiation, if any.
5.9 Future Research

This thesis aimed to study if more texturally complex foods had a greater impact on satiation. The study uses a Gel-based food model, which only considers some textures commonly found in food. Expanding the research to include a broader variety of textures might yield more comprehensive insights.

This thesis only studied the impact of textural complexity on satiation but did not consider the role of preference and visual imagery on satiation. Some studies have shown this was an important factor (Hutchings et al., 2012; Santagiuliana et al., 2018a; Engelen & Van Der Bilt, 2008; Hutchings et al., 2014). Further research could isolate the above factors and study their effect on satiation and any interplay with textural complexity. This would enable researchers to better understand how these various factors might affect satiation.

This current thesis did not link liking (preference) to satiation in any way. A goal for future research could be studying the correlation between liking and textural complexity on satiation. A more detailed questionnaire on liking could be designed to study the preference towards a particular complexity of texture.

One study found that when the element of expectation was met with experience, it resulted in greater satiation. For instance, biting into a soft apple was not associated positively with expectation; however, a soft sponge cake brings comfort and a positive experience, therefore, greater feelings of satiation (Szczesniak et al., 1971). Considering this, future research could focus on understanding participants' expectations of Gel foods before consumption. This way, a comparative analysis could be made between expectation, experience, and satiation.

5.10 Summary and Conclusion

Three complexities of Gels were developed to study the impact of textural complexity on satiation (low, medium, and high). Data revealed that there was a significant difference in complexity between Gels. However, textural complexity had no significant impact on
satiation. Oral processing time was studied to analyse if more texturally complex food Gels took longer to chew, which was the case. The results of the study show that textural complexity and any theorised effects of textural complexity on satiation may be negated by other factors such as liking, experience, and expectation, and more detailed research must be undertaken to isolate the effects of these factors.

Though liking was not the main subject of the experimental study, it was noted that most participants showed a preference towards Gel A with low textural complexity. However, studying how liking impacted satiation was beyond the scope of this thesis. Textural complexity was associated with texture sensations such as hardness, chewiness, and denseness, as the data revealed that these Gels were considered most texturally complex. The data further showed that expectation was not met with experience for Gel C. All three complexities looked identical and resembled a soft jelly-like desert. Based on the data collected, Gel C was furthest from the perception of the Gel being a soft jelly-like dessert. This could be the reason for Gel C scoring a low score on liking.

Although the hypothesis ‘that more texturally complex food Gels led to greater satiation’ was not supported, the definition of textural complexity, which was ‘the number and intensity of texture sensations, as well as their interactions and contrasts’ adapted from Patterson et al. (2023, p.2), was supported. Further studies would be conducted to understand better these various texture sensations (such as the intensity of hardness, chewiness, and sliminess) and whether any of these sensations affect satiation.
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[https://doi.org/10.1038/sj.ijo.0803776](https://doi.org/10.1038/sj.ijo.0803776)
Appendix A1: Participant Information Sheet

**Project Title:** Texture Complexity and Satiation

**Researchers:** Associate Professor Michael Hautus, Associate Professor Nicholas Gant, Niamh Patterson (PhD student), Sadhika Kampani (masters student), Luke Pringle (honours student).

**Researcher Introduction**

The researchers; Associate Professor Michael Hautus, and Associate Professor Nicholas Gant, are undertaking a research project studying the effect that textural complexity has on satiation. PhD student Niamh Patterson will be conducting the tests, with the help of Sadhika Kampani (masters student) and Luke Pringle (honours student). This research is funded by the Royal Society of New Zealand by a Marsden Grant.

**Project Description and Invitation**

We have recently demonstrated that eating food with complex texture accelerates the satiation response (so you feel fuller sooner). Complex textures might be a combination of many sensations (crunchy, creamy, crispy etc.) like a Ferrero Rocher chocolate, or a few textures sensed with high intensity, like a tooth-breakingly hard gingernut biscuit. Where current work in the field of oral processing has linked accelerated satiation to longer chewing time and effort, our work addresses an important knowledge gap by linking food texture directly to satiation, independent of other factors. We hypothesize the link between texture and satiation results from the cascade of sensations during chewing. We will take the novel approach of directly investigating the response of the brain to these sensations and linking them to food material properties and the perception of texture.
You are invited to be a participant in the “Satiation” strand of this research project, examining how model foods with different structures effect how full you feel and consequently, how much you eat.

