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Temporal sensory liking methods: An investigation with beef steaks from different production systems

Thesis presented by

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Declaration

I, Linda Corcoran, hereby declare that this thesis is my own work and effort and that it has not been submitted for another degree neither at the National University Ireland, Cork, nor elsewhere. Where other sources of information have been used, they have been acknowledged.

Linda Corcoran

Linda Corcoran

Abstract

Research on the impact of the diet of the animal on consumer liking of beef has yielded conflicting results. The aim of this study was to apply the traditional liking method and two temporal liking (TL) methods (free and structured) to determine consumer liking of beef derived from animals that were fed grain (GF), grass silage and grain (SG) or grazed grass (GG) during finishing and use different methods to determine the data quality and consumers variability. Three separate panels of regular beef-eating consumers (n=51; n=52; n=50) were recruited from students and staff at Teagasc Food Research Centre, Dublin, Ireland, to assess the liking of striploin steaks from animals fed either GF, SG, or GG, respectively.

Results of chapter 2 revealed significant differences ($p \leq 0.05$) in liking between diets in terms of overall liking, juiciness, and tenderness using the free TL method. These effects were not observed using the structured TL or traditional liking methods. Further statistical analysis of the TL methods found that the free TL method yielded more discriminative data than the structured TL method, with significant differences ($p \leq 0.05$) found for both overall liking and juiciness. Consumers also found the free TL method easier to perform compared to the structured TL method. The evolution of scores over time (changes in consumer scores over the scoring period) was significant ($p \leq 0.05$) for all attributes using the free TL method. These results show that free TL may give rise to new opportunities to elicit more in-depth insight from consumer studies using meat.

In addition to answering the research question, TL data also has the potential to give new insight into consumer behaviour in terms of how people approach temporal

sensory liking methods. Chapter 3 utilises this consumer behaviour approach to look at three temporal liking studies applying both structured and free TL in terms of data quality, presence or absence of temporality, and correlations between consumer response and self-reported difficulty. Interestingly, the assessment of temporality found that consumers who showed the ability to provide temporal data did not provide it for all attributes studied. The analyses have also demonstrated areas where fatigue and the natural variability in consumer responses may impact data quality.

Chapter 4 further analyses data from study 2 from chapters 2 and 3 as this had no missing data. Studies 1 and 3 had missing data due to consumers not providing responses to all time points and attributes during sensory testing. Two TL methods (free and structured) and a traditional liking method were employed to generate data from consumers on their liking of beef steaks derived from a grain supplementation diet for four attributes (overall liking, flavour, tenderness, juiciness). Consumers spent the most time and gave the most responses to the attribute flavour. High levels of variability were found within each liking method. High correlations were also found between attributes within each liking method. For the structured TL, overall liking was found to be significant over time. In addition, the free TL and traditional liking were found to be significantly different from each other ($p \leq 0.05$) for liking and flavour attributes and the structured TL and traditional liking were found to be significantly different from each other for flavour. However, the two temporal liking methods did not differ from each other. Two clusters of consumers were found for each attribute, one who slightly liked the attribute and one who slightly disliked the attribute. Some consumers changed cluster groups between attributes. This study has shown that the choice of TL method may make a difference on the data elicited.

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List of Abbreviations

ACH = Agglomerative Hierarchical Clustering

AEF = Attack-Evolution-Finish

AMSA – American Meat Science Association

ANCOVA – Analysis of Covariance

ANOVA = Analysis of Variance

AS = Attribute Specific

CATA = Check-All-That-Apply

CH = Charolais breed

CI = Confidence Interval

DA = Descriptive Analysis

DATI = Dual Attribute Time Intensity

DM = Descriptive Methods

FCP = Free Choice Profile

FL = Free Listing

FMS = Free Multiple Sorting

FP = Flash Profile

FS = Free Sorting

GDPR = General Data Protection Regulation

GF = Grain finishing diet

GG = Grazed grass finishing diet

HPP = High Pressure Processing

IMAX = maximum intensity

IMF = Intramuscular fat

Inc. = Incorporated

IP = Ideal Profile

IS = Intensity Scales

ISO = International Organization for Standardization

JAR = Just About Right Scales

LAM = Labelled Affective Magnitude Scales

LL = Longissimus Lumborum

LM = Limousin breed

LSD = Least Significant Difference

LTL = Longissimus Lumborum et Thoracis

MANOVA = Multivariate Analysis of Variance

MATI = Multi Attribute Time Intensity

MSA = Meat Standards Australia

OD = Overall difference

OEQ = Open-Ended Questions

OL = Overall Liking

OPD = Optimised Descriptive Profile

P = Time-period (Free TL)

P1 = Time-Period 1 (Free TL)

P2 = Time Period 2 (Free TL)

P3 = Time Period 3 (Free TL)

P4 = Time Period 4 (Free TL)

PAE = Preferred Attribute Elicitation

PCA = Principal Component Analysis

PEF = Pulsed Electric Fields

PiP = Pivot Profile

PM = Project Mapping

PPM = Polarised Projective Mapping

PSP = Polarised Sensory Positioning

QDA = Quantitative Descriptive Analysis

RATA = Rate-All-That-Apply

RDA = Ranked Descriptive Analysis

RDM = Rapid Descriptive Methods

RGM = Repertory Grid Method

SG = Grass silage and grain finishing diet

Std. Deviation = Standard Deviation

T= Time-point (Structured TL)

T1 = Time Point 1 (Structured TL)

T2 = Time Point 2 (Structured TL)

T3 = Time Point 3 (Structured TL)

T4 = Time Point 4 (Structured TL)

TCATA = Temporal Check All That Apply

TDE = Temporal Dominance of Emotions

TDS = Temporal Dominance of Sensations

TI = Time Intensity

TL = Temporal liking

TOS = Temporal Order of Sensations

UCC = University College Cork

UFP = Ultra Flash Profiling

UK = United Kingdom

US = United States

Project Outputs

Oral Presentation

Corcoran, L.C. (presenter), Schlich, P., Millar K.A., Moloney, A.P., Botinestean, C, Gallagher, E., O' Sullivan M.G., Crofton, E.C., *Comparing consumer liking of beef steaks from three different feeding systems using sensory temporal liking and traditional liking methods.* At the 49th Annual Food Science and Technology Virtual Conference, December 15 2020. Book of abstracts [link] https://doi.org/10.21427/1qxb-1s79

Poster Presentations

Corcoran, L.C., Schlich, P., Millar, K.A., Moloney, A.P., Botinestean, C, Gallagher, E., O' Sullivan, M.G., Crofton, E.C., *Application of two temporal liking methods to examine the differences in consumer liking of beef steaks from three different feeding systems.* At the 14th Pangborn Sensory Science Symposium, August 9-12, 2021.

Corcoran, L.C., Schlich, P., Millar, K.A., Moloney, A.P., Botinestean, C, Gallagher, E., O' Sullivan, M.G., Crofton, E.C., *Influence of consumer demographics on liking of beef steaks from three different finishing systems.* At the 14th Pangborn Sensory Science Symposium, August 9-12, 2021.

Corcoran, L.C., Schlich, P., Millar, K.A., Moloney, A.P., Botinestean, C, Gallagher, E., O' Sullivan, M.G., Crofton, E.C., *Application of two temporal liking methods to examine the differences in consumer liking of beef steaks from three different feeding systems.* At the Teagasc Walsh Scholars: The Next Generation Showcase, July 9 2021.

Corcoran, L.C., Crofton, E. C., *Impact of Demographic Factors on Consumer Liking of Beef Steaks from Three Different Grass-Based Feeding Systems.* At the 10th Annual oSTEM Conference + NOGLSTP's Out to Innovate Virtual Conference, November 12 2020.

Manuscript for Submission

Corcoran, L.C., Schlich, P., Millar, K., O' Riordan, E. G., Moloney, A.P., Botinestean, C., Gallagher, E., O' Sullivan M.G., Crofton, E.C. *Comparing consumer liking of beef strip loin steaks from three feeding systems using a combination of temporal and traditional liking methods*.

General Introduction

Consumers are becoming more interested in and concerned about the ethical, moral, and social dimensions of meat production in recent years (Gwin *et al.*, 2012; Henchion *et al.,* 2017; Regan *et al.,* 2018; Stampa *et al.,* 2020). However, although issues surrounding health and the environment are important to consumers, they also expect a highly palatable product of consistent eating quality (Banović *et al.*, 2009; Grunert *et al.*, 2004; Miller, 2020). Demand for grass-fed beef is increasing in many countries; however, commercially, and legally, the term "grass-fed" is not very well defined. Yet despite this lack of definition, consumer demand for "grass-fed" beef is soaring. In fact, in the US, it has been reported that consumer demand for grass-fed beef is greater than the supply (Hayek & Garrett, 2018).

Many different variables can influence meat quality, including animal feeding practices like ration (diet) composition. Animal feeding practices, such as diet composition, have been shown to affect several meat quality characteristics. The subcutaneous fat of beef from pasture-based production systems is often more yellow, while the muscle tends to be darker in colour when compared to cattle raised on a conventional indoor concentrate-based system (Moloney et al., 2021). Some studies utilising trained panels have found differences in the flavour profile (Baublits *et al.*, 2006; Duckett *et al.*, 2009; 2013; Wright *et al.*, 2015) and tenderness of beef using various ration compositions (Sapp *et al.*, 1999; Warren *et al.*, 2008); however, other trained panels have not found any differences (French *et al.*, 2000; 2001; Jiang *et al*., 2010; Moloney *et al*., 2008; 2011; Moran *et al.*, 2017; Sinclair *et al.*, 2001). Yet, even if some trained panels can detect differences in the eating quality of beef from different animal diets, debate exists around whether consumers can perceive these effects.

In the US and Canada, many studies in which the effect of animal diet on the sensory quality has been investigated have indicated that consumers prefer beef from grain-based systems (Corbin *et al.*, 2015; Cox *et al.*, 2006; Kerth *et al.*, 2007; Killinger *et al.*, 2004; Maughan *et al.*, 2012; Sitz *et al.*, 2005). However, other studies, some from the US (Chail *et al.*, 2017; Ron *et al.*, 2019; Simonne *et al.*, 1996; Umberger *et al.*, 2002), and similar studies from Europe have not observed this preference (Blanco *et al.*, 2017; Realini *et al.*, 2009;2013; Ripoll *et al.*, 2014). The disparity between the results of the US studies, in particular, has been associated with familiarity (Garmyn *et al.*, 2020; Killinger *et al.*, 2004; Sitz *et al.*, 2005). In summary, the current literature indicates that beef from animals fed grass, grain or grass supplemented with grain has no repeatable significant differences in perceived eating quality; however, all of these consumer studies have utilised static measures of sensory evaluation, which elicit only one overall response. The main drawback of these static sensory methods is that they do not account for oral processing, which may give us more information about the sensory perception and consumer opinions on food products.

Many novel methods have been developed in an attempt to capture more descriptive and dynamic data from consumers, including temporal methods like Temporal Dominance of Sensations (TDS) (Pineau *et al.*, 2009), Temporal Dominance of Emotions (TDE) (Jager *et al.*, 2014) and Temporal Check All That Apply (TCATA) (Castura *et al.*, 2016). One temporal method that has been developed to assess consumer liking while accounting for dynamic perception is temporal or dynamic liking (Ramsey *et al.*, 2018; Sudre *et al.*, 2012; Thomas *et al.*, 2015). This method instructs consumers to provide multiple scores at different times during the eating process. While all TL liking methods have utilised traditional scales, the way in which these scales can be used for tracking liking over time can be different. Two main types of “time-tracking” have emerged in the literature: continuous or free choice time assessments (Ramsey *et al.*, 2018; Sudre *et al.*, 2012; Taylor & Pangborn, 1990; Thomas *et al.*, 2015) and structured or pre-determined time assessment (Delarue & Loescher, 2004; Galmarini *et al.*, 2015; Sudre *et al.*, 2012; Verneau *et al.*, 2016). In addition, to date, TL methods have only been used to report on overall liking or pleasantness of a product.

Therefore, this study aimed to investigate TL as both a free choice and a structured temporal method for assessing consumer liking of overall liking, beef flavour, juiciness, and tenderness of beef steaks from various feeding systems. In addition, the TL methods will be compared to the traditional (static) liking method, and a deep dive will be taken into the data elicited from all methods. It is hypothesised that the TL methods will result in more in-depth data than the traditional liking method, which may give a clearer picture of consumer liking of beef steaks from various feeding systems than the literature currently produces. It is also hypothesised that consumers will be able to report TL for all four attributes when consuming the beef samples.

Chapter 1

Literature Review

1.1 Introduction

Sensory science is a multidisciplinary field of study that is becoming increasingly popular in industry as it can be applied throughout the product development process as well as in quality assurance and shelf-life applications (Heymann & Lawless, 2013). This is especially important in our fast-paced, increasingly consumer-led food industry, where there is more demand than ever for detailed insight into consumer perspectives and perceptions. Therefore, the methodologies used in sensory science and sensory evaluation are continuously evolving to keep up with these demands.

For many years, trained panels were used to profile products objectively, and consumers were used for acceptance and preference testing (Kemp *et al.*, 2009). Data from trained and consumer panels are not always complimentary, and it's often difficult to predict from objective data how consumers will assess products in a real-world setting. (Ares *et al.*, 2015; Hopfer & Heymann, 2014). In addition, the development of novel sensory techniques such as Check-All-That-Apply (CATA) and Temporal Dominance of Sensations (TDS) have helped to blur the lines between consumer and expert trained assessments, as these methods elicit sensory profiles but can be used with either consumers or trained assessors.

This review consists of four sections. In the first section, sensory evaluation methodologies will be introduced with an emphasis on novel methods encapsulating both rapid descriptive methods (RDM) and dynamic or temporal methods. The focus will be on consumer approaches involving meat, poultry, and their products; however, trained panel insights and other literature may also be included if gaps exist in the literature. A core objective of the research presented in this thesis is to determine whether animal diet impacts the consumer sensory liking of beef; therefore, beef as a product will be introduced in the second section of this review with a key focus on sensory quality. The third section will briefly introduce the animal feeding systems used as part of this research thesis. The research question of whether animal diet has an effect on the eating quality of beef will be introduced in the fourth section via a systemic review of current literature. This chapter then concludes by identifying the research gaps that led to the research objectives presented in this thesis.

1.2 An Introduction Sensory Methodology

Sensory evaluation is the most frequently used part of sensory science (Varela & Ares, 2017b) and can be best defined through the official definition adopted by the IFT, *'a scientific method used to evoke, measure, analyse and interpret those responses to products as perceived through the senses of sight, smell, touch, taste, hearing'* (Anonymous, 1975). Sensory evaluation can be broadly classified into three main groups; analytical tests, which include discrimination and descriptive tests; affective tests, which include consumer tests; and dynamic or temporal tests, which include time-based tests. However, the recent evolution in sensory testing research means all these classifications include both classic (i.e., traditional) and novel methods in the same categories, which may become confusing for the purpose of this review. In addition, some novel methods don't neatly fit into one of the traditional categories. Therefore, for this review, methods will be classified as either classic or novel and will be subdivided from there.

1.2.1. Classic Sensory Methods

Traditionally, sensory testing developed with the sole use of expert panels which were used for quality control, discrimination between products and product profiling. Over time, consumer testing developed separately from the work done by the expert panels and established its own methodology to gauge consumer acceptance and preference.

1.2.1.1. Discrimination methods

Discrimination methods are used to determine whether difference or similarity exists between products and are some of the most common tests utilised in sensory evaluation (Kemp *et al.*, 2009). Two or more products can be tested using these techniques, which can be further subdivided into two categories: overall difference (OD) and attribute specific (AS) tests (Kemp *et al.*, 2009; O’ Sullivan, 2017). Both can be performed with trained panels or naïve consumers, but not a combination of both. Many different types of discrimination tests exist, the most popular of which are the triangle test (OD), duo-trio test (OD), A/not-A (OD), the paired comparison (AS), and ranking test (AS) (Kemp *et al.,* 2009). An advantage of discrimination methods is that they are quick and easy to use. However, while these tests will determine whether a difference exists or not, the nature of the difference remains unknown. Therefore, setting clear objectives and understanding the objectives from the outset is vital.

1.2.1.2. Descriptive methods

Classic descriptive sensory methods can provide detailed knowledge of the sensory characteristics of a product in terms of appearance, aroma, flavour, texture, and taste (O’Sullivan, 2017). Popular descriptive methods include Flavour Profile by Cairncross & Sjostrom (Murray *et al.,* 2001), Quantitative Descriptive Analysis (Stone *et al.*, 1974) and the Spectrum method (Meilgaard *et al.*, 1991). Descriptive methods gained popularity due to the in-depth level of information generated from using them. Once a sensory lexicon is established, a scale is used to indicate the intensity of an attribute or attributes. The drawback to descriptive sensory methods is that they require the use of a trained/expert panel, and recruiting, training, and maintaining a trained panel can require a substantial amount of time, money, and patience.

1.2.2. Affective methods

Affective methods are consumer tests that can be quantitative or qualitative. Qualitative methods include various techniques, commonly focus groups and interviews. Quantitative affective methods can be subdivided into two groups: preference and acceptance tests. In general, large numbers of consumers are needed to form a consensus between consumers. As the name suggests, preference tests are used to determine if differences exist in preference between two or more products, either overall or for a particular attribute. On the other hand, acceptance tests measure levels of acceptance or liking. The hedonic scale, particularly the 9-point hedonic scale, is most frequently used to collect affective sensory data (Lim, 2009).

1.2.3. Temporal Methods

1.2.3.1. Temporal Aspects of Sensory Perception

The sensory perception of food begins before the food enters the mouth and continues throughout oral processing and beyond (Appleqvist *et al.*, 2016). Oral processing (i.e., eating) is a term that describes the changes that a food undergoes during the eating process, which consists of 4 stages; mastication, salivation, chewing and swallowing (De Wijk *et al.*, 2003; Chen, 2009; Di Monaco *et al.*, 2016). It is a dynamic process meaning the oral perception of aroma, taste (including aftertaste), flavour and texture of food changes during breakdown that can be influenced by many physiological and psychological aspects, such as oral physiology, sensory memory, dynamics of liking, and satiety (Hort *et al.*, 2017).

1.2.3.2. Time-Intensity

Sensory perception can be measured over the entire eating process, from seeing the food product until the aftertaste fades or just during chewing. Temporal methods attempt to record how sensory perceptions change by recording dynamic scores during eating, which sets them apart from all other consumer sensory tests. The earliest known study investigating temporality dates from 1937 (Holway & Hurvich) and was used to track the perception of salt over time (Cliff & Heymann, 1993). Other early temporal studies established discrete TI as a method particularly Sjiistriim (1954) and Jellinek (1964) while investigating how bitterness perception in beer changes at 1s time intervals (Cadena *et al.*, 2014; Cliff & Heymann, 1993; Dijksterhuis & Piggott, 2000). However, manual tracking of the time in conjunction with scoring an attribute was seen as a distraction to panellists. While there were several different developments in tracking methods and scoring materials, there were still significant mental demands placed on panellists. Larson-Powers and Pangborn (1978) were the first to use continuous time-intensity and utilised a moving strip-chart connected to a food pedal for starting and stopping. The introduction of computers gave time-intensity a boost in utilisation and led to the development of dual attribute time-intensity (DATI) (Duizer *et al.*, 1997; Zimoch & Findlay, 1998) and multiple attribute time-intensity (MATI). Time-intensity is still used today, albeit solely with trained panels, due to the risk of halo dumping effects (Clark & Lawless, 1994). However, newer temporal methods have overtaken it in popularity in recent times.

1.2.4. Disadvantages of Classic Sensory Methods

The time and cost of classic descriptive methods (DM) and temporal methods make them difficult to routinely apply for product development applications in the fast-moving food industry. However, traditional consumer testing, mostly preference and acceptability testing, also has drawbacks, including difficulty recruiting large numbers of consumers, which is necessary to generate robust and reliable data (Ares & Jaeger, 2013). Novel sensory methods have been developed to overcome some of these disadvantages and address industry's need for more rapid descriptive methods.

1.2.5. Novel Sensory Methods

Novel sensory methods (***Table 1.1***) can be broadly categorised into two different types: rapid descriptive methods (RDM) and dynamic or temporal methods). Both categories relate to methods that have been explicitly developed or adapted for use with either naïve sensory assessors (i.e.) consumers or semi-trained assessors to ensure quick results.

1.2.5.1. Rapid Descriptive Methods (RDM)

Rapid Descriptive Methods (RDM) is a broad category of profiling or descriptive sensory methods which have been specifically developed for use with consumers or semi-trained panels. They are termed rapid as the panellists require little to no training meaning sensory data is generated much faster and with less cost than trained panels. Contrary to the categorisation as "novel" sensory methods, many of them are not necessarily 'new'. The oldest methods, such as Free Choice Profiling and the Repertory Grid Method, date back to the 1980s, but they have gained significant traction in the last ten plus years as a 'hot topic' in sensory and consumer science (Varela & Ares, 2012; Varela & Ares, 2014b). The exact methods included in the category of RDM are continuously being updated; therefore, the most popular and utilised methods have been summarised in ***Table 1.1.*** The majority of RDM are suitable for consumers, except for Pivot Profile (PiP) and Optimised Descriptive Profile (OPD) methods, in which panellists require some training to produce reliable results.

Table 1.1 – Summary of novel sensory methods

Name (Abbreviation)	Type	Description	Suitable for consumers?
Ranking Descriptive Analysis (RDA)[1]	RDM	Subjects use ranking to compare samples simultaneously; no reference sample training is required.	Yes
Free Choice Profiling (FCP)[2]	RDM	Oldest RDM dates from the 1980s. Subjects assess samples according to their own list of characteristics and intensity scales used to rate characteristics.	Yes
Flash Profiling (FP)[1]	RDM	A mix of FCP and RDA. Subjects develop their own descriptive terms/ attributes and then rank samples according to intensity.	Yes
Free Listing (FL)[1]	RDM	Subjects generate terms related to samples.	Yes
Repertory Grid Method (RGM)[3]	RDM	Subjects are presented with three stimuli at once and asked to describe the similarities and the differences between them	Yes
Intensity Scales (IS)[1]	RDM	Subjects rate the intensity of set attributes on a structured (3/5/7-point) or unstructured line scale.	Yes
Project Mapping (PM)/ Napping[4]	RDM	Subjects group samples on a sheet of paper (A3/A4) according to their own terms. Full or partial PM can be run.	Yes
Ultra-Flash Profiling (UFP)[1]	RDM	Form of FP that is run directly after Napping. Quick generation of terms on sheets used for PM/Napping according to groupings.	Yes
Sorting/ Free Sorting (FS)/Free Multiple Sorting (FMS)[4]	RDM	Subjects group ('sort') sample set by similarities or differences. Free Sorting involves subjects choosing their own grouping, but generally, groups cannot contain only one sample. FMS requires sorting the samples multiple times by different attribute differences.	Yes

Check-All-That-Apply (CATA)[2]	RDM	Subjects are presented with a list of attributes, from which they select the ones relevant to the product.	Yes
Rate-All-That-Apply (RATA)[1]	RDM	A variation of CATA, subjects receive a list of attributes and are asked to rate the intensity of any that apply using a scale. It can be used for measuring attributes or emotions.	Yes
Optimised Descriptive Profile (ODP)[4]	RDM	Subjects receive minimal training using reference samples. All samples are evaluated simultaneously, one attribute at a time, over several sessions if necessary and rate the intensity on unstructured scales.	No, it requires some training
Ideal Product/ Ideal Profile Method (IP)[4]	RDM	Method used in conjunction with another RDM (CATA, JAR, IS). Subjects use that method to describe the product presented and then imagine their ideal product and describe it using attributes etc.	Yes
Preferred Attribute Elicitation (PAE)[2]	RDM	Subjects rank attributes by importance, then rate them using scales (7-/9-point structured). All subjects participate in discussions to decide on suitable attributes before partaking in a rating test of the attributes.	Yes
Open-Ended Questions (OEQ)[2]	RDM	Subjects describe samples using their own terms and relevant description.	Yes
Polarised Sensory Positioning (PSP)[2]	RDM	Samples are assessed by subjects who position them globally (set space) relative to reference samples.	Yes
Pivot Profile (PiP)[5]	RDM	Free description differences are collected between a product and a standard (or pivot). The pivot remains constant for all products evaluated.	No, it requires some training

Polarised Projective Mapping (PPM)[1]	RDM	Evaluation of differences and similarities, in a similar fashion to napping, but positioning is based on reference samples. Subjects then use own terms to describe samples.	Yes
Ranked-Scaling[6]	RDM	Several products are rated on scales and then positioned (ranked) based on attribute intensity.	Yes
Temporal Dominance of Sensations (TDS)[7]	Temporal	Panellists choose the most dominant (attention-catching) sensation from a list of attributes and change their selection as the most dominant attribute changes.	Yes
Temporal Check All That Apply (TCATA)[8]	Temporal	A temporal version of CATA where attributes can be unclicked as they fade/disappear.	Yes
Temporal Liking /Temporal Drivers of Liking (TL)[9]	Temporal	Track how liking changes throughout perception using the same scales as affective consumer testing (e.g.) 9-point hedonic.	Yes
Temporal Dominance of Emotions (TDE)[10]	Temporal	A version of TDS for tracking emotions.	Yes
Temporal Order of Sensations (TOS)[10]	Temporal	Panellists report the firstthree3 attributes they perceive during consumption.	Yes
Attack-Evolution-Finish (AEF)[11]	Temporal	A development of TOS where consumers name the first three attributes they perceive three times during the tasting period; at the beginning, in the middle and at the end of tasting.	Yes

1= de Aguiar et al. (2018); 2= Varela & Ares (2012); 3= Monteleone et al. (1997); 4= O'Sullivan (2017) ;5= Thuillier et al. (2015); 6= Pecore et al. (2015); 7= Labbe et al. (2009) ; 8= Castura et al. (2016); 9= Thomas et al. (2015); 10= Jager et al. (2014); 11= Visalli et al. (2020)

Due to their increased popularity in recent years, many reviews papers (Varela & Ares, 2012; Valentin *et al.,* 2012; de Aguiar *et al.*; 2018), book chapters (Ares *et al.,* 2018a; Ares & Varela, 2018c; Bredie *et al.*, 2018; Buck & Kemp, 2018; Cleaver, 2018; Munoz *et al*., 2018; O' Sullivan, 2017; Punter, 2018; Valentin *et al*., 2018) and even entire books (Varela & Ares, 2014b; Delarue *et al.*, 2015) have been published dedicated to discussing their methodology, characterisation and application.

1.2.5.2. Application of RDM to Meat and Poultry

The application of consumer RDM to meat and poultry and their products is summarised below in ***Table 1.2. Table 1.2*** only reflects rapid descriptive techniques performed on meat and poultry by completely naïve consumers and, therefore, does not include publications using trained or semi-trained panels. It is evident from ***(Table 1.2)*** that consumer RDM have been applied to many cured, fermented, and processed meat products, but not many studies have been undertaken on meat in its natural form (after ageing). Choi *et al.* (2015) applied CATA to investigate cross-cultural liking and disliking of marinated chicken breasts; however, the study's main purpose was to test the different marinades more than characterising the chicken itself. While ***Table 1.2*** shows that consumer RDM (e.g., CATA, RGM, RATA) for characterising meat products has gained popularity, especially since 2015, some specific trends stand out. First, the most popular meat product for consumer RDM is sausages and fermented sausages. Secondly, fat-replacement/reduction and salt-replacement/reduction are popular research topics for consumer RDM with meat. Also, the perception of meat replacement, either partially (Neville *et al.*, 2015) or completely (Schouteten *et al.*, 2015; Tan *et al.,* 2017) by insects or plant options, has been successfully characterised using consumer RDM (CATA, IP, RATA). This is important given the current interest in flexitarianism and increased interest in this product area. Furthermore, CATA appears to be the most popular consumer RDM technique applied to meat products, as Torrico *et al.* (2018) stated in a recent review. Finally, a combination napping and UFP method, first published by Perrin *et al.* (2008) using wine, has been used quite successfully with untrained assessors to provide more information about a meat/fish product.

Recently, RGM has been combined with Open-Ended Questions (OEQ) as a consumer method performed prior to CATA with muscle foods to elicit attributes suitable for the product being profiled (Massingue *et al.*, 2018; Yotsuyanagi *et al.*, 2016). The main reasons for this reinvention of RGM have been a lack of defined attributes in literature and a decline of in-house trained panels, resulting in a need for a short, quick, inexpensive method that can be performed with a small number of consumers.

Another interesting point is that many of the studies in ***Table 1.2*** were also run alongside acceptance tests (Galvão *et al.*, 2014; Heck *et al.*, 2017; Heck *et al.*, 2019; Henrique *et al.,* 2014; Neville *et al.,* 2017; Oliveira *et al.*, 2018; Yotsuyanagi *et al.*, 2016) or more commonly overall liking (Choi *et al.*,2015; De Andrade *et al.*, 2018; Dos Santos *et al.*, 2015; Dos Santos Alves *et al.,* 2017; Jorge *et al.,* 2015; Massingue *et al.,* 2018; Meier-Dinkel *et al.*, 2016; Nguyen *et al.*, 2017; Schouteten *et al.*, 2015, Saldaña *et al.*, 2019a; Saldaña *et al.,* 2018) to provide supplementary data. The majority were performed using a 9-point hedonic scale; however, some were performed using unstructured scales (Dos Santos *et al.*, 2015b; Fellendorf *et al.,* 2016; Vilar *et al.*, 2020) and one (Grasso *et al.*, 2017) was performed using a 15cm Labelled Affective Magnitude (LAM) scale. As expressed in Grasso *et al.* (2017), the LAM scale is ideal for consumer usage as it is reliable and easy to understand and has been found to reduce the underuse of certain scale categories; for example, consumers can sometimes underuse the “extreme” end of scales (i.e., very good/excellent, or very bad/poor) (Jaeger & Cardello, 2009; Schutz & Cardello, 2001). However, the 9-point hedonic scale remains the most popular scale to collect consumer information (Jaeger & Cardello, 2009).

Rapid descriptive techniques have also been used for meat applications with semi-trained panels such as Napping (Grossi et al., 2012), FP (Albert *et al.*, 2011; Ramirez-Rivera *et al.*, 2012) and CATA (Alexi *et al.*, 2018), and with expert assessors for FP (Dehlholm *et al.*,2012; Galvão *et al.*, 2014; Grossi *et al.*, 2012; Lorido *et al.*, 2018; Pintado *et al.*, 2016; Rason *et al.*, 2006), Napping (Dehlholm *et al.*,2012) and RGM (Vidal *et al.*, 2019). Looking at some of the studies mentioned above where trained assessors were used for FP (Galvão *et al.*,2014; Grossi *et al.*, 2012; Albert *et al.*, 2011), it is worth noting that all these studies also used consumer RDM alongside the trained panel RDM to gather more information. However, a major limitation to all RDM, along with affective (consumer) tests, whether performed by consumers or trained assessors, is that only singular ('overall') scores are recorded. This results in static data, which can provide interesting information about a product but fails to consider the changes that occur in sensory perception during oral processing.

1.2.5.3. Reliability of RDM

There is still much debate about the quality and reliability of descriptive sensory profiles generated by consumer panels. Therefore, much research has been conducted on RDM profiles generated by consumers vs RDM profiles from semi-trained or trained panels using classic DM. A systematic review by de Aguiar *et al.* (2018) looked at the correlation between classic DM and RDM conducted with semi-trained or consumer panels. They found that while RDM with semi-trained assessors correlated better with classic DM than with RDM with consumers, the results were method and product dependent. Focusing on muscle foods, Dos Santos *et al.* (2015)

found that for low-sodium sausages evaluated by CATA and FL, the results did not correlate with a trained Quantitative Descriptive Analysis (QDA) panel. Interestingly, Alexi *et al.* (2018) found that for CATA, a 1-hour training session with reference samples brought the resulting data closer to trained Descriptive Analysis (DA) data compared to untrained CATA for four fish species in terms of specific sample qualitative description. If this could be reproduced with other muscle foods, it would be advantageous as a 1-hour training session using CATA as an RDM method would considerably reduce the costs and time needed for classic descriptive analysis.

However, many authors of the papers reviewed in de Aguiar *et al.* (2018) study noted that some discriminatory attributes, especially complex characteristics of texture, were poorly understood by consumers and therefore did not feature as expected in the results (Jimenez *et al.*, 2014; Moussaoui & Varela, 2010; Ares *et al.*, 2015a; Bruzzone *et al.*, 2012; Albert *et al.*, 2011; Torri *et al.*, 2013). Oppermann *et al.* (2017) did not agree with this and found that consumer RATA data adequately represented minor discriminatory attributes for model double emulsions, but this would need to be corroborated for full product applications. Torri *et al.* (2013) concluded that when consumers completed project Mapping (PM), the mapping was more correlated to consumer liking of the attributes rather than the sensory profile. However, mapping consumer attribute liking could be useful from a product development perspective. In addition, Torri *et al.* (2013) and Kennedy & Heymann (2009) both commented on large variability between consumer ability to perform RDM, which would also support the concept of consumer mapping by liking. Although, both papers also concluded that averaging consumer data reduced the majority of this variability.

Table 1.2 – Application of consumer RDM to meat and meat products (including poultry)

Product	Technique (s)	Other tests	Research Question?	Sample no.	No of terms/ attribute	No of consumers	Reference
Beef, Horse, Elk, Bison	PAE	-	Comparison of PAE & CATA over 3 species	4	22	7	Popoola *et al.* (2019)
					27	11	
	CATA	Overall liking (9-point)			43	63	
Marinated chicken	CATA	Overall liking (9-point)	Cross-cultural acceptance marinades compared to QDA panel	5	25 liking 33 disliking	73 Korean & 86 USA	Choi *et al.* (2015)
Pork loin	Napping/ UFP	-	Comparison to QDA, products subject to 2 cooking methods with 3 cooking times	6 S1/ 3 S2	26	12	Gonzalez-Mohino *et al.* (2019)
Bacon	CATA/IP	Overall liking (9-point)	Smoking processes	6 (+IP)	32	100	Saldaña *et al.* (2019a)
	Napping/ UFP	-	Wood type on smoke flavour	7	66	93	Saldaña *et al.* (2019b)
Burgers	CATA	Acceptance (9-point)	Fat replacement	5	13	100	Heck *et al.* (2019)
		Acceptance (9-point)	Fat replacement & differing omega 6/3 ratio	5	21	100	Heck *et al.* (2017)
	RATA (5-point scale) EmoSensory wheel	Overall liking (9-point), Quality & Nutritiousness (7-point both)	Meat vs insect vs plant burgers	3	14 emotion, 12 sensory	53 – blind/ expected/ informed	Schouteten *et al.* (2015)
				3		38 – expected/ informed	
Burgers	CATA/IP		Reduced meat products	5 (+IP)	20	94	

Sausages		Acceptance (9-point)		5 (+IP)			Neville *et al.* (2017)
Sausages/ Fermented sausages	CATA /FL	-	Low sodium – comparison QDA panel	6	15	106	Dos Santos *et al.* (2015a)
	CATA	Overall liking (9-point)	Perception of sausages from boar tainted meat (2 types)	2	16	120	Meier-Dinkel *et al.* (2016)
	CATA	Acceptance (9-point)	Effect of amino acid addition on perception of low-fat & -salt sausages	5	14	100	Da Silva *et al.* (2020)
	FP	-	Substitute protein binder in sausages	10	24	10	Nguyen *et al.* (2017)
	-	Overall liking (9-point)			-	140	
	CATA	Acceptance (9-point)	Flavour enhancer impact on sausages with salt replacer	5	19	100	Dos Santos Alves *et al.* (2017)
	RGM/CATA	-	Impact of sodium reduction	3	34	20	Yotsuyanagi *et al.* (2016)
	JAR (5-point)	Acceptance (9-point)			-	100	
	RDA/IS (10-cm unstructured)	Acceptance (10-cm unstructured)	Perception of seaweeds in frankfurters	5	-	25	Vilar *et al.* (2020)
	Napping/ UFP	-	Texture/ consistency perception of salt replacer in HPP sausages	10 (S1) ** 6 (S2) **	9	10	Grossi *et al.* (2012)
Mortadella	CATA	Overall liking (9-point)	Perception of different non-animal fat % – DA vs CATA	5	41	84	Saldaña *et al.* (2018)
	RGM/OEQ	-		6	13	19	

	CATA	Overall liking (9-point)	Meat replacement - cheaper cuts (poultry) on lamb and mutton type			53	Massingue *et al.* (2018)
	RGM/OEQ	-	Perception of 4 different types of mortadella	4	20	11	Jorge *et al.* (2015)
	CATA	Overall liking (9-point)				86	
	UFP	Ranking by intensity	Prebiotic mortadella assessment	6	16	40	Santos *et al.* (2013)
	PM	-			13	45	
Salami	RATA (3-point)	-	Comparison with DA	5	23	50	Ares *et al.* (2018)
Deli-style turkey	CATA	Labelled Affective Magnitude Scales (15cm labelled)	Effect of health information on enriched turkey perception	2x blind 2x informed	29	80	Grasso *et al.* (2017)
Turkey Ham	CATA	Acceptance (9-point)	Impact of salt substitution on turkey ham perception	5	24	77	Galvão *et al.* (2014)
Ham	CATA	Overall liking (9-point)	Perception of HPP ham with or without salt reduction	4	20	51 – informed	Henrique *et al.* (2014)
						51 - blind	
	RG	-	Perception of low-fat ham with differing % lactulose	5	13	15	Oliveira *et al.* (2018)
	CATA	Acceptance (9-point)				50	
	FCP (100cm unstructured)	-	Application of untrained FCP to ham	11	-	18	Delahunty *et al.* (1997)

Meatballs	CATA	Familiarity, Suitability, Appropriateness & Expectation (9-point Likert)	Meat vs mealworm meatballs. Served with dairy drink & mealworm drink	1 x each of 4 Products	24 for meatball 24 for drinks	135	Tan *et al.* (2017)
Sheep Meat Coppa	CATA	Evoked context & Overall liking (9-point)	Sheep meat coppa (smoked/ unsmoked) vs standard (pork)	4 sheep +2 pork	16	101 - informed 101 - blind	De Andrade *et al.* (2018)
White Pudding	RDA	Overall liking (unstructured)	Different formulations (low salt/low-fat)	25 (5 x 5S) **	7	25-30 (5 S) **	Fellendorf *et al.* (2015)
Black Pudding	RDA	Overall liking (unstructured)	Different formulations (low salt/low-fat)	25 (5 x 5S) **	7	25-30 (5 S) **	Fellendorf *et al.* (2016)

(Adapted and updated from Ventanas et al., 2020)

***Only applicable to publications using CATA/RATA/RDA (by design), FP/UFP/RGM (generated) procedures.**

**** S = Session**

1.2.5.4. Novel Temporal Methods

Dynamic methods of sensory analysis, also known as temporal methods, are the second group of novel sensory methods adapted for use with consumers. Although not new, with the development of the original temporal method, Time-Intensity dating back to the 1930s (Cliff & Heymann, 1993), temporal methods have seen much advancement in the 21st century with the development of TDS (Labbe *et al.,* 2009) and related consumer temporal methods. It must be noted that two novel trained panel temporal methods have also been developed, which will not be covered here; Progressive Profiling (Jack *et al.*, 1994) and Sequential Profiling (Methven *et al.*, 2010).

Consumer temporal methods are a significant evolution in the research of sensory science. As previously mentioned, static scores, the use of just one "overall" score, are commonplace in consumer sensory science, but these do not take these dynamic changes in perception and liking into account. That means a plethora of information and data about food products is omitted during sensory assessments. This information could aid further prediction and understanding of consumer likes and dislikes, a topic that has dominated sensory research for decades.

1.2.5.4.1. Temporal Dominance of Sensations (TDS)

The development of Temporal Dominance of Sensations (TDS, (see ***Table 1.1*** for description) by Pineau, Cordelle and Schlich, which was first presented at the Pangborn Symposium in 2003 (Labbe *et al.*, 2009), changed the category of dynamic methods. It aims to detect the sequence and intensity of the dominant sensory attribute or perception of a product (Pineau & Schlich, 2015) with the "most dominant" defined as the most attention-catching (Varela *et al.,* 2018). This overcomes some of the disadvantages of TI and allows several attributes to be simultaneously evaluated

(Cadena *et al.*, 2014). TDS has been used successfully with trained panels (Varela *et al.*, 2018; Nguyen *et al.*, 2018; Meyners, 2016), semi-trained panels (Olegario *et al.*, 2020) and consumers (Dinnella *et al.*, 2012, Hutchings *et al.*, 2014, Jaeger *et al.*, 2018, Jaeger *et al.*, 2017; Rodrigues *et al.*, 2016; Varela et al., 2018). Some studies have even found that TDS provided more information than sensory profiling about subtle differences between products (Dinnella *et al*., 2012; Meillon *et al*., 2010). However, a drawback of TDS is that tracking the most dominant attributes does not provide profiling on all attributes that make up the sensory profile of the product (Cadena *et al.*, 2014).

1.2.5.4.2. TDS-related methodology

Four other temporal methods have also been developed based on the principles of the TDS method for tracking perception changes during eating; Temporal Check-All-That-Apply (TCATA) (Castura *et al.*, 2016), Temporal Dominance of Emotions (TDE) (Jager *et al.*, 2014), Temporal Order of Sensations (TOS) by Pecore *et al.* (Visalli *et al.*, 2020) and more recently Attack-Evolution-Finish (AEF) (Visalli *et al.*, 2020). TCATA has been used successfully with consumers (Ares *et al.*, 2016, Ares *et al.*, 2015b, Jaeger *et al.*, 2018, Jaeger *et al.*, 2017). TDE is a version of TDS for tracking emotions and has been applied not only for tracking emotions while eating (Jager *et al.*, 2014) but also to gain knowledge into consumer opinions of packaging suitability/aesthetics and product appearance (Merlo *et al.*, 2019). Only the first three attributes' panellists perceive during tasting are reported in the TOS method. Finally, AEF is a development on TOS where panellists report the first three attributes, they perceive at three distinct times during consumption: the beginning (attack), middle (evolution) and end (finish) (Visalli *et al.*, 2020).

1.2.5.4.3. Temporal Liking

Temporal Liking (TL) is a method that aims to track how liking changes throughout eating (Sudre *et al.*, 2012; Thomas *et al.*, 2015). It is gaining popularity as it utilises both the scales used in traditional affective testing (e.g., the 9-point hedonic scale) while also tracking changes in consumers' sensory perception over time. Two main types of "time-tracking" have emerged in the literature for liking: continuous or free choice time assessments (Ramsey *et al.*, 2018; Sudre *et al.*, 2012; Taylor & Pangborn, 1990; Thomas *et al.*, 2015) and structured or pre-determined time assessment (Delarue & Loescher, 2004; Galmarini *et al.*, 2015; Sudre *et al.*, 2012; Verneau *et al.*, 2016). TL methods have been applied to understanding consumer perceptions of various food products such as wheat flakes (Sudre *et al.*, 2012), beer (Ramsey *et al.*, 2018; Silva *et al.*, 2018), wine (Silva *et al.*, 2019), cheese (Thomas *et al.*, 2015; 2017) and chewing gum (Galmarini *et al.*, 2015). More recent literature has utilised multi-sip or multi-bite assessments TL (Rocha-Parra *et al.*, 2016), including some which have run another temporal method (TDS, TCATA or TDE) simultaneously with a multi-sip/bite TL (Silva *et al.*, 2018; 2019; Thomas *et al.*, 2016; 2017) in attempt to capture more information about the consumer eating experience. To the author's knowledge, temporal liking has not been applied to meat or meat products.

1.2.5.5. Application of Temporal Methods to Meat and Poultry

The application of temporal methods to meat and poultry and their products has increased since the validity of TDS has emerged in the literature. As complex products that undergo varying degrees of oral processing and, therefore, dynamic sensory changes, meat and poultry and their products are ideal products for analysis by temporal methods (Miller, 2020). From ***Table 1.3***, it is clear that uptake of temporal methods to meat, poultry and its products is slow but has been increasing in recent years. The vast majority of applications of novel dynamic methods to meat, poultry and its products have been completed by trained panels, and there are only five recent publications that use untrained consumers (***Table 1.3***). However, there are ample applications of the TI method using trained panels to assess meat, poultry, and its products, especially beef and ham (see *Appendix A*).

