Understanding Consumer Sensory Perception of Beer and Wine Body

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‘Interesting! But what does it mean?!’

© Jack Skellington, The Nightmare Before Christmas

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Declaration

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Natalja Ivanova 15/04/2022

Abstract

Changes in consumer preferences, health concerns associated with excessive alcohol consumption, governmental policies and environmental conditions have driven research efforts towards exploring and producing alcoholic beverages with reduced alcohol content, namely beer and wine. A highly desirable and widely accepted mouthfeel attribute in beer and wine with lower alcohol – *body*, is important for consumer appreciation, willingness to buy, and overall acceptance of beverages. Nevertheless, to date, the concept is ill-defined. With lower alcohol products described as *imbalanced* and *thin*, the development of beverages with high consumer acceptability is required. Research indicates there is growth in the volume of lower alcohol wines and beers being exported, thereby emphasising the importance of meeting market demand and emerging opportunities guided by the consumer.

Reviewed research strongly suggests that *body* is not simply a one-dimensional texture element but is a multi-dimensional sensory attribute. This research, therefore, aimed to (i) explore consumer language used to describe *body* of two beverage systems: beer and wine, in the UK and Australia; (ii) develop beers and wines varying in attributes found to be important for *body* using flavour chemistry and sensory techniques and (iii) evaluate the impact of the varied compositional factors on consumer *body* perception and acceptability. In order to achieve these aims, four studies were conducted.

Firstly, British consumers' understanding of beer and wine *body* was investigated using qualitative methods - Focus Groups and Free Choice Description. It was evident from this exploratory study that *body* involves several modalities, including flavour and mouthfeel. According to the consumers, other essential factors emerged related to the conceptual perception of beer and wine *body*, including aroma, appearance, and quality. It was also demonstrated that specific flavours for both beer and wine such as dark fruit (blackberry, cherry, plum), citrus and tropical fruit, Maillard reaction, cereal, and barrel-aged (chocolate, coffee, caramel, smoke, grain, roasted malt) for beer and oak for wine, and characteristics, such as velvety, smooth, and creamy were perceived to contribute to *body*.

As directed by the initial qualitative study, further three studies were designed to explore the significance of modified intensities of flavour and mouthfeel characteristics on the perceived *body* and overall liking of beer and wine. Model beers and wines were developed with manipulated composition to understand the contribution of the varying factors on *body*

perception, sensory perception and liking. Furthermore, as suggested by qualitative research, various techniques to segment consumers were explored to understand if different groups of consumers perceive body using different sensory modalities. The perceived mouthfeel and flavour of the model beer were varied by the addition of ethanol (to increase alcohol by volume (ABV)), carboxymethyl cellulose (to increase instrumental viscosity), iso-α-acids (to increase bitterness) and hop oil extract (to enhance hoppy aroma) in a 0.05% ABV base beer. Results found that perceived viscosity was not a single characteristic that influenced beer *body* as ethanol and flavour (bitterness and hoppy aroma) were also found to be significant drivers. Cluster analysis based on *body* intensity ratings revealed three consumer clusters: those who placed greater importance on viscosity, those who appeared to focus on flavour and those who found alcohol to be the main *body* driver. Similarly, a study conducted with model red wine used a 0.05% ABV base wine with added ethanol (to 5.5% ABV), carboxymethyl cellulose, grape seed extract and a flavour blend (enhanced berry flavour) to explore the impact of varying alcohol warming sensations, perceived thickness/viscosity, astringency and flavour on *body* perception. Increasing the viscosity with carboxymethyl cellulose did not contribute to wine *body*. Instead, consumers perceived *body* intensity to be positively driven by ethanol and negatively correlated with berry flavour additions, whilst liking was driven by ethanol and carboxymethyl cellulose additions and negatively impacted by the enhanced berry flavour. Furthermore, using a statistical tool, namely Fine Wine Instrument, developed to segment consumers based on wine connoisseur, knowledge and provenance variables, it was also found that consumers are not homogenous when defining *body* as they placed differing levels of importance on different compositional factors. Three consumer segments, based on their wine-related knowledge and level of involvement, emerged: Wine Enthusiasts, Aspirants and No Frills.

Furthermore, the effects of various flavour enhancements on consumer *body* perception in different base wines were investigated, as the enhancement of berry flavour was found to negatively impact *body* perception in the previous study. Consumers reported that within red wines with full-strength alcohol (14.5% ABV), those that were enhanced with woody and savoury aromas were perceived as higher in *body*. In contrast, enhanced red fruit flavour negatively influenced the perception of *body*, confirming the hypothesis that different flavour profiles affect *body* positively and negatively.

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I hope you enjoy this *body* of research.