**Project Procedures**

You will be asked to ensure you have not eaten anything for three hours prior to each session, sessions will occur at lunchtime so eating breakfast at a typical time will be fine. During each session you will be asked to fill out questionnaires to evaluate your appetite. You will be asked to eat a small serving of our model foods (described below) and then a lunch-time meal of pasta in a tomato sauce, followed by plain or chocolate sponge cake. You will be asked to eat until you are completely full. After each session you may be asked to fill out a basic food diary for the three hours after testing has finished, and send a text message to the researcher to indicate the time of your next main meal (e.g. dinner) on the day of testing.

**How long and where?**

The total time commitment will be approximately six hours, one hour per session over two x three weeks, sessions can be scheduled to suit you. Each evaluation session will take approximately 60 minutes. The evaluation will take place at the **University of Auckland in the Sensory Evaluation Laboratory, level 3, School of Science, Building 302, Room no. 302. 374 City Campus.**

**Food samples**

Please note that the samples contain (or may contain) some or all of the following ingredients: pectin, agar gel, carrageenan gel, xanthan gum, locust bean gum, sugar (sucrose), glucose syrup, food colouring, food flavouring, citric acid, glucono delta lactone (GDL), sodium alginate and potassium chloride. All ingredients are food grade and samples have been prepared under strict food hygiene conditions.
**Who should not take part?**

Potential participants will be ineligible from taking part in the research if they have an allergy or intolerance to any of the ingredients in the foods, are on restricted diets (e.g. low sugar) or if they dislike or cannot eat any of the ingredients for personal reasons. Smokers and people on medication which could affect their palate, people with stomach/bowel/thyroid disease/problems and people with loss of appetite will also be excluded along with people who have undergone dental surgery or gained or lost 5 Kg or more in the last 2 months.

Please do not participate if any of these apply to you.

**Possibility of Incidental Findings**

It is important that you consider the possibility of the food you are asked to eat causing an allergic reaction. You must notify the tester if you have any food allergies or dietary constraints that will influence what is safe for you to eat before you sample any food.

During these tests you may uncover a food allergy to a particular ingredient that you were previously unaware of. In case of a mild allergic reaction, you will be advised to visit Student Health on Campus or your primary health care provider (General practitioner/Nurse). In case of an acute reaction, such as anaphylactic shock, the Researcher will immediately dial 111 for emergency response.

**Consent and data gathering**

Each participant will be asked to read and sign a consent form, attached here, this form will be stored securely in the Faculty of Science for 6 years then destroyed. This form will be the only record of the participant’s identity and will only be accessible to the researchers.

If you are a student of the researchers, we give our assurance that your participation or non-participation in this study will have no effect on your grades or relationship with the University and that you may contact your HoD should you feel that this assurance has not been met.
Data storage/retention/destruction/future use

Hard copies of the consent forms will be stored for 6 years then destroyed by shredding.

**Right to Withdraw from Participation**

You are permitted to withdraw from involvement in the research project at any time, and do not have to give a reason. You will be identified by a 3-digit code, only available to the researchers. The key of codes and names will be destroyed once data analysis is complete. As such you may request your data be excluded from the study for up to 2 weeks after completion of the session in which you participated, and you are not required to offer an explanation.

**Confidentiality**

The identities of participants will not be revealed to any third party, through any disclosure of information. Identifying information (in the form of 3-digit codes) will be stored by the researchers only until data analysis is complete. All data will be treated confidentially and if any of this information is reported or published it will be done in a way that does not identify you as a source

**Dissemination of Results**

The results of this study will be published as journal articles and conference presentations and will be fully anonymized

**Compensation**

To thank you for your time and participation in this study you will receive Countdown vouchers with a value of $20 per session.
Contact Details

**Researcher:** Sadhika Kampani, Masters Student. Department of Psychology, Faculty of Science. Skam411@aucklanduni.ac.nz. 02041556623.

**Researchers/Supervisors:** Associate Professor Michael Hautus. Department of Psychology, Faculty of Science. M.hautus@auckland.ac.nz. +64 9 923 5924

**Researchers/Supervisors:** Associate Professor Nicholas Gant. Department of Exercise Sciences, Faculty of Science. n.gant@auckland.ac.nz. +64 9 923 6607

**Researchers/Supervisors:** Niamh Patterson, PhD Student. Department of Psychology, Faculty of Science. niamh.patterson@auckland.ac.nz

**Head of Department:** Suzanne Purdy. Department of Psychology, Faculty of Science. sc.purdy@auckland.ac.nz. +64 9 923 2073

For any queries regarding ethical concerns you may contact the Chair, University of Auckland Human Participants Ethics Committee, Office of Research Strategy and Integrity, University of Auckland, Private Bag 92019, Auckland 1142. Telephone 09 373-7599 ext. 83711, email: humanethics@auckland.ac.nz

Approved by the University of Auckland Human Participants Ethics Committee until 05/08/2025. Reference Number 023323.
Appendix A2: Consent Form

This form will be held for a period of 6 years

Project Title: Texture complexity and Satiation

Researchers: Associate Professor Michael Hautus, Associate Professor Nicholas Gant, Niamh Patterson (PhD student), Sadhika Kampani (masters student), Luke Pringle (honours student).