Table 1.3 - Application of novel dynamic methodology to meat, poultry and their products

Product	Method	Purpose	Type of panel	Reference
Beef steaks	TDS	Effect of freezing/chilling before PEF on dynamic perception of beef	Trained	Kantono *et al.* (2019)
	TDS	Effect of cooking method of beef from cattle slaughtered at two different ages on sensory perception	Trained	Wantanabe *et al.* (2019a)
Lamb	TDS	Effect of chilled/freezing and PEF on perception of lamb meat (rib, shoulder, loin)	Trained	Ma *et al.*, 2016
Pork loins	TDS	Differences in Perception of pork dependent on breed and diet	Trained	Wantanabe *et al.* (2019b)
Dry-cured ham	TDS	Three types of cured ham perceived by TDS	Trained	González-Mohino *et al.* (2021)
	TDS	Effect of pure breed (fed grass) vs mixed breed Iberian pigs (fed concentrate) and reduced/regular salt content on dynamic perception	Trained	Lordio *et al.* (2016)
	TDS	Characterisation of salt replacement in cured ham by three methods, two dynamic & FP	Trained	Lordio *et al.* (2018)
	TDS & TDE	3 Different types of cured ham perceived by TDS & TDE	Trained	Lordio *et al.* (2019)
Ham	TDS	Effect of cooking method on sensory properties of ham	Trained	Djekic *et al.* (2020)
	TDS	Assessment of ham with different salt and pork content	Untrained	De Oliveira Paula *et al.* (2020)

	TDS & TCATA	Assessment of sodium-reduced ham	Trained	Nguyen & Wismer (2022)
	TCATA	Assess five different hams using TCATA	Trained	Rizo *et al.* (2019)
Bacon	TDS	Consumer perception of bacon smoked with different woods	Untrained	Saldana *et al.* (2019c)
Beef Burgers	TDE	Emotions evoked by packaging, product appearance and the product itself	Untrained	Merlo *et al.* (2019)
	TCATA	Using TCATA & OL to determine drivers of liking	Untrained	Rios-Mera *et al.* (2020)
Sausages	TDS & TCATA	Determine drivers of liking in sodium & fat-reduced, emulsion-gel containing sausages	Untrained	De Souza Paglarini *et al.* (2020)
	TDS	Perception differences of addition or omission of preservative	Trained	Braghieri *et al.* (2016)
	TDS	Linking individual eating behaviour to dynamic perception of texture	Trained	Lavergne *et al.* (2015)
	TDS	Temporal properties of salt substitution in contrast with DA	Trained	Paulsen *et al.* (2014)

1.3 The Sensory Evaluation of Beef

Meat, such as beef, is among the least homogeneous food in terms of composition. The physicochemical and sensory properties of beef are dependent on many different pre- and post-slaughter factors, including but not limited to genetics, breed, sex, feeding, cooling, storage, and meat cut (Gajaweera *et al.*, 2017; Prieto *et al.*, 2009*)*.

1.3.1. Cuts of Beef

Beef consists of many cuts, and there can be inconsistency between papers in how they are named. The muscles can be described in Latin (***Figure 1.1***) or in butcher cuts (***Figure 1.2***). It is, therefore, necessary to explain what these names refer to. The muscle utilised in the research chapters of this thesis is the strip loin or top loin, which comes from the top section of the “short loin” (***Figure 1.2***) and is part of the *Longissimus lumborum* (LL).

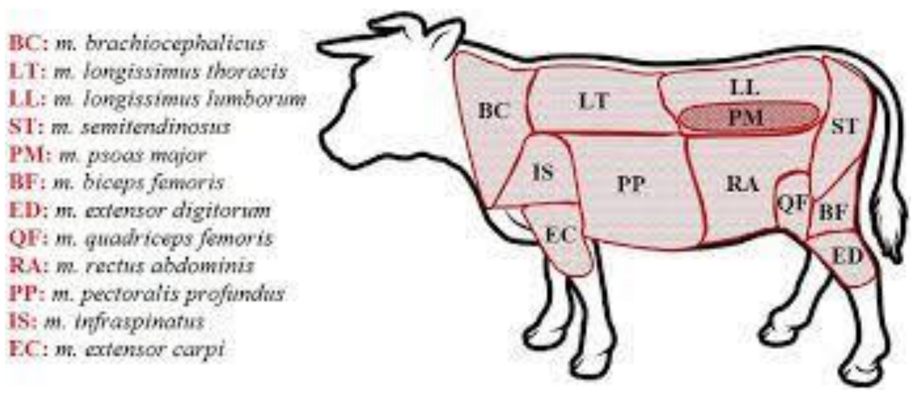

Figure 1.1 – Latin names of beef cuts (Source: Temizkan et al. (2019)

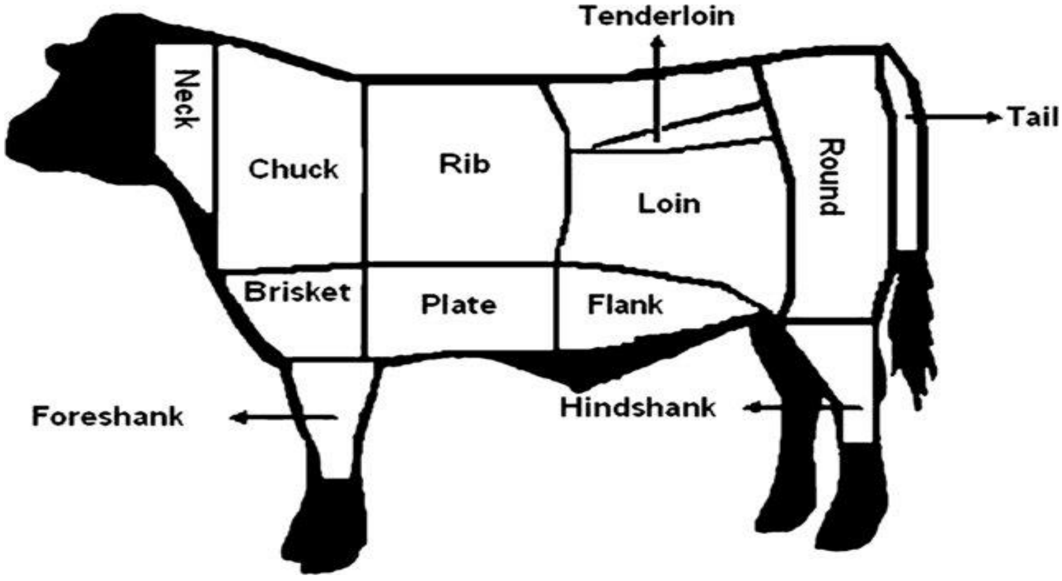

Figure 1.2 – Butcher cut names of beef cuts (Source: Valenzuela et al., 2009)

1.3.2. Meat palatability

The non-homogeneous matrix of beef leads to challenges in palatability, specifically in the lack of guaranteed quality of tenderness (Polkinghorne, 2018). While it has been shown that both intrinsic and extrinsic factors come into play, consumers often make their purchasing decision based on quality expectations determined by palatability characteristics (Thompson, 2004; Reicks *et al.,* 2011). It has also been found that the palatability of beef cuts greatly influences the repurchase decision (Miller *et al.*, 2001).

Consumers' desire to purchase and consume red meat is driven primarily by its characteristic sensory properties, of which tenderness, juiciness and flavour are considered the most important (Killinger *et al.*, 2001).

1.3.2.1. Tenderness

Tenderness is the most widely researched of all traits that influence meat palatability. Miller *et al.* (2001) showed that increased meat tenderness leads to higher consumer liking scores. Some sensory studies have split the assessment of tenderness into initial and overall tenderness, with initial tenderness being defined as the perception of tenderness on the first bite through the centre surface with the incisor teeth (Aldai *et* *al*., 2010). Tenderness can also be associated with several parameters, including initial tenderness, overall tenderness, ease of fragmentation, hardness/softness, firmness, and connective tissue (Font-i-Furnols *et al.,* 2015; Gajaweera *et al.,* 2017). Many factors have been found to influence beef tenderness, including breed and genetics (Dagne & Ameha, 2017; Spehar *et al.,* 2008), cooling after slaughter (rigor) (Font-i-Furnols *et al.,* 2015), ageing (Khan *et al.,* 2016), storage and muscle of testing (Calkin & Sullivan, 2007; Guerrero *et al.*, 2013). Some studies have found differences in sensory quality due to animal feeding practices, although that is a point of contention.

1.3.2.2. Juiciness

Juiciness refers to the amount of moisture released from beef during chewing. It is sometimes broken into two categories: initial juiciness and sustained juiciness. Initial juiciness refers to the quick release of water during the first few chews and has been linked to the water holding capacity of the meat and the cooking method. Aldai *et al.* (2010) defined initial juiciness as the perception of juiciness after 3-5 chews of the meat with the molar teeth. Sustained juiciness has therefore been described as the overall perception of juiciness which is rated just prior to swallowing or expectoration (Aldai *et al.,* 2010). Sustained juiciness is the result of mastication and has been found to be linked to intramuscular fat (IMF) content which is believed to play a part in increasing water-holding capacity (Berry *et al.,* 1974).

1.3.2.3. Flavour

Flavour is a combination of the five basic tastes (sweet, sour, bitter, salt and umami) and odour. Taste in beef occurs when water-soluble compounds in beef are released from the meat and dissolve in saliva, which allows them to bind to taste buds on the tongue and be perceived. Odour occurs when lighter volatile compounds float up behind the nose and bind to receptors in the olfactory bulb. It is thought that odour is the most important contributor when determining species-specific flavour differences. The development of proteins, lipids, and carbohydrates in beef during cooking have been found to play primary roles in flavour development, with lipids being cited as the most important for species-specific flavour (Khan *et al.*, 2015; Mottram, 1998). Studies have found that when tenderness is sufficient, flavour becomes the most important attribute to US consumers (O'Quinn *et al.,* 2012; Corbin *et al.*, 2015).

1.3.3. Current approaches to the sensory evaluation of beef

Predicting eating quality from carcass grading has been a topic of much research; however, it is complicated to consolidate the results as many different countries use different grading systems (e.g.) EUROP in Europe and USDA in the US. While advances in technology have made grading more accurate and consistent, most focus solely on tenderness and not juiciness or flavour, which weigh significantly on consumer liking (O'Quinn *et al.*, 2018).

1.3.3.1. Meat Standards Australia

Meat Standards Australia (MSA) is a living model for predicting meat eating quality. This means that it is constantly being tested and updated based on the feedback. Testing, which started in 1995, has shown that the basic carcass components (e.g.) sex, carcass weight and dentition (age) cannot predict meat quality alone. A unique aspect of MSA testing is that grades are not assigned to carcasses, but the cooked meat and different grades can be assigned to different muscles of the same carcass. In addition, much more pre- and post-slaughter factors are considered than in other grading systems. MSA protocol requires consumers to assess samples for overall liking, flavour, tenderness, and juiciness on an unstructured line scale. The use of many consumers is another positive of this method; MSA asks ten different consumers to taste the same cut. In addition, tests are run in many communities in the same country to ensure sampling bias is eliminated (Torrico *et al.*, 2018).

1.4 Brief Introduction to Cattle Diets

The composition of cattle diets can vary between regions/cultures and mainly revolve around the availability or lack thereof of grazing land and crops. Broadly, cattle production can be classed as extensive (grazing) or intensive (feedlots or slated sheds) (Greenwood, 2021).

In Ireland, where a temperate climate allows for grazing up to 10 months of the year, extensive systems dominate; however, some do use intensive or feedlot finishing. Finishing systems are the final stage of feeding for cattle and are used to achieve levels of growth/fattening required for slaughter (Greenwood, 2021). They can be of varying lengths, from one to several months.

In this thesis, three types of finishing systems will be utilised, which can be grouped into three broad categories: grain-finishing, grass-finishing, and grain-supplementation finishing. Grain finishing or feedlot finishing involves large quantities of available grain (barley commonly in Ireland), which gets cattle ready for slaughter quickly. Grass-finishing is where cattle are finished grazing on grass or forage lands or grass or forage-based silage or hay. This tends to be the longest type of finishing. Finally, grain-supplementation finishing is between these two categories, where cattle are grazed or fed silage, hay, or crop stalks, with a ration of grain and/or other proteins (e.g.) soybeans, cottonseed, linseed (Greenwood, 2021).

1.5 The effect of steer diet on meat eating quality

Many different factors can influence meat quality, including animal raising practices such as diet composition. Research has shown that ration composition can affect several meat quality characteristics, such as fatty acid composition (French *et al.*, 2000; Van Elswyk & McNeill, 2014) and colour (Dunne *et al.*, 2009; 2011; Priolo et al., 2001), however, the effects on eating quality are far from conclusive. While some studies have shown an effect of animal diet on sensory quality (Miller, 2020), others have reported there is little evidence of a consistent difference in sensory quality between grass-fed and concentrate-fed beef (Moloney *et al.*, 2022). Existing reviews on the effect of animal diet on meat quality which contain a sensory component, along with their focus, are shown in ***Table 1.4***. However, none of these reviews are systematic reviews. Furthermore, some of these reviews only focused on certain countries (Schor *et al.*, 2008; Van Elswyk & McNeill, 2014), and none focused solely on steers (castrated males).

Table 1.4 – Literature reviews investigating the effect of animal diet on meat eating quality

Reference	Objective	Topics covered
Brewer & Calkins (2003)	Grain or grass feeding on sensory quality	**Tenderness, Flavour**, Carcass traits
Daley *et al.* (2010)	Grass feeding on fatty acid profiles	Nutritional value, **sensory quality**
Geay *et al.* (2001)	Effect of nutrition on biochemical, structure & metabolic characteristics	Lipids, Nutritional value, **Sensory quality**
Melton (1990)	Effect of feed on flavour of lamb, pork & beef	**Flavour**
Moloney *et al.* (2001)	Effect of production systems on tenderness, flavour & nutrition	Fatty acids, **Tenderness, Juiciness, Flavour**
Muir *et al.* (1998)	Grass and grain feeding on meat quality	**Tenderness, Juiciness, Flavour,** Colour, Marbling
Oddy *et al.* (2001)	Effect of nutrition on muscle development	Cattle growth, Muscle growth, Colour, Intramuscular fat, Marbling, **Flavour,** Nutrition, water-holding capacity
Pighin *et al.* (2016)	Effect of production system on nutrient availability for humans	Lipids, Proteins
Priolo *et al.* (2001)	Effect of grass-feeding systems on colour & flavour	Colour, **Flavour/odour**
Schor *et al.*, 2008	Nutritional and eating quality of Argentinean beef	Composition, Nutrition, **Sensory quality**, breed
Scollan *et al.* (2006)	Effect of production system on beef fats	Fat content, Fatty acids, **Meat flavour**, Colour
Van Elswyk & McNeill (2014)	Grass vs Grain: US research	Fats & fatty acids, Other nutrients, **Sensory quality**

Therefore, it was decided to carry out a systematic review aimed to systemically search for, appraise, synthesise, and analyse research literature on the effect of finishing diet on the sensory quality of steer beef. Steers were chosen as the sole focus of this review as they are the experimental animals used in this thesis.

This meant that articles needed to meet three criteria to be included in the review: (i) steers as the research animal; (ii) finishing diet as part of the research question; (iii) sensory assessment (trained panel or consumer) of the meat. The search and screening of abstracts and articles were carried out in accordance with standards outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 (Page *et al.*, 2021).

1.5.1. Methodology

1.5.1.1. Search Strategy

Four websites were utilised for the literature search: Scopus, Web of Science, Science Direct, and PubMed. The search was carried out on all databases between the 16th and 17th of September 2021, and the search terms used in each search are available in *Appendix B*. Date restriction was not placed on searches. Where possible, “only English” and “only journal article” restrictions were included in the search. “Early view” and pre-prints/proofs were not eligible for this review. An overview of the process is available in ***Figure 1.3.***

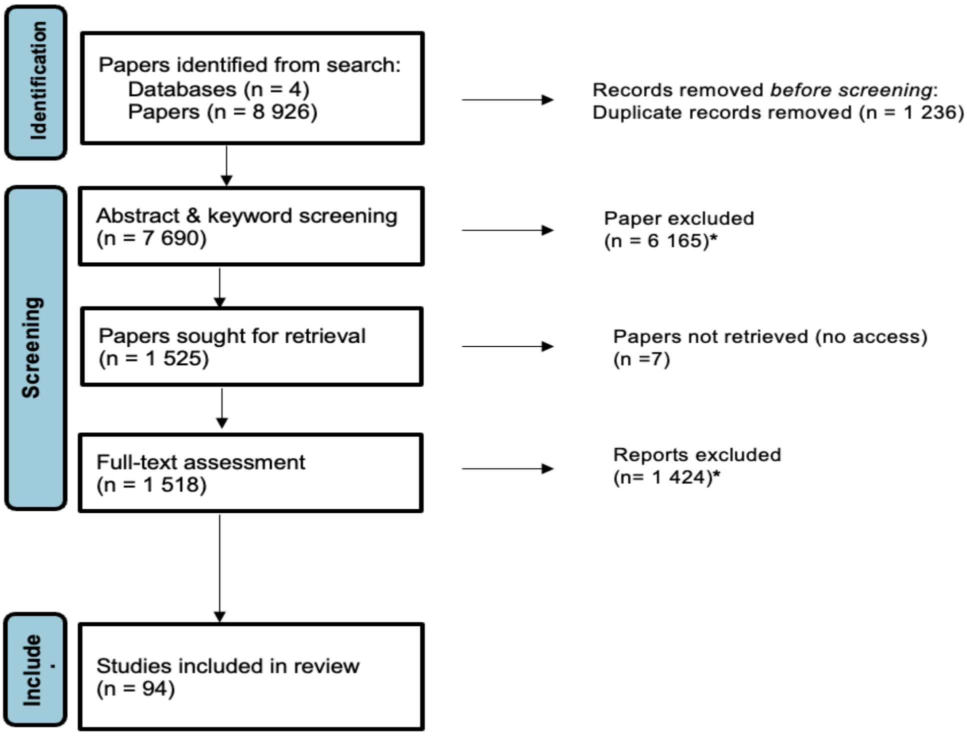

Figure 1.3 – PRISMA flowchart of systematic review process (flowchart template from Page et al., 2021)

****Full breakdown of reasons for rejections in Appendix B.***

1.5.1.2. Abstract and Keyword Screening

These searches yielded 7,690 articles after duplicates (1,236) were removed. During this stage, all articles were manually screened twice by title, abstract and keywords using Sysrev (2021) - a platform specifically built for reviews and data extraction, which randomised the order of articles. Articles (6,165) were excluded after this screening stage for 1 of 5 reasons, as outlined in *Appendix B.*

1.5.1.3. Full-Text Review

After the abstract screening, 1,518 articles were sought for full-text review. Seven articles could not be sourced due to lack of access, leaving 1,511 articles for manual review. Articles (1,424) were excluded after this screening stage for 1 of 13 reasons, as outlined in *Appendix B.*

1.5.1.4. Data extraction

Data were then extracted from the articles (94) identified as meeting the criteria for this review (i.e.) those that utilised steers, investigated finishing diet, and included sensory assessment by trained panel, consumers, or both. Information extracted from the studies was completed in stages. Where any information was not supplied in the articles, it was marked "unknown", and this category was included in all analyses.

1.5.1.5. Stage 1 – General information

Stage 1 involved extracting generic information about the articles (94), including establishing the country of animal raising, the number of animal diets listed, whether sensory analysis was carried out by trained panel, consumer panel or both, and the number of muscles and attributes utilised for each. For the trained panel, the number was split into the "regular" trained panel and the "flavour profile" trained panel. Any aroma or flavour attributes beyond the generic "flavour" or "beefy flavour" were counted separately from the rest of the trained panel attributes.

1.5.1.6. Stage 2 – Animal diets

Stage 2 involved garnering more information about the animal raising and diet whereby finishing diets were extracted separately from each article (i.e.) if there were two experimental diets in an article, these were extracted as two different data entries. The diets were then classed into one of three categories: grass, grain supplementation or grain. Grass diets were defined as grazing solely on grass or receiving only grass or grass-type silage or hays, where grass represents all forage and grass-based options for cattle. Grain diets were defined as a finishing diet where grain or grains represented at least 60% of the daily intake and grain supplementation represented anything in between. In addition to this, animal age at slaughter, length of time on finishing diet and implant status of cattle was also extracted where this information was given.

1.5.1.7. Stage 3 – Sensory Panel Assessments

Data were also extracted by individual diet during stage 3 and were completed separately for consumer and trained panel assessments. Yet some of the information extracted was the same for both; attributes, cut of meat used, form meat was presented in, cooking method and sensory scale utilised. In addition to this, the testing centre (home, central location, or sensory booth) and the number of consumers were also taken from the consumer articles.

1.5.1.8. Stage 4 – Direct Comparison of Grass and Grain diet

Data from both trained panel and consumer articles where grass and grain diets featured were directly compared, and information was extracted for four attributes: overall liking, juiciness, tenderness and (beef) flavour.

1.5.1.9. Analysis of Sensory Assessment

A fourth inclusion criterion added to the data extraction section was the use of a scale in the collection of sensory data. From this, the mean scores of each diet were collected for each attribute. Only 93 articles were used for this analysis as one article (Watanabe *et al.*, 2019a) utilised Temporal Dominance of Sensations (TDS) which does not use a scale, so it was unsuitable for this analysis. For the extracted data, the scores for each attribute were then reconfigured from the scale in the article (e.g.) 8-point scale, 9-point scale, 100mm line scale, to a scale of 0 to 1. This was so scores could be analysed and compared. For the trained panel assessments, each attribute (e.g.) tenderness, juiciness, with more than ten observations per diet category (grass, grain or grain supplemented), was analysed. For the consumer assessments, results were analysed for the top four attributes: overall liking, juiciness, tenderness and (beef) flavour.

1.5.1.10. Risk of Bias

A risk of bias analysis was carried out separately for the trained and consumer panel articles. Eight or nine variables were tested for each article, three animal/meat, which were constant, and 5/6 sensory, 5 for consumer articles and 6 for trained panel articles. The sensory variables were chosen based on general rules of sensory evaluation and sensory assessment of meat and were adapted from the risk of bias de Aguiar *et al.* (2018) in their systematic review of rapid descriptive and conventional sensory methodologies. For both types of panels, the animal/meat variables remained the same and were as follows: known origin of meat, an appropriate number of animals (at least 3 for each diet) and detailed diet composition. For the consumer panel assessment, the variables were: recruited regular consumers of beef, randomisation of samples, an appropriate number of assessors, replication of animals in the sensory test, and appropriate statistical analysis. For the trained panel assessment, the variables were: recruitment & selection of panel detailed, randomised sample presentation, an appropriate number of samples, repetition of animals, sensory booth assessment, and appropriate statistical analysis. For the three articles, which included both trained panel and consumer testing, the risk of bias was completed separately for each panel.

The results of the assessment were tabulated as follows; each variable was worth 1 point for each question answered yes, with a total of 8 points possible for the consumer panel assessments and 9 points possible for the trained panel assessments. If it was unclear if the answer to a question was yes or no, it was marked as such; however, it was still counted as negative towards the risk of bias. Results were then calculated as a percentage where the risk of bias was categorized as high (up to 49%), moderate (50-69%) or low (70% or greater) (Higgins & Green, 2011). If an article received a high (less than 50%) risk of bias, it was not included in this review.

1.5.1.11. Data Analysis

Data analysis was completed using XLSTAT-Sensory (Addinsoft, 2021). The data were analysed using descriptive measures (summary means, frequencies, standard deviations) at either article, diet, or attribute level. For the analysis of attributes, results are reported as mean scores. Differences in the mean scores of attributes between diets were analysed via ANOVA.

1.5.2. Results and Discussion

1.5.2.1. Journal Surveyed and Year of Publishing

Articles collected came from 29 Journals, with *Journal of Animal Science* and *Meat Science* the most frequently utilised for publishing, representing 27% and 20% of articles, respectively. The next most common journals were the *Canadian Journal of Animal Science* (10%), *Journal of Food Science* (9%) and *The Professional Animal Scientist* (4%). The other 30% of articles came from 25 different journals, each having 1 or 2 articles. The rest of these journals were a mix of animal and meat science journals (e.g.) *Animal Science, Journal of Muscle Foods,* and food science journals (e.g.) *Food Research International, International Journal of Food Science and Technology*.

The number of articles published each year varied throughout the 42 years represented in this review (***Figure 1.4***). The peak timeframe was 2009-2013, with 2009 being the single year with the most publications. There's been two "peaks" of publishing on the effect of animal diet on the sensory quality of beef, one in the mid-1990s and the other from 2005 to about 2010.

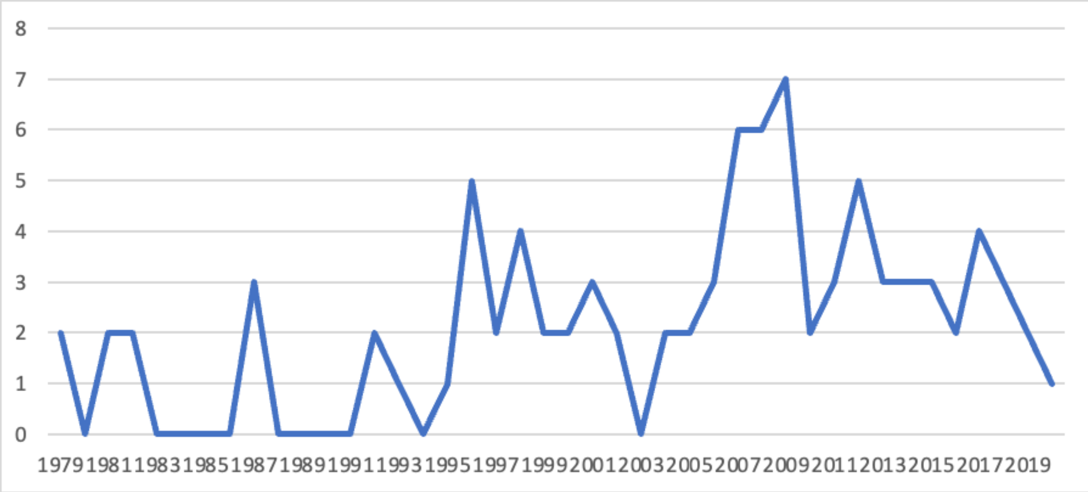

Figure 1.4 – Spread of data over the 42-year publication period

1.5.2.2. Animal data

There were 17 countries of animal raising in the 94 articles utilised in this review, with 50 of the 94 articles coming from the United States (US). The full breakdown of articles by country is given in ***Table 1.5.*** From the 94 articles, 293 diets were extracted. Diets per article ranged from 1 to 12, with an average of 3.234 diets and a mode of 2 (***Figure 1.5***). The 303 diets were then split into three categories based on major diet constituent (grass, grain, grain supplement – mixed), yielding 81 grass diets, 145-grain diets, and 67-grain supplement diets (breakdown by country available in ***Table 1.6***). A breakdown of the major diet constituent for each type of diet is available in ***Table 1.7.***

The number of animals subjected to each diet ranged from 2 to 103, with an average of 22 and a mode of 12. The average slaughter age where this was denoted in articles was 17 months for grain finishing, 21 months for grain supplementation, and 20 months for grass finishing. Although there was one outlier in the grain supplementation (33 months slaughter age) and without this value, the average age went down to 19.5 months. In addition, the average finishing time was 147 days, with a minimum of 28 days and a maximum of 721 days. Grain-based finishing ranged from 28 to 299 days, grain supplementation from 48 to 622 days and grass from 30 to 721 days. Most of the diets (226/303) either did not utilise hormone implants or did not mention them in the article. Those that did use implants came exclusively from the US and Canada.

Table 1.5 – Breakdown of articles in the systematic review by country

Country	Number of Articles
Argentina	1
Australia	2
Brazil	1
Canada	14
Chile	1
France	1
Ireland	6
Japan	1
Korea	1
New Zealand	1
South Africa	2
Spain	2
Thailand	1
UK	8
US	49
Uruguay	3
Total	94

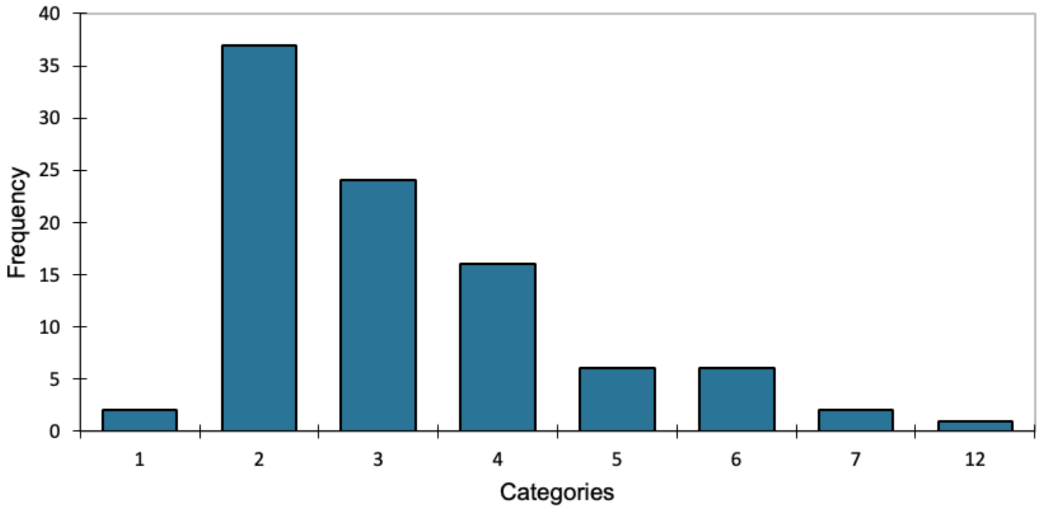

Figure 1.5 – Frequency of number of diets extracted from each article

Table 1.6 – Breakdown of individual animal diets by country

Country	Grain	Grain Supplement	Grass
Argentina	0	1	1
Australia	1	0	5
Brazil	1	1	1
Canada	27	11	12
France	0	3	0
Ireland	4	15	3
Japan	0	0	2
Korea	1	0	1
New Zealand	1	0	1
South Africa	2	0	4
Spain	3	4	2
Thailand	0	0	2
UK	5	9	9
US	99	18	35
Uruguay	1	5	3
Total	145	67	81

Table 1.7 – Breakdown of major diet composition by diet type

Grain finishing (Major grain/protein)	%	Grain supplementation	%	Grass	%
Corn	60	Grass/forage	30	Grass/Forage	49
Barley	14	Grass silage	12	Alfalfa grass/ hay/ silage	13
Unidentified concentrate	14	Corn silage	11	Ryegrass	10
Distiller grains	5	Unidentified Silage	11	Legume grass	6
Sorghum	3	Unidentified concentrate	8	Bermudagrass	4
Potato waste	2	Corn	5	Grass silage/ hay	4
Bread by-product	1	Ryegrass	5	Other mixed grass	4
50:50 corn: barley	1	Alfalfa grass	3	Lucerne hay	3
		Ryegrass	3	Rice straw	3
		Barley	3	Fescue	2
		Fescue	3	Meadow Brome	1
		Distillers' grains	3	Pearl millet grass	1
		Legume grass	2		

1.5.2.3. Sensory Assessment

Seventy-four articles included trained panel assessments, and 22 included consumer assessments, with three articles having both consumer and trained panel assessments. The mode number of muscles assessed in each study was 1, with the average being 1.19 muscles.

1.5.2.3.1. Trained panel

From the trained panel assessments, 1,320 attributes were extracted. There were between 2 and 10 attributes per article, with 4 being the mode (***Figure 1.6***). The top 10 most cited attributes in trained panel assessments were: juiciness, tenderness, beef flavour, off flavour, overall liking, connective tissue, initial juiciness, chewiness, initial tenderness, and flavour liking. However, while the top 10 cited attributes did vary depending on the diet category ***(Table 1.8***), juiciness was the top attribute cited for all diets. For comparative purposes, in this review, beef cuts were converted into the Latin muscle names of the largest muscle when the butcher cut was given in the article. Eight muscles were found to have been utilised in articles, the most prevalent of which was the *longissimus lumborum et thoracic* (LTL) or *longissimus dorsi* (79%). The beef was most commonly presented to assessors in the form of steaks (80.1%), followed by roasts (18.2%), with burgers (1.6%) and mince (0.2%) also presented. In over 50% of the trained panel assessments, the meat was grilled (54%), with oven cooking, broiling and water immersion cooking methods also used.

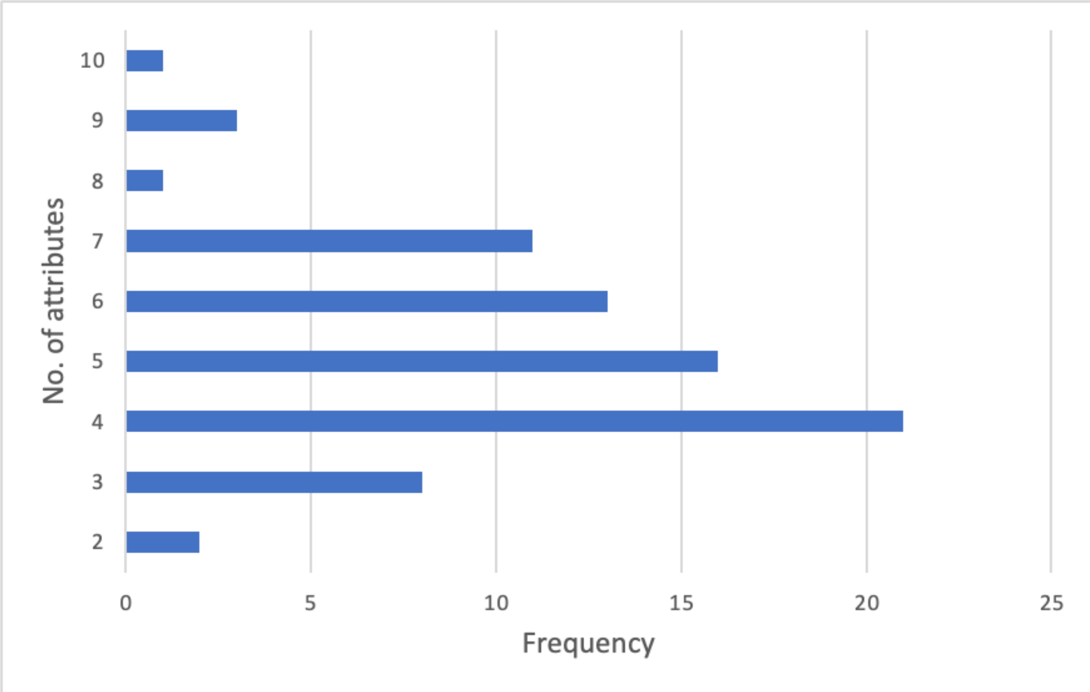

Figure 1.6 – Number of attributes in trained panel articles

Table 1.8 – Top 10 most utilised attributes by trained panel articles by diet

Grain	Grain Supplementation	Grass
juiciness	Juiciness	juiciness
tenderness	beef flavour	beef flavour
beef flavour	Tenderness	tenderness
off flavour	off flavour	off flavour
connective tissue	overall liking	overall liking
overall liking	Chewiness	chewiness
initial juiciness	Texture	texture
flavour liking	initial juiciness	initial juiciness
initial tenderness	initial tenderness	initial tenderness
chewiness	Toughness	toughness

As mentioned earlier, all trained panel articles utilised scales except one, which used TDS. The most prevalently used scale was the 8-point (47%), followed by the 100mm line scale (16%), 9-point scale (9%), and 10-point (6%). The usage of the top five scales since 2000 is shown in ***Figure 1.7***. It is clear to see that not only is the 8-point the most used, but its popularity has also remained over time. Yet, it is worth noting that only the 100mm scale has been used in articles published between 2020 and 2021.

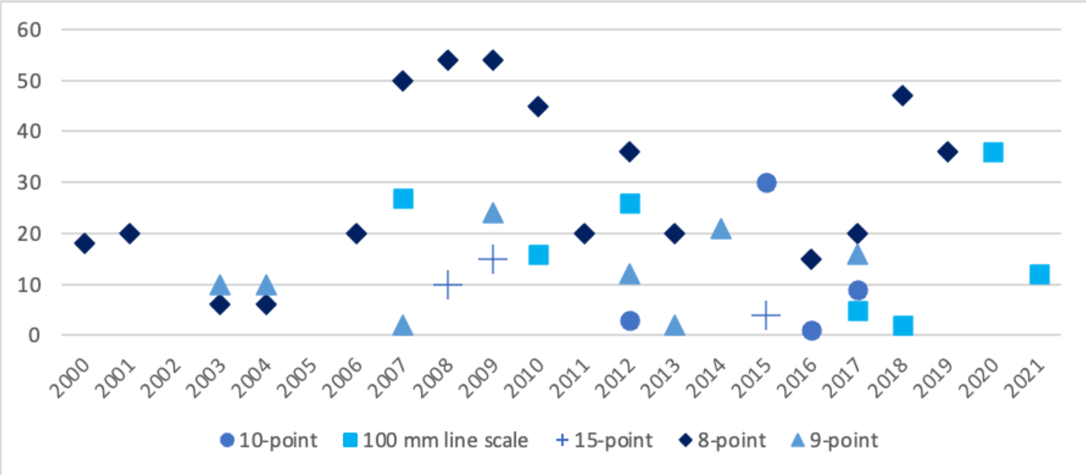

Figure 1.7 – Usage of the top five scales from 2000 to 2021

In addition, 20 articles were found to have completed additional flavour profiling beyond basic trained panel analysis, ranging from 2 to 18 flavour/taste attributes, with 40 attributes in all (detailed in ***Table 1.9***). Metallic and livery were the most frequently used flavour/taste descriptors (beyond beef/beefy).

Table 1.9 – Flavour and taste descriptors taken from articles included in review

acid	Green
animal-like	Leather
astringent	Livery
barny	metallic
beef fat	metallic aftertaste
beef-broth	milky-oily
bitter	off-note
browned	organ
burnt	painty
cardboardy	Rancid
charred	roast beef
chemical burn	salt
dairy	serumy/bloody
fatty/greasy	Sour
fishy	spoiled
foreign flavour	sweet
gamey	Umami
grain	unidentified
grassy	vegetable/grass
greasy aftertaste	warmed-over

1.5.2.3.2. Consumer data

Only 22 consumer articles were found to meet the criteria of this review; however, 74 diets were extracted from those articles (27 grass, 13-grain supplement, 34 grain).

With the exception of Realini *et al.* (2009), all consumer articles conducted their assessment in one country. This meant the consumers were all from the country where the meat was produced. However, Realini *et al.* (2009) utilised consumers from four European countries (UK, Germany, France, and Spain) to assess the liking of Uruguayan meat from different feeding systems. In addition, Torrico *et al.* (2015) studied the effect of animal diet on different cultures within the US. Therefore, articles included consumer liking of beef from different production systems from 7 different countries (**Figure 1.8**), with the majority again published from data generated in the US.

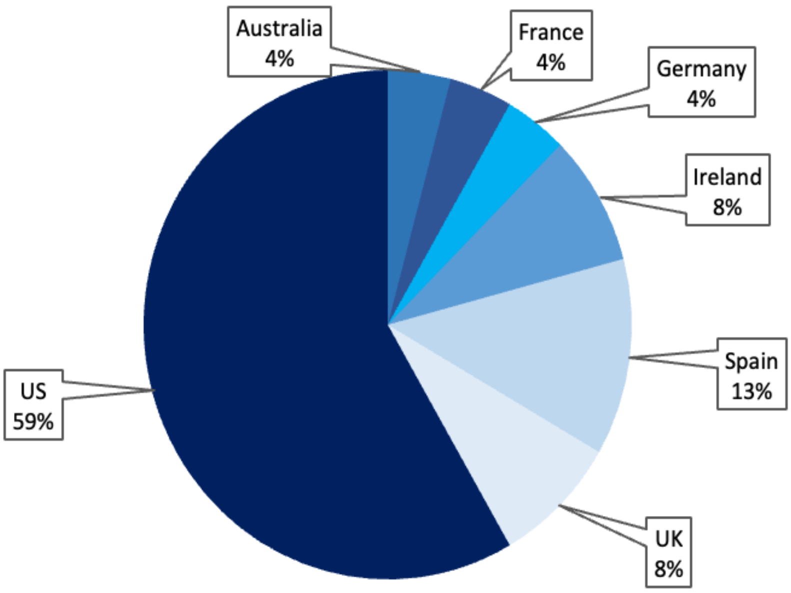

Figure 1.8 – Percentage of consumer data by animal raising country

Articles had a mode number of 4 attributes for the consumer assessment. The top attribute cited for grain diets was flavour, whereas the top attribute for grain supplementation and grass diets was overall liking, followed by flavour. The order of attribute citations for each diet is shown in Table 1.10.

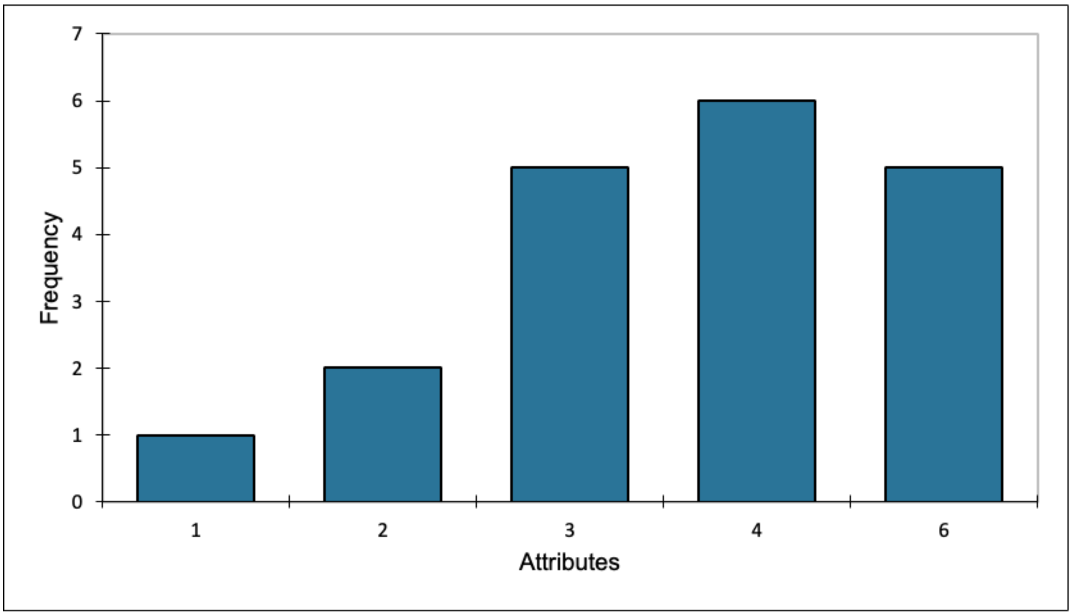

Figure 1.9 – Number of attributes utilised in consumer articles

Table 1.10 –Attributes utilised by consumer articles by animal diet

Grain	Grain Supplementation	Grass
flavour	overall liking	overall liking
tenderness	flavour	flavour
juiciness	tenderness	tenderness
overall liking	juiciness	juiciness
aroma	appearance	aroma
fattiness	aroma	fattiness
off flavour	texture	appearance
taste	flavour and aroma	fat liking
texture	taste	texture
toughness		flavour and aroma
		off flavour
		toughness

1.5.2.4. Direct comparisons of grass and grain feeding systems

1.5.2.4.1. Trained panel

Of the 74 articles including trained panel assessment, only 23 included the direct comparison of grass and grain diets (***Table 1.11)***. Of these 23 articles, 14 had a significant difference between grass and grain or at least one attribute. With the exception of Duckett *et al.* (2013) and Bruce *et al.* (2004), all significant differences were found in favour of grain feeding. All but one article uses the longissimus muscle.