Chapter 1

General Introduction

General Introduction

Experts recognise that mouthfeel is fundamentally important for beer and wine quality and value in their respective marketplaces (Lukinac et al., 2019; Reynolds, 2010). Previous research reported that mouthfeel plays a significant role in consumer palatability, acceptability and enjoyment, alongside a willingness to buy (Lee et al., 2006; Niimi et al., 2017). Body, a mouthfeel concept term frequently used by technical experts has been described as the *weight on the palate* in wine (Jackson, 2002) and *a taste of substantial character, a sense of substance as felt on the palate* in beer (Clapperton, 1973). Pioneering work by Clapperton (1974), Meilgaard et al. (1979), and Langstaff et al. (1991, 1993) explored terms used to describe beer mouthfeel, aroma and flavour and made important contributions to the beer terminology wheel. In wine, it is often associated with oral-tactile stimuli (i.e. texture/viscosity) unrelated to taste or aroma (Laguna et al., 2017). In contrast, beer body has been previously described as *an overall impression of beer flavour* (Langstaff & Lewis, 1993a). For consumers, understanding wine body, its role, and the characteristics associated with the term are less known (Niimi et al., 2017). It is believed to be induced by ethanol and influenced by sugars, glycerol and phenolics in wine (Jackson, 2002), and ß-glucans, dextrins, ethanol, glycerol and glycoproteins in beer (Langstaff & Lewis, 1993a).

Body of wine has previously been explored instrumentally and with trained sensory panels (Gawel et al., 2007; Laguna et al., 2019; Moran et al., 2018; Runnebaum et al., 2011; Skogerson et al., 2009; Yanniotis et al., 2007); however, little attention has been paid to other beverages, such as beer, and no controlled studies have compared body definitions and understanding between different beverage systems from the perspective of the end-user.

Low-alcohol beers and wines are often perceived as lacking in flavour intensity and mouthfeel attributes, including body, by consumers (Bucher et al., 2018; Chrysochou, 2014). Consumer mindfulness of the harmful effects of excessive alcohol consumption has grown in recent years (Baptista et al., 2017; Petticrew et al., 2017), and the availability of nutritional information increases consumer perceptions of the healthfulness of beer and wine (Wright et al., 2008). Therefore, the industry's ability to deliver beers and wines with reduced alcohol content, that are acceptable and palatable to consumers is crucial. Nevertheless, significant gaps remain in understanding and quantifying the impact of compositional factors on consumer perception of body in alcoholic beverages, such as beer and wine.

The research conducted for this thesis aimed to gain an enhanced understanding of the mouthfeel concept - *body* from both beer and wine consumers' perspectives and quantify the impact of compositional factors on consumer perception of body, hedonic response and other sensory characteristics, could lead to improved sensory quality of commercial beers and wines that are currently described as lacking in body, specifically the lower and low-alcohol counterparts.

1.1 Alcohol and Health

According to the latest available reports on societal alcohol statistics, England estimated 358,000 alcohol-related hospital admissions between 2018 and 2019, 6% higher than the 2017/18 period and 19% higher than 2008/09 (NHS, 2020). In 2019, the UK registered an 11.3% increase in alcohol-related deaths since 2001, bringing the nation's total to 7,565 (Statistical Bulletin, Office for National Statistics, 2021). Furthermore, the latest statistics on global alcohol-related deaths reveal that 3 million people died in 2016 due to harmful alcohol consumption (WHO, 2018). Despite these statistics, the proportion of adults in the UK at higher risk of harm from drinking has decreased, showing a 5% drop for men and a 4% drop for women drinking six or more units daily between 2006 and 2018 (NHS, 2020). Health consciousness and wellness have been identified among the primary drivers attributed to changes in alcohol consumption, and the trend is predicted to continue impacting the alcoholic drinks industry (Ledovskikh, 2017).

The alcoholic beverage industry is worth billions of dollars globally. The wine industry, including winegrape-growing, wine making and wine tourism contributes approximately $40.2 billion annually to the Australian economy and employs over 170,000 people, many in regional areas (Australian Grape & Wine, 2019). In Britain, the beer and pub sector contributes £22 billion to UK GDP, providing close to 900,000 jobs (BBPA, 2018), whilst the wine industry generates £19 billion in economic activity, including sales to shops, supermarkets, restaurants, pubs and bars, and 130,000 jobs (Wine and Spirit Trade Association Budget Submission, 2015).

To reduce the negative health-related consequences caused by alcohol consumption, Australian health-conscious consumers are moderating how much they drink, joining various alcohol-abstaining movements, opting to drink less but better quality, and switching to emerging and innovative products (Market Bulletin, Wine Australia, 2020). Campaigns such as *Beer the Beautiful Truth*, *Go Sober for October*, and *Dry January (Dry July)* attract greater participant numbers each year (from just over 4,000 participants in 2011 for *Dry January* to 3.2 million in 2018) (Alcohol Concern, 2018). Some evidence previously emerged on the consumption of lighter wine styles amongst younger Millennials (25 - 35 years old) and older Baby Boomers (52 – 65 years old) generations (Bruwer et al., 2011). Overall, these statistics emphasise that harmful levels of alcohol consumption are still a significant health concern; however, consumer awareness and attitudes are turning towards more mindful alcohol consumption and healthier lifestyle choices.