- I have read and understood the Participant Information Sheet. I have understood the nature of the research and am prepared to take part as a participant.

- I have had the opportunity to ask questions and have had them answered to my satisfaction.

- I understand the ingredients and the preparation of the food that I consume and to my knowledge I have no allergy or intolerance towards any of these ingredients.

- I understand that I am ineligible for this study if I am concerned about sugar in my diet, I am a smoker, I am on medication, which could affect my palate, I have a stomach/bowel disease, I have appetite loss, or in the last 2 months I have undergone dental surgery or gained/lost more than 5 Kg.

- I understand that data I produce will be treated confidentially, however the data collection will not be anonymous, as my name will be linked to my results data via a 3-digit code. The list of names and codes will be available only to the researchers and will be destroyed on completion of data analysis.

- I understand that if any of my provided data is reported or published in the future it will be done so in a way that does not identify me as a source.
o I understand that the consent form and the data I provide will be stored securely for 6 years, after which it will be destroyed. (If you would like to have access to your own results, please provide your email address below)

o I understand that my participation is voluntary and my agreement or refusal to participate will not affect my grades or my academic relationships with my department or with members of staff.

o I understand that if I have concerns that this agreement is breached I can communicate this concern to my Academic Head (HoD).

o I understand that I have the right to withdraw myself from the project at any time without any reason. Up until 2 weeks after the last data collection I can also request that my data is removed from the study.

Name _____________________
Email address to receive results (optional) _______________________________
Signature __________________________________________________________________
Date _________

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Appendix B1: Demographics

Contact number: ………………………………………………………………..

(Will only be used for the propose of following up)

Participant number: ……………………………………………………

Session number: ………………………………………………………

Age: ………………………………………………………………………

Ethnicity: …………………………………………………………………

Gender (Please tick the bubble)

  o Female
  o Male
  o Non-binary

Body Mass Index (BMI)* (Please tick the bubble)

  o <18.5
  o 18.5-24.9
  o ≥ 25.0

\[
\text{BMI} = \frac{\text{Weight (Kg)}}{\text{Height (m}^2\text{)}}
\]

………………………………………………………………………………
What did you eat for breakfast this morning?

…………………………………………………………………………………………………….
…………………………………………………………………………………………………….
…………………………………………………………………………………………………….
…………………………………………………………………………………………………….
…………………………………………………………………………………………………….
…………………………………………………………………………………………………….
…………………………………………………………………………………………………….

Please exclude yourself if any of these criteria apply to you. (Please tick the bubble)

- Dental conditions
- Dental surgery
- Allergies or intolerance to any of the ingredients in the foods
- Restricted diets (e.g., low sugar)
- Dislike or cannot eat any of the ingredients for personal reasons
- Smokers
- Medication which could affect the taste palate
- Stomach/bowel/thyroid problems
- Loss of appetite
- Gained or lost 5 Kg or more in the last 2 months.
- BMI outside the range of 18 - 25

Approved by the University of Auckland Human Participants Ethics Committee until 05/08/2025. Reference Number 023323.
Appendix B2: Appetite Questionnaire – Before Gel Consumption

Q1

1. How hungry are you?

Not at all

Extremely hungry / As hungry as I have ever been

2. How strong is your desire to eat?

Very weak /
 Extremely low

Extremely high / Extremely strong

3. How full are you?

Not at all

Extremely full / As full as I have ever been

4. How much do you think you could (or want to) eat right now?

Nothing at all

A very large amount

Approved by the University of Auckland Human Participants Ethics Committee until 05/08/2025. Reference Number 023323.
Appendix B3: Appetite Questionnaire – After Gel Consumption