Table 1.11 –Direct comparison of grass and grain feeding systems in trained panel articles

Reference	Raising Country	Meat cut	Overall liking*	Tenderness*	Juiciness*	Flavour*
Lafreniere *et al.* (2020)	Canada	Longissimus	Yes - Grain	Yes - Grain	No	Yes – Grain
Mandell *et al.* (1997)	Canada	Longissimus	N/A	No	No	No
McCaughey & Cliplef (1996)	Canada	Longissimus	No	No	No	No
Morales *et al.* (2015)	Chile	Longissimus	N/A	No	No	Yes - Grass
Bennett *et al.* (1995)	US	Longissimus	N/A	Yes – Grain	Yes - Grain	Yes - Grain
Duckett *et al.* (2007)	US	Longissimus	N/A	No	Yes – Grain	Yes – Grain
Duckett *et al.* (2013)	US	Longissimus	N/A	No	No	Yes – Grass
Mandell *et al.* (1998)	Canada	Longissimus	N/A	No	No	Yes – Grain
Roberts *et al.* (2009)	US	Longissimus	N/A	No	Yes – Grain	Yes - Grain
Sapp *et al.* (1999)	US	Longissimus	Yes - Grain	No	Yes – Grain	No
Chastain *et al.* (1982)	US	Longissimus	N/A	No	No	No
Gutowski *et al.* (1979)	US	Longissimus	N/A	Yes - Grain	No	Yes – Grain
Salm *et al.* (1981)	US	Longissimus	N/A	Yes - Grain	Yes – Grain	Yes - Grain
Medeiros *et al.* (1987)	US	Longissimus	Yes - Grain	Yes - Grain	Yes – Grain	Yes – Grain
Medeiros *et al.* (1987)	US	*Semimembranosus*	No	No	No	Yes – Grain

Hwang *et al.* (2017)	US	Longissimus	Yes - Grain	Yes - Grain	Yes – Grain	No
Hwang *et al.* (2017)	Korea	Longissimus	Yes - Grain	Yes - Grain	Yes – Grain	Yes – Grain
Bruce *et al.* (2004)	Australia	Longissimus	Yes - Grass	Yes - Grass	Yes – Grass	No
French *et al.* (2001)	Ireland	Longissimus	No	No	No	No
French *et al.* (2000)	Ireland	Longissimus	No	No	No	No
Fruet *et al.* (2018)	Brazil	Longissimus	N/A	No	No	No
Kerth *et al.* (2007)	US	Longissimus	N/A	Yes - Grain	No	Yes - Grain
MacKintosh *et al.* (2017)	UK	Longissimus	No	Yes - Grain	No	No
Muir *et al.* (1998)	New Zealand	Longissimus	No	N/A	N/A	N/A
Scaglia *et al.* (2012)	US	Longissimus	N/A	No	No	No

Where Yes = significant difference found between grass and grain diets, No= no significant difference found between diets, Grain = Grain diet higher score, Grass = grass diet higher score.

1.5.2.4.2. Consumer

Of the 22 articles utilised during this review process, only nine directly compared grass and grain feeding systems and all but one was from the US (***Table 1.12***). Each article was inspected for results of the consumer sensory analysis, and if significant differences were found, further inspection determined which animal diet was preferred by consumers. The majority (10/13) of articles assessed the longissimus muscle. There was a mixed result; however, most US articles found a significant difference for attributes, and where a significant difference was found, the grain diet was consistently more preferred. However, in the European studies, when a significant difference was found, there was a preference for the grass diet.

Table 1.12 –Direct comparison of grass and grain feeding systems in consumer articles

Reference	Country	Meat cut	Overall liking*	Tenderness*	Juiciness*	Flavour*
Bjorklund *et al.* (2014)	US	Longissimus	Yes - Grain	N/A	Yes - Grain	Yes - Grain
Chail *et al.* (2016)	US	Longissimus	Yes - Grain	Yes - Grain	Yes - Grain	Yes - Grain
Chail *et al.* (2017)	US	*Gluteus medius*	No	No	No	No
Chail *et al.* (2017)	US	*Triceps Brachii*	Yes - Grain	Yes - Grain	No	No
Cox *et al.* (2006)	US	Longissimus	Yes - Grain	N/A	N/A	Yes - Grain
Lorenzen *et al.* (2007)	US	Longissimus	Yes - Grain	No	Yes - Grain	Yes - Grain
Maughan *et al.* (2012)	US	Longissimus	No	N/A	N/A	N/A
Medeiros *et al.* (1987)	US	Several cuts	Yes - Grain	Yes - Grain	Yes - Grain	Yes- Grain
Realini *et al.* (2009)	France	Longissimus	Yes - Grass	Yes - Grass	N/A	Yes – Grass
Realini *et al.* (2009)	Spain	Longissimus	Yes - Grass	Yes - Grass	N/A	No
Realini *et al.* (2009)	UK	Longissimus	Yes - Grass	Yes - Grass	N/A	No
Realini *et al.* (2009)	Germany	Longissimus	No	No	N/A	No
Simonne *et al.* (1996)	US	Longissimus	No	No	No	No

Where Yes = significant difference found between grass and grain diets, No= no significant difference found between diets, Grain = Grain diet higher score, Grass = grass diet higher score.

1.5.2.5. Analysis of Attributes

The means scores from 93 articles were extracted. For this analysis, scales were required to have been utilised in the article. Several different scales were used across articles; therefore, the mean scores extracted from each article were rescaled between 0 and 1 so comparisons could occur. For reliable comparisons to take place, each muscle would have to be assessed separately. It was found that there were only enough observations to compare the longissimus muscle as this constituted majority of the articles. Therefore, data from other muscles were not analysed due to the low number of articles.

1.5.2.5.1. Trained Panel

Each attribute was assessed by diet for each article containing a trained panel assessment using the longissimus muscle. Results are reported for every attribute with over ten observations (***Table 1.13-Table 1.15***). For grain supplementation, these resulted in seven attributes (***Table 1.13***), 11 for grain (***Table 1.14***) and eight for grass (***Table 1.15***). Common attributes between diets were compared. Between all three diets, no significant differences were found for chewiness (p=0.390), flavour (p= 0.279), juiciness (p= 0.198), off flavour (p=0.186), overall liking (p=0.266), or tenderness (p=0.755). No significant differences were found between the grass and grain diets for initial juiciness (p=0.197) or initial tenderness (p=0.257). In short, no significant differences were found for any attribute tested from trained panel data from the articles included in this systematic review.

Table 1.13 –Attribute assessment for grain supplementation diet for trained panel articles using longissimus muscle

	Chewiness	**Flavour**	**Juiciness**	**Off flavour**	**Overall liking**	**Tenderness**	Texture
No. of observations	11	52	54	17	18	42	11
Mean	**0.656**	**0.617**	**0.593**	**0.562**	**0.528**	**0.563**	**0.655**
Minimum	0.541	0.060	0.070	0.197	0.249	0.065	0.530
Maximum	0.767	0.943	0.963	0.800	0.864	0.884	0.767
Standard deviation	0.081	0.170	0.144	0.156	0.178	0.197	0.087

Table 1.14 – Attribute assessment for grain diet for trained panel articles using longissimus muscle

	Chewiness	Connective tissue	**Flavour**	Initial Juiciness	Initial Tenderness	**Juiciness**	Myofibrillar Tenderness	**Off Flavour**	**Overall liking**	Softness	**Tenderness**
No of observations	15	31	90	24	18	100	10	38	31	11	90
Mean	**0.607**	**0.591**	**0.553**	**0.560**	**0.540**	**0.546**	**0.491**	**0.510**	**0.625**	**0.539**	**0.575**
Minimum	0.099	0.250	0.084	0.284	0.125	0.046	0.139	0.104	0.098	0.301	0.074
Maximum	0.933	0.860	0.880	0.775	0.774	0.980	0.960	0.955	0.960	0.678	0.880
Standard deviation	0.181	0.147	0.196	0.121	0.169	0.195	0.216	0.208	0.191	0.121	0.175

Table 1.15 – Attribute assessment for grass diet for trained panel articles using longissimus muscle

	Chewiness	**Flavour**	Initial Juiciness	Initial Tenderness	**Juiciness**	**Off Flavour**	**Overall Liking**	**Tenderness**
No of observations	10	44	10	10	48	20	22	34
Mean	**0.556**	**0.560**	**0.478**	**0.555**	**0.572**	**0.557**	**0.612**	**0.591**
Minimum	0.413	0.011	0.105	0.039	0.020	0.263	0.370	0.265
Maximum	0.656	0.813	0.688	0.823	0.975	0.939	0.863	0.985
Standard deviation	0.085	0.180	0.170	0.225	0.208	0.208	0.139	0.166

1.5.2.5.2. Consumer

Each attribute was assessed by diet for each article containing a trained panel assessment using the longissimus muscle. Results are reported for every attribute with over ten observations, which were four attributes (juiciness, overall liking, tenderness, and flavour) for each diet (***Tables 1.16-Table 1.18***). Significant differences ($p<0.05$) were found for all attributes. For juiciness, these differences were found between the grain supplement and grain diets ($p<0.001$) and between grass and grain diets ($p=0.005$). No significant difference was found between the grain supplement and grass diets. Similarly, for flavour and tenderness, significant differences were found between the grain supplement and grain diets ($p<0.0001$ and $p=0.002$ respectively) and the grass and grain diets ($p=0.001$ and $p=0.01$ respectively), but no significant differences were found between grain supplement and grass diets. In terms of overall liking, a significant difference was found between grain supplement and grain animal diets ($p=0.002$).

Table 1.16 - Attribute assessment for grain supplement diet for consumer articles using longissimus muscle

	Juiciness	Overall liking	Tenderness	Flavour
No of observation	10	19	12	17
Mean	**0.604**	**0.617**	**0.591**	**0.580**
Minimum	0.486	0.479	0.492	0.355
Maximum	0.801	0.846	0.790	0.722
Variance	0.011	0.007	0.010	0.012

Table 1.17 - Attribute assessment for grain diet for consumer articles using longissimus muscle

	Juiciness	Overall liking	Tenderness	Flavour
No of observation	28	18	32	33
Mean	**0.634**	**0.672**	**0.646**	**0.616**
Minimum	0.195	0.557	0.445	0.205
Maximum	0.732	0.831	0.779	0.772
Variance	0.012	0.004	0.008	0.020

Table 1.18 - Attribute assessment for grass diet for consumer articles using longissimus muscle

	Juiciness	Overall liking	Tenderness	Flavour
No of observation	16	28	19	21
Mean	**0.622**	**0.611**	**0.579**	**0.596**
Minimum	0.486	0.315	0.106	0.370
Maximum	0.800	0.831	0.790	0.760
Variance	0.011	0.012	0.025	0.011

1.6 Conclusions

There has been some use of novel sensory methods in meat application; however, few have been applied to beef. Specifically looking at the application of temporal methods to meat, the majority have been carried out by trained panels and not consumers, even though consumers can use many temporal methods. There is a clear need for more research on beef to be conducted with novel consumer sensory methodology. Specifically, regarding the effect of finishing method on the sensory quality of steer beef, the majority of research to date has been conducted with trained panels, and the results of the analysis undertaken here found no significant difference was found between the different diets. While much fewer consumer papers were found, the analysis of these found significant differences for all attributes tested. All this indicates that further research on the effect of finishing method on the sensory quality of beef may be best spent on consumer assessment.

1.7 Research aim and objectives

The main aims of this research were to compare consumer liking of strip loin steaks using a combination of classic and novel consumer liking methods and to investigate the data quality elicited using the novel liking methods. The objectives established to achieve this were to:

- Compare consumer liking of steaks from three different feeding systems (Chapter 2)
- Compare three different liking methods (free TL; structured TL; traditional liking) for generating consumer information (Chapter 2)
- Determine consumers' perceived difficulty in using each method (Chapter 2)
- Determine whether the experimental design of two different temporal methods (free TL and structured TL) impacted data quality (Chapter 3)
- Investigate if consumer self-reported difficulty in completing each method is correlated with missing data, number of responses (free TL), time to first score, or total time spent on the task (Chapter 3)
- Investigate if demographics, specifically nationality and age, affect consumer scores and the number of responses elicited (Chapter 3)
- Understand consumers' approach to temporal liking from “other” data elicited (e.g.) length of attribute responses (seconds), number of responses, and percentage of missing data (Chapter 3)

- To compare three different liking methods (free TL; structured TL; traditional liking) for generating consumer information on four attributes (overall liking; flavour; tenderness; juiciness) using Study 2 data (Chapter 4).
- Investigate consumer performance in each temporal method regarding the number of clicks (responses) and time spent using Study 2 data (Chapter 4).
- To study correlations and consumer variability within each liking method using Study 2 data (Chapter 4).
- To compare clustered consumer responses from the two different TL methods using Study 2 data (Chapter 4).

Chapter 2

Comparing consumer liking of beef strip loin steaks from three feeding systems using a combination of temporal and traditional liking methods

This thesis chapter will be submitted to Food Research International.

Abstract

Research on the impact of the diet of the animal on consumer liking of beef has yielded conflicting results. This study aimed to apply the traditional liking method and two temporal liking (TL) methods (free and structured) to determine consumer liking of beef derived from animals that were fed grain (GF), grass silage and grain (SG) or grazed grass (GG) during finishing. Three separate panels of regular beef-eating consumers (n=51; n=52; n=50) were recruited from students and staff at Teagasc Food Research Centre, Dublin, Ireland, to assess consumer liking of striploin steaks from animals fed either GF, SG, or GG, respectively. Results revealed significant differences ($p \leq 0.05$) in liking between diets in terms of overall liking, juiciness, and tenderness using the free TL method. These effects were not observed using the structured TL or traditional liking methods. Nationality was found to influence consumer liking of flavour substantially, with non-Irish consumers liking the flavour of beef from animals fed an SG diet more than that of the GF diet ($p \leq 0.05$). Further statistical analysis of the TL methods found that the free TL method yielded more discriminative data than the structured TL method, with significant differences ($p \leq 0.05$) found for overall liking and juiciness. Consumers also found the free TL method easier to perform than the structured TL method. The evolution of scores over time was significant ($p \leq 0.05$) for all attributes using the free TL method. These results show that free TL may give rise to new opportunities to elicit more in-depth insight from consumer studies using meat.

2.1. Introduction

Consumers worldwide are becoming increasingly concerned with the ethical, moral, and social aspects of meat production (Gwin *et al.*, 2012; Henchion *et al.*, 2017; Regan *et al.*, 2018; Stampa *et al.*, 2020). As a result, beef from grass-based production systems is becoming more popular with consumers largely due to its healthier nutritional profile (Evans *et al.*, 2011; Umberger *et al.*, 2009), environmentally sustainable image (Conner *et al.*, 2008; Grunert et al., 2004; Gwin *et al.*, 2012) and association with higher animal welfare practices (Evans *et al.*, 2011; Henchion *et al.*, 2017; Janssen *et al.*, 2016). Indeed, in the US, it has been reported that consumer demand for grass-fed beef is greater than the supply (Hayek & Garrett, 2018). However, although issues surrounding health and the environment are essential to consumers, they also expect a highly palatable product of consistent eating quality (Banović *et al.*, 2009; Grunert *et al.*, 2004; Miller, 2020).

Descriptive sensory profiling using a trained panel is typically considered the "gold standard" for assessing beef sensory quality. To date, the vast majority of literature investigating the effect of feeding systems on beef sensory quality has utilised some form of descriptive sensory profiling either on its own or in conjunction with traditional consumer hedonic tests. While a well-trained calibrated sensory panel can provide a detailed and robust map of the sensory profile of meat, it can be difficult to predict from trained panel data alone how consumers will perceive meat in a real-world setting (Lorenzen *et al.*, 2002; Warner et al., 2021). Over the past decades, the line between descriptive sensory profiling and consumer sensory testing has become blurred, and consumers today are often used in place of trained sensory panellists to profile food products (Ares & Varela, 2017; Varela & Ares, 2012). Several new sensory evaluation tools have been recently developed to generate more accurate and reliable consumer information in relation to the sensory properties and hedonic liking of beef (Gagaoua et al., 2021; Miller, 2020; Warner et al., 2021).

The sensory properties of beef, particularly tenderness, juiciness, and flavour, play an important role in consumers' perception of eating quality. Animal feeding practices, such as ration (diet) composition, have been shown to affect several meat quality characteristics, including sensory. The subcutaneous fat of beef from pasture-based production systems is often more yellow, while the muscle tends to be darker in colour when compared to cattle raised on a conventional indoor concentrate-based system (Moloney et al., 2021). However, research on the impact of animal diet on the flavour and texture profile of beef is conflicting. Some studies utilising descriptive trained panels have shown differences in flavour (Baublits *et al.*, 2006; Duckett *et al.*, 2009; 2013; Wright *et al.*, 2015) and tenderness (Sapp *et al.*, 1999; Warren *et al.*, 2008) of beef using various ration compositions, while other data from trained sensory panels have found no differences (French *et al.*, 2000; 2001; Jiang *et al.*, 2010; Moloney *et al.*, 2008; 2011; Moran *et al.*, 2017; Sinclair *et al.*, 2001). In addition, much debate exists with respect to whether sensory differences observed by trained sensory panels are also perceived by consumers. Little to no information exists on whether animal diet impacts perceived sensory quality among consumers in Ireland.

Studies in the US and Canada that have investigated the effect of animal diet on sensory quality show that consumers typically prefer beef from grain-based systems compared to grass-based systems (Corbin *et al.*, 2015; Cox *et al.*, 2006; Kerth *et al.*, 2007; Killinger *et al.*, 2004; Maughan *et al.*, 2012; Sitz *et al.*, 2005). However, other research based on US data (Chail *et al.*, 2017; Ron *et al.*, 2019; Simonne *et al.*, 1996; Umberger *et al.*, 2002) and similar studies from Europe (Blanco *et al.*, 2017; Realini *et al.*, 2009; 2013; Ripoll *et al.*, 2014) have not observed this preference by consumers. Consumer differences in sensory preference for grass-fed vs concentrate-fed beef can often be explained by cultural factors and product familiarity, whereby higher levels of familiarity with a product tend to positively influence its liking score. Studies that have observed sensory differences between grass-fed and grain-fed beef have shown that flavour preferences are more likely to differ across countries than preferences in terms of tenderness (Miller, 2020). Nonetheless, there is no evidence in the literature of a consistent sensory difference in the eating quality of beef from animals fed grass, grain, or grass supplemented with grain.

In the vast majority of consumer studies, beef sensory attributes have been assessed using traditional hedonic methods. During traditional hedonic testing, consumers are typically instructed to assess specific sensory attributes, such as tenderness or flavour, for liking or preference using a categorical scale at a single point in time (AMSA, 2016). While traditional hedonic methods are generally easy for consumers to understand, the dynamics of the eating process are not considered as only one score per attribute is recorded from consumers, typically after the product has been consumed. During eating, food undergoes a series of changes in the mouth, causing sensory perception and liking of the sensory attributes to change during the process (Chen, 2009; de Wijk *et al.*, 2003; Foster *et al.*, 2011). For meat, perception of aroma, flavour, and texture attributes can change as the food is being broken down and manipulated in the mouth, so recording one score per attribute is unlikely to capture the complexity of changes in liking that can occur during eating.

A range of temporal sensory methods have been developed in an attempt to capture more dynamic data from consumers (Castura *et al.*, 2016; Jager *et al.*, 2014; Pineau *et al.*, 2009). One method that has been developed to assess consumer liking while accounting for dynamic perception is called temporal or dynamic liking (Ramsey *et al.*, 2018; Sudre *et al.*, 2012; Thomas *et al.*, 2015). This method instructs consumers to provide multiple scores at different times during the eating process. Previous studies have utilised temporal liking to characterise various food and beverages, including wheat flakes cereals (Sudre *et al.*, 2012), beer (Ramsey *et al.*, 2018; Silva et al., 2019), wine (Silva et al., 2018), cheese (Thomas *et al.*, 2015; 2017) and chewing gum (Galmarini *et al.*, 2015). While temporal liking methods have utilised the traditional hedonic scale, how these scales can be used for tracking consumer liking over time can differ. Two types of "time-tracking" have emerged in the literature: continuous or free choice time assessments (Ramsey *et al.*, 2018; Thomas *et al.*, 2015; Sudre *et al.*, 2012; Taylor & Pangborn, 1990) and structured or pre-determined time assessment (Delarue & Loescher, 2004; Galmarini *et al.*, 2015; Sudre *et al.*, 2012; Verneau *et al.*, 2016). Other researchers have utilised multi-sip or multi-bite assessments using temporal liking (Rocha-Parra *et al.*, 2016), while others have applied the method in conjunction with other temporal methods (e.g., TDS, TCATA or TDE) in an attempt to capture more information about the consumer eating experience (Silva *et al.*, 2018, 2019; Thomas *et al.*, 2016, 2017). To the best of the author's knowledge, there has been no application of the temporal liking method to fresh or processed meat products to date.

There is a lack of literature on the impact of animal diet on consumer liking of beef in Ireland. In addition, a study investigating the effect of temporal liking methods on generating consumer liking information is also lacking. Therefore, this research aims to fill this void by setting the following objectives: (i) investigate the effect of three different finishing diets (grain finishing, silage plus grain and grazed grass) on consumer liking of beef steaks; (ii) compare the consumer sensory data generated from three different sensory liking methods (free temporal liking; structured temporal liking; traditional liking), (iii) to determine consumers perceived difficulty in using each method and (iv) to investigate whether each attribute evolves over time with the structured and the free temporal liking methods and whether these evolutions are identical among animal diets.

2.2. Materials and Methods

2.2.1. Animal production and slaughter

Animal production was conducted at Teagasc, Grange, Ireland, between October 2017 and July 2019. All animal procedures performed in this study were subject to Teagasc Ethics Approval (TAEC181-2018) and conducted in accordance with the Cruelty to Animals Act 1876 and the European Communities (Amendment of Cruelty to Animals Act 1876) Regulation 2002 and 2005.

2.2.1.1. Animals

Fifty-four weaned suckler-bred bulls were sourced at eight months of age from commercial farms and transferred to Grange research centre in mid-October, at 7.5 months of age. This study was originally designed to only look at diet; however, 54 sucker-bred bulls of one breed could not be sourced, so two large-frame breeds were used: 34 Limousin (LM) and 20 Charolais (CH). Following arrival at Grange, animals were treated for internal and external parasites (Ivermectin and Closantel, Closamectin, Norbrook Laboratories, Monaghan, Ireland) and vaccinated against Clostridial (Covexin 10, MSD Animal Health, Dublin, Ireland) and respiratory diseases (Rispoval 3 and Rispoval IBR Intra-nasal, Zoetis Ireland Ltd.) as per the manufacturer’s instructions. Four weeks post-arrival, the animals were castrated via “burdizzo” by a veterinarian.

2.2.1.2. Experimental design and management

Steers were weighed on two consecutive days, blocked on descending mean live weight, and within a block were randomly assigned to one of 9 groups. Each group was randomly assigned to one of three production systems (grain finishing, silage plus grain and grazed grass), with the breed split roughly 2:1 LM: CH within each (***Figure 2.1***). Within each system as relevant, steers were offered (i) offered grass silage *ad libitum* + 1.5 kg concentrates per head daily over the first winter, followed by 123 days at pasture, re-housed and offered concentrates *ad libitum* for 120 days – slaughter age, 21 months, hereafter referred to as grain finishing (GF); (ii) offered grass silage *ad libitum* + 1.5 kg concentrates per head daily over the first winter, followed by 196 days at pasture, re-housed and offered grass silage + 3.8 kg concentrates DM daily for 124 days – slaughter age, 24 months, hereafter referred to as grass silage plus grain (SG); and (iii) offered grass silage *ad libitum* over the first winter, followed by 196 days at pasture, re-housed and offered grass silage *ad libitum* for 136 days, followed by 97 days at pasture – slaughter age, 28 months, hereafter referred to as grazed grass (GG). The actual slaughter date was based on the mean live weight, and an assumed kill out proportion to achieve a target carcass weight of 390 kg for each production system. Two animals were removed from this study, one from the GF system (LM breed) and one from the GG system (CH breed). This resulted in final animal (with breed) numbers with each diet system being as follows; 17 animals GF (11 LM, 6 CH), 18 animals SG (11 LM, 7 CH), and 17 animals GG (11 LM, 6 CH).

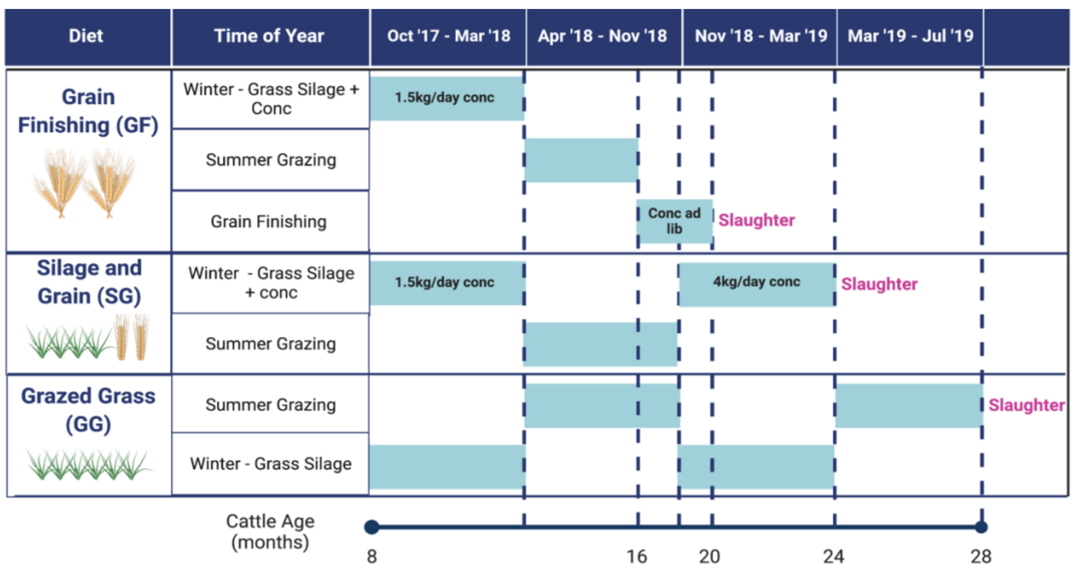

Figure 2.1 – Timeline showing the feeding of steers from each of the three different systems (GF, SG and GG) used in this study, by both season and cattle age

2.2.1.3. Animal slaughter and carcass storage

Animals were transported approximately 22 km to a commercial slaughter plant (Kepak Clonee, Dublin, Ireland) and slaughtered within one hour of arrival. Cold carcass weight was estimated as 0.98 of the hot carcass. Carcasses were graded mechanically for conformation and fat score according to the EU beef carcass classification system using a 15-point scale (Conroy *et al.*, 2009). Carcasses were placed in a chill within one hour after slaughter. The longissimus muscle (strip loin cut) from between the 12th and 13th rib on the left side of each carcass was excised and marked for sensory analysis. The carcasses were aged for 15 days before freezing and transportation to Teagasc Ashtown, where they were stored frozen (-18°C) for between 6 and 8 months before sensory testing occurred.

2.2.2. Participants

Three separate panels of regular beef-eating consumers (n=51; n=52; n=50) (***Table 2.1***) were recruited from students and staff at Teagasc Food Research Centre, Dublin, Ireland, to assess striploin steaks from animals fed either GF, SG, or GG, respectively. Consumers were included only if they consumed beef steak at least once a month. Consumers were informed that they would be tasting beef steaks but were not given any other information about the project. Informed written consent was obtained from consumers prior to their participation. Each participant received a €5 meal voucher for their involvement in the sensory trial.

Table 2.1 – Demographic breakdown of beef meat consumer panels

	GF diet[a]	SG diet[a]	GG diet[a]	Summary
Participants (n)	51	52	50	153
Consumer Demographics	**%**	**%**	**%**	**%**
Sex Assigned at Birth				
Female	57	73	70	67
Male	43	27	30	33
Age				
18-36	76	44	40	53
36-66	24	56	60	47
Nationality				
Irish	51	60	52	53
Non-Irish[b]	49	40	48	47
Years in Ireland				
Since Birth	50	59	52	54
10+ years	2	4	8	5
6 – 9 years	10	15	16	14
3 – 5 years	18	10	6	11
1 – 2 years	12	2	8	7
<1 year	8	10	10	9
Beef eating frequency				
1+ times/week	71	79	88	79
1-3 times/month	29	21	12	21

a – where GF = grain finishing, SG = grass silage plus grain and GG = grazed grass.

b – Non-Irish refers to all consumers who declared a nationality other than Irish

2.2.3. Sample preparation

While frozen, the strip loin muscle was cut into steaks of 2.54cm thickness using a bandsaw. The steaks were then individually vac-packed in pre-labelled bags and placed back in the freezer at -20°C until sensory analysis. Prior to sensory analysis, steaks were defrosted for 24h at a refrigerated temperature (<5°C). The fat was trimmed from each steak prior to cooking, and the muscle was seared for 1 minute on each side using a pre-heated (210°C) one-sided clam grill (Velox 400V 3 Phase Model) and turned every 2 minutes until an internal temperature of 71°C was reached (AMSA, 2015). The internal temperature was monitored using a hand-held digital thermometer (Eurolec TH103TC). Cooked steaks were wrapped in aluminium foil and allowed to rest for 2 minutes prior to cutting. Each steak was cut into cubes of approximately $2cm^3$ and re-wrapped in aluminium foil with an assigned 3-digit code.

2.2.4. Sensory assessment

Due to differences in slaughter age of cattle (***Figure 1.2***), a between-subject design was employed in which beef from each feeding system (GF, SG, and GG) was assessed by one of the three groups of consumers recruited for this study. Each trial consisted of six sensory sessions with a maximum of 9 consumers attending each session. As this study also aimed to compare consumer sensory data generated by three different liking methods (traditional, temporal liking and structured liking), each consumer assessed meat from the same animal for each sensory method to reduce any potential variation caused by animal effects on the sensory scores. The order in which each sensory method was presented to consumers was fixed across all sessions as follows: familiarisation task, free temporal liking, structured temporal liking and traditional liking. The rationale for presenting each sensory method in the same order is because if the consumer completed the structured temporal liking task first, it is likely that they would use a similar approach for scoring samples during the subsequent free temporal liking task. During each method, consumers were asked to rate each sample for overall liking (hereafter referred to as liking), followed by beef flavour (hereafter referred to as flavour), tenderness and juiciness, on a 9-point structured hedonic scale ranging from “dislike extremely” to “like extremely”. Consumers assessed samples in individual sensory booths (ISO, 2014) under red lighting to mask potential appearance differences between samples. Each session lasted 1 hour. Water and crackers (Jacob’s, UK) were provided as palate cleansers between tastings, and all data were collected using Compusense Cloud Software (Compusense Inc., Ontario, Canada).

2.2.4.1. Familiarisation task

A familiarisation task was carried out to eliminate first-order bias (MacFie *et al.*, 1989), to introduce consumers to the concept of temporality of liking (i.e. how the perception of liking can change during eating), and how to use the 9-point hedonic scale to communicate any changes in liking perceived during consumption of samples.

2.2.4.2. Temporal liking (TL) assessment

Two different TL methods were conducted, a “free” temporal liking (Free TL) and a “structured” temporal liking (Structured TL). As per the literature (described briefly above), two approaches can be used to generate temporal data. In this study, for the “free” TL method, consumers were “free” to change their liking scores for each attribute continuously. In contrast, for the “structured” TL method, four different pre-defined time periods were presented (Table 2), and consumers were instructed to indicate their liking for each attribute at each time point, resulting in 4 scores per attribute.

2.4.2.1. Free temporal liking

Free TL was conducted in the form of continuous TL based on the method described by Sudre *et al.* (2012). Each consumer received four cubes of beef and was asked to rate their liking for the four attributes, using one cube for each attribute. However, instead of providing one score for each attribute (as typically conducted in traditional hedonic tests), consumers were asked to continuously rate their liking for an attribute from the moment they placed the steak in their mouth until it was swallowed. Consumers were instructed to press the timer button on the consumer screen just before placing the piece in their mouth and press stop just after swallowing. All four attributes were presented simultaneously on the screen in the same order.

2.4.2.2. Structured temporal liking

Structured TL was carried out in a similar format as described by Sudre *et al.* (2012). Pre-determined time points, defined as T1-T4 (Table 2), were explained to consumers. Similar to the free TL method, all four attributes were presented simultaneously on the screen, and consumers had the freedom to score the samples for each attribute in any order. Consumers were instructed to give one score per time point, per attribute. Consumers received four cubes of meat, one for each time point.

Table 2.2 – Time points for the structured temporal liking assessment

Time point	Stage of chewing	Definition
T1	Beginning of chewing	After 2-3 bites
T2	Middle of chewing	Self-assessed
T3	Just before swallowing	Self-assessed
T4	Just after swallowing	Self-assessed

2.2.4.3. Traditional liking assessment

Consumers were instructed to evaluate the beef samples for the traditional liking method and provide one overall score for each attribute. Each consumer received four cubes of meat, one for each attribute to be assessed.

2.2.4.4. Consumer self-reported difficulty

Following the completion of each method, consumers were also asked to rate their perceived difficulty of performing each method on a 7-point scale, where one = very easy and 7 = very difficult.

2.2.5. Statistical analysis

All models were run for each variable (liking, flavour, tenderness, and juiciness). All analyses were run using the Mixed SAS Procedure (Version 9.4; SAS Institute Inc.), except for the analysis of the perceived difficulty of methods which was run using the GLM SAS Procedure.

2.2.5.1. Comparative analysis between diets

The traditional liking data were analysed using mixed models ANOVA (analysis of variance). Animal was considered a random effect, and animal diet, breed, and the diet*breed interaction as fixed effects. As each consumer scored the meat from a single animal, with two or three consumers scoring each animal, the consumer effect is confounded with the residual term of the model; it actually measures the heterogeneity between consumers having evaluated the same animal. The random animal effect is nested within the diet*breed interaction since each animal was fed one diet and was either from the CH or the LM breed. This mixed model can be written as:

(Eq. 1) Liking = Diet + Breed + Diet*Breed + Animal (Diet*Breed) + Residual

The three fixed effects were tested by a Fisher test using the Animal (Diet*Breed) mean square as the error term. Due to the unbalanced design, when significantly different, the levels of fixed effects were compared using their least squares means at the 5% level by Least Significance Difference using the animal mean square as the error term. In addition, the 95% confidence intervals of the least square means are graphically reported.

In order to compare structured TL, free TL and the traditional methods, the same model was used. This required averaging the four structured scores given at the different stages and the different free TL scores by consumer. The average of the free TL scores was weighted by the duration of the scores. The duration of a free TL score was defined as the elapsed time between one score and the next one; the duration of the last free TL score was the elapsed time between that score and the end of the evaluation.

2.2.5.2. Effect of sensory method on consumer scores

In order to statistically compare the overall magnitude of the liking across attributes and to assess whether the fixed effects are the same in the three methods, a joint ANOVA model was fitted using only the 138 consumers that performed the three methods. This model was based on the one given in ***Eq. 1*** above; however, in this analysis, "method" was added as a fixed effect together with its interactions with each of the three fixed effects of the model (***Eq. 1***). A pairwise comparison was run post-hoc.

2.2.5.3. Perceived difficulty of methods

Each of the 153 consumers provided an easiness score for each of the three methods. A two-way additive model of ANOVA was run with the consumer and the method as the two factors of variation. The method effect was tested by a Fisher test using the residual as the error term. Then the means scores of the three methods were compared by Least Significance Difference (LSD, p=0.05).

2.2.5.4. Consumer demographic variables

The four consumer descriptors (sex assigned at birth, age, nationality, and frequency of beef consumption) were included as fixed effects in Eq. 1, together with their six 2-way interactions and eight 2-way interaction with the diet and breed factors. Significant effects were investigated using the corresponding least square means.

2.2.5.5. Temporal data analysis

For the structured TL, a categorical factor identifying the four stages of the evaluation was added to the model of (***Eq. 1***) together with its interactions with Diet, Breed and Diet*Breed factors. By doing so, it is possible to test whether each attribute differs among stages and possibly whether these differences are not the same among diets and breeds.

For the free TL, because it was not possible to define a categorical stage factor, the standardized time was kept as a continuous factor acting as a covariate in a mixed ANCOVA (analysis of covariance) model, which is the same as the ANOVA of the structured TL data with the continuous standardized time replacing the categorical stage factor.

2.3. Results

2.3.1. Effect of diet

2.3.1.1. Traditional method

No animal diet*breed interactions were found for any attributes. Animal diet did not affect consumer liking of striploin steaks for any of the attributes studied using the traditional method (***Table 2.3***). Consumers tended to provide a higher score for the liking of juiciness for SG steaks (p=0.0655).

2.3.1.2. Free TL

No significant diet*breed interactions (P>0.05) were found using the free TL method. Using the free TL method, animal diet was found to have a significant effect in terms of liking (p=0.0317), tenderness (p=0.0328), and juiciness (p=0.0017) between the GF and SG diets, and the GF and GG diets (***Table 2.3***). Animal diet did not have a significant effect (p=0.0764) on consumer liking of flavour.

Table 2.3 –Table of LSMeans (with confidence intervals) of the three diets

Task	Attribute	GF	GG	SG
Traditional	Liking	6.47±0.43	6.73±0.43	7.04±0.42
Traditional	Flavour	6.73±0.51	6.60±0.51	7.27±0.50
Traditional	Tenderness	5.97±0.49	6.39±0.50	6.49±0.48
Traditional	Juiciness	6.17±0.50	6.65±0.51	7.01±0.49
Free	Liking	5.88±0.45[a]	6.70±0.45[b]	6.51±0.44[b]
Free	Flavour	5.76±0.46	6.48±0.46	6.31±0.46
Free	Tenderness	5.70±0.54[c]	6.61±0.49[d]	6.44±0.48[d]
Free	Juiciness	5.29±0.55[e]	6.39±0.50[f]	6.6±0.49[f]
Structured	Liking	6.10±0.55	6.15±0.46	6.41±0.45
Structured	Flavour	6.00±0.51	6.42±0.43	6.48±0.42
Structured	Tenderness	5.98±0.56	6.18±0.47	6.30±0.46
Structured	Juiciness	5.85±0.56	6.27±0.45	6.46±0.44

a/b/c/d = Significance level <0.05 e/f = Significance level <0.01

Means labelled with a different letter within a row are significantly different

2.3.1.3. Structured TL

There was a significant amount of missing data in the structured TL responses in the GF beef trial. As a result, data from 15 consumers were removed, and statistical analysis was performed on responses from 36 consumers in the GF trial. No significant diet, breed, or diet*breed interactions were found using the structured TL method for any attribute.

2.3.2. Effect of method on sensory scores

No interactions were observed between method and diet, method and breed, and method and diet*breed for any attributes. The sensory method was found to have a significant effect on the scores obtained for liking, flavour, and juiciness (***Figure 2.2***).

Results of a pairwise comparison found that the traditional sensory method elicited significantly higher liking scores for flavour compared to the free TL (p=0.0129) and structured TL (p=0.0290) methods (***Figure 2.2***). The traditional method also resulted in significantly higher juiciness scores than free TL (p=0.0516). In addition, overall liking scores elicited using the traditional method were significantly higher than those elicited using the structured TL method (p=0.0305). No significant differences were found for tenderness scores elicited using the three different sensory methods.

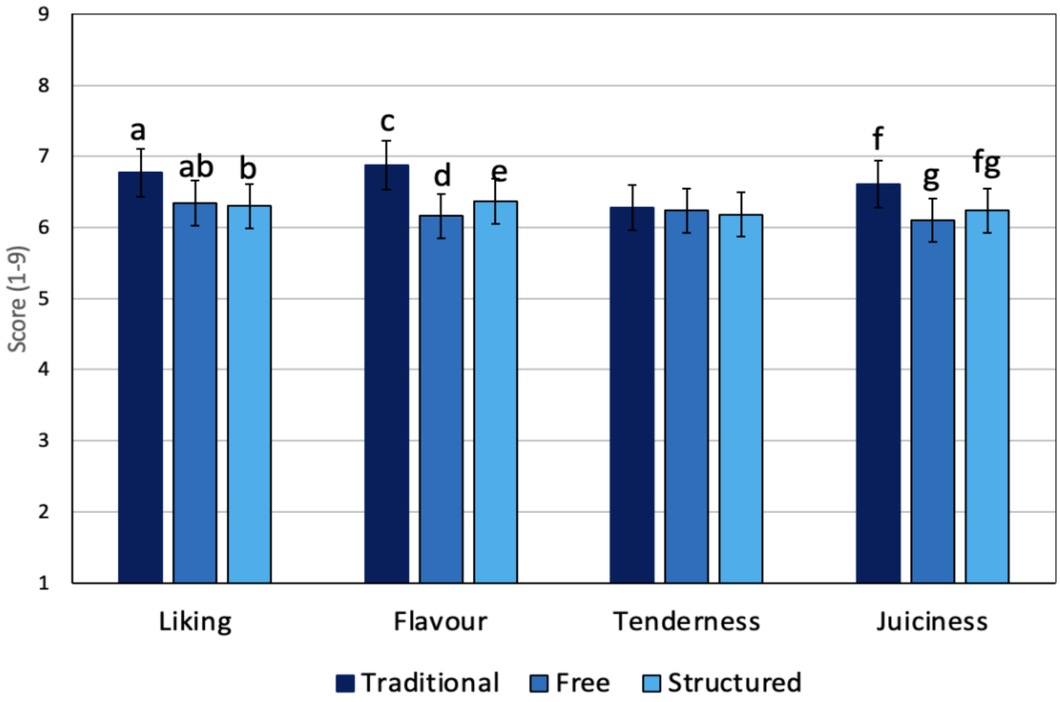

Figure 2.2 – Bar charts showing the effect of method on scores for each attribute

a/b/ab/c/d/e/f/g/fg - means within an attribute marked with a different letter differ significantly (P≤0.05)

2.3.3. Consumers' self-reported difficulty

Consumers' self-reported difficulty to perform each method is illustrated using a box plot in ***Figure 2.3***. A significant difference (p≤0.05) was found between all three sensory methods, with the structured TL method perceived as the most difficult method to perform (mean 2.8) and the traditional method being the least difficult (mean 1.6).

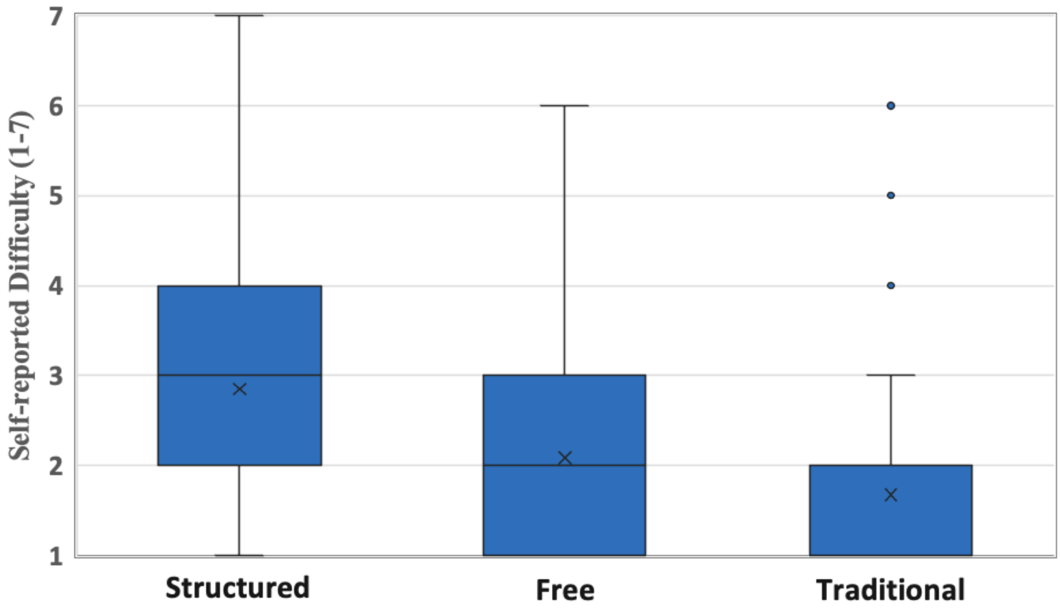

Figure 2.3 – Box plot of consumers' perceived difficulty of sensory tasks (rated using a 7-point scale where 1=very easy, 7=very difficult)

2.3.4. Consumer demographic

All consumer demographic descriptors except for "Years in Ireland" were included in the statistical model. The variable "Years in Ireland" was not included in the data analysis as the individual groups within this question had small sample sizes. Sex assigned at birth or beef eating frequency did have a significant effect on consumer liking of animal diet.