1.2 Sensory Properties of Lower Alcohol Beers and Wines

Increased commercial demand for low and no-alcohol beverages has stimulated researchers and alcohol producers to innovate to deliver sensorially acceptable, low-alcohol products to satisfy consumer demand (De Francesco et al., 2018; Krebs et al., 2019; Salgado et al., 2017). In hotter climate regions that produce the majority of wine by volume consumed in Central Spain, Australia, South Africa, South America and the US, grapes contain higher fermentable sugars resulting in higher alcohol contents. Similarly, the alcohol content of wines has been on the rise in cooler climate regions, including Bordeaux and Tuscany, due to shorted vintages evoked by the warming climate. Examinations of temperature and precipitation values in the grape-growing regions are insufficient to explain climate change trends, as climate modifications are vastly complex. Therefore, several bioclimatic indices, including Huglin index (Huglin, 1978), Cool night index (Tonietto, 1999), Winkler or growing degree day index (Winkler et al., 1974), number of days with maximum temperatures higher than 30 °C (Ramos et al., 2018), number of days with precipitation <1mm (Dry spell index) (Moisselin and Dubuisson, 2006) are commonly used in viticulture to provide a better insight into climate change trends. At the global scale, trends in wine region climates have resulted in warmer growing seasons that have allowed many regions to produce better wine, while future climate projections indicate more benefits for some regions and challenges for others, such as undesirable higher alcohol content in the final product (Jones et al., 2005).

In beers, alcohol-reduction techniques include biological processes, namely, arrested fermentation, use of special yeasts and altered mashing (Brányik et al., 2012); and physical processing using thermal techniques (i.e. rectification or thin-film evaporation), as well as membrane techniques (i.e. dialysis, osmotic distillation, pervaporation, nanofiltration and RO) (Blanco et al., 2016; Brányik et al., 2012). In wine, these include pre-fermentative juice substitution with water (Schelezki et al., 2020a), early grape harvest (Teng et al., 2020), high-power ultrasounds (Martínez-Pérez et al., 2020), using special and immobilised yeast (Puškaš et al., 2020; Schmitt et al., 2019), and alcohol-removing techniques, namely, reverse osmosis (RO), evaporative perstraction and distillation methods, among others. Unfortunately, these methods significantly affect sensory characteristics, including tannin properties and overall volatile and flavour profiles of wines (Schelezki et al., 2020b) and beers (Blanco et al., 2016; De Francesco et al., 2020; Ramsey et al., 2021). In wine, the alcohol content influences taste perception by inducing textural (Pickering et al., 1998), sweetness and bitterness (Lesschaeve et al., 2012; Mattes & DiMeglio, 2001) and palate hotness changes (King & Heymann, 2014), in which affects balance and harmony between sensory properties in wines with manipulated alcohol content.

Despite efforts made by research and industry to develop acceptable lower alcohol beverages, consumers are still uncertain about their taste (Chrysochou, 2014; Myles et al., 2020). The shift in harmony between sensory properties must be rectified as the *balance of flavours,* and wine body are among the most important descriptors when choosing wine for purchase (Niimi et al., 2017). In beer, Ramsey et al. (2018) used a temporal approach to evaluate the effects of ethanol on sensory profile in lager beer and reported reduced consumer perception of maltiness. In de-alcoholised beers, De Francesco et al. (2020) found several crucial aroma and taste attributes were affected: fruity/estery, alcoholic, worty flavours, sweet and sour tastes, as well as observed diminished body and shorter aftertaste. Therefore, it seems that both beverage systems suffer from similar challenges in developing acceptable low-alcohol products.

1.3 Texture, Mouthfeel and Body Perception in Beer and Wine

The texture and mouthfeel of foods and beverages have been extensively studied as major determinants of consumer acceptance and preference (Guinard & Mazzucchelli, 1996). In earlier research, texture has commanded little attention compared to flavour attributes of foodstuffs and beverages and is still largely under-investigated in alcoholic drinks. Early definitions of texture focused on the somatosensory system, whereas later definitions include inputs from auditory and visual systems. Matz (1964) proposed a definition of oral texture, which stated that texture is *'the mingled experience deriving from the sensations of the skin in the mouth after the ingestion of food or beverage, as it relates to density, viscosity, surface tension and other physical properties of the material being sampled'*. Bourne (1975) defined texture as *'the response of the tactile senses to physical stimuli that result from contact between some parts of the body and food'*, with a later definition from Szczesniak (1990), which read '*the sensory manifestation of the structure of the food and the manner in which this structure reacts to the applied forces, the specific senses involved being vision, kinaesthesia and hearing*'. Lastly, the most referred-to definition was presented by the International Standard Organisation (ISO, 1994), stating that texture is '*all the mechanical, geometrical and surface attributes of a product perceptible by means of mechanical, tactical and, where appropriate, visual and auditory receptors*', accenting the current understanding of texture as a multi-modal experience.