Q2

1. How hungry are you?

Not at all

Extremely hungry / As hungry as I have ever been

2. How strong is your desire to eat?

Very weak / Extremely low

Extremely high / Extremely strong

3. How full are you?

Not at all

Extremely full / As full as I have ever been

4. How much do you think you could (or want to) eat right now?

Nothing at all

A very large amount

Approved by the University of Auckland Human Participants Ethics Committee until 05/08/2025. Reference Number 023323.
Appendix B4: Appetite Questionnaire – After Ad-Libitum (Pasta) Consumption

Q3

1. How hungry are you?

2. How strong is your desire to eat?

3. How full are you?

4. How much do you think you could (or want to) eat right now?

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Appendix B5: Appetite Questionnaire - After Ad-Libitum (Cake) Consumption

Q4

1. How hungry are you?

Not at all  
Extremely hungry / As hungry as I have ever been

2. How strong is your desire to eat?

Very weak / Extremely low  
Extremely high / Extremely strong

3. How full are you?

Not at all  
Extremely full / As full as I have ever been

4. How much do you think you could (or want to) eat right now?

Nothing at all  
A very large amount

Approved by the University of Auckland Human Participants Ethics Committee until 05/08/2025. Reference Number 023323.
Appendix B6: Food Diary

Q6

Please record the type and amount of food and/or beverage you consume within the next 3 HOURS in the following table.

After 3 HOURS please fill in the appetite questionnaire below. Please text the researcher (number provided) when you eat your next main meal (e.g. dinner), so we can collect the time of meal.

<table>
<thead>
<tr>
<th>Time</th>
<th>Type of Food/Beverage</th>
<th>Consumed Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>e.g., 1.45 pm</td>
<td>e.g., Cereal Bar</td>
<td>e.g., 80 g</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Please complete **AFTER 3 HOURS**

1. How hungry are you?

Not at all  
Extremely hungry / As hungry as I have ever been

2. How strong is your desire to eat?

Very weak /  
Extremely low  
Extremely high / Extremely strong

3. How full are you?

Not at all  
Extremely full / As full as I have ever been

4. How much do you think you could (or want to) eat right now?

Nothing at all  
A very large amount

Approved by the University of Auckland Human Participants Ethics Committee until 05/08/2025. Reference Number 023323.
Appendix C1: Oral Processing Time

Participant number........
Session Number............
Sample Number.............

INSTRUCTIONS

1) Place sample in mouth (at this time a stopwatch will start).
2) Start to chew normally.
3) As soon as you are ready to swallow indicate by raising your hand (at this time the stopwatch will stop).
4) Have a drink of the water provided.
5) Answer the questions below.

Q.1. How much did you like the sample? (Place one mark on the line)

Not at all

Like extremely

Q.2. How texturally complex do you think the sample was? (Place one mark on the line)

Not at all

Extremely complex

Q3. What did you base your judgement of textural complexity on?

________________________________________

________________________________________

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Appendix D1: Qualitative Data for Dinner Time

Table D1

The table describes the qualitative data for dinner eaten by participants post testing.

<table>
<thead>
<tr>
<th>Participant No.</th>
<th>Time Food Consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7:30 pm</td>
</tr>
<tr>
<td>2</td>
<td>9:00 pm</td>
</tr>
<tr>
<td>3</td>
<td>8:30 pm – 09:30 pm</td>
</tr>
<tr>
<td>4</td>
<td>6:30 pm</td>
</tr>
<tr>
<td>5</td>
<td>6:30 – 7:30 pm</td>
</tr>
<tr>
<td>6</td>
<td>6:00 – 7:00 pm</td>
</tr>
<tr>
<td>7</td>
<td>9:00 – 10:00 pm</td>
</tr>
<tr>
<td>8</td>
<td>Left study</td>
</tr>
<tr>
<td>9</td>
<td>7:00 - 8:30 pm</td>
</tr>
<tr>
<td>10</td>
<td>6:30 – 7:30 pm</td>
</tr>
<tr>
<td>11</td>
<td>7:00 - 8:30 pm</td>
</tr>
<tr>
<td>12</td>
<td>6:30 pm</td>
</tr>
<tr>
<td>13</td>
<td>7:00 - 8:30 pm</td>
</tr>
<tr>
<td>14</td>
<td>8:00 - 9:30 pm</td>
</tr>
<tr>
<td>15</td>
<td>7:00 - 8:30 pm</td>
</tr>
<tr>
<td>16</td>
<td>8:00 - 9:30 pm</td>
</tr>
<tr>
<td>17</td>
<td>6:30 – 7:30 pm</td>
</tr>
<tr>
<td>18</td>
<td>7:00 - 8:30 pm</td>
</tr>
<tr>
<td>19</td>
<td>6:00 – 7:00 pm</td>
</tr>
<tr>
<td></td>
<td>Time</td>
</tr>
<tr>
<td>---</td>
<td>--------------</td>
</tr>
<tr>
<td>20</td>
<td>8:00 - 9:30 pm</td>
</tr>
<tr>
<td>21</td>
<td>6:00 – 7:00 pm</td>
</tr>
<tr>
<td>22</td>
<td>7:00 - 8:30 pm</td>
</tr>
<tr>
<td>23</td>
<td>6:30 pm</td>
</tr>
<tr>
<td>24</td>
<td>6:00 – 7:00 pm</td>
</tr>
<tr>
<td>25</td>
<td>6:00 – 7:00 pm</td>
</tr>
<tr>
<td>26</td>
<td>7:00 - 8:30 pm</td>
</tr>
<tr>
<td>27</td>
<td>7:00 - 8:30 pm</td>
</tr>
<tr>
<td>28</td>
<td>7:00 - 8:30 pm</td>
</tr>
<tr>
<td>29</td>
<td>8:00 - 9:30 pm</td>
</tr>
<tr>
<td>30</td>
<td>7:00 - 8:30 pm</td>
</tr>
</tbody>
</table>