2.3.4.1. Effect of age on consumer liking

Consumers were divided into two groups according to their age (18-35 or 36-66 years). There was a significant difference (p=0.0247) in consumer liking of flavour between these two age groups (***Table 2.4***). A trend in liking was observed for breed (p=0.0720) was also found for the effect of age on consumer liking of flavour, without a diet influence. Consumers aged 18-35 tended to score steaks from the CH breed (7.03±0.95) higher than the LM breed (5.92±0.57) steaks, and consumers aged 36-66 tended towards the opposite, scoring steaks from the LM (5.73±0.66) breed higher than those from the CH (5.29±0.92) breed. No other breed interactions were found, and there were also no diet*breed interactions for any attributes. Age had no significant effect on consumer liking or liking of tenderness or juiciness of the steaks.

Table 2.4 – LS Mean (with confidence interval) for flavour by consumer age

Attribute	Age (years)	LS Mean (w/ CI)
Flavour	18-35	6.47±0.59[a]
Flavour	36-66	5.51±0.57[b]

a, b – means marked with a different letter differ significantly (P<0.05)

2.3.4.2. Effect of nationality on consumer liking

Nationality was found to influence consumer liking of flavour substantially, with non-Irish consumers liking the flavour of beef from animals fed an SG diet more than that of the GF diet (p=0.0523). Due to the small sample size of non-Irish consumers, nationality was grouped as Irish (54%) and non-Irish (46%). The non-Irish grouping included all consumer self-reported nationalities that were not Irish (21 in total). Non-Irish consumers tended to provide higher flavour scores than Irish consumers (***Table 2.5***).

Table 2.5 – LS Mean (with confidence interval) for flavour by nationality and diet

Attribute	Nationality[a]	Diet[b]	LSMeans (w/ CI)
Flavour	Irish	GF	5.96±0.81
Flavour	Non-Irish	GF	4.45[c]±0.96
Flavour	Irish	SG	6.26±0.94
Flavour	Non-Irish	SG	6.73[d]±0.98
Flavour	Irish	GG	5.95±1.05
Flavour	Non-Irish	GG	6.61±0.95

a –Self-reported measure, where Non-Irish refers to all consumers who did not indicate they were Irish, all other nationalities were grouped due to small amounts of consumers from many individual countries (n=21)

b – Animal Diet where GF = Grain Finishing, SG = Silage plus Grain Finishing and GG = Grazed Grass Finishing

c, d – means marked with different letters differ significantly (p<0.05)

2.3.5. Temporal analysis of the effect of animal diet on liking

2.3.5.1. Free TL

No significant interactions for breed and diet*breed were found. Significant differences were found in liking between the GF and SG diets (p=0.03) (***Figure 2.4)***. A significant difference in liking of juiciness was also observed between the GF and GG (p<0.001) and the GF and SG diets (p=0.002) (***Figure 2.7***). No significant differences were found for flavour (***Figure 2.5***) or tenderness (***Figure 2.6***). Time (i.e., the evolution of scores over the eating process) was found to play a significant role in scores for all attributes: liking (p=0.0201), flavour (p=0.0122), tenderness (p=0.0070), and juiciness (p=0.0519).

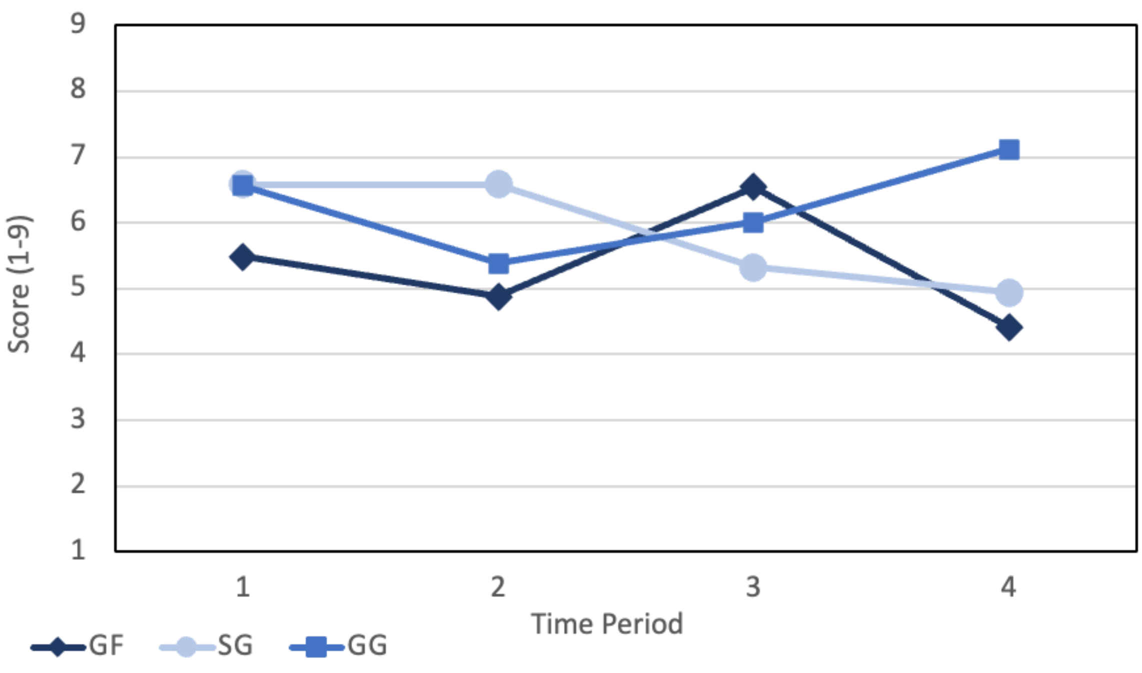

Figure 2.4 - Free temporal liking method results for overall liking

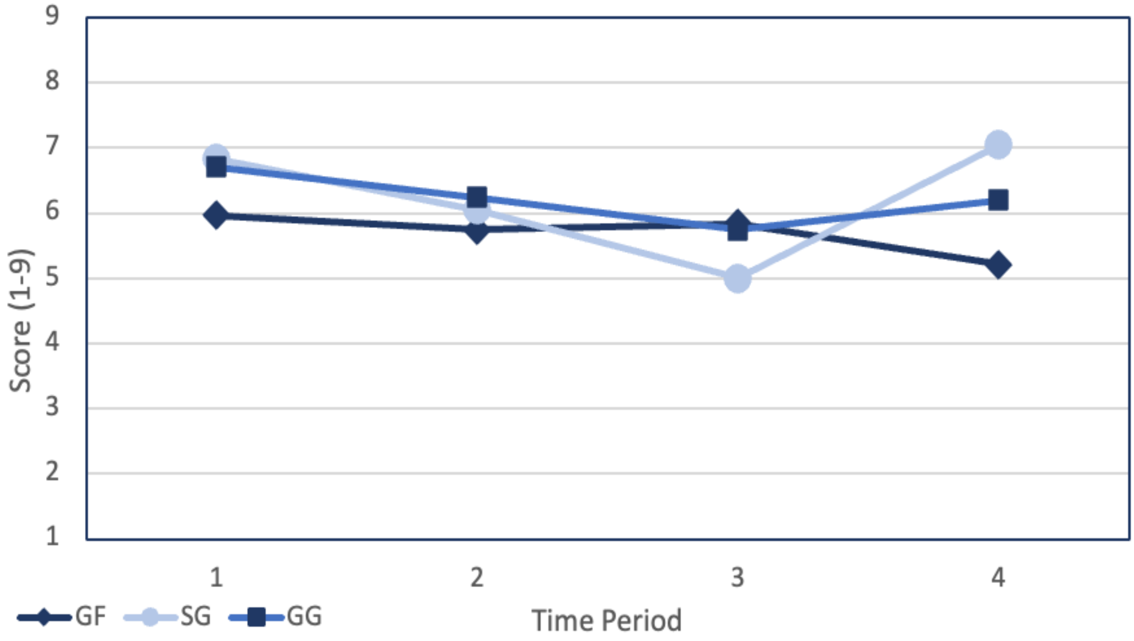

Figure 2.5 - Free temporal liking method results for flavour

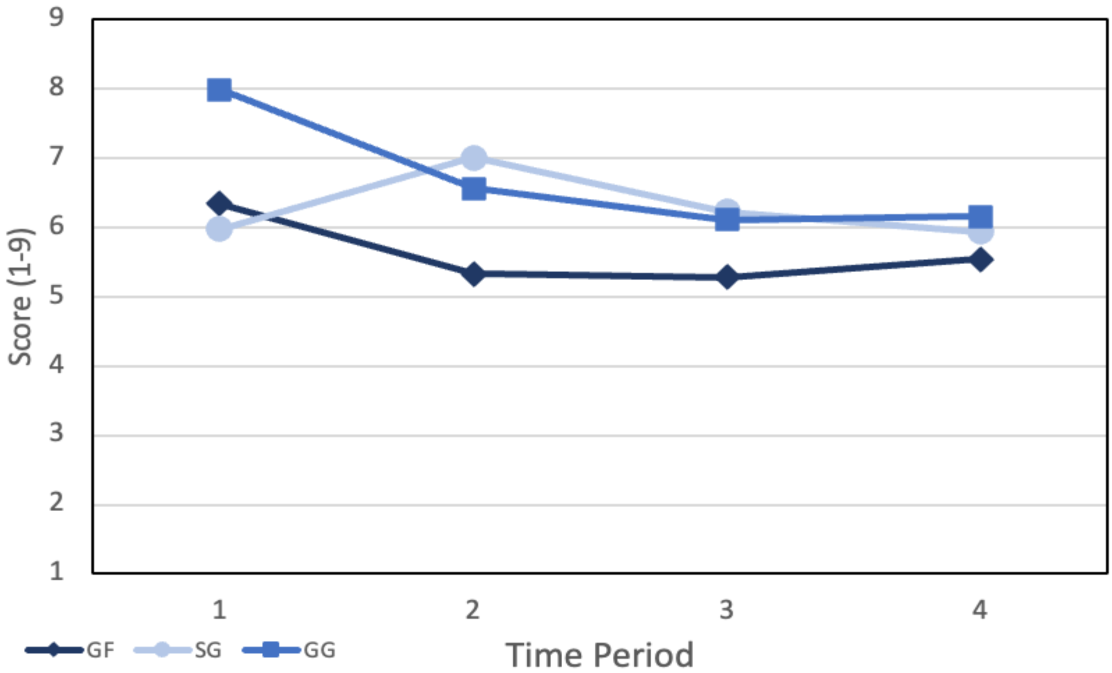

Figure 2.6 - Free temporal liking method results for tenderness

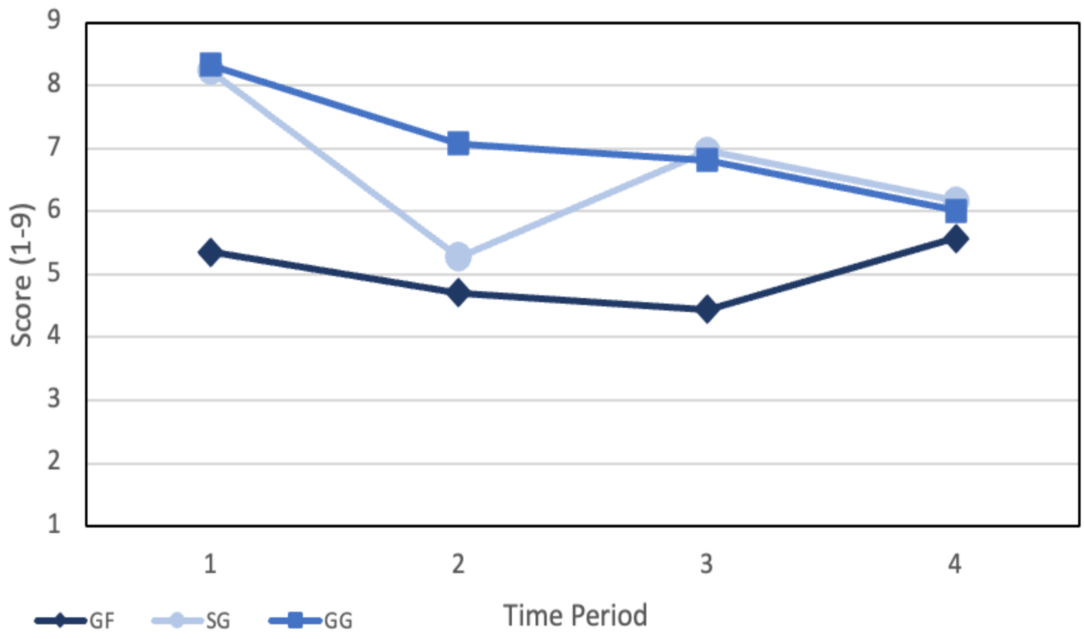

Figure 2.7 - Free temporal liking method results for juiciness

2.3.5.2. Structured TL

Analysis of the structured TL data found no breed or diet*breed interactions. A significant difference was found in liking of juiciness (***Figure 2.11)*** between GF and SG diets (p=0.0167) and was trending towards significant between GF and GG (p= 0.0636). No significant differences were found for any other attribute (***Figures 2.8, 2.9, 2.10***). Scores had a tendency to differ over time-period, for liking and a trending difference was found between T1 and the other three periods (T2-T4) (p=0.07), but T2-T4 did not differ from each other. A similar trend was observed for juiciness (p=0.09) between T1 and T3 and T1 and T4.

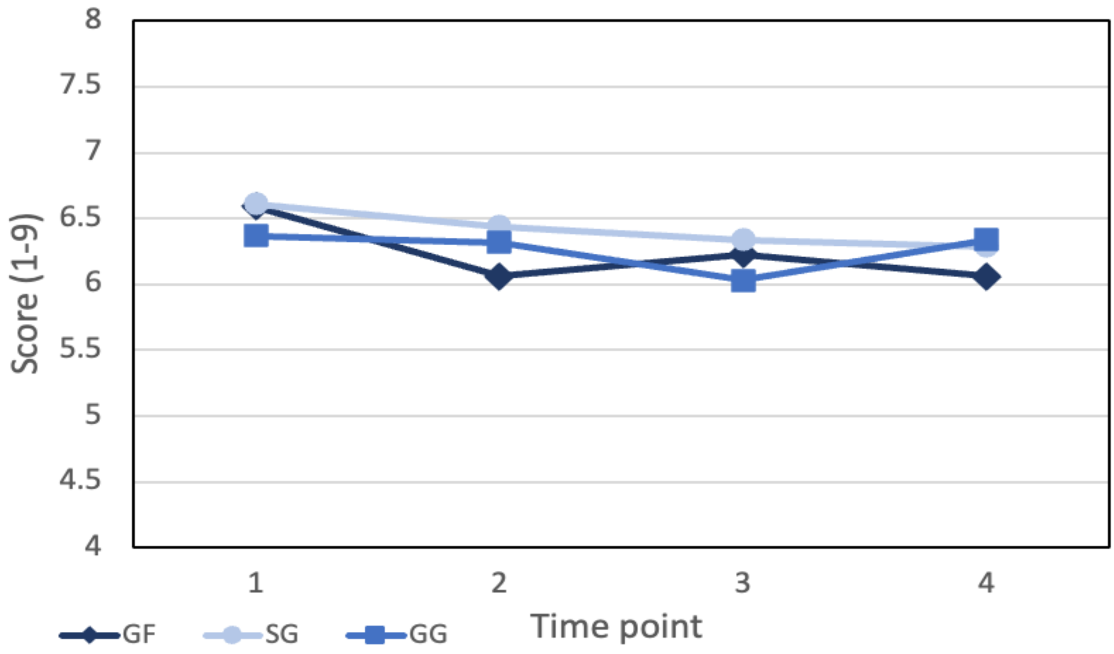

Figure 2.8 - Structured temporal liking method results for overall liking

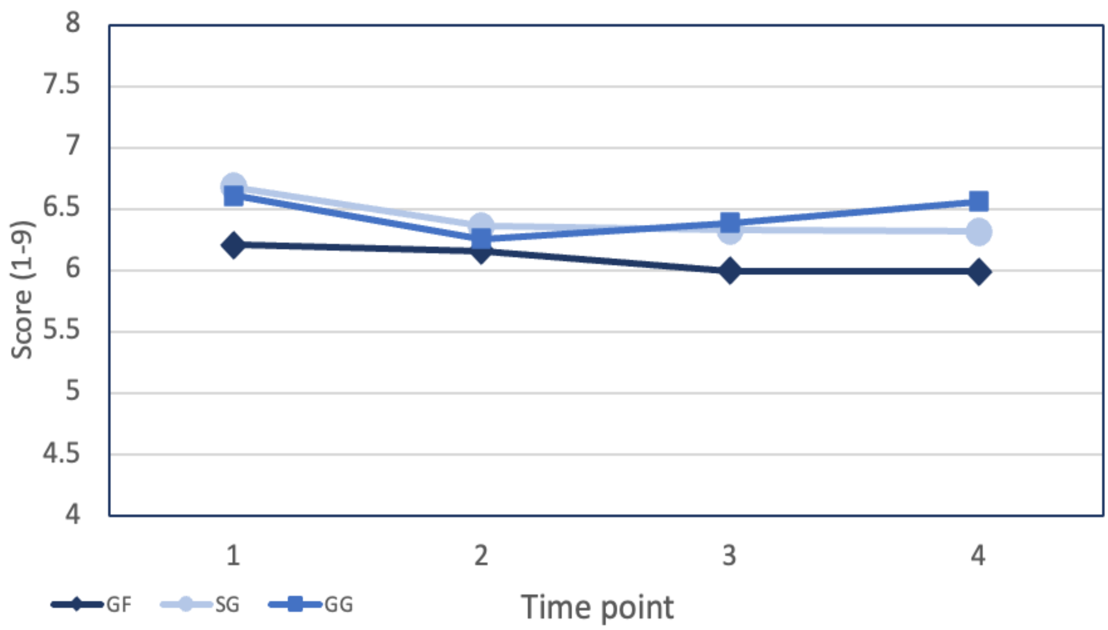

Figure 2.9 - Structured Temporal Liking method results for flavour

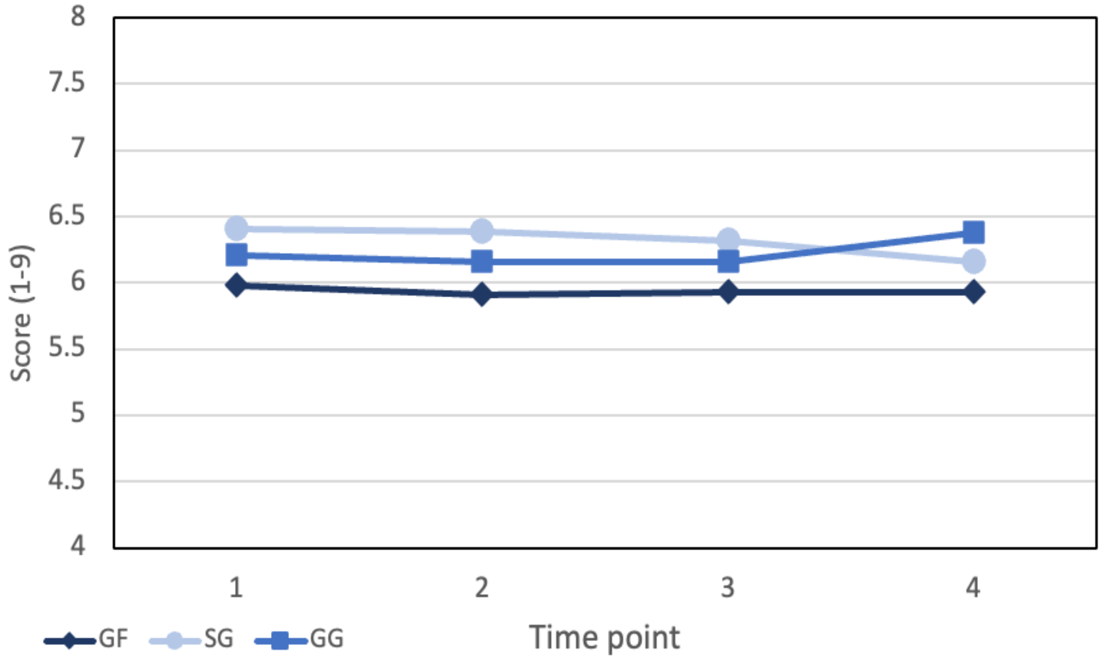

Figure 2.10 - Structured temporal liking method results for tenderness

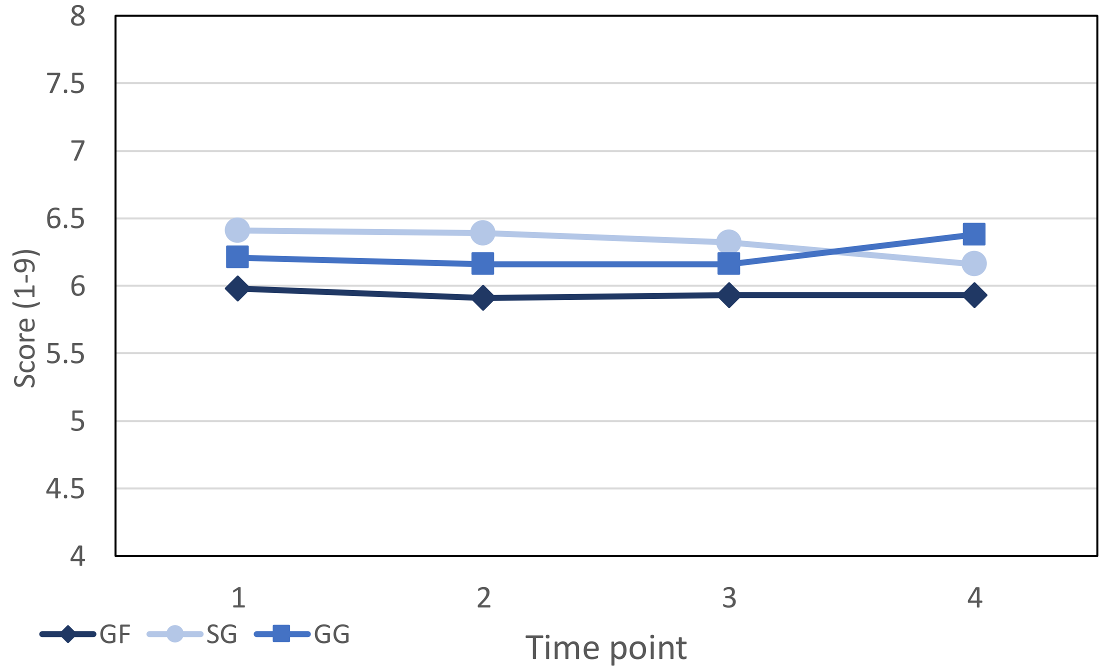

Figure 2.11 - Structured temporal liking method results for juiciness

2.4. Discussion

In this study, two different statistical analyses were conducted to investigate the effect of animal diet on consumer liking: a comparative analysis and a temporal data analysis. The comparative analysis, which will be discussed first, was carried out to allow the results from the two TL methods to be directly compared to the traditional liking. This analysis also allows the results of this study to be put into the context of existing literature, as there are currently no other consumer studies that apply TL or any temporal methods to beef. It is acknowledged that the results from the comparative analysis do not reflect the temporal aspect of the TL method. In this respect, removing time as a factor removes the main value of conducting TL methods created to profile products over time.

The traditional liking method yielded no significant differences between diets for any attribute. The tendency for SG to be perceived as juicier than GG is similar to some US studies (Bidner *et al.*, 1981; Bueso *et al.*, 2018; Ron *et al.*, 2019; Simonne *et al.*, 1996; Umberger *et al.*, 2002), which found consumers scored steaks from grass supplemented with grain cattle to be juicier than steaks from grain or feedlot finished cattle. However, in contrast, many other US studies involving steers have found consumers rated grain-finished steaks significantly juicier than grass (silage) supplemented with grain steaks (Garmyn *et al.*, 2020; Kerth *et al.*, 2007) or grass-fed steaks (Chail *et al.*, 2016, 2017; Corbin *et al.*, 2015; Killinger *et al.*, 2004; Sitz *et al.*, 2005).

Comparing the traditional liking method results in our study to those generated in similar studies conducted in Europe, Ripoll *et al.* (2014) also found no significant differences in overall liking, flavour, or tenderness of beef from finishing diets of grass plus grain and grain *ab libitum.* Blanco *et al.* (2017) and Realini *et al.* (2009, 2013) found that European consumers scored beef derived from a finishing diet of grass supplemented with grain higher than grain-finished beef, with significant differences for some of their parameters. Consumers in Moran *et al.* (2019) also found silage plus grain steaks more acceptable than grain-finished steaks from bulls slaughtered at 15 months. However, consumers also found the grazed grass beef steaks to be significantly less acceptable than the silage plus grain steaks. Interestingly, the same authors did not find significant differences in acceptability when bulls finished on grain or fed grain and then grazed were slaughtered at 19 months (Moran, 2020).

Using the comparative analysis, the free TL method was more discriminating than the structured TL and the traditional liking methods. However, it must be noted that this analysis involved averaging a large number of consumer scores, which may be why it was found to be more discriminative. The free TL method also elicited significantly lower scores for all attributes except for tenderness than the traditional liking method, indicating that consumers score attributes higher when asked to give an overall score rather than having to change it in real-time.

As previously mentioned, responses from 15 consumers were removed from the analysis of the structured TL in the GF trial due to missing data. The removal of missing data was completed in a manner that ensured at least two consumer responses per animal remained in the analysis, meaning some consumers with missing data were included. However, it must be noted that all consumers with missing data were removed from the same trial. The structured TL method was perceived to be the most difficult method to complete by consumers, despite the perceived difficulty, only scoring a mean of 2.8 on a 7-point scale. Although Sudre *et al.* (2012) investigated both structured and free TL methods (similar to this study), information regarding consumer perceived difficulty in completing the tests was not reported. It could be that consumers preferred the freedom of changing their liking score in real-time in the free TL method rather than having pre-determined time-points in the structured TL method in which they were prompted to provide a score. Another possibility could be that the pre-determined time points were considered difficult to understand by consumers, as 3 of the four time points were self-determined (i.e., T2 was in the middle of chewing, T3 was just before swallowing, and T4 was just after swallowing). A future study examining consumer responses while assessing samples using a structured TL method with specific times (e.g., 30 seconds, 2 minutes, etc.), and one with self-determined time-points, would be interesting.

Consumer demographics can have a considerable influence on liking scores. Similar to Ripoll *et al.* (2014) and Umberger *et al.* (2002), this study found no influence of sex assigned at birth (termed gender in many papers) on liking scores. However, contrary to this, Sanchez *et al.* (2012), Hwang *et al.* (2008), Morales *et al.* (2013) and Kubberød *et al.* (2002) found that consumer acceptability and preferences for beef differed by gender.

Nationality/culture can influence the consumer liking of food products in general (Köster, 2009; Prescott *et al.*, 2002; Torrico *et al.*, 2019), and beef is no different (Banović et al., 2012; Borgogno *et al.*, 2015). Specifically, in relation to the effect of ration type on the eating quality of beef, familiarity with products related to the feeding or production systems is the common reason given for differences in consumer liking (Garmyn *et al.*, 2020; Killinger *et al.*, 2004; Sitz *et al.*, 2005). Contrary to this literature, in this study, non-Irish consumers scored the flavour of silage plus grain steaks significantly higher than the grain-finished steaks. This was unexpected, as most non-Irish consumers in our study originated from cultures where grain finishing is the norm.

We are not aware of studies where the impact of consumers living in a different country than their country of birth was considered a factor of consumer liking of beef. Torrico *et al.* (2015) found significant differences in the cross-cultural acceptance of steaks from three different grass and one conventional feeding system using the US, Asian and Hispanic consumers, with culture having a significant effect on the scores for all attributes: appearance, aroma, liking, flavour, juiciness, and tenderness. The Torrico *et al.* (2015) study appears to be the closest comparison to this study as all consumers were recruited in the same country; however, it is not clear if these consumers were immigrants to the US or if they were divided purely on ethnicity and were in the US since birth, as ethnicity and country of origin are both used to describe these populations.

The temporal data analysis (structured and temporal TL) revealed significant differences in liking of juiciness between the GF and SG diets. Significant differences were also found for overall liking (free TL) and between GF and GG for juiciness (free TL). This is different from the results of the comparative analysis in which scores elicited from both TL methods were averaged over time. Temporal methods, such as TL, were developed to capture how perception and liking change during the eating process. In this study, the evolution of scores over time was significant for all attributes using the free TL method. Numerous studies investigating the juiciness and tenderness of beef have been conducted using Time Intensity (TI), which is a temporal method performed by trained panels. Using this method, Zimoch & Gullett (1997) concluded that the intensity of juiciness could be perceived for the entire chewing process at varied intensity; however, the sensation of tenderness subsided quickly. Gomes *et al.*

(2014) also found that differences in the tenderness of steaks cooked using different methods were only significant at the first bite. This may contribute to the lack of variability in tenderness between the methods and why the majority of the tenderness curves trend immediately downwards. Although, results from the structured TL method found that some GF and GG curves trend upwards at the end, meaning liking increased at the end/toward the end of consumption. This may be due to consumer variability in the perception of tenderness; however, the reasoning is not clear to the authors.

Participant variability (differences between individual participants) in tracking intensity perception over the eating process was noted in many TI studies using trained panels (Brown *et al.*, 1996; Butler *et al.*, 1996; Duizer *et al.*, 1996; Gomes *et al.*, 2014; Zimoch & Findlay, 1998; Zimoch & Gullett, 1997). In fact, Duizer *et al.* (1996) found participant differences in the IMAX (curve peak) duration of chewing and number of chews using beef derived from five treatments of differing cattle size, diets, and ages; however, the effect of these factors were only analysed collectively and not individually. This participant variability would only be amplified when applied to consumers, so it may account for some of the diet and time interactions found using the free TL method in this study, as different consumers were used for the different diet assessments. This study would need to be repeated with the same consumers assessing samples from all diets to investigate what proportions of the diet and time interactions are due to diet differences and what proportion is due to consumer variability.

2.5. Conclusion

In this study, two temporal liking methods were successfully applied to investigate the differences in consumer liking of beef steaks from different finishing systems. This is the first temporal liking study to measure more than overall liking, and this study shows that temporal liking data can be generated for a range of different attributes. With regard to animal diet, the silage plus grain steaks were generally preferred by consumers for all attributes. In addition to being easier to perform by consumers, the free TL method yielded more discriminative data than the structured TL method, with significant differences found for both juiciness and overall liking across animal diets. The significant evolution of scores over time for all attributes using the free TL method shows that consumers can track their liking of attributes over the eating process of steaks. These results show that free temporal liking may give rise to new opportunities to elicit more in-depth information from consumer studies using beef.

Chapter 3

Insights into using new consumer temporal liking methods for understanding hedonic responses to beef: 3 Case Studies

Abstract

Temporal Liking (TL) is a temporal method that is gaining interest for its application with consumers. In addition to answering the research question, TL data also has the potential to give new insight into consumer behaviour in terms of how people approach temporal sensory liking methods. This chapter utilises this consumer behaviour approach to look at three temporal liking studies applying both structured and free TL in terms of data quality, presence or absence of temporality, and correlations between consumer response and self-reported difficulty. Interestingly, the assessment of temporality found that consumers who showed the ability to provide temporal data did not provide it for all attributes studies. The analyses have also shown many areas where fatigue and the natural variability in consumer responses may impact data quality.

3.1 Introduction

It is well accepted that perception is a time-bound process that changes with oral processing (i.e., eating) (Cliff & Heymann 1993; Dijksterhuis & Piggott, 2000; Foster *et al.*, 2011). The changes that occur with eating can be tracked by many different sensory methods, including temporal methods (Hort *et al.*, 2017). A temporal method called 'Time-Intensity' (TI) was introduced in the 1950s in an attempt to track changes in perceived attribute intensity in beer over time (Cliff & Heymann, 1993). Over the past decades, this method has evolved into a standalone category of sensory methods that can be used with both consumers and trained panels. Examples of temporal methods include Temporal Dominance of Sensations (TDS) (Pineau *et al.*, 2009), Temporal Check All That Apply (TCATA) (Castura *et al.*, 2016) and Temporal Liking (TL), also referred to as Dynamic Liking (Sudre *et al.*, 2012). Temporal drivers of liking have also been recently determined (Thomas *et al.*, 2015). In addition, a method has been created to track consumer emotional responses over time, known as Temporal Dominance of Emotions (TDE) (Jager *et al*., 2014).

Temporal Liking (TL) is a temporal method that is gaining interest for its application with consumers. It both utilises the scales used in traditional affective testing, such as the 9-point hedonic scale and tracks changes in consumers' sensory perception over time. While the first mention in the literature of dynamic liking dates back to 1986 (Lee and Pangborn, 1986), the temporality of liking with consumers is still being explored. To date, TL methods have been applied to understanding consumer perceptions of wheat flakes cereals (Sudre *et al.*, 2012), beer (Ramsey *et al.*, 2018; Silva et al., 2018), wine (Silva et al., 2019), cheese (Thomas *et al.*, 2015; 2017) and chewing gum (Galmarini *et al.*, 2015). Several authors have successfully applied TL concurrently with other temporal methods such as TDS or TDE (Silva *et al.*, 2018; 2019; Thomas *et al.*, 2016; 2017) and while using a multi-bite/sip experimental approach (Rocha-Parra *et al.*, 2016; Thomas *et al.*, 2017), to learn more about the temporality of liking and perception during the eating process.

A drawback of the dynamic data elicited using TL and other temporal methodologies in comparison to non-temporal methods is that the data is more complex and requires cleaning to ensure it is accurate, consistent, and usable (for further information, see Section 3.3.5). The studies that have been published to date have used several different approaches to transform temporal liking data, including treating the TL data as TI data (Rocha-Para *et al.*, 2016), analysing global liking (Sudre *et al.*, 2012), and dividing the data into several time-periods (Ramsey *et al.*, 2018; Thomas *et al.*, 2015; 2016). One issue that has come up in the literature is the fact that some consumers do not provide dynamic data during product assessment. Sudre *et al.* (2012) reported removing three consumers for not providing dynamic data, and Silva et al. (2018) removed 11 consumers for not following instructions. However, neither of these papers investigated or hypothesized why consumers may not have provided dynamic data.

An advantage of the TL method is that, in addition to answering a specific research question, the data collected provides novel information about how liking scores evolve during eating. However, there is also potential to use this type of data to better understand how consumers approach and perform during temporal sensory tests. However, temporal liking data has not been examined in much depth to date. Thomas *et al.* (2017) looked at the number of liking responses, duration of responses, and time to first response, as measures of consumer behaviour according to demographics (country of testing). Silva *et al.* (2018) compared the number of data responses, time to first response, and range of responses across wines when coupled with TDS or TDE. While these studies are fascinating, it is also important to explore how consumers use these methods to ensure studies are robustly designed and enhance the reliability of the findings.

Therefore, this chapter looks at data from 3 studies that applied both free and structured TL liking methods with consumers with four objectives to; (1) determine whether the experimental design of two different temporal methods (free TL and structured TL) impacted data quality; (2) investigate if consumer self-reported difficulty of completing each method is correlated with missing data, number of responses (free TL), time to first score, or total time spent on the task; (3) investigate if demographics, specifically nationality and age, impact consumer scores and number of responses elicited; and (4) determine consumers approach to performing temporal liking from “other” data elicited, for example, length of time to respond to attributes (seconds), number of responses, and percentage of missing data.

3.2 Materials & Methods

3.2.1 Studies & Participants

Steaks from one of three different production systems (grain-finished, silage and grain-finished, grazed grass-finished) were used in three separate studies consisting of 51, 52 and 50 consumers, respectively (*Table 3.1*). Consumers were recruited from staff and students at Teagasc Food Research Centre, Dublin, Ireland. (Demographic details are shown in *Table 2.1* in *chapter 2, section 2.2*). Written informed consent, compliant with ethics and GDPR (General Data Protection Regulation) regulations, was obtained, and each consumer received a €5 meal voucher for participating. Consumers also completed a questionnaire about beef consumption habits. The results showed that >70% of consumers in each study consumed beef at least once per week, with >74% of consumers regularly eating higher quality beef cuts, such as sirloin, striploin, and fillet.

3.2.2 Samples

All three studies utilised grilled strip loin steaks (12^{th}-13^{th} rib), as the tasting sample was sourced from cattle raised in Teagasc, Grange specifically for these studies. Cattle raising and slaughter were as detailed in Chapter 2, Section 2.1.2. All animal procedures performed in this study were subject to Teagasc Ethics Approval and conducted in accordance with the Cruelty to Animals Act 1876 and the European Communities (Amendment of Cruelty to Animals Act 1876) Regulation 2002 and 2005.

Briefly, Charolais and Limousine steers (54) were raised at Teagasc Grange, Ireland, from approximately eight months and were randomly assigned to one of three finishing systems, Grain Finishing (GF; study 1), Silage and Grain (SG; study 2) and Grazed Grass (GG; study 3) before slaughter at 21, 24 and 28 months. Animal numbers (52) presented for slaughter are detailed in *Table 3.1*, and 2 animals were removed from this study. After ageing (15 days), carcasses were frozen for approximately eight months before steak preparation, and sensory analysis commenced.

For sensory testing, steaks were cut (2.54cm thick) from carcasses while frozen using a standing band saw. Samples were defrosted for 24hrs at refrigerated temperatures (<5°C), and the fat was trimmed prior to cooking. A one-sided clam grill (Velox Grill CG3 400C 3 Phase Model) preheated to 210°C was used for cooking. Muscle was seared for 1 minute on each side and then turned every 2 minutes until an internal temperature of 71°C was reached, monitored using a hand-held digital thermometer (Eurolec TH103TC). Cooked steaks were wrapped in aluminium foil and allowed to rest for 2 minutes before cutting. Each steak was cut into 12 pieces (4 pieces per consumer), approximately 2cm x 2cm x 2cm, re-wrapped in aluminium foil, and assigned a 3-digit code.

Table 3.1 – Overview of the three studies detailing the finishing diets, number of animals and number of consumers per study

Study	Finishing Diet	Animals	Consumers (n)
1	Grain Finished Steaks	17	51
1a[1]	Grain Finished Steaks	17	38
2	Silage and Grain Finished Steaks	18	52
3	Grass Finished Steaks	17	50

1 - Study 1a is a subset of the data (38 consumers) from study 1.

3.2.3 Experimental Procedure

A between-subjects experimental design was used for the three studies, with each study carried out using the same procedure. The trials were conducted approximately three months apart from each other in order of slaughter date. Consumers were told they would be consuming beef steaks but were not given any other information about the project.

Each study consisted of three sensory tasks presented to the consumer in a set order: familiarisation, free temporal liking (free TL) and structured temporal liking (structured TL), and four attributes (overall liking, flavour, tenderness, juiciness) were assessed during each task. These tasks were based on the methods detailed in Sudre *et al.* (2012), which applied both structured TL and free TL methods to investigate changes in liking using wheat flakes. However, for this study, both TL methods were adapted for multiple attributes from Sudre *et al.* (2012), in which only overall liking was measured. In the studies reported here, all sensory tasks were conducted using a 9-point hedonic scale ranging from dislike extremely to like, extremely, with attributes presented to the consumer in the same order for each sensory trial.

Verbal and written instructions were provided to consumers on how to complete each task. As mentioned above, the presentation order of tasks was fixed so that consumers who were presented with the structured temporal task would not be influenced to automatically use the same 'restrictive' approach to provide scores during the free-temporal method. For all tasks, consumers were instructed to click a start button while placing the first sample in their mouth and then score one attribute at a time, pressing the stop button after scoring the fourth attribute. The familiarisation task was conducted first to familiarise consumers with the concept of temporality and how to use the scale. The familiarisation task more closely resembled the format of the free TL task. Therefore, for the familiarisation task and free TL, consumers were asked to continuously rate their liking from the moment they placed the steak piece in their mouth until just after swallowing, indicating any change in liking of the given attribute by changing the score. For the structured TL, four predetermined time points were used, as defined as T1-T4 (*Table 3.2*), in which consumers were instructed to provide one score per attribute per time point. The presentation order of attributes on the screen was fixed for all tasks as follows: overall liking, flavour, tenderness, and juiciness; however, consumers could score the attributes in any order they wished.

As these studies involved the assessment of beef steaks, consumers tasted meat from the same animal for each sensory task to reduce any potential variability in results across tasks that the animal could have caused. Each animal was tested by at least two to three consumers, with the majority (94%, 49 out of 52 animals) tested by three. Analysis was conducted in ISO standard sensory booths (ISO, 2014) under red lighting to mask potential appearance differences. Filtered water and crackers (Jacob's, UK) were provided for consumers to cleanse their palate between tastings. Data were collected using Compusense Cloud (Compusense Inc., Ontario, Canada). Immediately after completing the free TL and structured TL tasks, consumers rated the difficulty to perform the task on a 7-point scale where 1= very easy and 7= very difficult.

Table 3.2 – Time points of structured TL task as defined to consumers

Time point	Stage of chewing	Definition
T1	Beginning of chewing	After 2-3 bites
T2	Middle of chewing	Self-assessed
T3	Just before swallowing	Self-assessed
T4	Just after swallowing	Self-assessed

3.2.4 Missing Data Analysis

For the structured TL method, missing data were computed by comparing the expected and the received number of responses per study, time point, attribute, and animal. Upon preliminary inspection of the datasets, it was clear a substantial amount of data from study 1 (see Table 3.1) was missing from the structured TL method. Therefore, consumers (n=15) with the highest amount of missing data were removed to ensure robustness of the analysis. Data quality (i.e., percentage of missing data was then re-analysed, and this subset of study 1 was named study 1a. Study 1a consisted of 38 consumer responses for the free TL and structured TL method. The full dataset from study 1 was also retained, and both study 1 and its subset study 1a were analysed separately to determine any differences between them from section 3.4.2 onwards.

For the free TL and familiarisation task, "missing data" was defined as eliciting "no response for any particular attribute" within each sensory task. Therefore, any consumer giving ≥1 response per attribute was considered "quality" data. Pearson's R Correlations were performed to investigate the relationship between the familiarisation and free TL tasks, as well as between the structured TL and free TL tasks (study 1 only).

3.2.5 Data Cleaning

Data cleaning is a term used to encapsulate many different processes to transform raw data into a dataset (Ilyas & Chu, 2019). Processes and tasks in cleaning quantitative data include data exploration and quality analysis (finding missing data, extreme outliers, and duplication), error detection, error fixing, and data transformation (Dasu & Johnson, 2003; Ilyas & Chu, 2019).

Due to the complexity of the temporal liking method, which involves consumers providing multiple liking scores for each attribute over time, rigorous data cleaning was performed to ensure data were of reliable quality. In this case, data cleaning included three forms: inspection, transformation, and standardisation of data. After the dataset was analysed for missing data (as detailed above), further data cleaning was conducted, mainly to the free TL and familiarisation data due to its unstructured nature. Firstly, the free TL and familiarisation data were inspected to assess the data for "temporality" (i.e.) did consumers provide dynamic or static data. Secondly, data from all methods were analysed to assess the amount of time taken to place the first score after consumers had pressed start and the amount of time that elapsed after the last score before consumers pressed stop. The data were transformed for structured and free TL based on the results. The familiarisation data was not transformed as familiarisation is carried out to eliminate first-order bias and is not meant to be analysed. Finally, the free TL data underwent time standardisation and division into discrete time periods. This cleaning and organisation were completed with Excel and R software, version 4.0.2 (R Core Team, 2020).