1.3.1 Oral Physiology: The Somatic Sensory System

The sensation is defined as a *receptor response to the stimulation*, whereas perception is defined as *awareness through the senses interpreted in the light of experience* (Oxford University Press, 2013). The somatic sensory system includes two distinct sub-systems: (i) for the detection of mechanical stimuli, including touch, vibration and pressure, and (ii) for the detection of painful stimuli and temperature (Purves et al., 2001). Furthermore, it applies four principles that describe significant functions of the system, including (i) an ability to recognise the size, shape and texture of foodstuffs and beverages, referred to as discriminative touch (mechanoreceptors); (ii) jaw static positioning or movement mechanism, known as proprioception; (iii) pain sensations as a result of oral and/or nasal tissue damage (nociception); as well as (iv) sensations evoked by the temperature (thermoreception). It is well known that different parts of the body have different levels of tactile sensitivity, illustrated by the sensory homunculus, where the mouth, tongue, lips and hands have a greater density of receptors than other parts of the body.

Mechanoreceptors are responsible for sensing pressure, stretching, and tapping on the skin. Three different types of mechanoreceptors have been identified in the mouth, oral mucosa and lip area, including (i) slowly adapting nerve units type I (SA I), (ii) type II (SA II), which end in Merkel cells and Ruffini cylinders, and rapidly adapting nerve units (iii) type I (RA I), ending in Meissner corpuscles. Due to differences in receptive fields, slowly adapting receptors are better suited for resolving fine details due to small and well-defined receptive fields (oral mucosa and the transitional zone of the lip), whereas rapidly adapting receptors (found on the tongue) only respond to the application and removal of the stimuli, due to the larger and less well-defined receptive fields. By eliminating superficial mechanoreceptors of the tongue and palate with a topical anaesthetic, the influence on thickness, texture and overall mouthfeel perception could be silenced (Fujiki et al., 2001), suggesting that within the oral cavity, the texture is mainly perceived by mechanoreceptors on the tongue and tissue lining the oral cavity.

Proprioceptors. Two sub-modalities of proprioception exist: sense of (i) stationery limb positioning and (ii) limb movement. It was previously reported that proprioception plays a minor role in the perception of thickness and texture, whereas mechanosensors contribute largely to these mouthfeel sensations (Kutter et al., 2011).

Nociceptors. Nociceptors mediate pain sensation through specialised nerve endings. The stimuli, including intense pressure, extreme temperature or burning, activates nociception and may produce tissue damage; therefore, the main function of nociception is protective. The vanilloid receptor-1 (VR1), expressed on the peptidergic nociceptors, elicited a burning sensation via administration of capsaicin and subsequent release of neuropeptides, which is a similar sensation that is reported when consuming alcohol. The burning response to ethanol was previously studied and was evident in smaller concentrations (0.1 – 3.0% ABV). Ethanol caused a concentration-dependent neuropeptide release from the central (dorsal spinal cord) and peripheral (oesophagus and skin) terminals of capsaicin-sensitive nociceptors (Trevisani et al., 2002). Irritation of the tongue caused by ethanol acting as a chemical stimulus mediated through nociception (Green, 1988) may play a role in the perception of fullness.

Thermoreceptors. Thermoreceptors mediate the thermal sensation resulting from temperature differences of the air, objects or foodstuffs and the average skin temperature. Guest et al. (2008) studied area activations in the brain whilst liquids of different temperatures were presented into the mouth. Although the focus of the Guest et al. (2008) study was on the relationship between temperature and the evoked pleasure of oral stimuli, results showed that the bilateral activation of the primary somatosensory cortex (SI) was apparent during the presentation of hot (50^{o}C) and cold (5^{o}C) liquids, but not the glucose solution of neutral temperature (20^{o}C), suggesting the thermoceptive nature of the SI response, rather than hedonic or gustatory. It was also proposed by Guest et al. (2008) that the insula is responsible for hedonic aspects of oral temperature, where it overlaps with the taste coding. Mid-insula was also proposed as a somatosensory and taste-independent region in the brain that codes the viscosity of liquids (Verhagen et al., 2004).