*Note. The table describes the approximate time that participants ate their dinner after testing.*
Appendix E1: Qualitative Data for Textural Complexity

Table E1

Illustrates the qualitative data for textural complexity.

<table>
<thead>
<tr>
<th>Gel A</th>
<th>Count</th>
<th>Gel B</th>
<th>Count</th>
<th>Gel C</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth</td>
<td>149</td>
<td>Grainy</td>
<td>106</td>
<td>Hard</td>
<td>177</td>
</tr>
<tr>
<td>Soft</td>
<td>89</td>
<td>Balls</td>
<td>99</td>
<td>Chewy</td>
<td>49</td>
</tr>
<tr>
<td>Melted</td>
<td>34</td>
<td>Gritty</td>
<td>49</td>
<td>Dense</td>
<td>32</td>
</tr>
<tr>
<td>Dissolved</td>
<td>33</td>
<td>Bubbles</td>
<td>42</td>
<td>Firm</td>
<td>31</td>
</tr>
<tr>
<td>Slimy</td>
<td>17</td>
<td>Moderate</td>
<td>12</td>
<td>Chunky</td>
<td>17</td>
</tr>
<tr>
<td>Jelly</td>
<td>9</td>
<td>Bits</td>
<td>6</td>
<td>Lumps</td>
<td>14</td>
</tr>
<tr>
<td>Slippery</td>
<td>7</td>
<td>Jam</td>
<td>6</td>
<td>Rough</td>
<td>7</td>
</tr>
<tr>
<td>Easy</td>
<td>7</td>
<td>Crunchy</td>
<td>6</td>
<td>Solid</td>
<td>6</td>
</tr>
<tr>
<td>Watery</td>
<td>6</td>
<td>Easy</td>
<td>5</td>
<td>Disc</td>
<td>5</td>
</tr>
<tr>
<td>Blobby</td>
<td>4</td>
<td>Granules</td>
<td>4</td>
<td>Thick Jam</td>
<td>5</td>
</tr>
<tr>
<td>Enjoyable</td>
<td>2</td>
<td>Lumps</td>
<td>3</td>
<td>Spongy</td>
<td>4</td>
</tr>
<tr>
<td>Gooey</td>
<td>2</td>
<td>Crystals</td>
<td>3</td>
<td>Pearl</td>
<td>2</td>
</tr>
<tr>
<td>Squishy</td>
<td>1</td>
<td>Sticky</td>
<td>2</td>
<td>Grainy</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soft</td>
<td>2</td>
<td>Crunchy</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Circles</td>
<td>2</td>
<td>Rice Grains</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sprinkles</td>
<td>2</td>
<td>Coconut</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Salmon</td>
<td>2</td>
<td>Boba</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gristly</td>
<td>3</td>
<td>Lolly</td>
<td>1</td>
</tr>
<tr>
<td>Texture</td>
<td>Count</td>
<td>Description</td>
<td>Count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>-------</td>
<td>--------------------</td>
<td>-------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granules</td>
<td>1</td>
<td>Gooey</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bumpy</td>
<td>2</td>
<td>Hard Lolly</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smooth</td>
<td>1</td>
<td>Thick</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chewy</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* The table provides a detailed documentation of the words used by the participants to evaluate the textural characteristics of the gel samples served to them.