3.2.6 Data Analysis

Statistical analyses were performed using XLSTAT-Sensory (Addinsoft, 2021). As a between-subjects design was utilised, and each consumer tasted meat from the same animal, animal diet was not considered a factor in this analysis. In addition, the data from each study were analysed separately, using the same set of procedures. Means were considered significant at $\alpha \leq 0.05$. Descriptive statistics, including mean, median, mode and frequency, are reported for each analysis.

3.2.6.1 Time Spent and Number of Responses per Attribute

Duration of scoring time ("time spent") and the number of responses elicited per attribute and over all attributes (referred to as "overall") were analysed within each study for each consumer. Where appropriate, chi-squared analyses, t-tests, or ANOVAs were conducted to compare these variables with each other and with age and nationality. All means were considered significant at $\alpha \leq 0.05$.

3.2.6.2 Consumer Self-Reported Difficulty of each Task

Each consumer was asked to record how difficult they perceived each task to complete. Consumer self-reported difficulty was reported for the structured TL and free TL and was analysed for each study (1, 1a, 2, 3) separately using paired t-tests. The variance between studies 1 and 1a also was investigated using a separate paired-test test to investigate differences in self-reported difficulty between those who had high amounts of missing data and those who did not.

The structured TL data from study 1a was segmented into three sub-categories by missing data percentage (none, low-medium, medium-high) to learn more about the consumers who provided missing data. The data from the free TL tasks were organised by the same missing data categories for comparison. The free TL data were separately segmented into categories by the number of responses for separate analysis. Correlation between consumers' self-reported difficulty and missing data categorisation for each of the sensory tasks (structured TL and free TL) was conducted using Pearson's R Correlation.

3.2.6.3 Demographics

The demographic questionnaire filled out by consumers was grouped for analysis according to age (18-35 and 36-66 years) and nationality (Irish and non-Irish). Using a chi-squared analysis, no significant differences were found between the demographic groups within each study, except for age in study 1, in which there was a significantly higher percentage of younger than older consumers (18-35 years 76%, $p<0.001$). Where relevant during subsequent analysis (temporality assessment, number of responses), demographic groups were analysed for significant differences via linear regression.

3.3 Results & Discussion

3.3.1 Missing Data

3.3.1.1 Structured TL

Given the design of the structured TL method (i.e., four attributes to be scored by consumers at four pre-determined time points), a total of 16 responses were expected per consumer. Due to restrictions in the software used for temporal data collection, the sensory test layout allowed consumers to move on from the structured TL without scoring all attributes at each predefined time point. Unfortunately, many consumers did indeed move on without scoring all attributes and time points, resulting in significant missing data (11.6% overall), mainly concentrated in the structured TL responses in study 1 (*Table 3.3*). A response was considered missing for the structured

TL if there were no responses for an attribute within a time point. For the free TL, if there were no responses for an attribute, it was considered missing data. This high rate of missing data was discovered after study 1 was completed, and it was found that 34% of data was missing from the structured TL data, consisting of 281 missing responses from 33 consumers (out of 51). Although a clear set of instructions was provided to consumers in the first study, and all consumers completed a familiarisation task (Jaeger et al., 2017), in the remaining two studies, the importance of the need to complete all attributes before moving on to the next page was emphasised explicitly to all participants at the beginning of the trial. This resulted in no missing data in study 2 and only 3 (total) missing responses from 2 consumers in study 3 and demonstrates the importance of clear and effective verbal instructions from researchers to consumers during a sensory trial.

Table 3.3 – Overview of Missing Data from the Structured TL Method

Study	Consumers No.	Actual Responses	Expected Responses	% Missing Data
1	51	535	816	34.4%
2	52	832	832	0.00%
3	50	797	800	0.38%

A quality analysis conducted on the structured TL data from study 1 determined the nature of the missing data. It was discovered during this quality analysis of study 1 that the missing data increased per time point, with only 2.45% of data missing from time period 1, but 38.24%, 43.14%, 53.92% missing data from time points 2-4, respectively (*Table 3.4*). Rates of missing data per attribute were at approximately 17% for all attributes except juiciness (25%) (*Table 3.5*) which may have something to do with the fact it was the last attribute in the list of attributes presented to consumers. The missing data could potentially be due to consumers misunderstanding the task or confusion when conducting it. Alternatively, it may be due to fatigue, as missing data increased with each time point and attribute order down the page; for example, (i.e.) overall liking was presented first and had the least missing data, while juiciness was presented last and had the most missing data (*Figure 3.1*).

Table 3.4 –Missing Data by Predetermined Time point from Study 1 (Structured TL Method)

Time point	Actual Responses	Expected Responses	Missing Data %
T1	199	204	2.45%
T2	126	204	38.24%
T3	116	204	43.14%
T4	94	204	53.92%
Overall	535	816	34.44%

Table 3.5 –Missing Data by Attribute from Study 1 (Structured TL Method)

Attribute	Actual Responses	Expected Responses	Missing Data %
Liking	143	204	29.90%
Flavour	135	204	33.82%
Tenderness	133	204	34.80%
Juiciness	124	204	39.22%

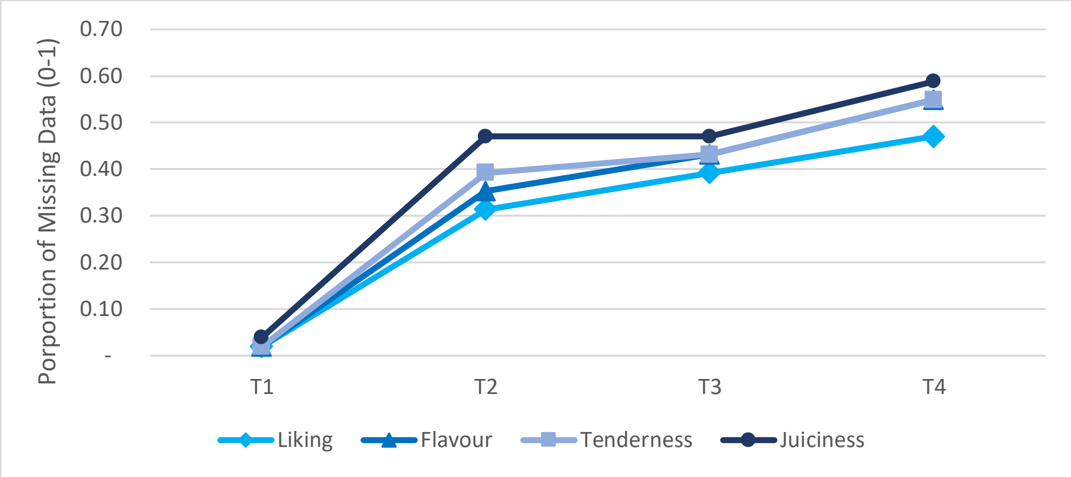

Figure 3.1 – Evolution of Missing Data over Time point (T) by Attribute (Structured TL)

Per the original research question, "to examine consumer liking of beef steaks using temporal methods," the analysis of data collected in the sensory evaluation of beef requires multiple consumers to score meat from the same animal to reduce the chance of animal variability influencing the score. Therefore, consumer data quality for each animal tasted was also investigated for study 1; as for the original research question, at least two responses per animal were required for analysis. Overall missing data per animal (data from 2-3 consumers; 94% three consumers, 6% two consumers) was found to vary, with rates of missing data between 0% (animals 8 and 11) to 73% (animal 14).

3.3.1.1.1 Removal of Consumers from the Structured TL Method

It was decided to remove consumers with the most missing data (consumers with the highest percentage) from study 1. No data were removed from study 2 or 3, as the overall percentage of missing data was low. However, to ensure at least two consumer responses remained for each individual animal in the original research question's analysis, the data was removed in a structured format to reduce missing data as much as possible. A total of 15 consumers showed the highest percentage of missing data within the data for each animal, and their responses were removed from the analysis as appropriate (*Table 3.6*). Consumers removed had missing data percentages of 56.25% to 81.25%.

Table 3.6 – Consumers Data Removed from Study 1 (Structured TL method)

Animal	Consumer	Expected (total)	Received (total)	By Stage				Missing Data
				T1	T2	T3	T4	%
1	2	16	3	3	0	0	0	81.25%
2	12	16	7	4	2	1	0	56.25%
3	13	16	4	4	0	0	0	75.00%
5	6	16	7	4	2	1	0	56.25%
4	9	16	4	4	0	0	0	75.00%
6	18	16	4	4	0	0	0	75.00%
7	19	16	4	4	0	0	0	75.00%
9	25	16	4	4	0	0	0	75.00%
10	30	16	4	4	0	0	0	75.00%
12	36	16	4	4	0	0	0	75.00%
13	37	16	4	4	0	0	0	75.00%
14	40	16	4	1	1	1	1	75.00%
15	44	16	4	4	0	0	0	75.00%
16	46	16	4	4	0	0	0	75.00%
17	50	16	7	4	1	1	1	56.25%

3.3.1.1.2 Data Quality after Removal of Consumers

After the removal of consumers, the data were re-analysed for quality to determine the effect removing consumers had on the dataset quality and to ensure the original research question of this study could be answered. The structured removal of the data, as described above, left some missing data in the dataset after the removal of consumers (18.92%; *Tables 3.7-3.8*); however, the rate of missing data was much reduced from the original 34.44% (*Figure 3.2*). The subset of consumers, named study 1a (36 consumers), was then used for the analysis of data from the structured TL method both for its original research question and for the remainder of this chapter.

Table 3.7 – Missing Data Analysis by Time Period for Study 1a

Stage	**Actual**	**Expected**	**Missing Data %**
T1	143	144	0.69%
T2	120	144	16.67%
T3	112	144	22.22%
T4	92	144	36.11%
Overall	467	576	18.92%

Table 3.8 – Missing Data Analysis by Attribute for Study 1a

Attribute	**Received**	**Expected**	**Missing Data %**
Liking	120	144	16.67%
Flavour	120	144	16.67%
Tenderness	119	144	17.36%
Juiciness	108	144	25.00%

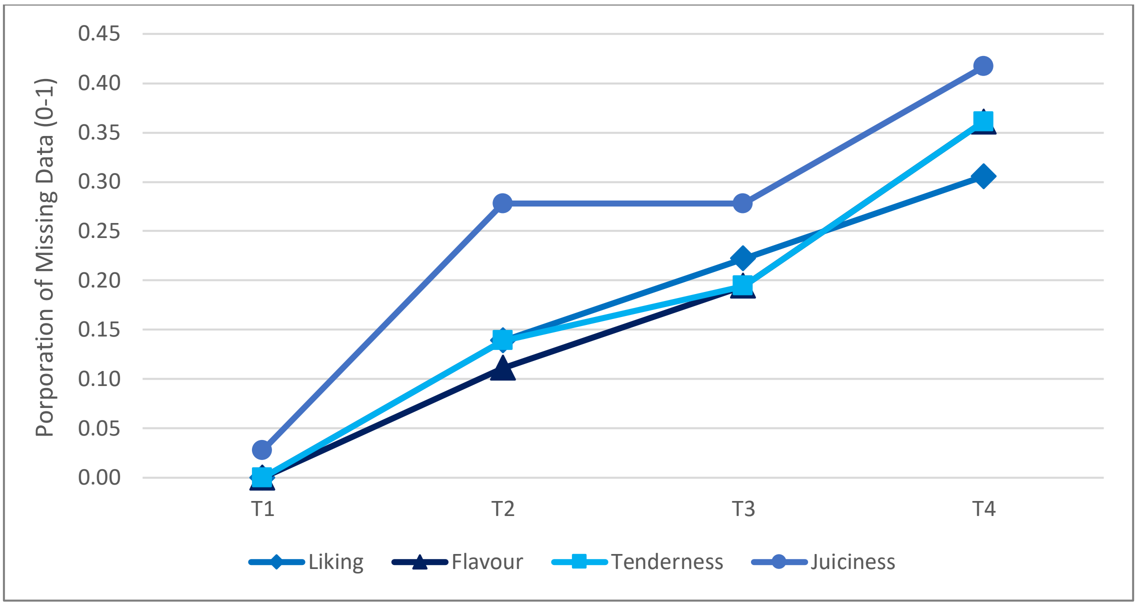

Figure 3.2 – Evolution of Missing Data over Time point (T) by Attribute for Study 1a (Structured TL)

3.3.1.2 Free TL

Data quality from the free TL method was also examined, albeit much differently from the structured TL method above, as consumers had more freedom in their response to this method. Therefore, it was decided to define quality data as "eliciting a minimum of one response per attribute" for each consumer. Analysis of the free TL data found that all consumers except 2 (consumers 2 and 3, 75% and 50% of data missing, respectively) met this requirement. The decision was made not to remove these consumers from the dataset, as they had provided some responses, and both had scored meat from the same animal.

3.3.1.3 Familiarisation

Data quality from the familiarisation method was also examined to determine if the familiarisation step, which more closely resembled the free TL than the structured TL, had similar levels of missing data to the free TL or if this step aided in reducing missing data. As the familiarisation was similar to the free TL method, the same analysis was used as the free TL. Results showed that 12 consumers over the three studies had missing data under the parameters of "at least one response per attribute" (*Table 3.9*). Surprisingly, only 1 of the two consumers (consumer 2) who had missing data in the free TL also had missing data in the familiarisation stage as we would have expected that if consumers had provided all data for the familiarisation, they would have provided all data for the free TL. In addition, there were three consumers from study 1, 4 consumers in study 2, and 4 consumers in study 3 who "learned" from the familiarisation method, resulting in no missing data in the free TL stage.

Table 3.9 - Consumers Missing Data Breakdown for the Familiarisation

Study	Consumer	Liking	Flavour	Tenderness	Juiciness	Missing Data (%)
1	1	1	0	0	0	75%
1	2	0	0	1	1	50%
1	25	1	0	0	0	75%
1	45	4	0	0	0	75%
2	70	2	2	2	0	25%
2	82	1	0	0	0	75%
2	84	2	0	1	1	25%
2	97	4	0	0	0	75%
3	105	3	0	0	0	75%
3	137	5	0	0	0	75%
3	142	0	3	3	3	25%
3	151	1	2	0	0	50%

3.3.1.4 Correlation of Missing Data between Structured TL and Free TL

Using a paired comparison test, a significant difference was found in terms of missing data between the structured TL and free TL for study 1 ($p \leq 0.0001$), with more missing data found in the structured TL task. However, no significant difference was found for studies 2 ($p=1.000$) or 3 ($p=0.182$). A Pearson's R correlation was carried out for study 1 to determine if missing data in the free TL was an indicator of missing data in the structured TL task. However, no correlation was found (*Figure 3.3*). Studies 2 and 3 were not correlated as there was no missing data from consumers for the free TL. All correlation, intercept, and p-values from Pearson's R can be found in *Appendix C.*

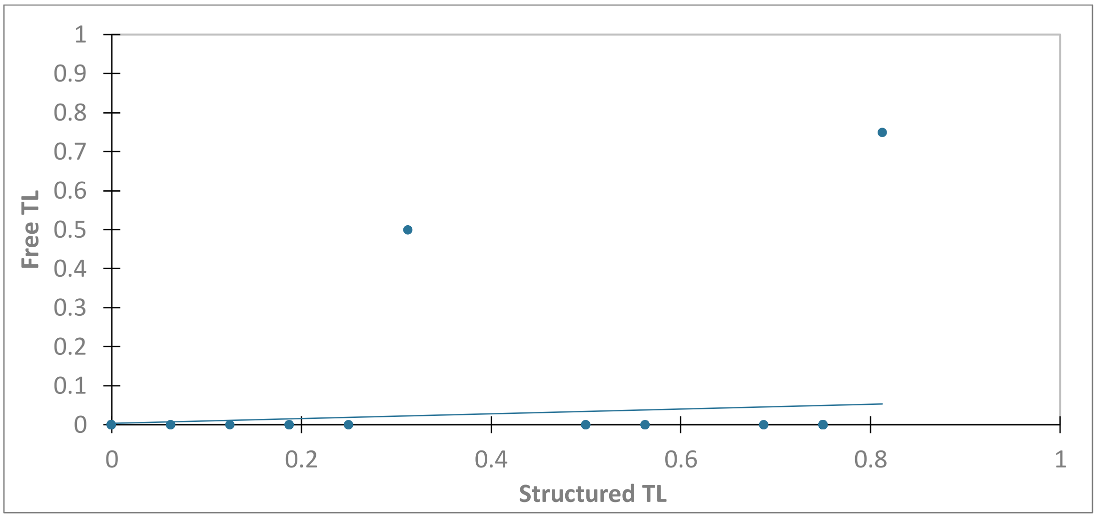

Figure 3.3 – Correlation of Missing Data from Structured TL and Free TL Method (Study 1)

3.3.1.5 Correlation of Missing Data between Free TL and Familiarisation

A paired t-test between the familiarisation and free TL data for study 1 found no significant difference between the data ($p=0.293$). The difference was trending (just above significance) between the familiarisation and free TL data for study 2 (p=0.073) and study 3 (p=0.060). No correlation (R=0.06) was found between missing data between familiarisation and free TL for study 1. Studies 2 and 3 were not analysed as there was no missing data in the structured TL. The correlation, intercept, and p-values from Pearson's R can be found in *Appendix C.*

3.3.2 Assessment of Temporality

The missing data analysis found less missing data in the free TL task compared to the familiarisation task. However, this was under the parameter of at least one response. Yet, consumers only providing one response per attribute is not technically temporal data; rather, it is static data. As these studies were intended to collect temporal data, the free TL and familiarisation data were therefore assessed for temporality (i.e.) did the consumers provide dynamic (temporal) or static data for four attributes (overall liking, flavour, tenderness, juiciness), and two parameters (did consumers provide temporal data for at least one attribute and did consumers provide temporal data to all attributes) were assessed.

3.3.2.1 Free TL

The numbers of consumers who did not meet the criteria for temporality for the free TL (i.e., those who provided static data) varied depending on the attribute and study. Study 1 had the lowest levels of temporality, with all attributes over 50% static data (54.9-72.5%; Figure 3.5), meaning that the majority of consumers only provided one response for the attribute and did not provide dynamic data. There are two possibilities for this high rate of static data, either there was a lack of understanding by consumers of temporality in study 1, or consumers genuinely felt their liking of the meat did not change over time. However, as this trend was not observed in the other studies, then we can argue that the issue was most likely due to a lack of understanding by consumers of the actual task. Previous research has shown that short a familiarisation session (approx. 7 to 10 minutes) can result in a small improvement in a consumer's ability to perform a sensory trial (Jaeger et al., 2017). We included a short familiarisation task in this trial, but perhaps a longer familiarisation session is required for a complex sensory technique such as temporal liking.

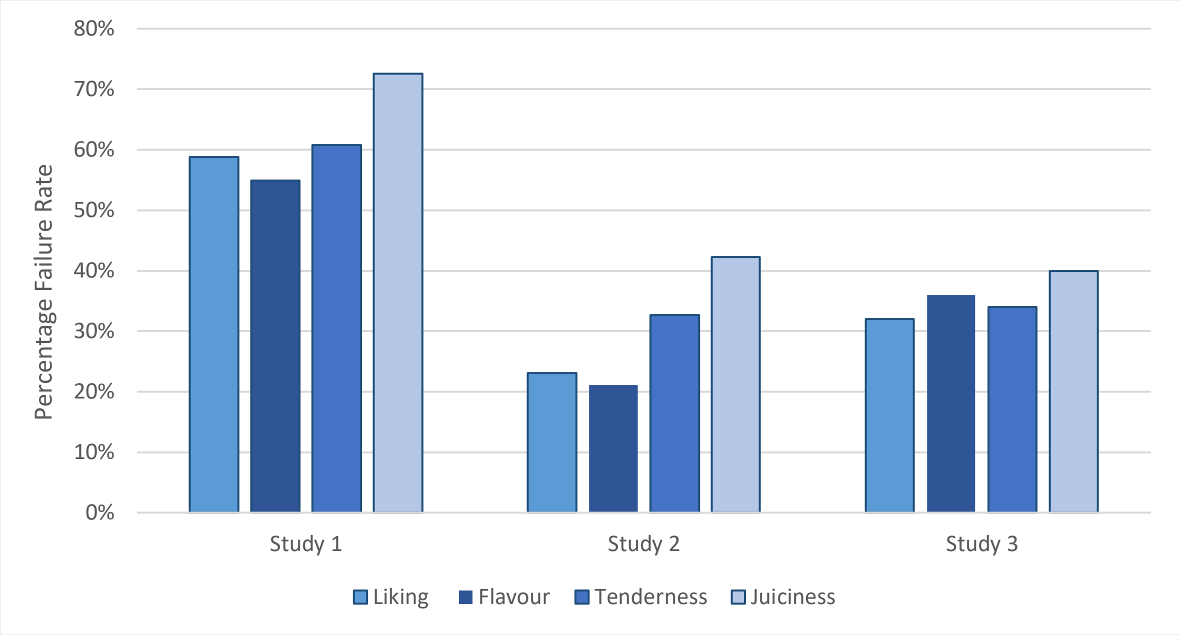

Figure 3.4 – Percentage of consumers who did not meet temporality for the free TL task

For study 1, a significant difference was found between those who provided static and those who provided dynamic data for tenderness and juiciness, those who gave at least one attribute temporal data ("at least one attribute") and those who gave all attributes temporal data ("all attributes") (*Table 3.10*) using a z-test for proportions. The number of consumers who provided static and those who provided dynamic data was not found to be significantly different for liking and flavour for study 1. Age and nationality were found to have no effect on the rate of static data received for studies 1 or 2; however, nationality was found to influence study 3 for all attributes and parameters assessed. A significant difference was found for all parameters, with more Irish consumers providing dynamic data than static.

Table 3.10 – P-values of z-test for proportion and linear regressions for Free TL

Task	Liking	Flavour	Tenderness	Juiciness	At least one attribute	All attributes
Study 1	0.108	0.426	**0.043**	**<0.0001**	**<0.0001**	**<0.0001**
Study 1*Age	0.196	0.639	0.709	0.645	0.326	0.577
Study 1* Nationality	0.822	0.150	0.735	0.753	0.216	0.454
Study 2	**<0.0001**	**<0.0001**	**0.000**	0.165	**<0.0001**	0.555
Study 2*Age	0.864	0.239	0.434	0.785	0.547	0.246
Study 2* Nationality	0.174	0.319	0.397	0.664	0.574	0.253
Study 3	**0.000**	**0.007**	**0.002**	0.066	**<0.0001**	0.841
Study 3*Age	0.131	0.228	0.144	0.287	0.518	0.108
Study 3* Nationality	**0.010**	**0.006**	**0.027**	**0.014**	**0.018**	**0.014**

3.3.2.2 Familiarisation

It is clear that the familiarisation stage was successful in teaching consumers about the concept of temporality and the methodology in study 2 and study 3, as there was a significant decrease ($p \leq 0.05$) in static data provided between the familiarisation and free TL. However, while there was some decrease in static data in study 1 in the free TL, the percentage of static data actually increased for juiciness (Figure 3.5).

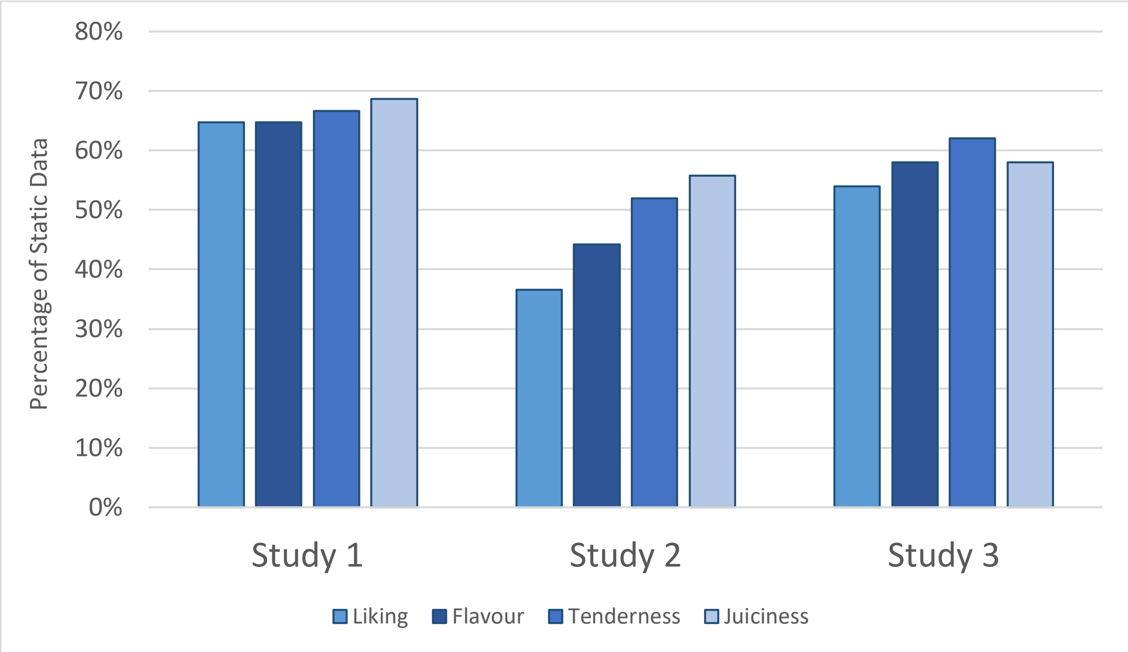

Figure 3.5 – Percentage of consumers who did not meet temporality for the familiarisation task

For study 1, a significant difference was found between those who provided static and those who provided dynamic data using a chi-square analysis for all attributes ($p<0.0001$). Consumer age was found to have no significant impact on temporality assessment for any attribute (*Table 3.11*) for study 1.

Similarly, for study 2, a significant difference was found between those who provided static data and those who provided dynamic data using a chi-square analysis for all attributes ($p<0.0001$). Using linear regression, age was found to play a significant role on all attributes except overall liking and the parameter of consumers who provided temporal data for all attributes ("all temporal data"); flavour ($p=0.026$), tenderness ($p=0.008$), juiciness ($p=0.008$) and all temporal data ($p=0.006$) for study 2. Older consumers were significantly more likely ($p=0.008$) to have not provided temporal data for tenderness. Age was found to play no significant role on temporality assessment for overall liking in study 2 (p=0.140) or for any attribute in study 3 (p>0.05) (*Table 3.11*).

Table 3.11 – P-values of z-test for proportion and linear regressions for Familiarisation

Task	Liking	Flavour	Tenderness	Juiciness	At least one attribute	All attributes
Study 1	**0.004**	**0.004**	**0.001**	**0.000**	**0.004**	**<0.0001**
Study 1*Age	0.255	0.255	0.560	0.072	0.325	0.461
Study 1* Nationality	0.836	0.565	0.850	0.108	0.433	0.514
Study 2	**0.008**	0.324	0.844	0.324	**<0.0001**	**<0.0001**
Study 2*Age	0.140	**0.026**	**0.008**	**0.008**	0.170	**0.006**
Study 2* Nationality	**0.036**	0.723	0.216	0.991	0.365	0.378
Study 3	0.547	0.156	**0.023**	0.156	**<0.0001**	**<0.0001**
Study 3*Age	0.826	0.887	0.895	0.508	0.818	0.639
Study 3* Nationality	0.456	0.292	0.344	0.306	0.466	0.051

For study 2, significant differences were found between Irish consumers who provided static data and those who provided dynamic data for overall liking. In addition, significant differences were also found between non-Irish consumers who provided static and dynamic data for tenderness and juiciness for study 2. In terms of nationality, no significant differences were found for any attributes or parameters in all studies, except for liking in study 2. This difference was found among Irish consumers, between those who provided static data and those who provided dynamic data, with more providing dynamic data.

3.3.2.3 Comparison of Free and Familiarisation TL

Differences between the rates of those who provided static and temporal data in the temporality assessment between the familiarisation and free TL were also investigated (*Table 3.12*). A significant difference was found for flavour between the free TL and familiarisation task for study 2 (p=0.018) and study 3 (p=0.040). In study 3, a significant difference was found between the proportion of static data for liking, flavour, tenderness, and the number of all temporal responses (*Table 3.12*). No significant differences were found between the free and familiarisation frequencies for any attribute or number of temporal responses in study 1 or any other attributes in studies 2 or 3. This shows that familiarisation increased the amount of temporal data received from consumers for study 2 and study 3. However, it is clear that even though some temporal data was collected in study 1, the level of temporal data collected was lower than expected. The potential reasons for this have been discussed above.

Table 3.12 –Rates of Static Data for Free TL and Familiarisation (Temporality Assessment)

Study 1	**Free**	**Familiarisation**	**P-value**
Liking	58.82%	64.71%	0.683
Flavour	54.90%	64.71%	0.417
Tenderness	60.78%	66.67%	0.680
Juiciness	72.55%	68.63%	0.828
At least one temporal response	27.45%	35.29%	0.521
All temporal responses	88.24%	94.12%	0.483
Study 2	**Free**	**Familiarisation**	**P-value**
Liking	23.08%	36.54%	0.193
Flavour	21.15%	44.23%	**0.018**
Tenderness	32.69%	51.92%	0.069
Juiciness	42.31%	55.77%	0.235
At least one temporal response	11.54%	13.46%	1.000
All temporal responses	53.85%	90.38%	**<0.0001**
Study 3	**Free**	**Familiarisation**	**P-value**
Liking	32.00%	54.00%	**0.038**
Flavour	36.00%	58.00%	**0.040**
Tenderness	34.00%	62.00%	**0.007**
Juiciness	40.00%	58.00%	0.104

At least one temporal response	20.00%	24.00%	0.809
All temporal responses	52.00%	92.00%	**<0.0001**

Although not significant, juiciness was found to have the lowest level of dynamic data across all studies for both free TL and familiarisation, except in the familiarisation session in study 3. As juiciness was the last attribute presented on the screen, this potentially could be due to fatigue, combined with some consumers not understanding the concept of temporality, as even in study 2 for the free TL, where all attributes were under 50% of consumers providing static data (21.1-42.3%), the juiciness static data rate was higher than all other attributes. There is some evidence in the literature that some consumers find it difficult to understand the concept of temporality, as Sudre *et al.* (2012) removed three consumers from the analysis for not providing dynamic data, while Silva *et al.* (2018) removed 11 participants for not complying with the protocol. However, more studies did not disclose if consumers were removed or not (Ramsey *et al.*, 2018; Thomas *et al.*, 2015; 2016; 2017) or if static data was potentially treated as a flat curve. There is the potential that liking may not change during consumption even if attributes change, and removing such consumers could be removing valid responses from the dataset.

For the studies that did disclose how the data was treated, the numbers of consumers who provided static data are lower than those in this study, which may be due to the fact that multiple attributes were presented in our study, or the fact consumers were given more freedom to answer as they wish than is shown in published literature. Silva *et al.* (2018) structured their temporal liking intothree3 sips, and Rocha-Para *et al.*

(2016) structured their temporal liking into three sips of 20 seconds. Thomas *et al.* (2015) had the scoring box fade and change from black to white after three seconds to encourage subsequent scores. These results could indicate that while most consumers are able to use temporal methods, as shown in literature, they require a structured questionnaire. In short, too much freedom or not enough prompting to change the liking score may lead to more static or non-temporal data.

This is the first study to evaluate more than overall liking using temporal liking methodology, and we estimated that consumers could report on up to four attributes when asked to consider temporality. It is possible that the engagement and concentration levels necessary for giving completing each task were more than consumers had allotted for or were willing to contribute to this study. This would lead us to believe that it is also plausible that displaying all four attributes on one page was too much for consumers and that it may be better to split the scales up to one to two per page. Another explanation is that consumers do not perceive temporal liking for all the assessed attributes. While there was an improvement in numbers after the familiarisation tasks, less than 50% of consumers in each study gave dynamic responses to all attributes for the free TL, 11.76% in study 1, 46.15% in study 2 and 48% in study 3. Most consumers gave a dynamic response to at least one attribute in study 1, study 2, and study 3 (72.55%, 88.46%% and 80%, respectively), meaning that with the exception of study 1, the actual numbers of consumers that did not give any dynamic data (only one score for all attributes) is lower, six consumers for study 2 (11.5%) and 10 for study 3 (20%), and more in line with rates reported in the literature.

3.3.3 Number of Responses

3.3.3.1 Free TL

For the free TL, consumers in studies 2 and 3 gave the most responses for the attribute flavour, with consumers in study 1 giving the most responses to overall liking. Consumers in all three studies gave the least number of responses to juiciness (*Tables 3.13-3.15*). For all studies, the number of responses consumers gave to each attribute was found to be significantly different from each other (all $p<0.0001$). All attributes were presented on the screen in the same order, which potentially impacted consumer time allocation between attributes; this may explain why juiciness received the least time and the least responses as it was the last attribute to be assessed. In this scenario, it would be expected that overall liking would receive the most time and responses from consumers, as it was the first attribute presented. Interestingly, this did not happen for studies 2 and 3, as flavour, the second attribute, received the most responses. It would be necessary to repeat this experiment with the attributes randomised to determine whether presentation order impacts the level of temporal data generated.

Table 3.13 – Descriptive Statistics for Number of Responses (Study 1) Using the Free TL

Responses	Liking	Flavour	Tenderness	Juiciness	Overall
Total	95	89	81	78	343
% of Data	27.70%	25.95%	23.62%	22.74%	100%
Mean	1.86	1.75	1.59	1.53	6.73
Min	1	0	0	0	1
Max	8	5	8	7	21
Median	1	1	1	1	6
Mode	1	1	1	1	4

Table 3.14 – Descriptive Statistics for Number of Responses (Study 2) using the Free TL

Responses	Liking	Flavour	Tenderness	Juiciness	Overall
Total	155	159	156	155	625
% of Data	24.8%	25.4%	25.0%	24.8%	100%
Mean	2.98	3.06	3.00	2.98	12.02
Min	1	1	1	1	4
Max	15	18	23	23	74
Median	2	2	2	2	8.5
Mode	2	2	2	1	7

Table 3.15 – Descriptive Statistics for Number of Responses (Study 3) using the Free TL

Responses	Liking	Flavour	Tenderness	Juiciness	Overall
Total	169	179	166	157	671
% of Data	25.19%	26.68%	24.74%	23.40%	100%
Mean	3.38	3.58	3.32	3.14	13.42
Min	1	1	1	1	4
Max	14	19	17	12	56
Median	2.5	2.5	2	2	10
Mode	1	1	1	1	4

3.3.3.2 Familiarisation

For the free TL, consumers in studies 2 and 3 gave the most responses for the attribute overall liking, with consumers in study 1 giving equal responses to overall liking and flavour. Consumers in studies 1 and 2 gave the least number of responses to tenderness during familiarisation, while consumers in study 3 gave the least number of responses to juiciness (Tables available in *Appendix C*).

3.3.3.3 Comparing Familiarisation and Free TL in terms of Number of Responses

The amount of missing data in terms of the number of responses was found to decrease between the familiarisation and the free TL tasks. This may indicate that consumers learned more about temporality as a concept and/or how to communicate temporality via the 9-point scale for all attributes. The mean number of responses for each attribute increased for every attribute between the familiarisation and the free TL task, with the median increasing over all attributes and the max number of responses increasing for all attributes except overall liking. Although the max responses did decrease for overall liking, the mean number of responses still increased between the familiarisation and the free TL task, with a higher percentage of consumers giving more than one score after the familiarisation. As a between-subjects design was used to study the effect of animal diet on consumer liking, a different group of consumers was used in each study. Consumers in study 1 appear to have provided fewer responses overall and per attribute on the free TL and familiarisation tasks.

3.3.4 Free TL data cleaning

3.3.4.1 Time to First Score

Although consumers were instructed to press the start button as they were putting the first piece of meat in their mouth, there was a wide variation across consumers in the amount of time it took them to place their first score. This ranged from less than a second (0.73s) up to a max of 58.4 seconds, with an average of 9.7 seconds. Due to this, the decision was made to move the first score that was made on the 9-point scale to time 0 for each consumer individually. This ensured that any differences in liking over time were not caused by a lag in a consumer's response time.

3.3.4.2 Time After Last Score

After consumers had finished scoring, they were instructed to press a stop button. As a high variance was observed in time to first score across consumers, the time between the placement of the last score and the end of the test was investigated to see if consumers were ending the test in a timely manner. It was found that some consumers had left a lot of time after their last score until they pressed stop, so the decision was made to cut off the time 10 seconds after the last score. Precedent exists for making this decision, as Meyners (2016) removed data more than 5 seconds after the last score when cleaning temporal liking data. The adjusted dataset produced for free TL for all three studies (as 1 and 1a are identical for free TL) will be utilised in the rest of this chapter instead of the raw data.

3.3.4.3 Division of Time-periods and Standardisation of Time

Data from the free TL is elicited as continuous inputs, which can be analysed in several different ways. The common analyses are treating the TL data as TI data (Rocha-Para *et al.*, 2016), analysing global liking (Sudre *et al.*, 2012), and dividing the data into several time periods (Ramsey *et al.*, 2018; Thomas *et al.*, 2015; 2016). For this manuscript, it was decided to divide the free TL into several time periods. Only the free TL data liking required this time-period division as the structured TL was analysed according to the four pre-determined time-points, and thus, the data were divided into four time periods, and studies 1, 2, and 3 were analysed. Data cleaning (described previously as moving the first score to time 0 and cutting off the timer 10 seconds after the last score) was performed prior to this analysis, and only the adjusted dataset was used for the division of time periods.

Setting the time periods to 4 to match the structured TL data meant the usual method of deciding the number of time periods using either the mean, mode, or median number of responses was not employed. 4 time periods were higher than both the mean and median number of responses for studies 1 and 2 (*Table 3.16*). Unlike previous literature utilising temporal liking to determine overall liking (Ramsey *et al.*, Sudre *et al.*, 2012; Thomas *et al.*, 2015), multiple attributes were assessed in this study, and it was decided to treat the data as per its "traditional liking" counterpart; as such, each attribute was considered to be independent and was divided into four time-points for each consumer. In the case where consumers did not provide temporal data (i.e., they only provided one score), it was considered that the liking was constant over time and that one score was valid for each time period. Each score was weighted by time duration within its respective time period. Examples of this process are available in *Table 3.17-3.19*.

Each attribute specified was considered an independent curve rather than a multi-bite assessing attributes one after another (by modality). It is unknown whether this decision could impact the results as there is currently no literature comparing data from temporal studies where the data that could have been considered to be either a multi-sip/bite sensory testing (as it was in Rocha-Para *et al.*, 2016 for TL) or testing by modality (as was utilised by Nguyen *et al.*, 2018 for TDS) was analysed both ways. This question will not be investigated in this chapter; however, future analysis will be necessary to assess the potential impact of such a decision.

Table 3.16 – Mean and Median Number of Responses by Attribute for Each Study Elicited using Free TL

	Liking	**Flavour**	**Tenderness**	**Juiciness**	**Overall**
Mean Study 1	1.86	1.75	1.59	1.53	6.73
Median Study 1	1	1	1	1	6
Mean Study 2	2.98	3.06	3.00	2.98	12.02
Median Study 2	2	2	2	2	8.5
Mean Study 3	3.38	3.58	3.32	3.14	13.42
Median Study 3	2.5	2.5	2	2	10

Table 3.17 – Division of Free TL data into Time Periods for Consumer 1 (Short time spent)

Attribute	**Start (s)**	**Stop (s)**	**P1***	**P2***	**P3***	**P4 ***	**Period Length (s)**	**Row Time (s)**	**No of Periods**
Liking	0	5	1	1	1	1	1.25	5.00	4.00
Flavour	5	11.28	1	1	1	1	1.57	6.28	4.00
Tenderness	11.28	16.7	1	1	1	1	1.36	5.42	4.00
Juiciness	16.7	19.28	0.82	0	0	0	3.15	2.58	0.82
Juiciness	19.28	29.28	0.18	1	1	1	3.15	10.00	3.18

**Where P=Time Period for free TL*

Table 3.18 – Division of Free TL data into Time Periods for Consumer 2 (includes Missing Data)

Attribute	**Start (s)**	**Stop (s)**	**P1**	**P2**	**P3**	**P4**	**Period Length (s)**	**Row Time**	**No of Periods**
Liking	0	9.77	1	0.30	0	0	7.49	9.77	1.30
Liking	9.77	18.75	0	0.70	0.50	0	7.49	8.98	1.20
Liking	18.75	29.96	0	0	0.50	1	7.49	11.21	1.50
Flavour	29.96	40.84	1	1	0.08	0	5.22	10.88	2.08
Flavour	40.84	50.84	0	0	0.92	1	5.22	10.00	1.92
Tenderness	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Juiciness	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 3.19 – Division of Free TL data into Time Periods for Consumer 103 (Longer time spent)

Attribute	Start (s)	Stop (s)	P1	P2	P3	P4	Period Length(s)	Row Time	No of Periods
Liking	0	5.67	1	1	0.76	0	2.06	5.67	2.76
Liking	5.67	8.22	0	0	0.24	1.00	2.06	2.55	1.24
Tenderness	8.22	9.7	1	1	1	1	0.37	1.48	4.00
Juiciness	9.7	24.48	1	1	1	1	3.70	14.78	4.00
Flavour	24.48	33.89	0.38	0	0	0	24.75	9.41	0.38
Flavour	33.89	42.39	0.34	0	0	0	24.75	8.50	0.34
Flavour	42.39	113.47	0.28	1	1	0.60	24.75	71.08	2.87
Flavour	113.47	123.47	0	0	0	0.40	24.75	10.00	0.40

3.3.5 Time Spent on Attributes

3.3.5.1 Free TL

For the free TL, consumers in studies 1, 2 and 3 spent the most time on the attribute of overall liking, flavour, and tenderness, respectively. As mentioned above, consumers spent the least amount of time on juiciness across all studies (*Tables 3.20-3.22*), which may be because the attribute juiciness was the last attribute presented to consumers. Studies in Ireland have determined that Irish consumers hold flavour and tenderness in equal regard for steak liking (Chong *et al.*, 2019), which may be why similar time was spent on both of these attributes in studies 1 and 3.

Table 3.20 – Descriptive Statistics for Time Spent (seconds) using the Free TL (Study 1)

	Liking	**Flavour**	**Tenderness**	**Juiciness**	**Overall**
Mean	19.72	17.48	17.74	13.1	68.04
Min	2.11	0.00	0.00	0.00	14.19
Max	67.50	85.97	52.02	61.69	145.57
Mode	10.00	N/A	N/A	10.00	N/A
Median	17.04	13.75	17.79	10.00	59.87

Table 3.21 – Descriptive Statistics for Time Spent (seconds) using the Free TL (Study 2)

	Liking	**Flavour**	**Tenderness**	**Juiciness**	**Overall**
Mean	27.40	30.20	23.10	18.49	99.18
Min	4.17	0.84	1.48	0.47	26.38
Max	73.22	89.13	46.85	134.42	245.24
Mode	N/A	N/A	N/A	10	N/A
Median	22.67	25.575	21.49	11.175	87.75

Table 3.22 – Descriptive Statistics for Time Spent (seconds) using the Free TL (Study 3)

	Liking	**Flavour**	**Tenderness**	**Juiciness**	**Overall**
Mean	25.98	26.14	26.86	18.14	97.13
Min	1.26	2.4	2.09	3.04	14.03
Max	88.99	75.58	82.53	50.12	293.1
Mode	N/A	N/A	N/A	10	55.26
Median	25.13	22.4	23.545	14.96	89.635

3.3.5.2 Correlating Time Spent and Number of Responses

It was found that consumer responses increased with time spent on attributes for studies 1 and 3 (Figures available in *Appendix C*). For study 1, correlation (R^2) was found to be 0.164 (*Table 3.23*); however, when consumers over 90 seconds of time spent were removed, this correlation increased to 0.235. No correlation was found for study 2. For study 3, time spent by consumers on the free TL was found to be slightly correlated (R2= 0.376) with the number of responses received from consumers (Table 3.23).