It was suggested that unlike the responsibility of specialised receptors for taste perception, the detection of texture and mouthfeel perception involves a number of different sensory systems of a multi-modal nature (Kutter et al., 2011). In the mouth all types of receptors, except the photoreceptors sensitive to electromagnetic energy, are present. The chemical receptors include taste and odour; the mechanoreceptors mediate sensations of touch and proprioception; the thermoreceptors sense the temperature of the body and objects that we come in contact with; and nociceptors signal sensations of pain. All these types of receptors contribute to the total sensation and perception of food that is ingested. However, in the sensation and perception of oral texture, tactile stimuli are probably the most prominent clues to texture.

1.3.2 The Gustatory System

The chemical sense of gustation (taste) involves the detection of five fundamental taste categories (sweet, sour, bitter, salty and umami) (Chaudhari & Roper, 2010), which are extremely important in alcoholic beverages. The membranes of the taste receptor cells contain ion channels that are organised into taste buds and allow the binding of the tastant molecules. Beverage systems, namely beer and wine, contain sugars eliciting sweetness, acids eliciting sourness, iso-acids and phenolic compounds eliciting bitterness, with fewer compounds eliciting saltiness or umami. Papillae number on the tongue can influence oral tactile and taste sensitivity. Four different papillae structures are found on the tongue: filiform, fungiform, foliate and circumvallate (Bennett, 2004) (Figure 1.1).

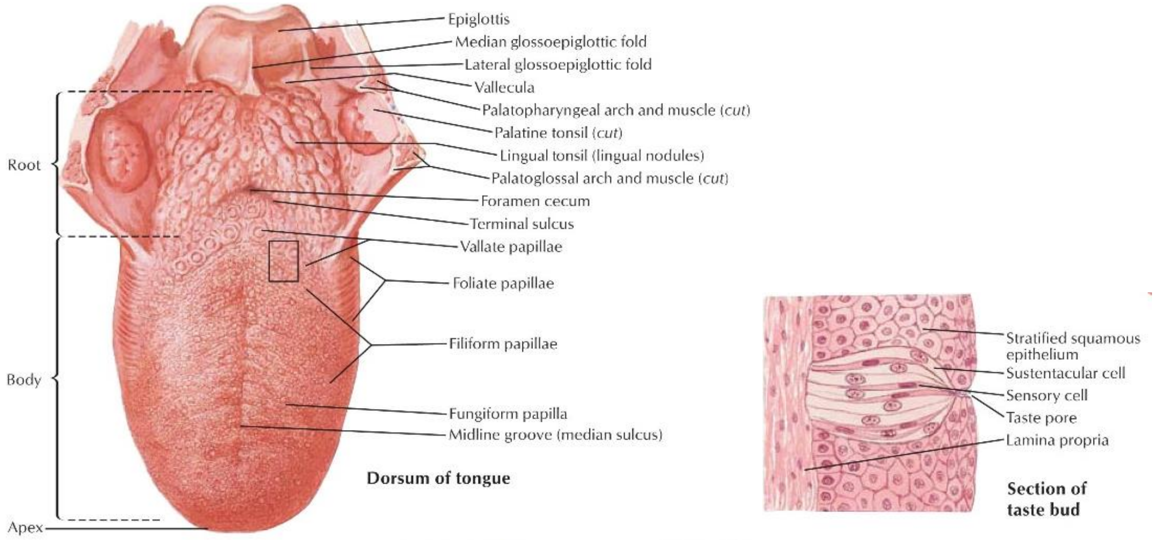

Figure 1.1: Schematic representation of tongue and taste bud anatomy. Licensed by Netter Images © Elsevier, Inc.

Due to the lack of taste receptors but susceptibility to mechanical, thermal and nociceptive stimuli through the nerve endings, filiform papillae are believed to be responsible for mechanical perception (Dimitrijevic & Pantic, 2016). Fungiform papillae are surrounded by trigeminal neurons responsible for innervating tactile perception (Whitehead et al., 1985), influencing the perception of mouthfeel when food or beverage is consumed (Nachtsheim & Schlich, 2013). The signal from the stimuli presented to the filiform papillae transfers sensory input through the trigeminal ganglion to the brainstem by the trigeminal nerve (Jacobs et al., 2002). Previously, a positive relationship between tactile sensitivity and fungiform papillae density was found via a modified letter identification task (Bangcuyo & Simons, 2017), suggesting that fungiform papillae density can act as a tactile sensitivity predictor and influence mouthfeel perception. Furthermore, some evidence suggests that stratified squamous epithelium covering the oral cavity may play a role in mouthfeel, as demonstrated by the procyanidin binding to the epithelial cells and related to astringency perception in wine (Payne et al., 2009).