Table 3.23- Results of a Pearson's R Correlation Between Time Spent and Number of Responses for the Free TL

Study	Range Number of Responses	Range Time Spent (s)	x	Intercept	R^2
Study 1	1-21	14.19-140.34	0.404	3.883	0.164
Study 2	4-74	26.38-245.24	0.034	8.613	0.012
Study 3	4-56	14.030-293.10	0.148	-0.922	0.376

3.3.6 Consumer Self-Reported Difficulty

Significant differences in difficulty were found between the free and structured TL in consumers' self-reported difficulty for both studies 1, 2 and 3 (*Table 3.24*) using a t-test. Using Fisher's F-test, no significant differences were found in consumers' self-reported difficulty in free TL (p=0.300) or structured TL (p=0.560) between studies 1 and 1a. This may be mainly due to minimal change in the means with the removal of the consumers that had the most missing data and retention of the same minimum and maximum values within the dataset. Significant differences in difficulty were found between the free and structured TL within each study for all studies using a t-test.

Table 3.24 – Descriptive Analysis of Consumers' Self-Reported Difficult (All Studies)

Study	Sensory Task	Consumers (n)	Min	Max	Mean	Std. deviation
1	Free	51	1.000	5.000	1.902[a]	1.171
1	Structured	51	1.000	6.000	2.373[b]	1.442
1a	Free	36	1.000	5.000	1.639[c]	0.990
1a	Structured	36	1.000	6.000	2.417[d]	1.574
2	Free	52	1.000	6.000	2.019[e]	1.321
2	Structured	52	1.000	7.000	2.962[f]	1.508
3	Free	50	1.000	6.000	2.340[g]	1.379
3	Structured	50	1.000	7.000	3.220[h]	1.670

a/b/c/d/e/f/g/h – Means within each study with the different letter differ significantly ($p \leq 0.05$).

3.3.7 Self-reported Difficulty Correlated with Missing Data

3.3.7.1 Structured TL

For study 1, consumers' self-reported difficulty in performing the structured temporal liking task was correlated with missing data. The original data set (before the exclusion of consumers) was used to test this correlation. Consumer missing data percentages were segmented into three categories according to the structured TL: none (0%), low-medium (1%-40%) and medium to high (41% to 100%) (*Table 3.25*). Due to the lack of impactful missing data in studies 2 and 3, this analysis was not performed for these studies. Unexpectedly, there was a trend for consumers' self-reported difficulty to decrease with increased missing data, according to the mean and the max values. It is suggested that this may be due to variability in consumer understanding of the concept of temporality or indicate a need for a longer familiarisation session.

Table 3.25 – Frequency Table of Missing Data Categories for the Structured TL (Study 1)

Category	Criteria (%)	Frequency	Percentage
None	0%	18	35%
Low-Medium	1-40%	10	20%
Medium-High	41-100%[1]	23	45%

1 – Highest missing data in the dataset was 81%

3.3.7.2 Free TL

3.3.7.2.1 By Structured TL Missing Data Segmentation

Due to the unexpected results when looking at the mean self-reported scores from the structured temporal liking, the consumers' self-reported difficulty from study 1 for free TL was investigated using the same missing data categories from the structured TL, as the categories were already formed in section 3.5.1. This was done to assess self-reported difficulty using the same consumer categorisation. As studies 1a, 2, and 3 did not include impactful levels of missing data; this analysis was only performed for study 1. Like the structured TL scores, the range of difficulty scores decreased with increased missing data categorisation (*Table 3.26)*.

Table 3.26 – Consumers' Self-Reported Difficult (Study 1) of the Free TL Method

Category	Mean	Min	Max	Median	Mode
Overall	1.90	1	6	1	1
None	1.83	1	6	1	2
Low-Medium	1.50	1	5	1	3
Medium-High	2.13	1	4	1	2

1 – where overall is the average of the data segments (none, low-medium and medium-high).

3.3.7.2.2 By Number of Responses

Consumer self-reported difficulty for the free TL was also analysed using categories according to the number of overall responses given by consumers. These categories were divided on the basis of a descriptive analysis of the number of responses in each study (*Tables 3.13-3.15)*. For studies 2 and 3, self-reported difficulty increased with the number of responses; however, the same trend was not observed for study 1 (Tables available in *Appendix C*). It bears noting that the mean and range of difficulty scores from study 1 were less than studies 2 and 3, so fewer consumers were categorised in the medium and high number of responses categories, which may have impacted levels of self-reported difficulty.

3.4 Conclusion

This is the first study to examine how consumers approach a temporal sensory liking task. The results highlight the importance of the familiarization task when conducting a TL study with consumers. There is much to be learned about the consumer approach to temporal liking from the “other” data (data beyond that sensory scores) that is often overlooked. While variation in individual consumer responses is expected in consumer sensory studies, leveraging measures such as those outlined in this chapter may allow for a greater understanding of the ways consumers approach sensory methods and provide a greater understanding of their sensory scores. Understanding more about these experiences could enable better questionnaire design to facilitate more reliable data collection. The reported studies and analyses have also raised many additional questions about how temporal liking studies should be designed to account for consumer fatigue. For example, perhaps performing the familiarization task and data collection within the same session may have contributed to consumer fatigue in terms of the ability to discriminate samples using the TL approach. In particular, further research is needed to identify the optimum number of attributes that consumers can score using the TL method and whether the presentation order of attributes has an effect on the responses elicited. In addition, an assessment of temporality found that consumers who showed the ability to provide temporal data did not provide it for all attributes studies. Additional research would be needed to see if this is replicated in other studies. Finally, it would be necessary to investigate the effect of data cleaning and choice of data organisation (analysing data like TI, by modality or as separate attributes) on the analysis of temporal liking data.

Chapter 4

Effect of Liking Method on Data Elicited Across 4 Attributes

Abstract

Temporal Liking (TL) is a temporal method that is gaining interest for its application with consumers. Two TL methods (free and structured) and a traditional liking method were employed to generate data from consumers on their liking of beef steaks derived from a grain supplementation diet for four attributes (overall liking, flavour, tenderness, juiciness). Consumers spent the most time and gave the most responses to the attribute flavour. High levels of variability were found within each liking method. High correlations were also found between attributes within each liking method. For the structured TL, overall liking was found to be significant over time. In addition, the free TL and traditional liking were significantly different from each other ($p \leq 0.05$) for liking and flavour. The structured TL and traditional liking were found to be significantly different from each other for flavour. However, the two temporal liking methods did not differ from each other. Two clusters of consumers were found for each attribute, one who slightly liked the attribute and one who slightly disliked the attribute. Some consumers changed clusters between attributes. This study has shown that the choice of TL method may make a difference on the data elicited.

4.1. Introduction

Temporal Liking (TL) is a method that aims to track how liking changes throughout perception (Sudre *et al.*, 2012; Thomas *et al.*, 2015). TL is gaining popularity as it utilises the scales used in traditional affective testing, such as the 9-point hedonic scale, and tracks changes in consumers' perception over time, making it a potential evaluation tool for generating new consumer sensory information. TL methods have been applied to a wide range of food products, including wheat flakes (Sudre *et al.*, 2012), beer (Ramsey *et al.*, 2018; Silva et al., 2018), wine (Silva et al., 2019), cheese (Thomas *et al.*, 2015; 2017) and chewing gum (Galmarini *et al.*, 2015). To the best of the author's knowledge, temporal liking has not been applied to meat or meat products. Multi-sip and multi-bite TL, which involves tracking perception over multiple sips or bites of food, has also been utilised (Rocha-Parra et al., 2016; Weerawarna, 2021), and some have run another temporal method (e.g. TDS, TCATA or TDE) simultaneously with a multi-sip/bite TL (Silva et al., 2018, 2019; Thomas et al., 2016, 2017), in an attempt to capture more information about the consumer eating experience.

Two main types of "time-tracking" have emerged in the literature for temporal liking: continuous or free choice time assessments (Ramsey *et al.,* 2018; Sudre *et al.,* 2012; Taylor & Pangborn, 1990; Thomas *et al*., 2015) and structured or pre-determined time assessment (Delarue & Loescher, 2004; Galmarini *et al*., 2015; Sudre *et al.*, 2012; Verneau *et al.*, 2016). However, only Sudre *et al.* (2012) has compared the two time-tracking methods to date.

To date, TL methods have just been applied to understand the perceived overall liking or pleasantness of food products. During traditional hedonic testing of beef, consumers are typically instructed to assess key quality attributes, such as tenderness, flavour, or juiciness, for liking or preference. Temporal methods such as TDS and TCATA have shown that perception of sensory attributes does change over time and that consumers can identify these changes. Therefore, it makes sense that consumers may also perceive changes in liking for specific attributes over time. An opportunity exists for gaining more information about the temporal experience of eating by applying the temporal liking method to a range of attributes during testing.

Based on the data generated across chapters 2 and 3, the second consumer study of this thesis (Silage and Grain Production System) was selected for further analysis as there was no missing data. Therefore, we felt it would be interesting to compare the data within this specific trial instead of comparing data across the three trials, which the approach was taken in previous chapters. Taking the data from this trial, this chapter investigates free and structured TL liking as well as traditional liking methods with consumers with four objectives; to (i) compare three different liking methods (free TL; structured TL; traditional liking) for generating consumer information on four attributes (overall liking; flavour; tenderness; juiciness); (ii) investigate consumer approach during each temporal method in terms of the number of clicks (responses) and time spent on attributes; (iii) to study correlations and variation within each liking method; and (iv) to compare clustered consumer responses from the two different TL methods.

4.2. Materials & Methods

4.2.1. Participants

Consumers with a willingness to assess striploin steaks (52) were recruited from staff and students at Teagasc Food Research Centre, Dublin, Ireland (18-66 years old, 73% female, 60% Irish). Consumers were told they would be consuming beef steaks but were not given any other information about the project. Written informed consent, compliant with ethics and GDPR (General Data Protection Regulation) regulations, was obtained, and each consumer received a €5 meal voucher for participating. A questionnaire about beef eating frequency and regular beef cut (high quality or low and restructured beef) was also filled out, which found that 79% of consumers in each study consumed beef at least one time per week, and 74% regularly ate high-quality beef cuts (e.g.) sirloin, striploin, fillet.

4.2.2. Samples

Steaks from silage and grain-finished steers were used sourced from cattle raised in Teagasc, Grange specifically for this study. Cattle raising and slaughter were as detailed for the SG trial in Chapter 2, Section 2.2.1.2.

Briefly, Charolais and Limousine steers (18) were raised at Teagasc Grange, Ireland, from approximately eight months in conventional Irish standards (grass in summer, grass silage and minor grain supplementation in winter) before finishing on Silage and Grain (SG) for four months prior to slaughter at 24 months (carcass weight approx. 390kg). After ageing (15 days), carcasses were frozen for approximately eight months before steak preparation, and sensory analysis occurred. All animal procedures performed in this study were subject to Teagasc Ethics Approval and conducted in accordance with the Cruelty to Animals Act 1876 and the European Communities (Amendment of Cruelty to Animals Act 1876) Regulation 2002 and 2005.

4.2.3. Preparation of samples

Samples preparation was as described in *Chapter 3, Section 3.3.3.*

4.2.4. Experimental procedure

The study consisted of three sensory methods presented in a set order: free temporal liking (free TL), structured temporal liking (structured TL) and traditional liking, and consumers were instructed to assess four attributes (overall liking, flavour, tenderness, juiciness) during each method. These methods were carried out as per *Chapter 3, Section 3.3.4.*

4.2.5. Data cleaning to free TL

Rigorous data cleaning was performed due to the complexity of the free temporal liking test and took three forms; inspecting, transformation and standardisation of data. All of this cleaning was conducted to the free TL due to its unstructured nature, as described in *Chapter 3, Section 3.3.6.*

4.2.6. Data Analysis

Statistical analyses were performed using XLSTAT-Sensory (Addinsoft, 2021). Means were considered significant at $\alpha \leq 0.05$.

4.2.6.1. Temporality assessment

For the free TL, consumers were free to give as many or as few scores as they wished, which meant there was a possibility that consumers would not provide true temporal data. Therefore, the data were assessed for temporality (i.e.) did the consumers provide more than one score per attribute. The four attributes elicited from consumers (overall liking, flavour, tenderness, and juiciness) were assessed along with two other parameters: "at least one temporal attribute" – did consumers provide temporal responses to at least one attribute, and "all temporal data" – did consumers provide temporal responses for all four attributes for dynamic data. Each attribute and parameter was also analysed via linear regression to determine if the consumer variables of age and nationality had an impact on collected temporal data.

4.2.6.2. Consumer approach (time spent and number of responses)

Duration of scoring time ("time spent") and the number of responses elicited per attribute and over all attributes (referred to as "overall") were compared for each consumer. Where appropriate, chi-squared analyses, t-tests, or linear regressions were conducted to compare these variables with each other and with age and nationality.

4.2.6.3. Analysis within liking methods

For each liking method, scores generated per attribute were correlated using Pearson's Correlation. An ANOVA was run to determine the significance of consumer variables; however, the consumer variables only entered the analysis if they were significant. The consumer variables that were used in this model were age (18-35 or 36-66 years) and nationality (Irish vs non-Irish). Finally, each liking method was analysed via MANOVA.

4.2.6.4. Comparison of traditional method to temporal methods

Mean scores from each method were compared using ANOVA and LSD as a post-hoc. Correlations and variance between traditional and free TL and traditional and structured TL were run using linear regressions.

4.2.6.5. Comparison of temporal liking methods

Correlations between the two temporal methods were run for each time point (structured TL) and time period (free TL). Variance was then analysed using t-tests. Data for the free TL and structured TL was then clustered using Agglomerative Hierarchical Clustering (AHC) by attribute and method, and an ANOVA was run between the resulting clusters. Finally, a Principal Component Analysis (PCA) was performed for each attribute of the free TL and structured TL.

4.3. Results & Discussion

4.3.1. Data Cleaning

4.3.1.1. Assessment of Temporality

A temporality assessment was carried out for the free TL data. The demographics of age and nationality were also analysed via linear regression and were found to have no effect on the type of data elicited. However, the numbers of consumers who did not meet the criteria for temporality varied over attribute (Table 2), with flavour resulting in the most dynamic (76.92%) and juiciness resulting in the least dynamic (57.69%) data. The attributes were presented in the same order, and as juiciness was the last attribute to be assessed, consumers may have been fatigued when assessing this attribute. However, flavour generated the most dynamic/temporal data, despite it not being the first attribute assessed by consumers. This may be due to the fact that consumers were tasting beef rather than a sensory reason, as studies in Ireland have found that Irish consumers hold flavour and tenderness equally as the most important attributes when tasting beef (Chong et al., 2019).

Table 4.1 –Rates of Static Data in the Temporality Assessment for Free TL

	Free TL
Liking	23.08%
Flavour	21.15%
Tenderness	32.69%
Juiciness	42.31%
At least one temporal response	11.54%
All temporal responses	53.85%

It must be noted, however, that number of consumers who provided no temporal data at all (only static data) was lower (11.54%, six consumers) than any of the individual attributes. This could be due to several possible reasons, such as fatigue or a lack of understanding of how to perform a temporal liking trial. There is some evidence in the literature that some consumers don't understand the concept of temporality (Silva et al., 2018; Sudre et al., 2012). The authors could find no other reporting of participants not providing temporal data in the literature. In this case, while the number of consumers who did not provide temporal data to individual attributes is higher than that described in the literature, the number who provided no temporal data at all would be in line with them.

Based on the results of the temporality assessment, six consumers who provided no temporal data for any attribute were removed from the dataset leaving 46 consumers in total. It was found that 23 out of 46 consumers had provided non-temporal / static data (1 response) to at least one attribute, which may plausibly explain that all consumers may not perceive the temporality of all attributes. The number of non-temporal responses varied by consumer and attribute, with 11 consumers providing static responses for one attribute, nine consumers providing static responses for two attributes, and three consumers giving static responses for three attributes. The breakdown according to attribute for providing static data was six consumers for overall liking, six consumers for flavour, 11 consumers for tenderness, and 15 consumers for juiciness. There did not appear to be any pattern in the attributes receiving static data other than fewer responses were given with each subsequent attribute, suggesting fatigue may have been an issue. In addition, the actual food product being used to study temporal liking may also need to be considered, and perhaps performing a temporal liking task on multiple attributes of beef added to the complexity of the study.

As this is the first study to evaluate more than overall liking using temporal liking methodology, the authors estimated that consumers could report on up to four attributes when asked to consider temporality. It is possible that consumers simply do not perceive temporal liking for all the attributes assessed.

4.3.1.2. Empty time (Free TL)

Empty time refers to the time after the consumers pressed start before they started scoring as well as the time after consumers stopped scoring before they pressed stop. Empty time was dealt with as detailed in *Chapter 3, Section 3.4.4.1 & Sections 3.4.4.2.* In summary, the decision was made to cut the empty time, moving the first score consumers gave to time 0 and cutting off the timer 10 seconds after the last score.

4.3.1.3. Division of Time-periods and Standardisation of Time

Time periods were divided, and time was standardised for the free TL method as detailed in *Chapter 3, Section 3.4.4.3.*

4.3.2. Consumer Approach

The consumer approach to the free TL and structured TL was analysed and compared through selected indicators (Lepage et al., 2014; Silva et al., 2018; Thomas et al., 2017). The indicators used were: the average number of clicks (responses) per attribute and the average time of scoring overall. For the structured TL, the average number of clicks was set at 4 for each attribute. T-tests were used to compare the average scores for each indicator.

4.3.2.1. Number of Clicks

For the free TL, consumers gave the most clicks (response) for the attribute flavour, and they gave the least number of clicks to juiciness (Table 3). Consumer variability in the number of clicks was found to be significant for flavour and tenderness ($p \leq 0.05$). However, no significant differences were found between the number of clicks received between the different attributes ($p \leq 0.05$). It must be noted that the attributes were presented on the screen to consumers in a fixed format, which potentially impacted the results. However, in this scenario, it would be expected that overall liking, being the first attribute presented, would receive the most clicks. However, this did not happen. It would be necessary to repeat this experiment with the attributes randomised to determine variables affecting customers' focus on each attribute.

When the number of responses per time period was investigated for the free TL, it was found that time period 1 (P1) received the most clicks for all attributes except juiciness, whereas time period 2 (P2) received the most (Table 2). For liking and tenderness, there was no significant difference between P1 and P2; however, there were significant differences found between all other time periods. For flavour, a significant difference was found between P1 and P3, P1 and P4, and P2 and P4. No significant differences were found between time periods for juiciness.

However, clicks may be carried overtime periods which means that Table 2 is not representative of when consumers gave or changed their responses but rather the spread of data throughout the four time periods. Therefore, it was decided to look at the unweighted responses to investigate when consumers gave or changed their responses.

Table 4.2 – Mean number of responses per time period by attribute (free TL)

	Liking	Flavour	Tenderness	Juiciness
Mean Number of Responses	3.17	3.33	3.33	3.24
Mean P1*	1.87	2.02	1.91	1.70
Mean P2*	1.83	1.72	1.89	1.72
Mean P3*	1.37	1.41	1.37	1.50
Mean P4*	1.13	1.15	1.13	1.33

**Where P1=Period 1, P2=Period 2, P3=Period 3, P4= Period 4*

Assessing the data for when consumers gave the clicks and not weighing for length (no carrying overtime period) shows that consumers gave the most number of clicks in time period 1 for each attribute. The number of attributes was then found to decrease with each subsequent time period (Table 3). For tenderness and liking, all time periods were found to be significantly different from each other ($p \leq 0.05$). For flavour and juiciness, the number of responses in P1 was found to be significantly different from P2, P3 and P4, respectively. In addition, P2 and P4 were also found to be significantly different for flavour. However, no other time periods were found to be significantly different from each other for flavour or juiciness.

Table 4.3 – Mean number of new clicks per time period by attribute with no carryover (Free TL)

	Liking	Flavour	Tenderness	Juiciness
Mean Number of Responses	3.17	3.33	3.33	3.24
Mean P1*	1.83	2.00	1.91	1.67
Mean P2*	0.87	0.72	0.91	0.72
Mean P3*	0.35	0.46	0.37	0.52
Mean P4*	0.13	0.15	0.13	0.35

**Where P1=Period 1, P2=Period 2, P3=Period 3, P4= Period 4*

When comparing the number of clicks for the free TL to the structured TL, it was found that a majority of consumers (34/51 for flavour, juiciness, tenderness, 35/51 for liking) gave less than four responses during the free TL. The consumers who gave less than four responses tended to use the same approach for all attributes. Of the 12 (13 for liking) consumers who gave at least four responses to the attributes using free TL, eight consumers were consistent for three attributes (i.e.) they gave ≥4 clicks to at least three attributes. In fact, five consumers gave ≥4 clicks to all attributes. This result indicates that the number of responses may be less indicative of attributes and may be due to individual consumer responses. It would be interesting to repeat this experiment with a larger group of consumers to get a deeper insight into the range of individual temporal responses across consumers. For future research, it may also be interesting to correlate the number of clicks from free TL to taster status and aspects of food behaviour to help explain why consumers varied in their temporal response.

4.3.2.2. Time Spent on each attribute

For the free TL, consumers spent the most time on the attribute of flavour and the least amount of time on juiciness (Table 4). A significant difference was found between the time consumers spent scoring individual attributes using the free TL. The significant differences in time spent scoring were found between flavour and juiciness and liking and juiciness ($p<0.05$).

Table 4.4 – Descriptive statistics for time spent (seconds) by time period using the free TL

	Liking	Flavour	Tenderness	Juiciness
Mean (all time periods)	28.27	29.15	26.79	19.88
Mean (per time period)	7.07	7.29	6.7	4.97

For the structured TL, there was also wide variability in the time consumers spent on scoring each attribute as well as time spent in each time period (T). Consumers spent the most time in T1 and the least time on T2 for all attributes except tenderness, where the least time was spent on T4 (Table 5).

Contrary to the results of the free TL, in which consumers spent the most time scoring flavour, consumers spent the least amount of time on flavour using the structured TL for all time periods. From the attributes utilised in this study, it is possible that flavour was the most obvious or easiest to score for the consumers as it received the most responses using the free TL, which is why consumers spent marginally more time on it using the free TL. When it came to the structured TL, consumers found this more complex than the free TL, but if the flavour was more obvious to them, then this could be why it was the attribute where the least time was spent using this method. Using the structured TL, consumers spent the most time on overall liking. In addition, consumers spent the most time on the first time period and the least on the second time period.

Table 4.5 – Descriptive statistics for time spent (seconds) by time period using the structured TL

	Liking	**Flavour**	**Tenderness**	**Juiciness**
Mean (all T's)	93.26	38.49	74.27	62.08
Mean T1	30.88	14.83	26.56	23.60
Mean T2	18.93	7.31	15.76	11.29
Mean T3	20.51	7.41	16.79	13.53
Mean T4	22.95	8.93	15.16	13.66

4.3.3. Consumer Variability and Data Correlations within Liking Methods

4.3.3.1. Traditional Liking

Consumer liking of steaks was 7.02 for overall liking, 7.23 for flavour, 6.98 for juiciness, and 6.48 for tenderness (*Figure 1*). Overall liking (*Table 6*) was correlated with tenderness (R^2=.650) and juiciness (R^2=0.612) and slightly correlated with flavour (R^2=0.505). Using ANOVA, nationality (Irish vs non-Irish) was found to be a significant cause of variability for both flavour (p=0.038) and juiciness (p=0.032). However, this only explained 16% and 25% of the variability liking scores for flavour and juiciness across consumers, respectively. Although it must be noted that this regression analysis only utilised consumer variables and the individual animal as variables, so further analysis with more animal variables (e.g.) fat conformation, cooking loss, IMF percentage, may yield more informative results.

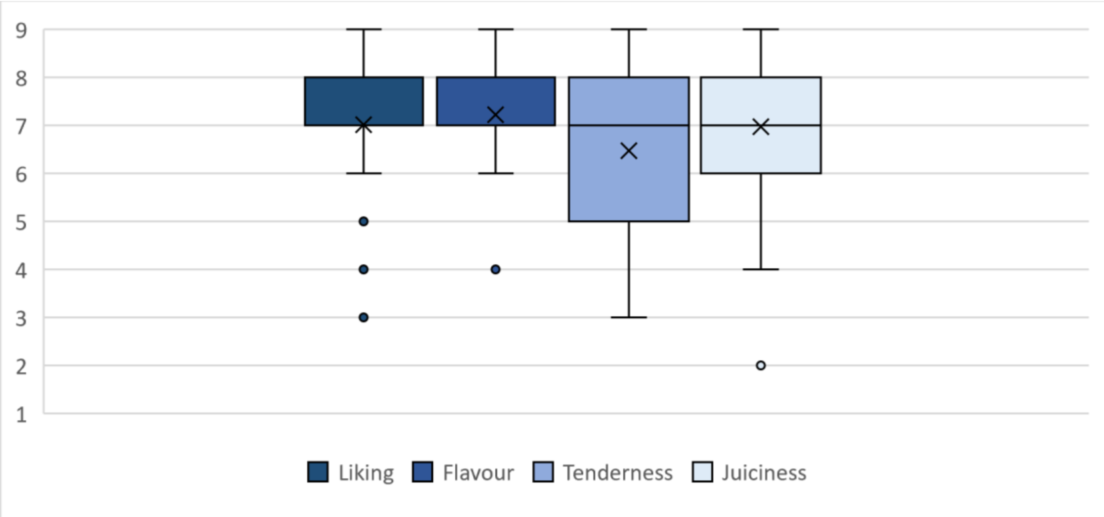

Figure 4.1 – Box plot of consumer responses per attribute

4.3.3.2. Free TL

Consumer liking of steaks varied over each time period *(Figures 2-6*). Consumer variability in scores was found to be significant within each time period for all attributes; however, using MANOVA, no significant differences were found between time periods. In addition, all attributes were found to be highly correlated with each other (Table in *Appendix D*).

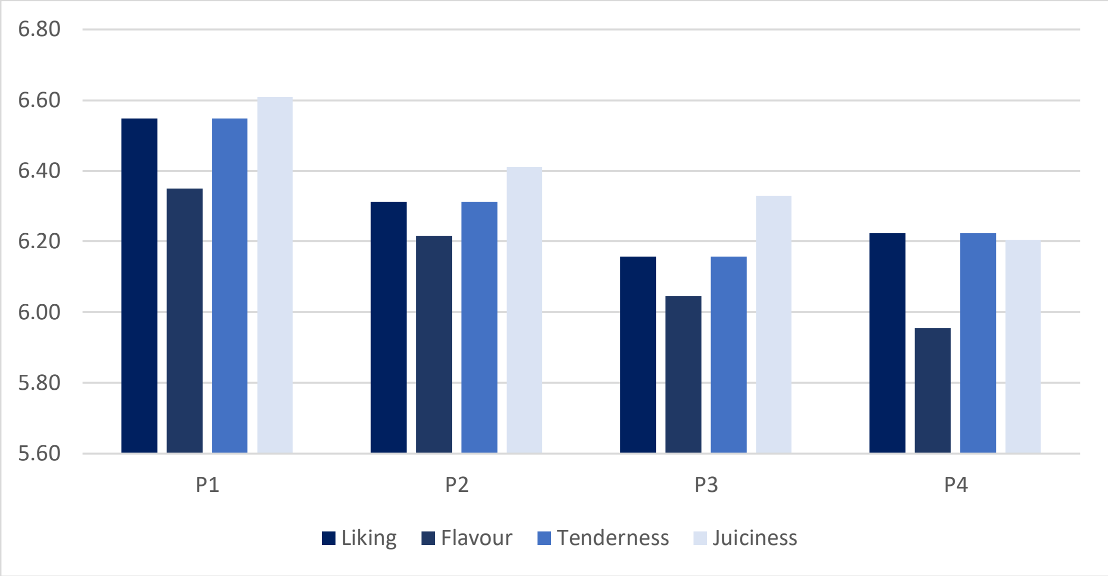

Figure 4.2 – Summary plot of consumer liking per time period (all attributes)

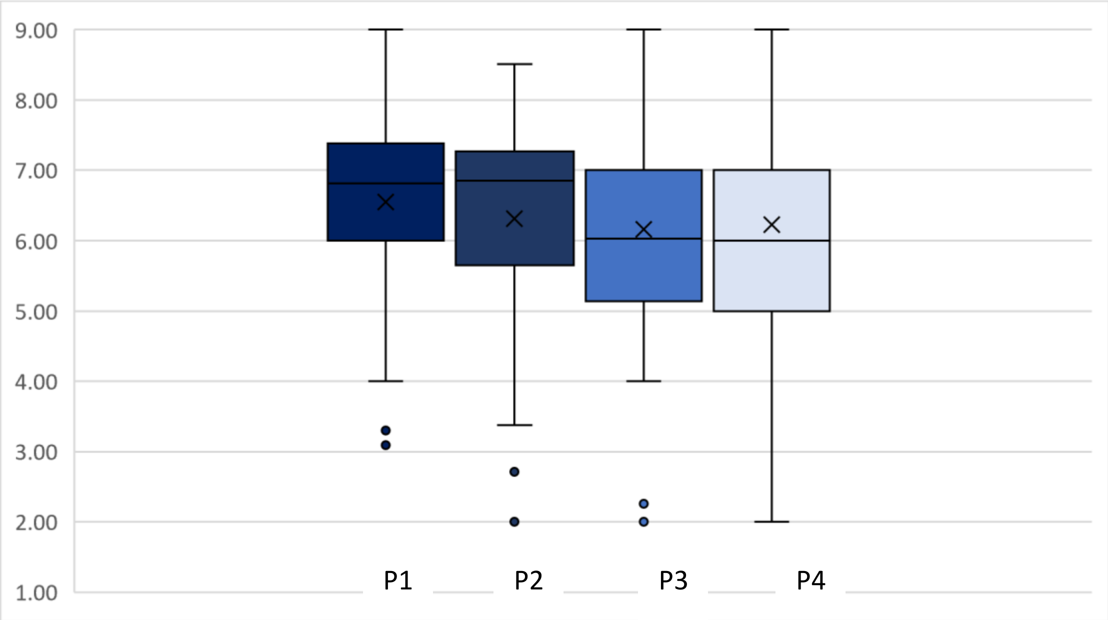

Figure 4.3 – Box plot of consumer variability of responses for liking across time periods

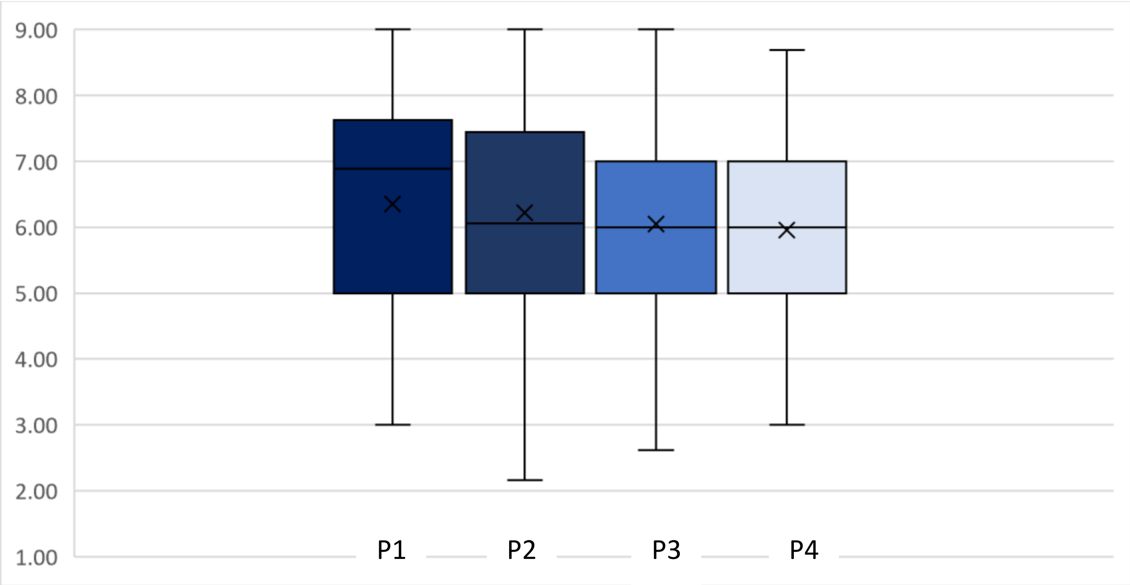

Figure 4.4 – Box plot of consumer variability of responses for flavour across time periods

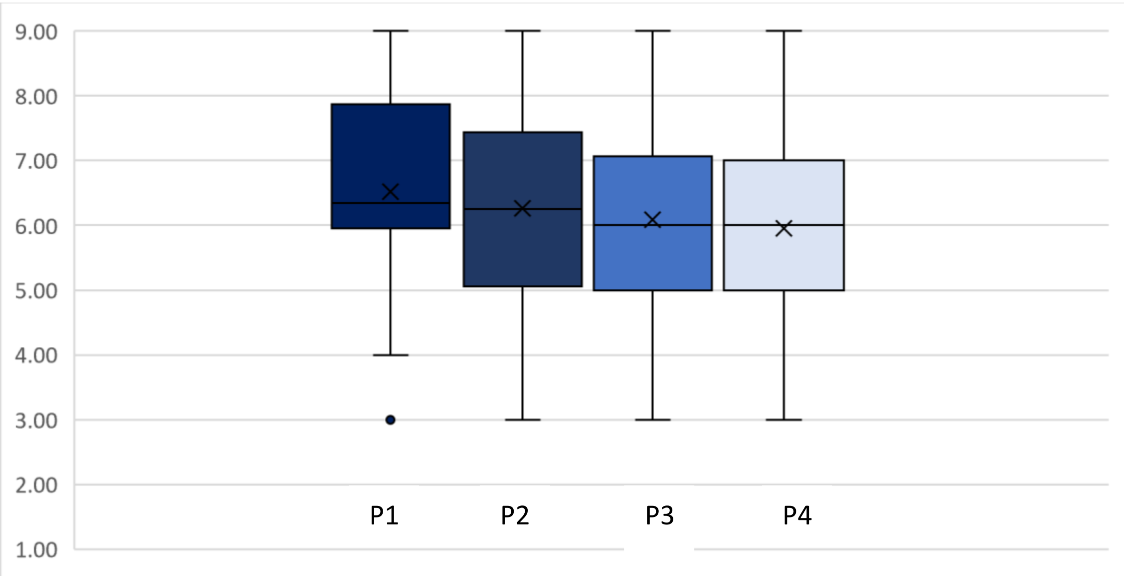

Figure 4.5 – Box plot of consumer variability of responses for tenderness across time periods

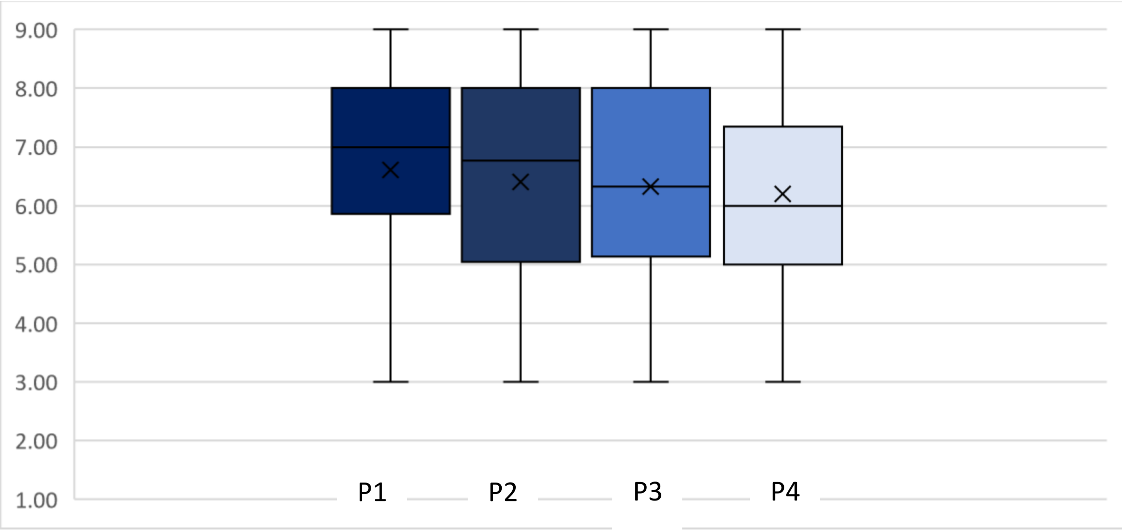

Figure 4.6– Box plot of consumer variability of responses for juiciness across time periods

4.3.3.3. Structured TL

Consumer liking of steaks varied over each time period (*Figure 7-11*). Consumer variability of scores was found to be significant within each time period for all attributes. Using MANOVA, liking was found to be significant across time periods. However, no other attribute was found to be significant. Strong correlations were found between all attributes (*Table 8*). No consumer variables (age, nationality) were found to be significant using an ANOVA. Although again, it must be noted that this regression analysis only utilised consumer variables and the individual animal as variables, so further analysis with more animal variables (e.g.) fat conformation, cooking loss, IMF percentage, may yield more informative results.

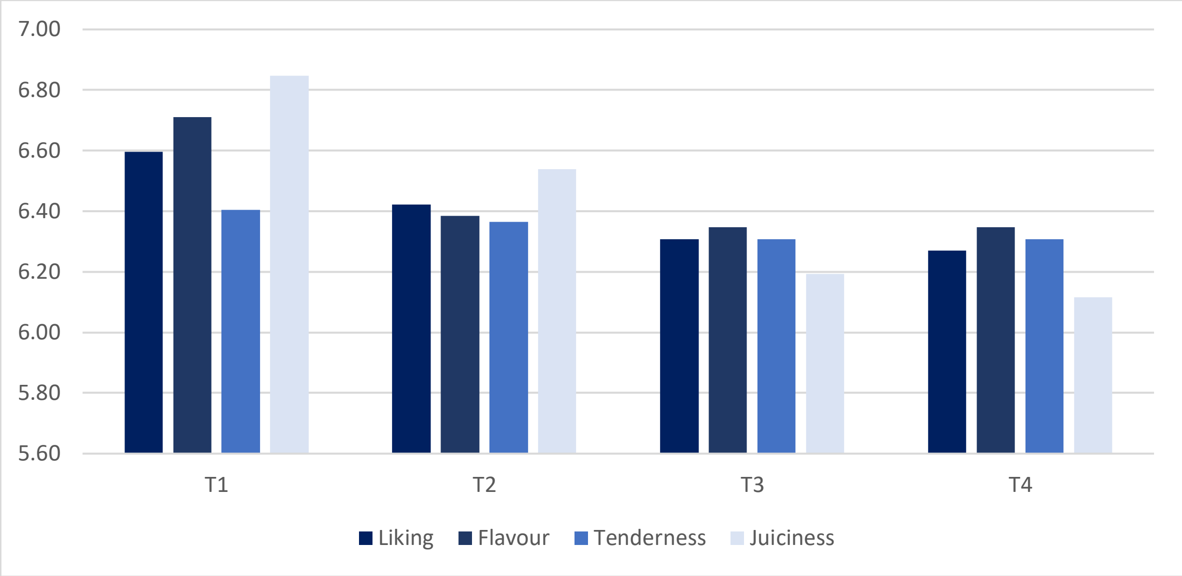

Figure 4.7 – Summary plot of consumer liking per time point (all attributes)

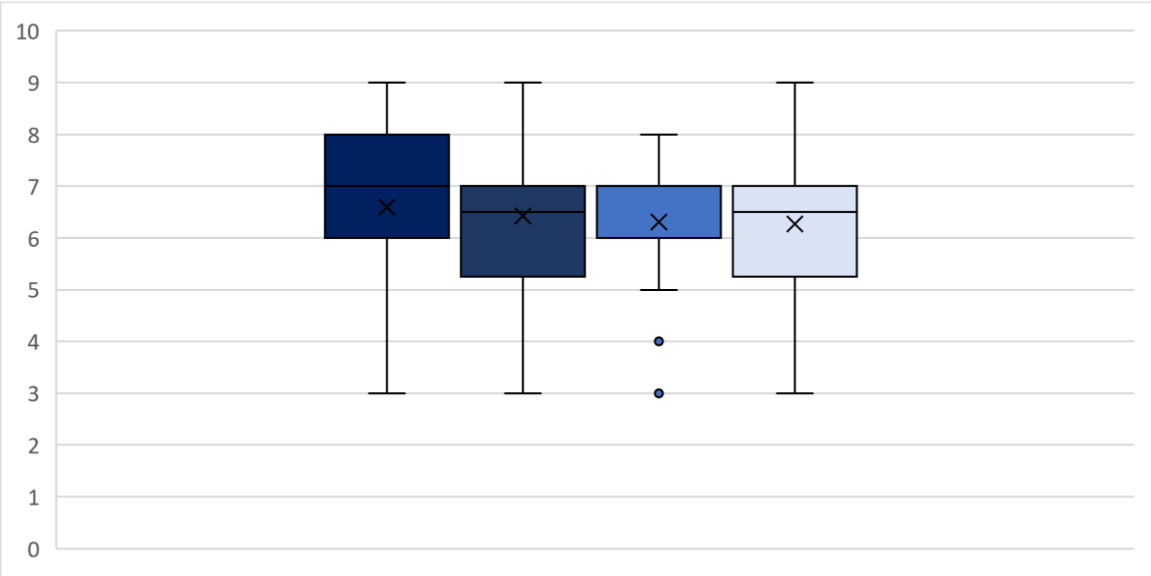

Figure 4.8 – Box plot of consumer variability of responses for liking across time points

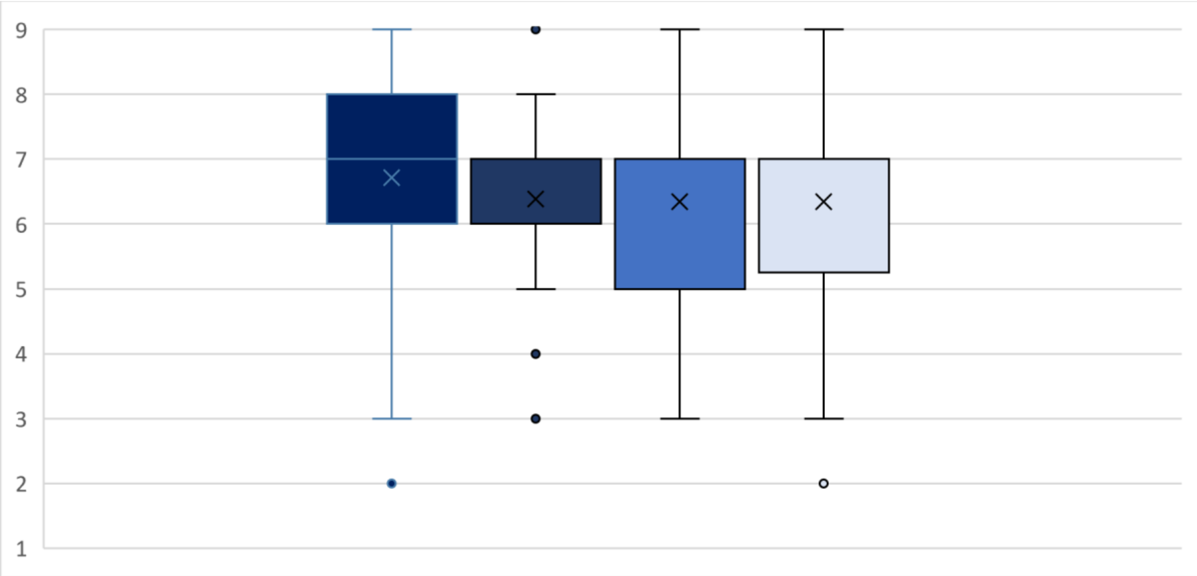

Figure 4.9 – Box plot of consumer variability of responses for flavour across time points

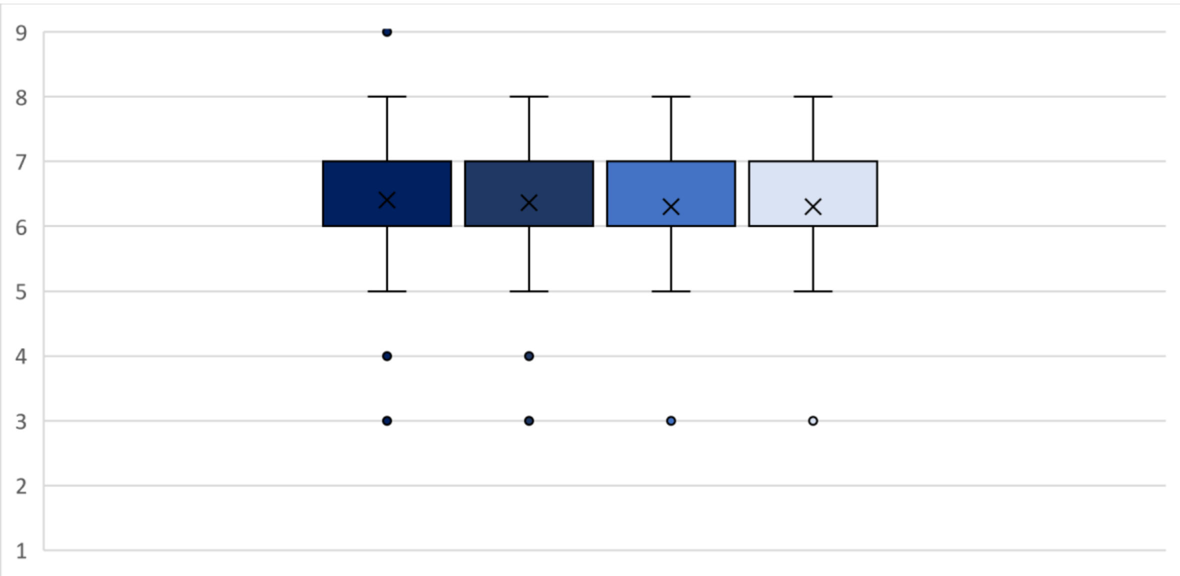

Figure 4.10 – Box plot of consumer variability of responses for tenderness across time points

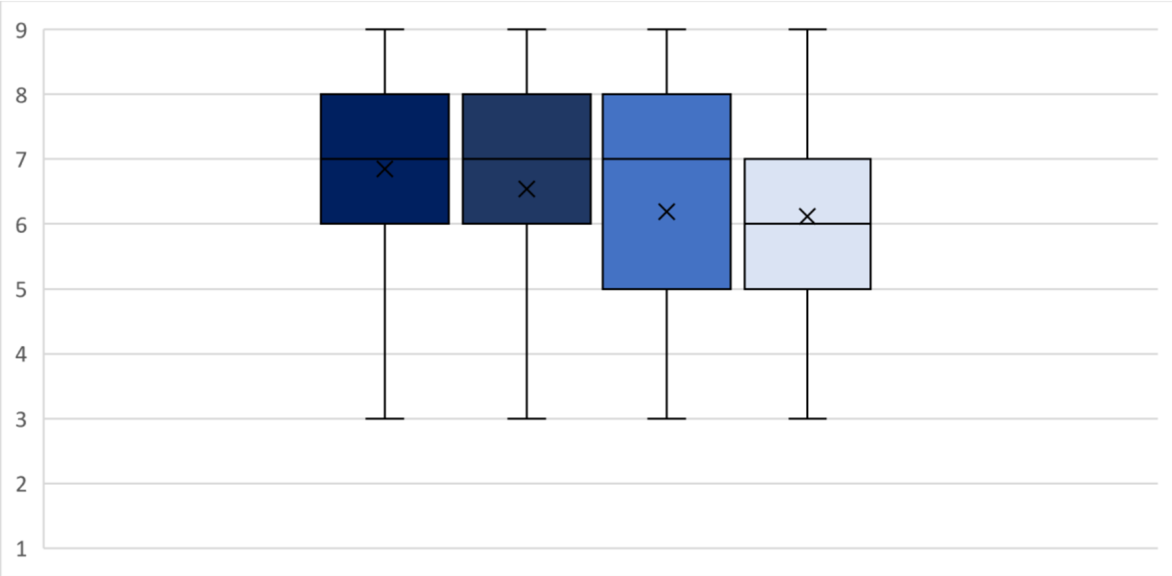

Figure 4.11 – Box plot of consumer variability of responses for juiciness across time points

Table 4.6 – Correlation between attribute scores for structured TL

	Liking	Flavour	Tenderness	Juiciness
Liking	1	-	-	-
Flavour	**0.861**	1	-	-
Tenderness	**0.858**	**0.768**	1	-
Juiciness	**0.827**	**0.909**	**0.803**	1

4.3.4. Variance between Liking Method Means

All calculations and analyses were carried out with the 46 consumers that provided temporal data using the temporality assessment described above. To compare the three methods to each other, an overall mean was calculated for the structured and free TL methods so they could be compared to the overall liking (*Figure 12*). Using ANOVA and post-hoc (LSD), the free TL was found to differ significantly from the traditional liking method in terms of liking (p=0.033) and flavour (p=0.001). There was also a significant difference between the structured TL and the traditional liking method for flavour (p=0.007). The difference between the traditional liking and structured TL methods for liking was just above significance (p=0.053). The two TL methods did not significantly differ from each other for any attribute. No significant differences were found for tenderness or juiciness.

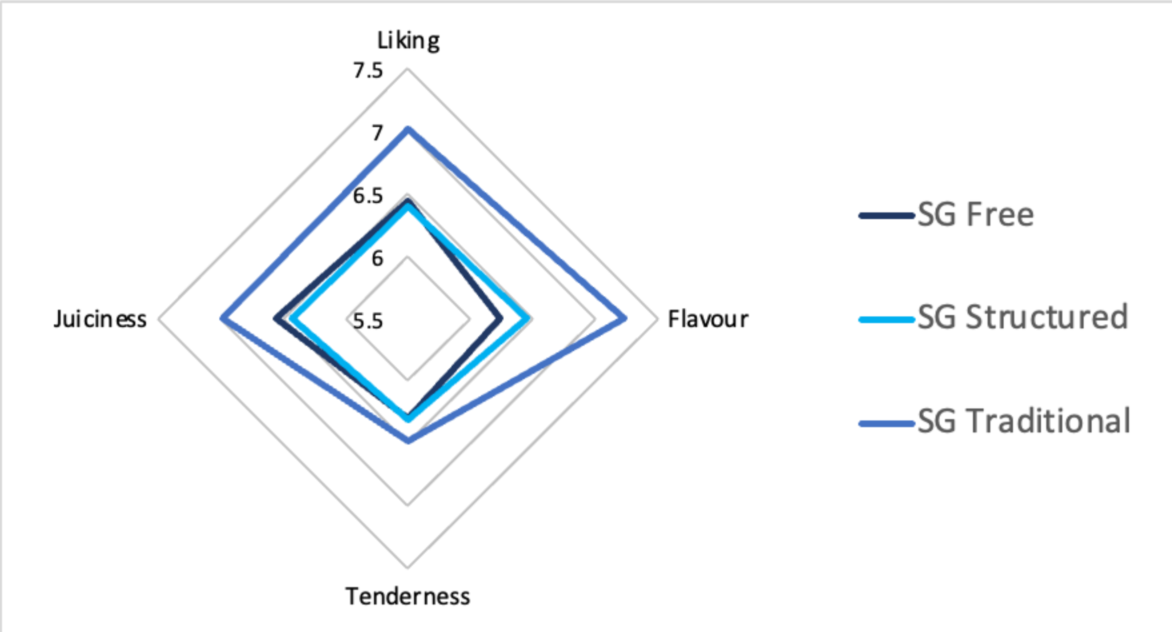

Figure 4.12 – Spider plot of the mean scores from the three liking methods

4.3.5. Correlation and variation between traditional and temporal liking methods

4.3.5.1. Traditional and Free Temporal Liking

A linear regression was carried out to determine which of the time periods in the free TL, the traditional liking most emulated (Tables in *Appendix D*). For liking and flavour, it was found that the traditional liking method was correlated with all time periods with the free TL, with time-period 2 having the strongest correlation (R^2 = 0.548 and R^2 = 0.450, respectively). In addition, all time periods were found to be significantly different from the traditional liking score for liking and flavour (*Table 9-10*). Tenderness and juiciness were also found to correlate with the traditional liking; however, these correlations were weaker than those of liking and flavour. In addition, all time periods were found to be significantly different from the traditional liking score for tenderness and juiciness. The correlation coefficients found in this study are similar to or higher than rates found by Thomas *et al.* (2015) between traditional liking and free TL using six types of fresh cheese. Thomas *et al.* (2015) found traditional overall liking correlated with free TL with an $R^2 = 0.4$.

4.3.5.2. Traditional and Structured TL

Linear regression was applied to determine the correlation between the traditional liking and the structured TL method. (*Tables in Appendix D*). For the attribute liking, it was found that the traditional liking method was correlated with all time points in free TL, with time point one being the most strongly correlated. In addition, all time points were found to be significantly different from the traditional liking score for liking (*Table 13*). Scores for flavour, tenderness and juiciness were also found to correlate with the traditional liking; however, these correlations were weaker than those of liking. In addition, all time periods were found to be significantly different from the traditional liking scores for flavour, tenderness, and juiciness, except for T2 for juiciness (*Table 16*).

4.3.6. Correlation and Variation between temporal liking methods

4.3.6.1. Correlation

Correlation was performed to investigate if the scores from two temporal methods correlated well with each other across time points (structured TL) and time periods (free TL). Variability was also investigated to determine differences between the two TL methods. Correlations between time periods and time points were analysed using Pearson's Correlation. Flavour was found to be the most strongly correlated, specifically P1 (free TL) and T1 (structured TL) and T2 and P2. Tenderness was also found to be correlated between the two TL methods with P1 and T1, and P1 and T2 were found to be correlated. P2 and T2 were found to be correlated for liking. However, only weak correlations were found for juiciness (Tables in *Appendix D*).

4.3.6.2. Variation across methods

Cluster analysis was performed to understand the variation in consumer scores across methods. For the variation between the two TL methods, each time period was compared to its time point counterpart (i.e.) P1 was compared to T1, P2 was compared to T2, and so on. Using paired t-tests, no significant differences were found for any of the attributes. As previously mentioned, significant differences were found across time periods for the structured TL but not for free TL. This is similar to results found by Sudre et al. (2012), who also found a significant difference in liking from start to finish for their structured TL ("four-step method") but not their free TL for two of their three products.

It was decided to perform an AHC for each attribute to compare the individual consumer variance between the two TL methods. It was found that although there were no significant differences between the datasets of the two TL methods, the individual consumers clustered quite differently. For each attribute, 2 clusters of varying sizes were obtained for each TL method (*Table 21 & 22; Appendix D*). For overall liking using the free TL, cluster 1 showed a higher liking score for the beef, which remained pretty stable for the consumption period, whereas cluster 2 showed a neutral to the slight disliking of the beef from the start, which then decreased and remained stable for the rest of consumption at disliking. A similar trend was observed for the structured TL; however, one difference is apparent in cluster 2: liking started at slightly disliking for the free TL, then slightly increased, and decreased again before finishing by slightly increasing. Using ANOVA, a significant difference was found between the two clusters for each time period for the free TL and between each time point for the structured TL. Interestingly, only four consumers remained constant in cluster 2, the "disliking" cluster between the free TL method and the structured TL method, even though consumers received the same cut of meat from the same animal for both methods. This is similar to Sudre et al. (2012), who found 2 clusters for overall liking using free and structured TL. However, Sudre et al. (2012) tested three different products just for overall liking, whereas this study only utilised one meat source and tested four attributes.

A PCA was also run for each TL method (*Figure 13*). For tenderness, there was a stark change between the data received for the free TL and structured TL methods (*Tables 21 & 22*). Again, two clusters were formed of similar grouping (like and dislike). There were more consumers in the "disliking" cluster for the free TL but more consumers in the "liking" cluster for the structured TL method (*Figure 14*). Although the methods were different, consumers received meat from the same animal. A PCA was also conducted (*Figure 15*). The PCAs (Figures 13 & 15) show further information on consumer liking of overall liking and tenderness. These PCAs show the variation in consumer liking patterns which are spread in all directions. For the most part, consumers from cluster 1, the "liking" cluster, are present on the right-hand side of the

PCA axes and consumers in cluster 2, the "disliking cluster", are present on the left-hand side. However, outliers can also be seen, for example, consumer 59 in overall liking (Figure 13A). Cluster and PCA data for flavour and juiciness are available in *Appendix D*.

Table 4.7 – Numbers of consumers in the free TL clusters by attribute

	Liking	**Flavour**	**Tenderness**	**Juiciness**
Cluster 1 (n)	37	33	19	34
Cluster 2 (n)	9	13	27	12

Table 4.8 – Numbers of consumers in the structured TL clusters by attribute

	Liking	**Flavour**	**Tenderness**	**Juiciness**
Cluster 1 (n)	35	19	35	28
Cluster 2 (n)	11	27	11	18

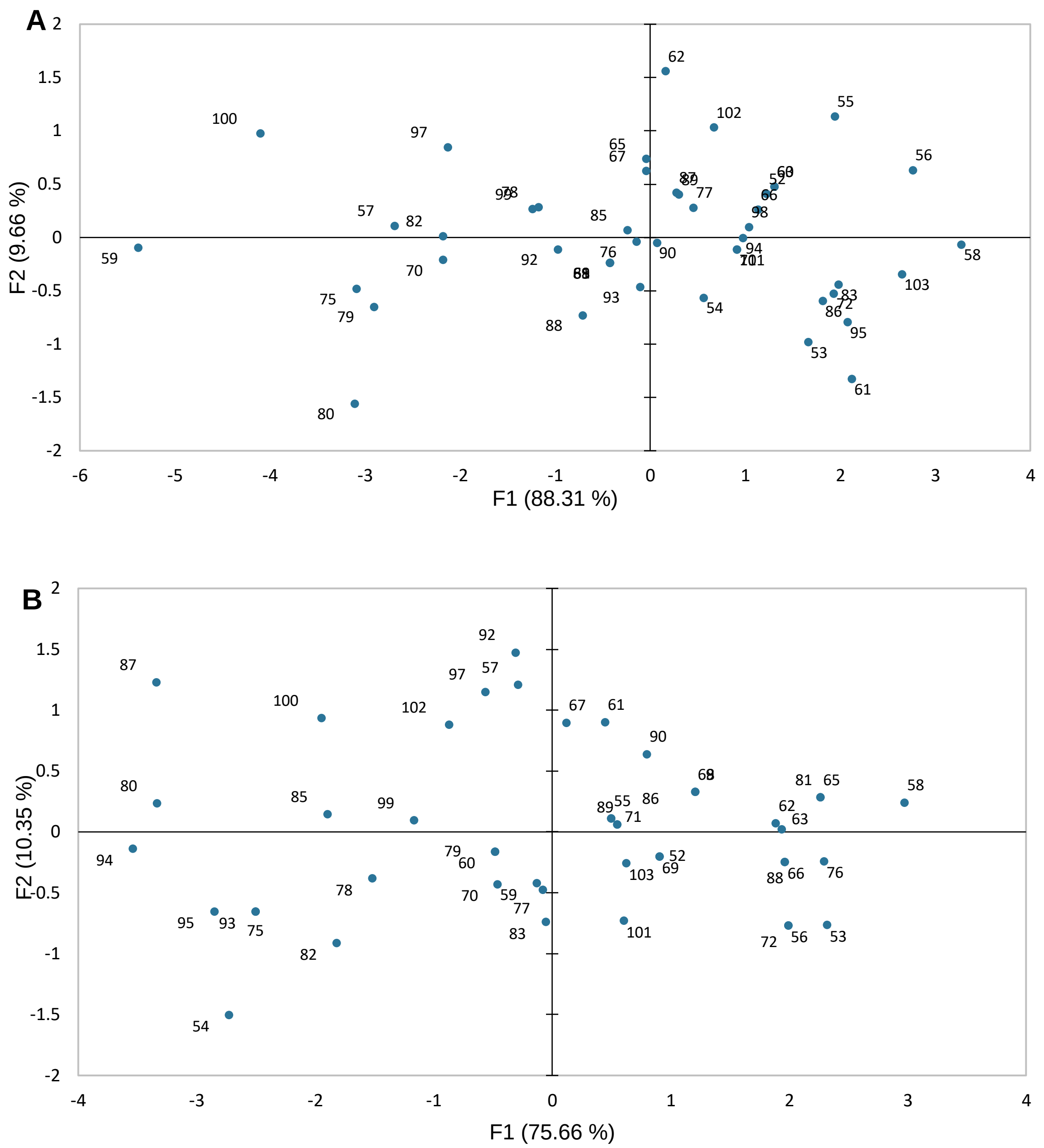

Figure 4.13 – PCA of data for overall liking for the (A) Free TL and (B) Structured TL

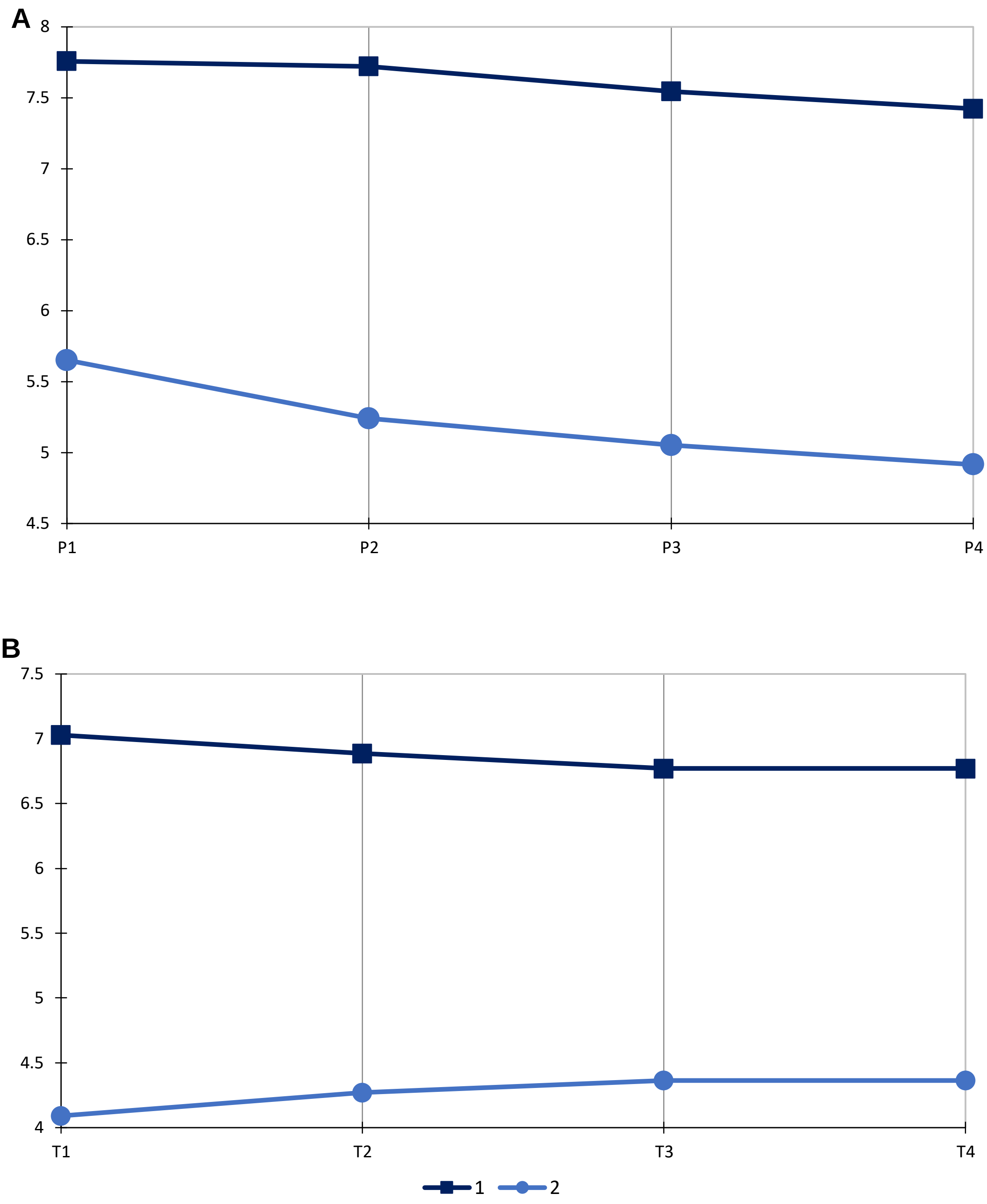

Figure 4.14 – Cluster curves for tenderness for the (A) free TL and (B) structured TL

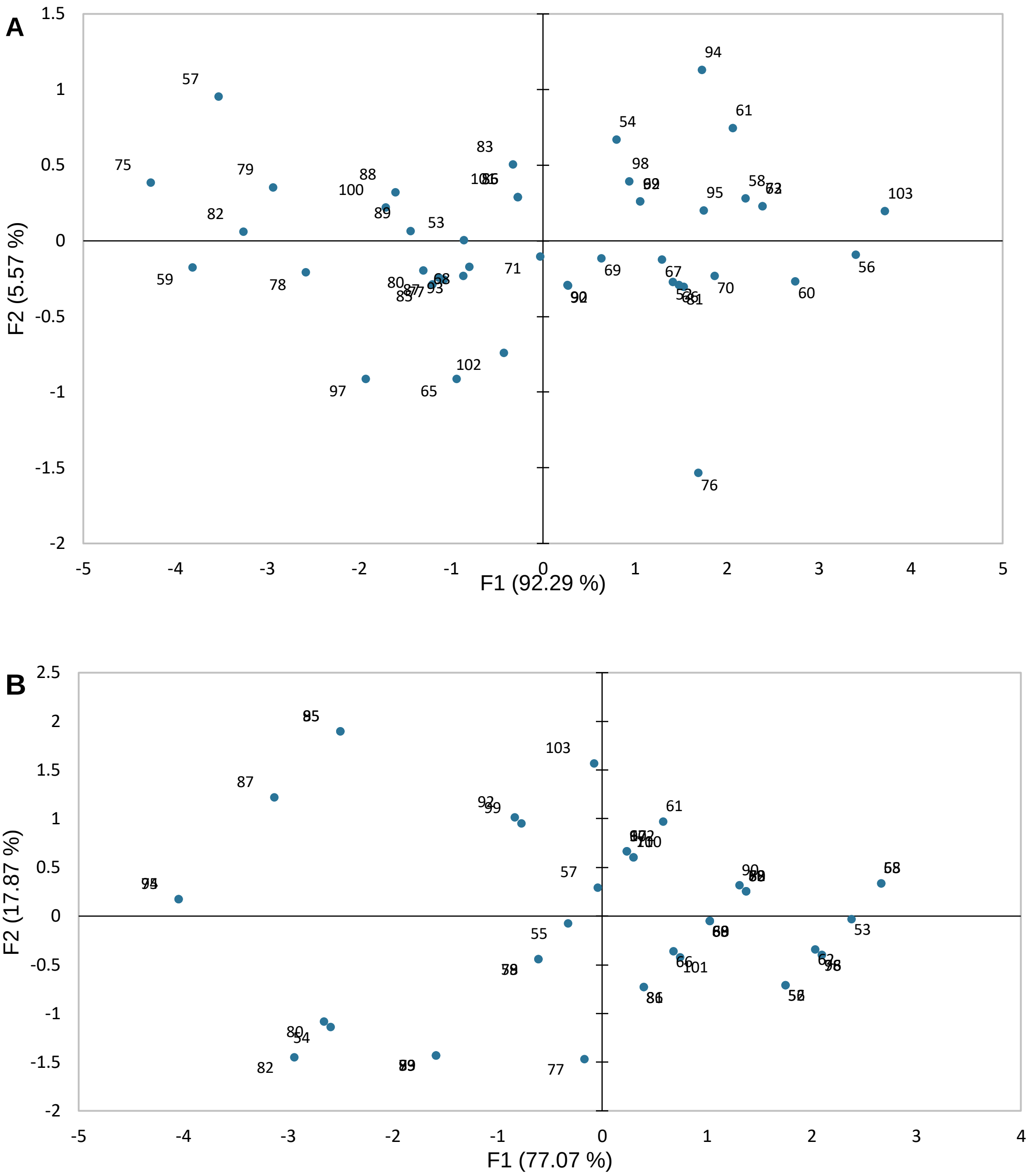

Figure 4.15 – PCA of data for tenderness for the (A) Free TL and (B) Structured TL

4.4. Conclusion

The objective of this study was to take the data from study 2 (silage and grain diet) and to investigate how consumers performed the three liking methods (traditional liking, free TL, and structured TL) across the four attributes study within the same study. This is the first study showing how the dynamics of consumer liking may change utilising multiple attributes. It is also the first study that utilises meat. It was shown that most consumers could perform the temporal liking method in the manner expected for at least one attribute. The fact that temporal data was not provided for all attributes and that consumers who could provide temporal data did not do so for all attributes is interesting and something that will need further study. Although no significant differences were found overall between the scores of the free TL and the structured TL methods, correlations between scores varied from slightly correlated to correlated, and many consumers changed liking clusters using the two methods. Therefore, the type of temporal liking chosen for an experiment may make a difference in terms of the type of data generated.

2.6. General Conclusions

This thesis has studied the potential of utilising temporal liking method and their analysis to better understand consumer liking of beef steaks from various feeding systems. This is the first temporal liking study to measure more than overall liking, and this study shows that temporal liking data can be generated for a range of different attributes. In addition, this is the first temporal liking study to utilise meat as the testing medium.

Published literature on the impact of the diet of the animal on consumer liking of beef has yielded conflicting results. An analysis performed as part of the systematic review in this thesis found no significant difference for any attributes tested using trained panel data. However, significant differences were found for all attributes tested using consumer data. This may be due to the lack of consumer studies (22 consumer vs 74 for trained panel), but it also may be due to the difference in liking being more consumer-based than meat-based. The lack of studies, as well as the significant difference in results, indicate that further research should focus on consumer studies on this topic. Familiarity and the effect of information given as part of the studies may be topics of interest for this research.

In this thesis, two temporal liking methods, as well as a traditional liking method, were successfully applied to investigate the differences in consumer liking of beef steaks from different finishing systems. In chapter 2, the silage plus grain steaks were generally preferred by consumers for all attributes. The free TL method was found to be easier to perform using consumer self-reported data. In addition, the free TL method yielded more discriminative data than the structured TL method. The significant evolution of scores over time for all attributes using the free TL method shows that consumers are able to track their liking of attributes over the eating process of steaks.

In chapter 3, the results highlight the importance of the familiarization task when conducting a TL study with consumers. The importance of the "other" data (data beyond that sensory scores) was shown in this chapter. While variation in individual consumer responses is expected in consumer sensory studies, leveraging measures such as data quality, the number of responses provided, and time spent by consumers on a study may allow for a greater understanding of the ways consumers approach sensory methods. Understanding more about these experiences could enable better questionnaire design to facilitate more reliable data collection. Consumer fatigue was also a factor in these studies and will need to be accounted for in future research. For example, perhaps performing the familiarization task and data collection within the same session may have contributed to consumer fatigue in terms of the ability to discriminate samples using the TL approach. Further research is needed to identify the appropriate number of attributes for consumer TL methods and whether the presentation order of attributes has an effect on responses. In addition, an assessment of temporality found that consumers who showed the ability to provide temporal data did not provide it for all attributes studies, which is something that requires a further look. Finally, it would be necessary to investigate the effect of data cleaning and choice of data organisation (analysing data like TI, by modality or as separate attributes) on the analysis of temporal liking data.

The objective of this chapter 4 was to take the data from study 2 (silage and grain diet) and to investigate how consumers performed the three liking methods (traditional liking, free TL, and structured TL) across the four attributes study within the same study. It was shown that most of the consumers were capable of performing the temporal liking method in the manner expected for at least one attribute. The fact that consumers who did provide some temporal data did not do so for all attributes is interesting and something that will need further study. Although no significant differences were found overall between the scores of the free TL and the structured TL methods, correlation between scores varied from slightly correlated to correlated, and many consumers changed liking clusters using the two methods, especially for tenderness. Therefore, the type of temporal liking chosen for an experiment may make a difference in terms of the type of data generated.

This thesis highlights that TL is a sensory method that consumers can use to produce quality data when designed well. There are some learnings to be gained in the design and sensory scientist approach from this thesis. In addition, this thesis has highlighted some drawbacks of this methodology, mainly in terms of the statistical analysis. As was shown, there is much that can be done with TL data in terms of statistics; however, this requires in-depth data cleaning, time, and a scientist with high levels of statistical knowledge. This added time and cost may be a barrier to uptake of temporal liking by industry. In addition, statistical consultants may be needed adding further costs to any potential study. Further, the lack of consensus on how the TL data should be cleaned/processed and analysed may be off-putting and produce another barrier to uptake.

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Appendix A

Table A1 - Application of Time Intensity to meat and meat products

Product	**Purpose**	**Type of panel**	**Reference**
Beef roasts	TI analysis of tenderness	Trained	Butler *et al.* (1996)
Beef steaks	Compare consumer & trained panel TI for beef	Trained & Untrained	Brown *et al.* (1996a)
	Consumer perception of tenderness & juiciness using TI	Untrained	Brown *et al.* (1996b)
	TI analysis of tenderness	Trained	Duzier *et al.* (1993)
	Relationship between tenderness perception and chewing patterns	Trained	Duizer *et al.* (1994)
	Relationships between time-intensity, electromyography and instrumental beef tenderness	Trained	Duizer *et al.* (1996)
	Different in cooking methods and end point temperature on perception of tenderness & juiciness	Trained	Gomes *et al.* (2014)
	Dual attribute time intensity to assess meat tenderness	Trained	Zimoch & Findlay (1998)
	Temporal differences amongst panellists in perception of juiciness and tenderness of beef	Trained	Zimoch & Gullett (1997)
Beef & pork roasts	Association between chewing patterns and TI of tenderness	Trained	Braxton *et al.* (1996)
Pork Meat	TI analysis of pungency sensations	Trained	Djekic *et al.* (2021)

Pig meat	Track improvement of TI panel scores with training – change in perceived texture.	Trained	Peyvieux & Dijksterhuis (2001)
Dry-cured loin, liver pate, cured sausage	Difference in perception of 3 Iberian meat products as tracked by TI	Trained	Lordio *et al.* (2014)
Dry-cured ham	Effect of IMF content and serving temp on Iberian ham that was sliced and vac packed.	Trained	Fuentes *et al.* (2013)
	Effect of fat content & HPP on dynamic perception.	Trained	Fuentes *et al.* (2014)
	Dynamic perception of HPP on Serrano and Iberian ham.	Trained	Lordio *et al.* (2015a)
	Dynamic perception of salt and intramuscular fat of Serrano and Iberian ham.	Trained	Lordio *et al.* (2015b)
	Effect of pure breed (fed grass) vs mixed breed Iberian pigs (fed concentrate) and reduced/normal salt content on dynamic perception.	Trained	Lordio *et al.* (2016)
	Characterisation of salt replacement in cured ham by 3 methods, 2 dynamic & FP.	Trained	Lordio *et al.* (2018)
Beef burgers	Sodium reduction in beef burgers	Trained	Mattar *et al.* (2017)
Sausages	Comparison of perception overtime of sausages of various fat & salt contents	Trained	Ventanas *et al.* (2010)

Pork patties	Determine dynamic perception of oral burn using spiced pork patties served at 3 temperatures.	Trained	Reinbach *et al.* (2009)
	Dynamic perception of oral burn using two types of chilli products and two types of texture. Interaction of meat flavour, texture and oral burn.	Trained	Reinbach *et al.* (2007)
Spicy chicken & beverages	Determine which of 5 beverages reduces residual spiciness of chicken consumed.	Trained	Samant *et al.* (2016)

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Appendix B

Table B1– Search terms utilised in literature search by website

Website	Search terms	Number of Articles
Science Direct	Sensory (Quality OR Palatability OR Acceptance OR Liking OR Preference OR Profiling) AND (Cattle OR Steer OR Bull OR Heifer OR Beef) Feed OR Grass OR Forage OR Pasture OR Grain OR Concentrate OR Supplementation OR Finishing)	2 619 results
Scopus	(sensory AND (quality OR palatability OR acceptance OR liking OR preference OR perception OR profiling) AND (feed* OR grass* OR forage OR pasture OR silage OR grain OR concentrate OR supplementation OR finishing OR production) AND (cattle OR steer OR bull OR heifer OR beef)	4 000 results
Web of Science	(Sensory AND (Quality OR Palatability OR Acceptance OR Liking OR Preference OR Perception OR Profiling) AND (Feed* OR Grass* OR Forage OR Pasture OR Silage OR Grain OR Concentrate OR Supplementation OR Finishing OR Production) AND (Cattle OR Steer OR Bull OR Heifer OR Beef)	1 240 results
PubMed	(Sensory AND (Quality OR Palatability OR Acceptance OR Liking OR Preference OR Perception OR Profiling) AND (Feed* OR Grass* OR Forage OR Pasture OR Silage OR Grain OR Concentrate OR Supplementation OR Finishing) AND (Cattle OR Steer OR Bull OR Heifer OR Beef)	1 067 results

Table B2– Exclusion criteria and breakdown of paper exclusion numbers from abstract screening round

Number	Exclusion Reason	No. of papers (n= 6 165)
1	No sensory/feeding	515
2	Not beef	2650
3	Not relevant/not meat	2002
4	Review/Book chapter/Opinion/Commentary	325
5	Irrelevant beef products/processing	532
X	Duplicates	141

Table B3 – Exclusion criteria and breakdown of paper exclusion numbers from full text review

Number	Exclusion Reason	No. of papers (n= 1 424)
1	not sensory/not feeding/ other post-slaughter factor	652
2	not beef	23
3	not relevant/not meat	35
4	review/book	30
5	dairy lactation, pregnancy, or milk composition	114
6	post-slaughter factors/beef meat products	39
7	not in English	4
8	role of information on consumer acceptance	4
9	Not steer/ no separation of steer and other sex	362
10	Not reported/not clear sex	25
11	Research diet component not >20% diet	95
12	not enough information for data extraction	35
X	Duplicate	6

Appendix C

Table D1- Results of a Pearson's R Correlation between Missing Data Percentage from the Structured TL and Free TL

Study	Range Structured TL	Range Free TL	R	X	Intercept	P-value
Study 1	0-0.81	0-0.75	0.026	0.061	0.0035	0.065
Study 2	0	0	N/A	N/A	N/A	N/A
Study 3	0-0.13	0	N/A	N/A	N/A	N/A

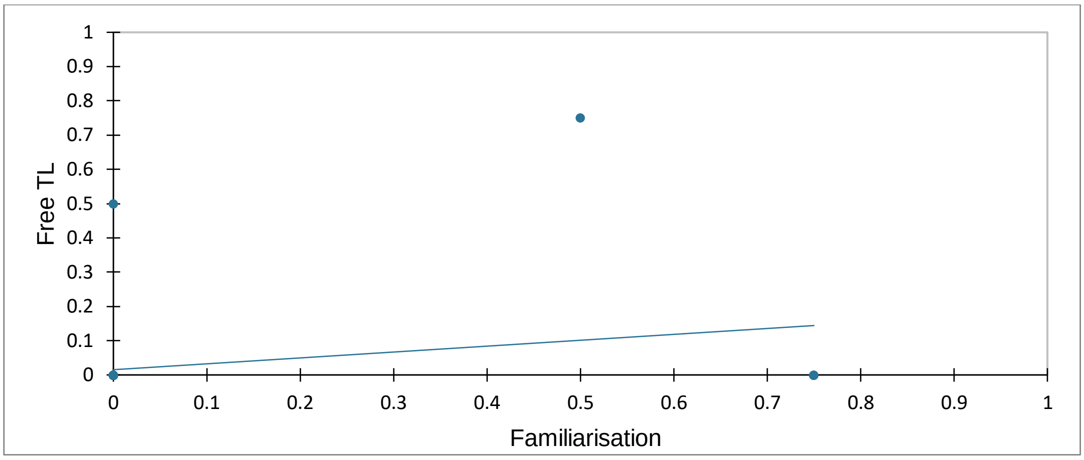

Figure D1 – Correlation of Missing Data from Familiarisation and Free TL Method (Study 1)

Table D2 - Results of a Pearson's R Correlation between Missing Data Percentage from the Familiarisation and Free TL

	Range Familiarisation	Range Free TL	R	X	Intercept	P-value
Study 1	0-0.75	0-0.75	0.068	0.172	0.015	0.065
Study 2	0-0.75	0	N/A	N/A	N/A	N/A
Study 3	0-0.75	0	N/A	N/A	N/A	N/A

Table D3 – Descriptive Statistics for Number of Responses (Study 1) for Familiarisation

Responses	Liking	Flavour	Tenderness	Juiciness	Overall
Total	80	80	76	78	314
% of Data	25.48%	25.48%	24.20%	24.84%	100%
Mean	1.57	1.57	1.49	1.53	6.16
Min	0	0	0	0	1
Max	6	5	5	8	21
Mode	1	1	1	1	4
Median	1	1	1	1	5

Table D4 – Descriptive Statistics for Number of Responses (Study 2) for Familiarisation

Responses	Liking	Flavour	Tenderness	Juiciness	Overall
Total	131	115	111	115	472
% of Data	27.75%	24.36%	23.52%	24.36%	100%
Mean	2.52	2.21	2.13	2.21	9.08
Min	1	0	0	0	1
Max	17	11	14	14	56
Mode	1	1	1	1	4
Median	2	2	1	1	7

Table D5 – Descriptive Statistics for Number of Responses (Study 3) for Familiarisation

Responses	Liking	Flavour	Tenderness	Juiciness	Overall
Total	128	124	126	108	486
% of Data	26.34%	25.51%	25.93%	22.22%	100%
Mean	2.56	2.48	2.52	2.16	9.72
Min	0	0	0	0	3
Max	11	14	20	13	57
Mode	1	1	1	1	4
Median	1	1	1	1	5

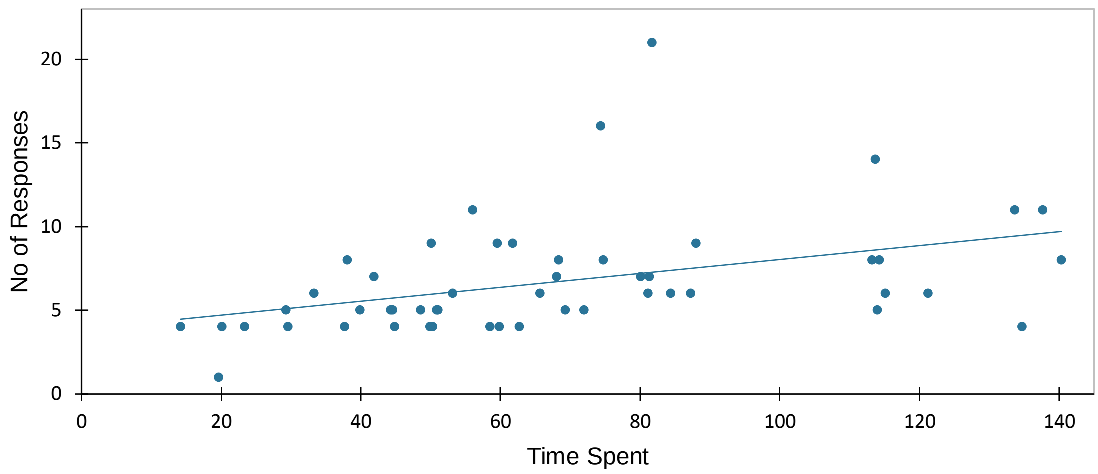

Figure D2 – Correlation of Time Spent and Number of Responses for Study 1 (Free TL)

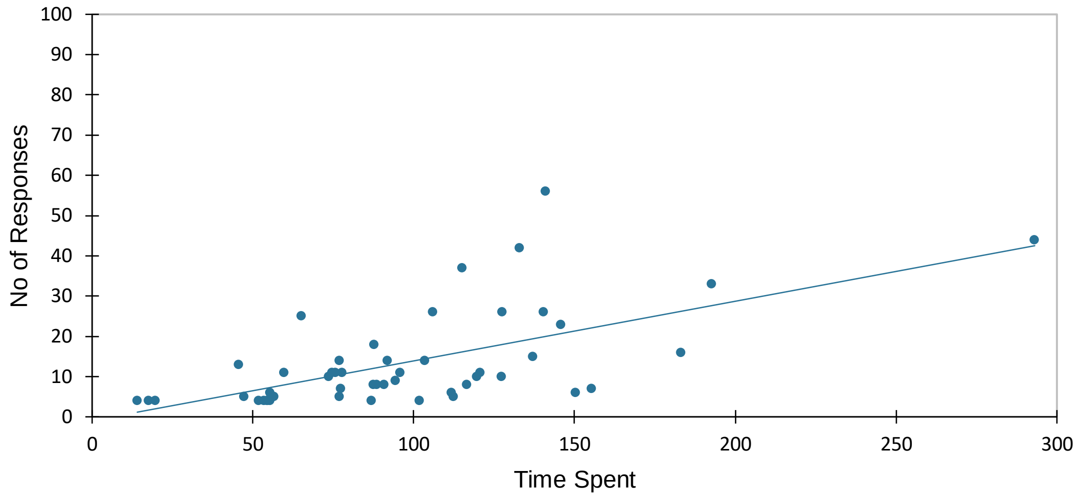

Figure D3 – Correlation of Time Spent and Number of Responses for Study 3 (Free TL)

Table D6 – Summary Number of Responses for the Free TL Method by Study

Study	Mean	Min	Max	Median	Mode
1	6.7	1.0	21.0	4.0	6.0
2	12.0	4.0	74.0	7.0	8.5
3	13.4	4.0	56.0	4.0	10.0

Table D7 – Frequency of Categorisation of the Free TL Method by Number of Responses

Study	Category	Criteria (Responses – All Attributes)	Frequency	% of Consumers (Within Each Study)
1	Low	1-5	22	43
1	Medium	6-10	23	45
1	High	11+	6	12
2	Low	1-5	9	17
2	Medium	6-10	24	46
2	High	11+	19	37
3	Low	1-5	14	28
3	Medium	6-10	13	26
3	High	11+	23	46

Table D8 – Consumers' Self-Reported Difficulty (Study 1) of the Free TL Method by Missing Data Categorisation

Category	Mean	Min	Max	Median	Mode
Low	1.86	1	5	2	1
Medium	2.04	1	5	1	1
High	1.50	1	3	1	1

Table D9 – Consumers' Self-Reported Difficulty (Study 2) of the Free TL Method by Missing Data Categorisation

Category	Mean	Min	Max	Median	Mode
Low	1.22	1	2	1	1
Medium	2.08	1	6	2	1
High	2.32	1	5	2	1

Table D10 – Consumers' Self-Reported Difficult (Study 3) of the Free TL Method by Missing Data Categorisation

Category	**Mean**	**Min**	**Max**	**Median**	**Mode**
Low	1.57	1	4	1	1
Medium	2.23	1	6	2	2
High	2.87	1	6	3	2

Appendix D

Table E1 – Correlation between attribute scores for free TL

	Liking	Flavour	Tenderness	Juiciness
Liking	1	-	-	-
Flavour	**0.999**	1	-	-
Tenderness	**0.999**	**0.998**	1	-
Juiciness	**1.000**	**0.999**	**0.999**	1

Table E2 – Correlation and variation between traditional liking and free TL time periods for liking

	P1	**P2**	**P3**	**P4**
Correlation	0.528	0.548	0.442	0.487
F-statistic	16.992	18.883	10.711	13.646
P-value	**0.000**	**<0.0001**	**0.002**	**0.001**