1.3.3 Oral processing

Most sensations associated with texture occur when food or beverage are consumed, manipulated, deformed or moved across the oral receptors. Texture perception has been previously related to consumer behaviour of chewing and swallowing (Brown et al., 1994). Within the setting of the sensory experiment, the manipulations in the mouth and swallowing behaviour may not be representative, as savour time and muscle work rate may act as major discriminating factors where individuals with shorter processing time might perceive texture differently. For example, in a study on no-alcohol beers (ethanol content <0.5% alcohol by volume (ABV)), the undesired by-product, namely worty off-flavour as a result of the de-alcoholisation process, has been investigated (Missbach et al., 2017) and the worty off-flavour was been most pronounced before swallowing; therefore, a faster swallowing behaviour was proposed to bypass worty-off exposure dominance. Similar manipulations to avoid or allow certain textural characteristics might shed light on differences in textural perception between individuals.

As texture perception is a highly dynamic process, beverages will undergo continuous modification during consumption, including dilution by saliva and increased temperature (Stokes et al., 2013). Therefore, the assessment of the same beverage could differ due to large inter-individual variations of these oral physiological parameters. It is unclear if there are large differences in oral tactile acuity due to variations in the number of texture receptors, their spatial acuity or oral receptor sensitivity, but these factors could also contribute to variation in perception.

1.3.4 Multisensory Texture Perception

Interactions within modalities are well documented, a phenomenon called `mixture suppression' was observed by Pangborn (1961, 1963, 1964), who noted that a mixture of two or more tastants results in lesser taste intensity than the sum of tastant taste intensities individually. Later studies have identified taste-taste interactions across the five basic tastes resulting in both suppression and enhancement dependant on tastant and concentration (Indow 1969; Breslin 1996; Keast et al. 2003).

The texture is multi-dimensional, incorporating the perception of various attributes relevant to beer and wine, such as thickness, roughness, coarseness, smoothness, stickiness, or density, with some of those attributes sensed across modalities. Even before the texture is assessed in the oral cavity, the first textural impressions of a beverage can be sensed visually (Kutter et al., 2011) or retronasally (Bult et al., 2007; Niimi et al., 2017). Colours are readily associated with tastes and flavours and are studied excessively (Ballester et al., 2009; Fernández-Vázquez et al., 2014; Frank et al., 1989; Harrar et al., 2011; Koch & Koch, 2003; Lavin & Lawless, 1998;

Morrot et al., 2001; Zampini et al., 2007), yet the effect of colour on texture is less examined. In foods, the cross-modal influence of colour on the perception of mouthfeel sensations, such as spiciness (perceived piquancy) (Levitan & Shermer, 2014), warming and cooling (Ho et al., 2014), creaminess and crunchiness (Chylinski et al., 2015) were previously explored. When exploring food and drink pairings, consumers reported that angular-shaped foods with more complex flavours were better to pair with carbonated beverages (Spence & Gallace, 2011). The high carbonation and bitterness in beer were associated with hard, angular shapes (Deroy & Valentin, 2011). A study explored the colour influence on perceived flavour in alcoholic cider drinks and found that cider sample coloured red was perceived as fuller in body (as well as fruitier and sweeter) (Sugrue & Dando, 2018). The effect on expectation and overall experience of colour in beer was also previously studied. Interestingly, findings revealed that the expectations of the mouthfeel component – body – were altered based on the colour of the beer (i.e. darker beer was expected to have more body) (Carvalho et al., 2017). Overall the findings suggest that the visual system may influence texture and mouthfeel expectations and, subsequently, tasting experiences.

Furthermore, investigations into aroma and mouthfeel perception in beverages, including beer and wine, are of great interest to researchers; however, reports are limited (Thomas-Danguin et al., 2016). Previously, a limited number of studies determined cross-modal sensory interactions, in beverage matrices, between volatile stimuli and texture perception and demonstrated significant effects. A study explored the impact of cocoa flavour added to the milk base containing caffeine and measured the perceived responses for basic tastes, including bitter, sour and sweet, as well as body. It was reported that body intensity did not significantly change when the cocoa flavouring was present. The intensities of overall flavour, thickness and creaminess were measured by the participants who were presented with a cream odour ortho or retronasally at certain times, whilst milk-like foods with manipulated viscosities were presented in the mouth (Bult et al., 2007). Bult et al. (2007) reported that the increased viscosity of the liquid negatively affected perceived flavour intensity irrespective of aroma stimuli presentation (ortho or retronasally), whereas the retronasal presentation of the aroma stimuli increased the intensities of thickness and creaminess. Furthermore, different volatile extract compositions and their effects on the perception of astringency and other sensory characteristics in reconstituted wines were studied, and the results showed that volatile extract exhibiting fruity characteristics decreased astringency and bitterness perception, and increased sweetness in white wine (Sáenz-Navajas et al., 2010), suggesting a multi-modal effect.

Furthermore, panellists reported perceiving ciders as more astringent when evaluating samples without wearing a nose clip (Symoneaux et al., 2015), indicating that retronasal aroma contributes to mouthfeel perception.

Niimi et al. (2017b) evaluated the effects of alum-volatile combinations on flavour, astringency and sourness in aqueous solutions and reported that astringent mouthfeel was significantly enhanced by the addition of 3-isobutyl-2-methoxypyrazine (IBMP, green flavour), suggesting that the two perceptions were harmonious, as per the notion highlighted by Prescott (2012) who indicated that for cross-modal enhancement to occur, congruency between the two stimuli is required when combined (Prescott, 2012; Small & Prescott, 2005). The enhancement can also be explained by specific learning and conditioning effects from exposure to other foods, such as unripe and astringent fruit exhibiting green flavour character (Jiang & Kubota, 2004). In a later study, the green character was linked to the vegetal aroma, astringency, green flavour and dry tannins in red wine (Sáenz-Navajas et al., 2018). However, another study found no significant effects of aroma, sourness or bitterness on astringency intensity in red wines (de-la-Fuente-Blanco et al., 2017), suggesting that cross-modal interactions are not relevant to the perception of astringency. The difficulty for such investigations may lie in dissociating physicochemical effects (between aroma stimuli and constituents producing texture) from cognitive effects that are processed centrally.

1.3.5 Texture Processing in the Brain

Texture, similarly to flavour, is multi-motor and an active sense, perceived through the relevant motor systems that activate the sensory pathways and central brain systems. Tasteless and odourless viscosity modification using carboxymethyl cellulose (CMC) was used to investigate the representation of the stimuli in the human brain using functional magnetic resonance imaging (fMRI) (De Araujo & Rolls, 2004). The results revealed that the viscosity of the oral stimuli was represented in the primary taste cortex in the anterior insula and mid-insula region that was posterior to the taste cortex. When fat was present using fatty vegetable oil, additional regions, including the hypothalamus and the dorsal mid anterior cingulate cortex, were activated (De Araujo & Rolls, 2004). Specific neurons in the orbitofrontal cortex (OFC) were found to encode the particulate quality of food. They were shown to respond (measured as the increased firing rate) to viscosity (CMC) alone (bk244) and viscosity and certain tastes exhibited by glucose (sweet), HCl (sour), and quinine (bitter). The neurons did not respond to oils or capsaicin (Rolls, 2005), suggesting that independent neurons in the brain react to sensory stimuli, such as viscosity or a combination of stimuli. In combination with oral texture, neurons in the insular primary taste cortex also responded to temperature (Kadohisa et al., 2005). It was argued previously that taste and viscosity activate single neurons in the OFC and amygdala, whereas different neurons depending on stimuli are activated in the primary taste cortex, based on the hierarchical organisation illustrated in Figure 1.2 (Rolls et al., 2010).

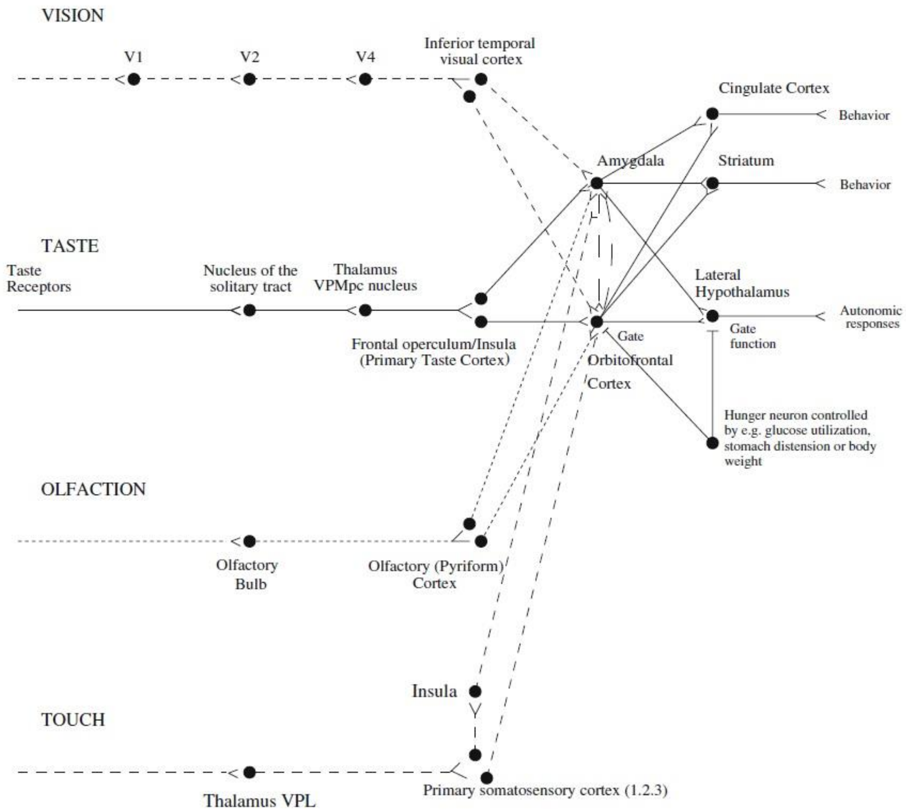

Figure 1.2: A schematic representation (Rolls et al., 2010) of taste and related olfactory, somatosensory and visual pathways in primates (including humans). V1, V2, V3: visual cortical areas; VPMpc: ventral posteromedial thalamic nucleus; VPL: ventral posterolateral nucleus