Table E3 – Correlation and variation between traditional liking and free TL time periods for flavour

	P1	**P2**	**P3**	**P4**
Correlation	0.342	0.450	0.422	0.373
F-statistic	5.834	11.168	9.543	7.121
P-value	**0.020**	**0.002**	**0.003**	**0.011**

Table E4 – Correlation and variation between traditional liking and free TL time periods for tenderness

	P1	**P2**	**P3**	**P4**
Correlation	0.350	0.406	0.418	0.356
F-statistic	6.146	8.669	9.342	6.366
P-value	**0.017**	**0.005**	**0.004**	**0.015**

Table E5 – Correlation and variation between traditional liking and free TL time periods for juiciness

	P1	P2	P3	P4
Correlation	0.356	0.364	0.382	0.328
F-statistic	6.402	6.719	7.506	5.290
P-value	**0.015**	**0.013**	**0.009**	**0.026**

Table E6 – Correlation and variation between traditional liking and structured TL time periods for liking

	T1	T2	T3	T4
Correlations	0.563	0.522	0.414	0.402
F-statistic	20.411	16.511	9.103	8.472
P-value	**<0.0001**	**0.000**	**0.004**	**0.006**

Table E7 – Correlation and variation between traditional liking and structured TL time periods for flavour

	T1	T2	T3	T4
Correlations	0.393	0.467	0.342	0.339
F-statistic	8.056	12.278	5.812	5.716
P-value	**0.007**	**0.001**	**0.020**	**0.021**

Table E8 – Correlation and variation between traditional liking and structured TL time periods for tenderness

	T1	T2	T3	T4
Correlations	0.473	0.393	0.329	0.329
F-statistic	12.703	8.043	5.327	5.327
P-value	**0.001**	**0.007**	**0.026**	**0.026**

Table E9 – Correlation and variation between traditional liking and structured TL time periods for juiciness

	T1	T2	T3	T4
Correlations	0.388	0.269	0.375	0.344
F-statistic	7.813	3.422	7.207	5.916
P-value	**0.008**	0.071	**0.010**	**0.019**

Table E10 – Correlation between free Tl and structured TL time periods for liking

	T1	T2	T3	T4
P1	0.364	0.490	0.259	0.301
P2	0.229	**0.529**	0.290	0.337
P3	0.106	0.457	0.236	0.311
P4	0.159	0.453	0.228	0.337

Table E11 – Correlation between free Tl and structured TL time periods for flavour

	T1	T2	T3	T4
P1	**0.605**	**0.641**	0.388	0.434
P2	0.539	**0.629**	0.355	0.450
P3	0.467	**0.611**	0.354	0.436
P4	0.442	0.468	0.208	0.448

Table E12 – Correlation between free Tl and structured TL time periods for tenderness

	T1	T2	T3	T4
P1	**0.513**	**0.509**	0.331	0.331
P2	0.392	0.479	0.317	0.317
P3	0.372	0.453	0.249	0.249
P4	0.351	0.415	0.158	0.158

Table E13 – Correlation between free Tl and structured TL time periods for juiciness

	T1	T2	T3	T4
P1	0.423	0.422	0.254	0.184
P2	0.364	0.379	0.202	0.167
P3	0.382	0.350	0.137	0.199
P4	0.363	0.321	0.051	0.148

Overall Liking

Table E14 – Breakdown of consumer clusters by agglomerative hierarchical clustering (AHC) for overall liking

Free TL		Structured TL	
Cluster 1	Cluster 2	Cluster 1	Cluster 2
52	57	52	54
53	59	53	75
54	70	55	78
55	75	56	80
56	79	57	82
58	80	58	85
60	82	59	87
61	97	60	93
62	100	61	94
63		62	95
65		63	100
66		65	
67		66	
68		67	
69		68	
71		69	
72		70	
76		71	
77		72	
78		76	
81		77	
83		79	
85		81	
86		83	
87		86	

88		88	
89		89	
90		90	
92		92	
93		97	
94		98	
95		99	
98		101	
99		102	
101		103	
102			
103			

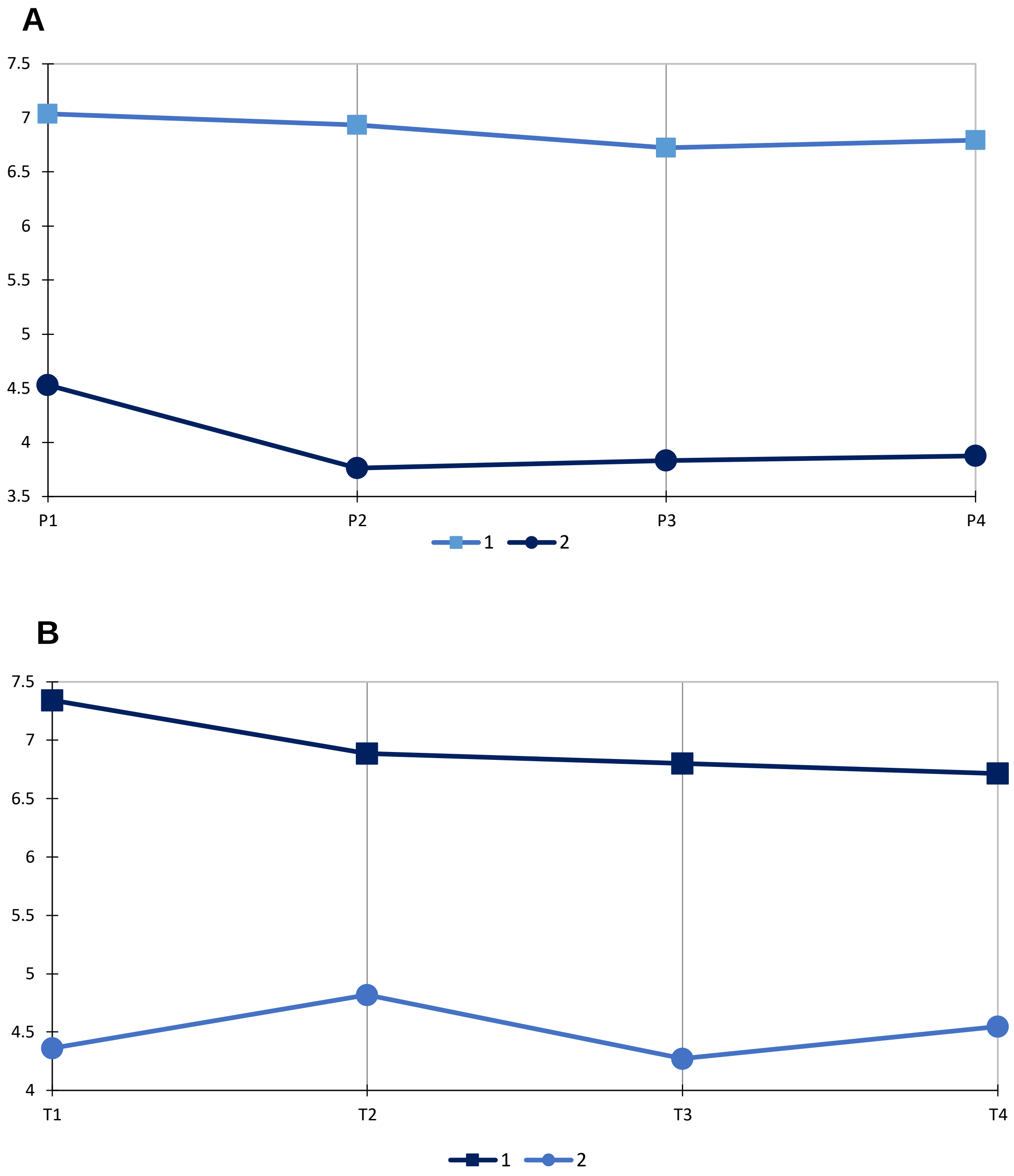

Figure E1 - Cluster curves for overall liking for the (A) free TL and (B) structured TL

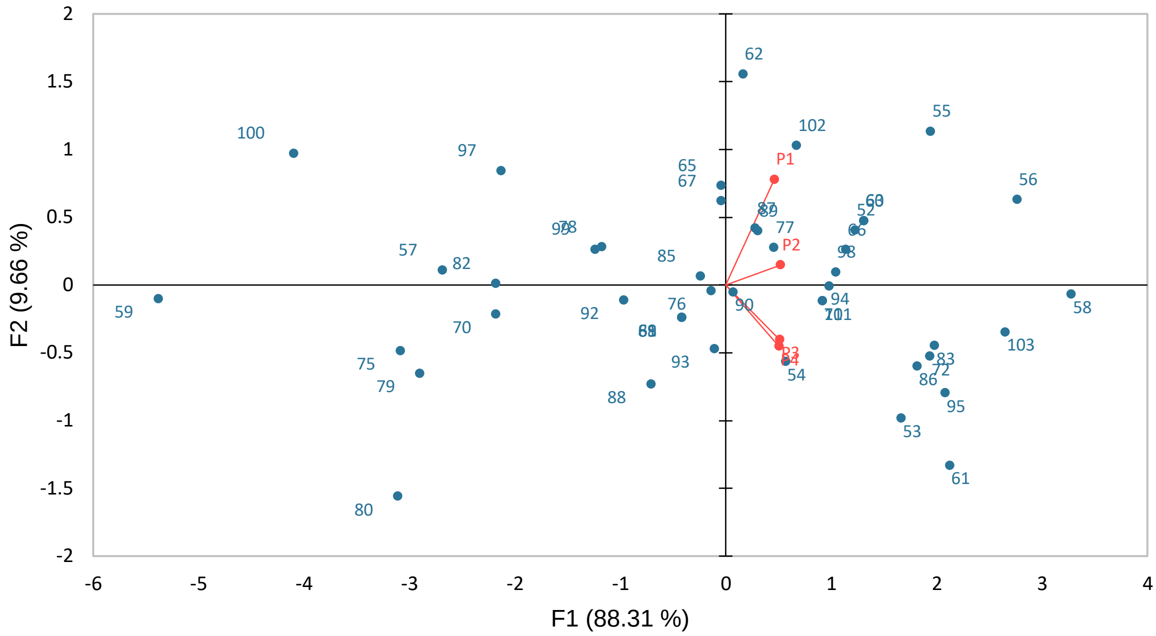

Figure E2 - Biplot for overall liking for the free TL

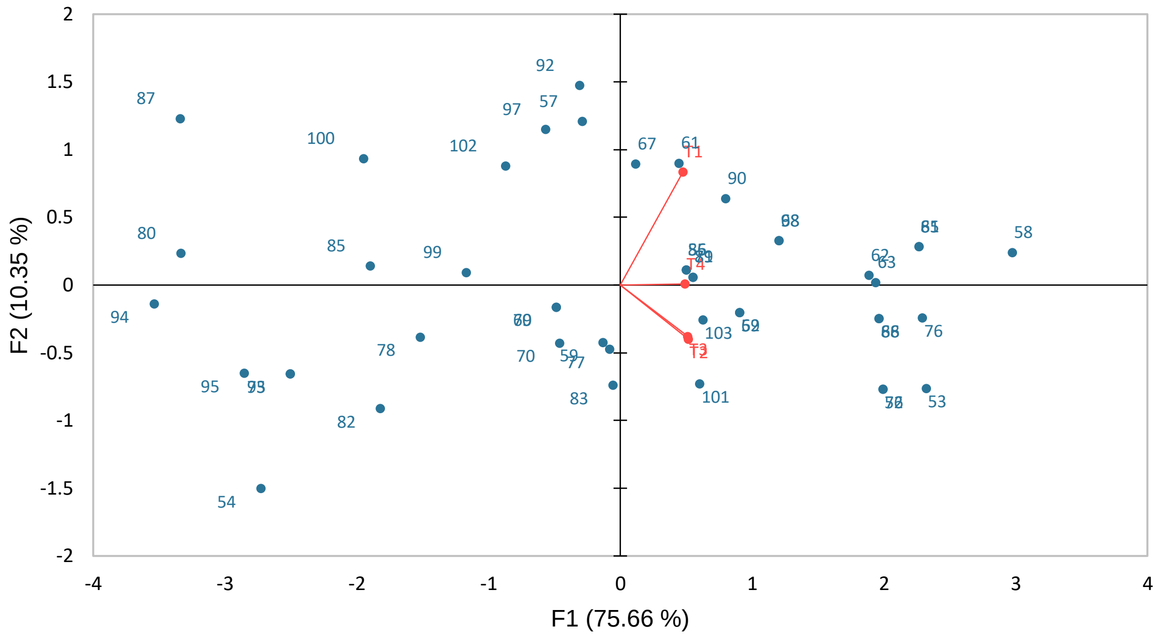

Figure E3 - Biplot for overall liking for the structured TL

Flavour

Table E15 – Breakdown of consumer clusters by agglomerative hierarchical clustering (AHC) for flavour

Free TL		Structured TL	
Cluster 1	Cluster 2	Cluster 1	Cluster 2
52	57	52	53
53	70	54	55
54	75	61	56
55	78	70	57
56	79	75	58
58	80	78	59
59	82	80	60
60	83	82	62
61	85	83	63
62	89	85	65
63	97	87	66
65	100	92	67
66	102	94	68
67		95	69
68		97	71
69		99	72
71		100	76
72		102	77
76		103	79
77			81
81			86
86			88
87			89
88			90
90			93

92			98
93			101
94			
95			
98			
99			
101			
103			

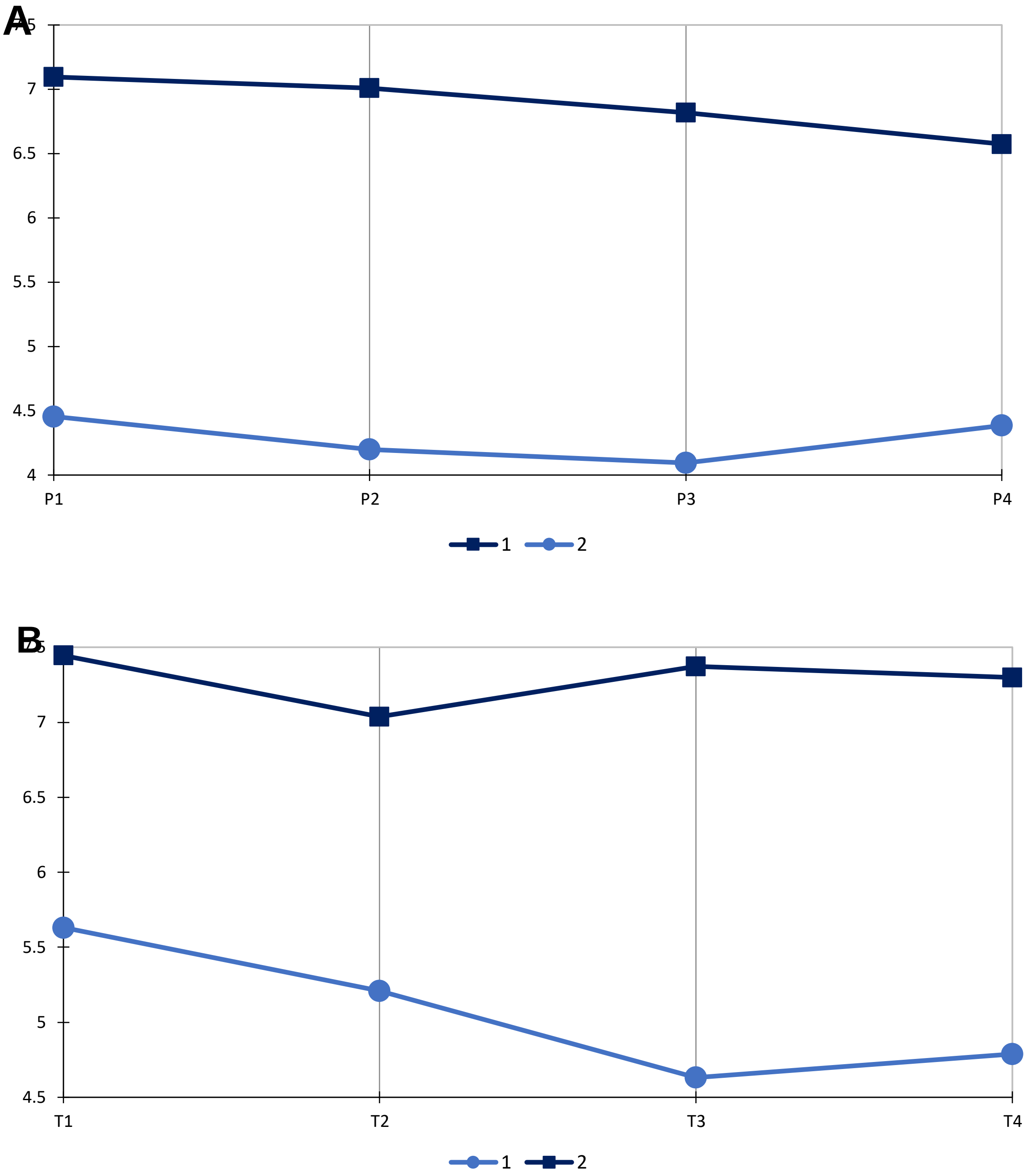

Figure E4 - Cluster curves for flavour for the (A) free TL and (B) structured TL

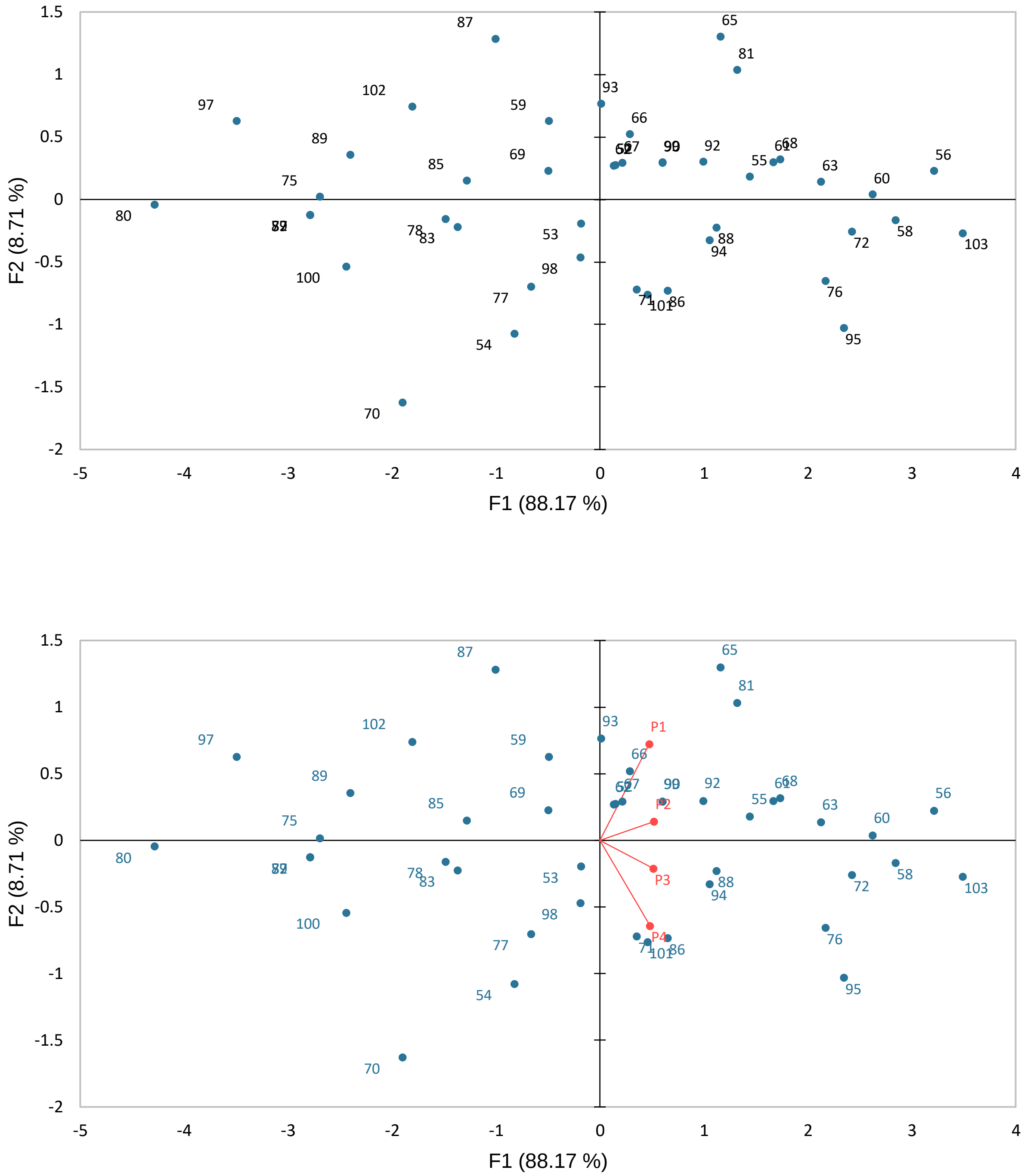

Figure E5 – PCA and biplot for flavour for the free TL

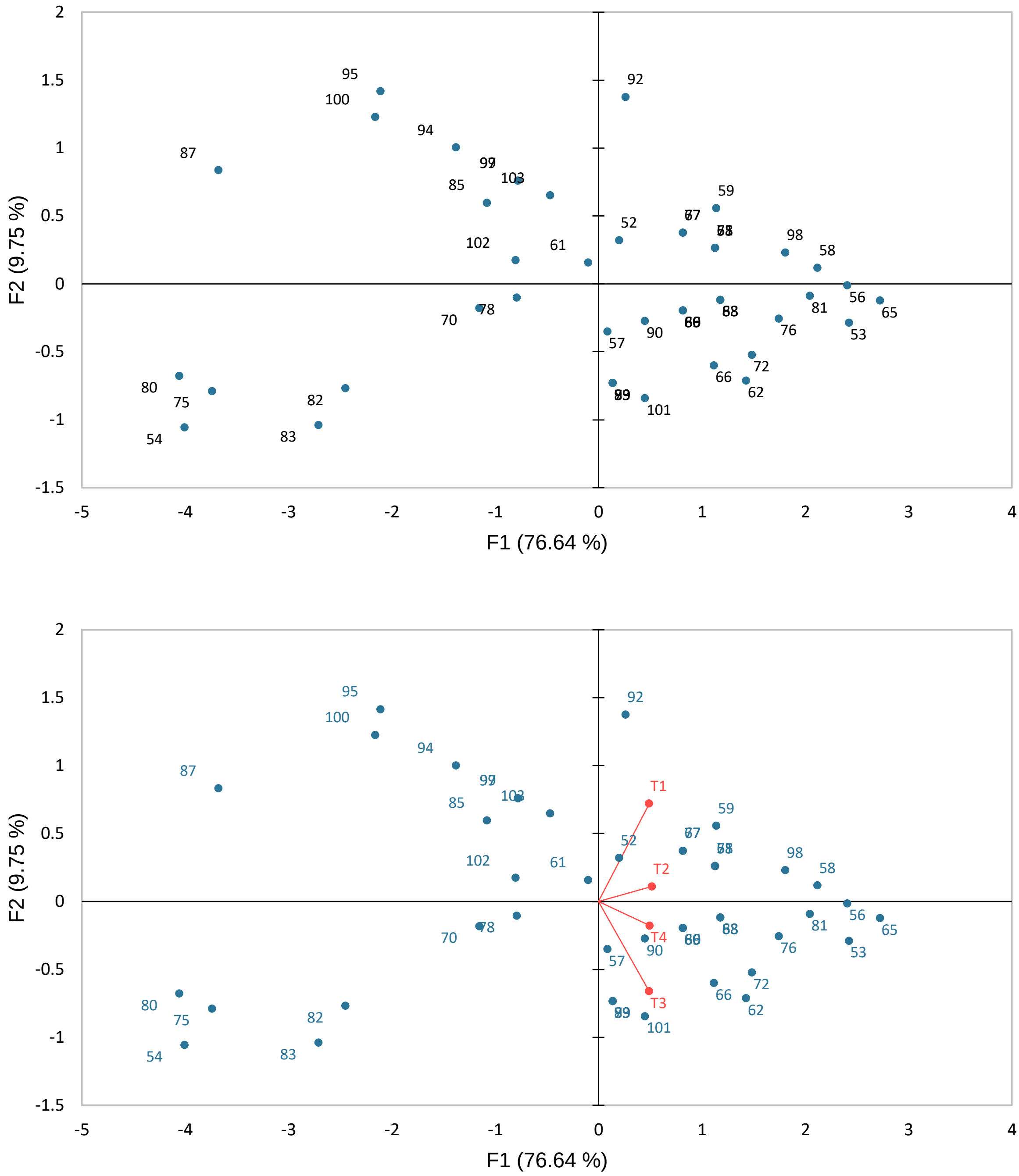

Figure E6 - PCA and biplot for flavour for the structured TL

Tenderness

Table E16 – Breakdown of consumer clusters by agglomerative hierarchical clustering (AHC) for tenderness

Free TL		Structured TL	
Cluster 1	Cluster 2	Cluster 1	Cluster 2
52	53	52	54
54	55	53	75
56	57	55	79
58	59	56	80
60	65	57	82
61	68	58	85
62	69	59	87
63	71	60	89
66	75	61	93
67	77	62	94
70	78	63	95
72	79	65	
76	80	66	
81	82	67	
94	83	68	
95	85	69	
98	86	70	
99	87	71	
103	88	72	
	89	76	
	90	77	
	92	78	
	93	81	
	97	83	
	100	86	

	101	88	
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		100	
		101	
		102	
		103	

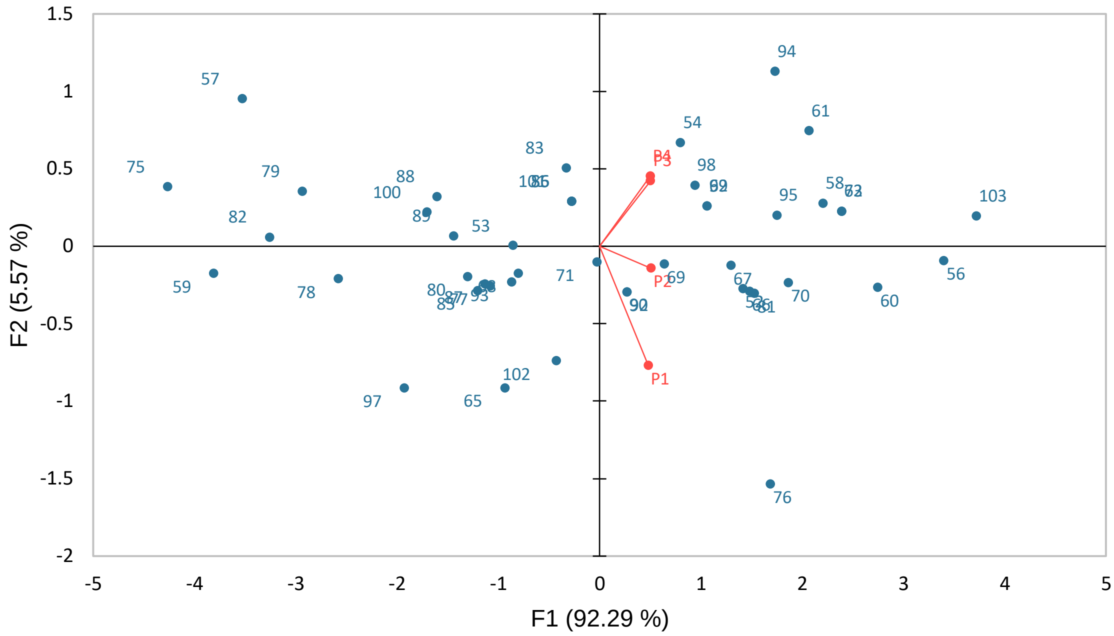

Figure E7 - Biplot for tenderness for the free TL

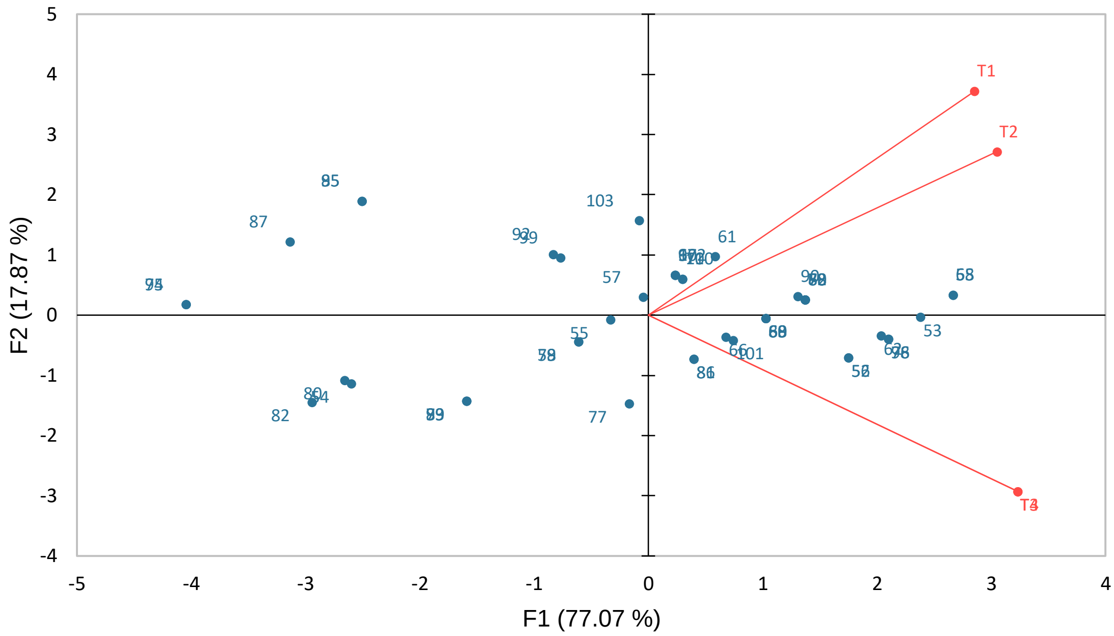

Figure E8 - Biplot for tenderness for the structured TL

Juiciness

Table E17 – Breakdown of consumer clusters by agglomerative hierarchical clustering (AHC) for juiciness

Free TL		Structured TL	
Cluster 1	Cluster 2	Cluster 1	Cluster 2
52	57	52	54
53	68	53	61
54	75	55	67
55	78	56	75
56	80	57	80
58	82	58	82
59	85	59	83
60	87	60	85
61	89	62	87
62	90	63	90
63	94	65	92
65	100	66	94
66		68	95
67		69	97
69		70	99
70		71	100
71		72	102
72		76	103
76		77	
77		78	
79		79	
81		81	
83		86	
86		88	
88		89	

92		93	
93		98	
95		101	
97			
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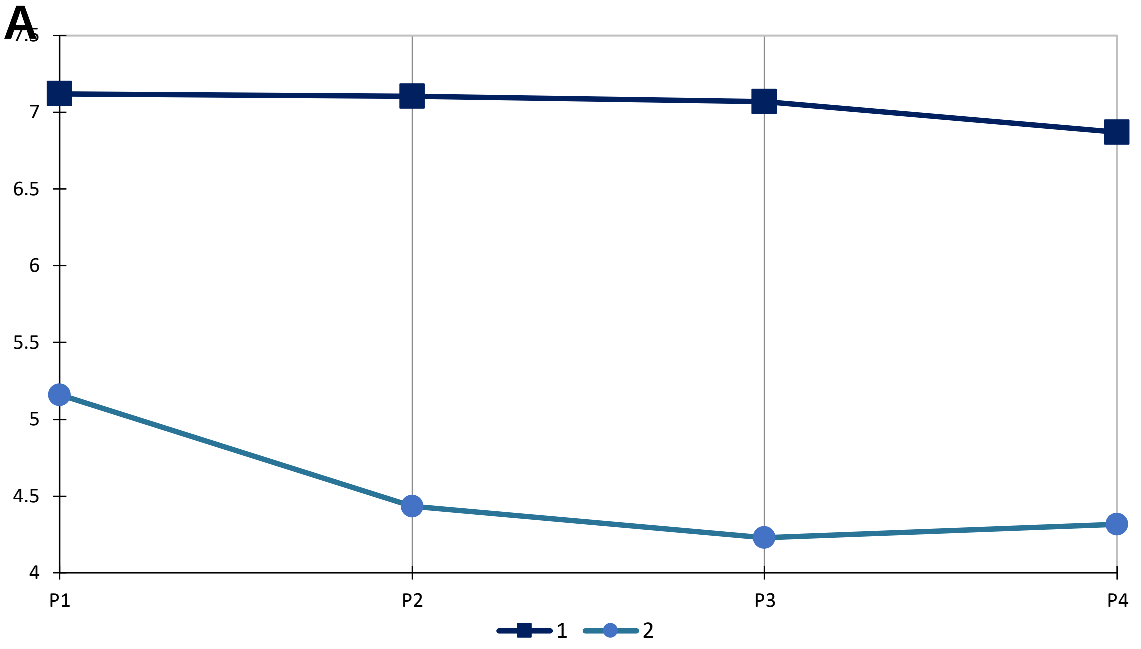
102			
103			



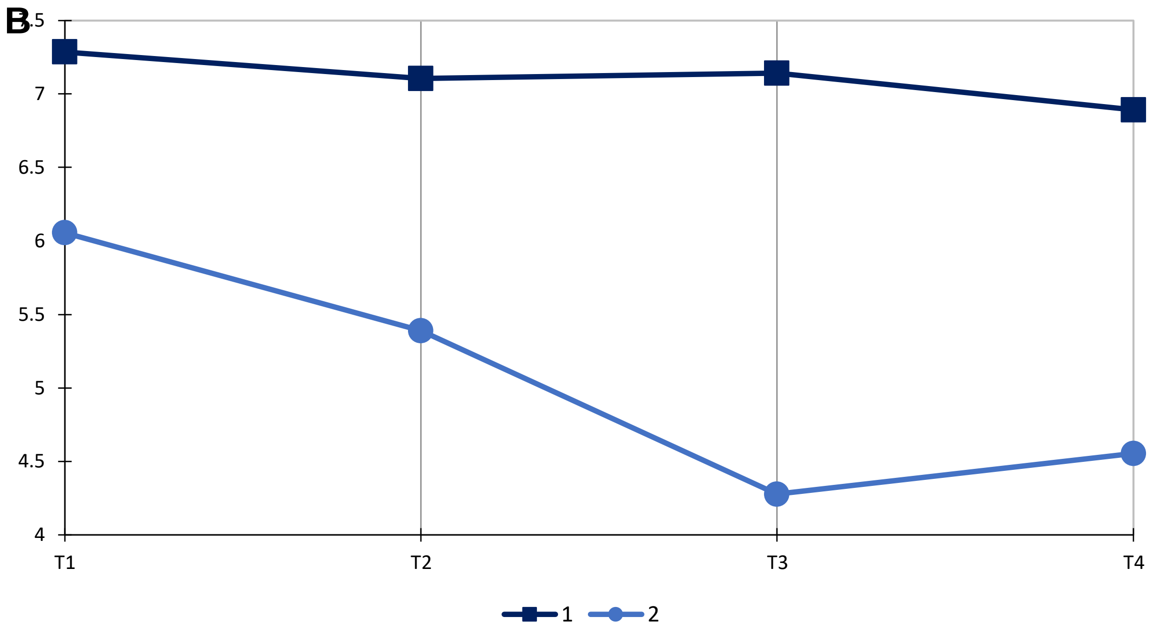
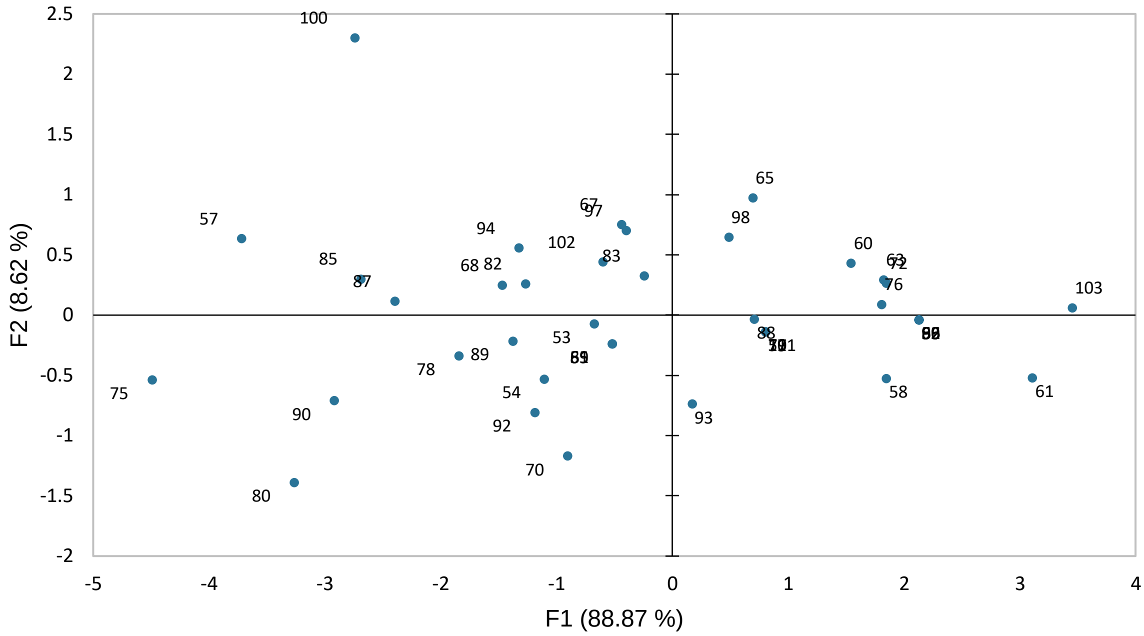


Figure E9 - Cluster curves for juiciness for the (A) free TL and (B) structured TL



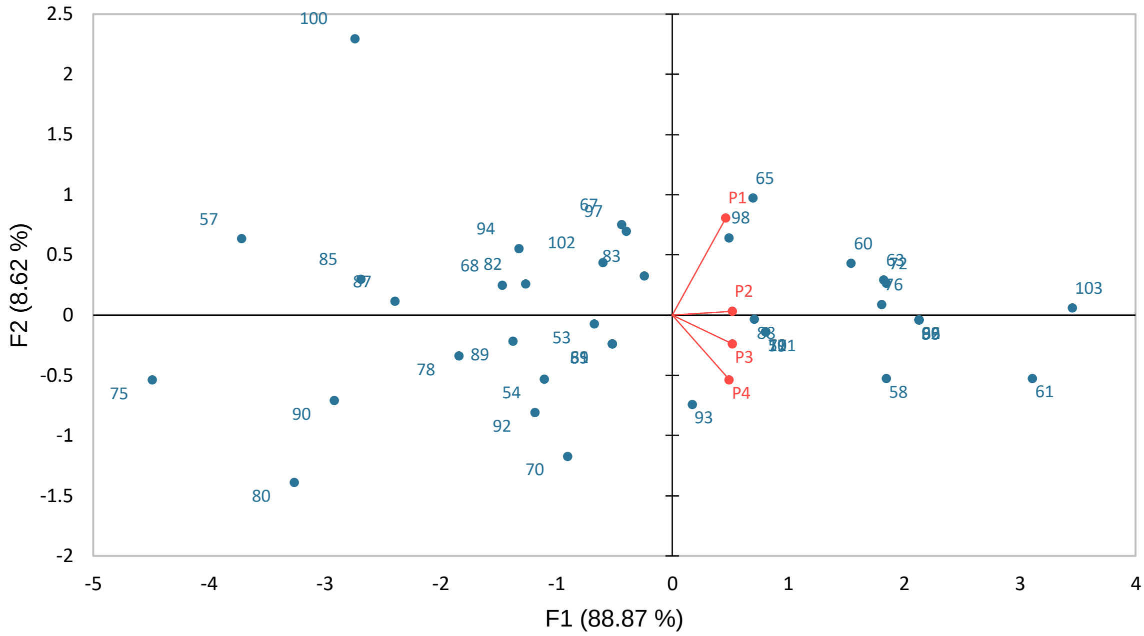


Figure E10 - PCA and biplot for juiciness for the free TL

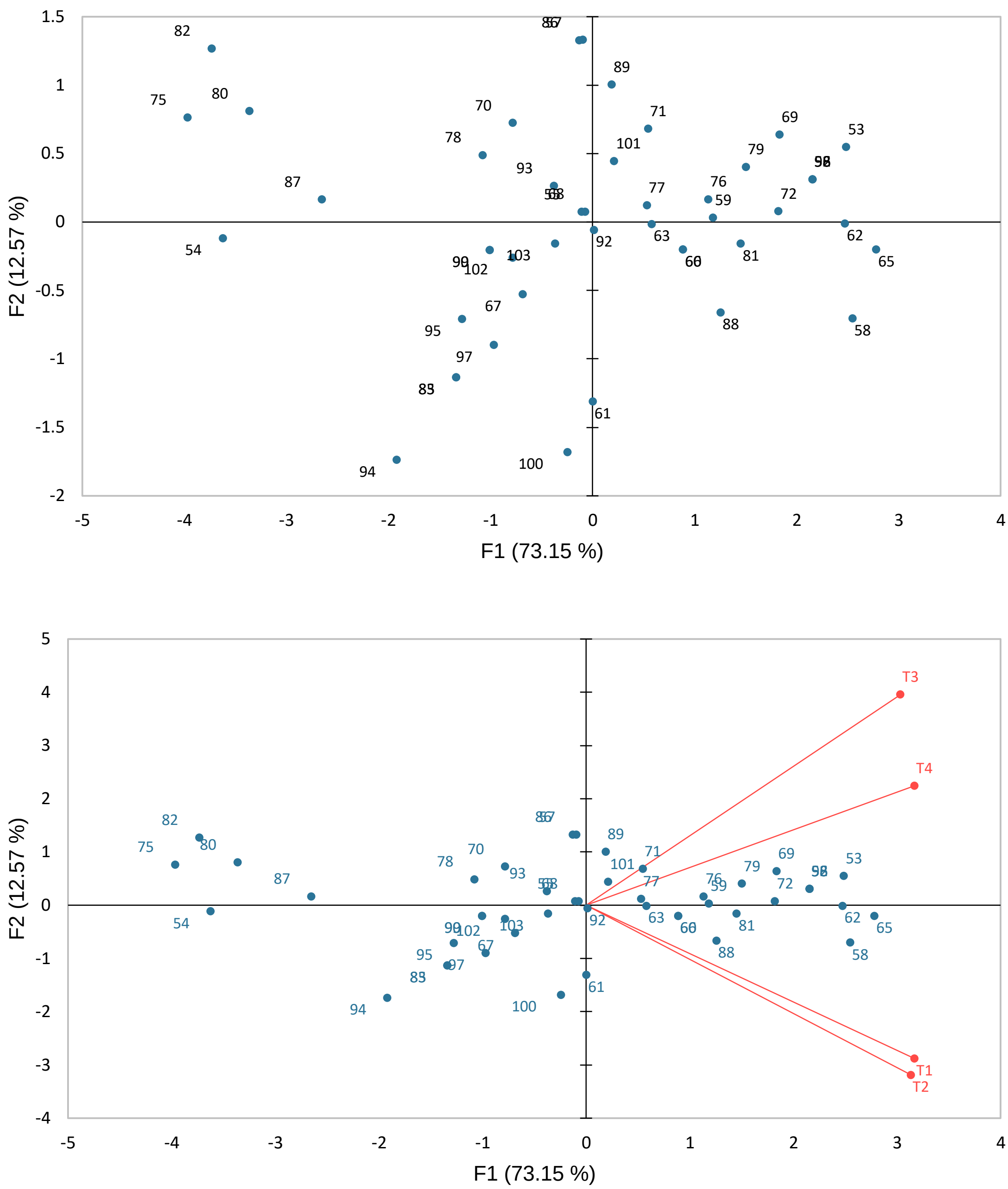


Figure E11 - PCA and biplot for juiciness for the structured TL