Humans use complex procedures that require higher cognitive functions, such as memory and emotions, when integrating several sensory modalities, including vision, taste and olfaction. Castriota-Scanderbeg et al. (2005) demonstrated activations in areas during a wine tasting implicated in the high-level cognitive processes, including working memory and selection of behavioural strategies, namely the dorsolateral prefrontal cortex. Furthermore, the activation of the cerebral network (left insula and adjoining OFC) responsible for gustatory and olfactory integrations (Cerf-Ducastel & Murphy, 2001) was also seen in the experienced sommeliers during wine tasting. In contrast, naïve participants showed activation in brain areas implicated in emotional processing including the amygdala (Sergerie et al., 2008) and the primary gustatory cortex (Castriota-Scanderbeg et al., 2005).

1.4 Mouthfeel and Body Classification

A well-defined and agreed-upon characterisation and classification of sensory attributes in food and beverage products are the backbone of sensory research. Various sensory lexicons and attribute wheels have been developed and proposed to characterise products, including those of interest, namely beer and wine. The aim of the agreed-upon and standardised vocabularies used by the sensory and industry experts, including product developers and marketers, is to objectively describe the product's sensory properties and effectively communicate those to the consumers (Demiglio & Pickering, 2008; Gawel et al., 2000).

One of the first efforts to classify and define texture and mouthfeel terms in beverages was made by Szczesniak (1979). The study examined the lexicon used by 103 panellists, who provided mouthfeel terms for 33 different drinks. It concluded that mouthfeel could be reduced to 11 categories, including viscosity-related terms, feel on soft tissue surfaces, carbonation-related, body-related terms, chemical effects, coating of the oral cavity, resistance to tongue movement, after-feel, after-physiological, temperature- and wetness-related terms. Body-related terms were presented as *heavy*, *watery* and *light*. The two major mouthfeel terms in beer were identified as *body* and *viscosity* (Brown et al., 1978); however, no comprehensive definitions were proposed. Other attributes included in Brown et al. (1978) work were *warming, carbonation, powdery, astringent, metallic, mouth-coating* and *alkaline*. Three dimensions of beer mouthfeel were proposed later by Langstaff et al. (1991), namely after-feel (stickiness, astringency, oily mouth-coating), fullness (viscosity and density) and carbonation (carbon dioxide, foam volume, bubble size, sting), suggesting that fullness is a function of texture. A mouthfeel wheel for red wines was proposed by Gawel et al. (2000). It included several overarching and interacting sensations: acidity, sweetness, bitterness, retronasal aroma perception (flavour), viscosity, warmth, and astringency. Pickering and Demiglio (2008) proposed a white wine mouthfeel wheel, with a comprehensive review of white wine mouthfeel released later by Gawel et al. (2018). Table 1.1 summarises the main attribute groups included in the dedicated mouthfeel and flavour wheels for beer, white and red wine.

Table 1.1: Summary of main attribute groups of the mouthfeel attributes in the sensory wheels for beer, white and red wine

Product	Mouthfeel attributes included		References
Beer	Mouthfeel	Warming	Brown et al. (1978)
		Carbonation	
		Powdery	
		Astringency	
		Metallic	
		Mouth-coating	
		Alkaline	
	Fullness	Body	
Beer	Carbonation	Sting	Langstaff et al. (1993)
		Bubble size	
		Foam volume	
		Total carbon dioxide	
	Fullness	Viscosity	
		Density	
	After-feel	Oily mouth-coat	
		Astringency	
		Stickiness	
Beer	Mouthfeel	Tingly	Schmelzle (2009)
		Warming	
		Astringent	
		Pungent	
	Body	Viscosity	
		Density	
	Foam	Foam structure	
		Foam volume	
White wine	Early	Taste (sweetness, acidity, saltiness)	Gawel et al. (2000); Pickering & DeMiglio (2008)
		Tingle	
		Pucker	
		Mouth-water	
		Mousse dynamics	
		Fullness (viscosity & weight)	
		Surface texture	
	Finish	Irritation	
		Mouth-coat	
		Taste (bitterness)	
		Overall drying	
		Length	
	Integrated	Volume, depth & smoothness	
		After-feel/finish	
		Balance & overall impression	

Red wine	Feel	Weight (watery, thin, full, viscous)	Gawel et al. (2000)
		Texture	
		Heat	
		Irritation	
	Astringency	Particulate	
		Surface smoothness	
		Complex	
		Drying	
		Dynamic	
		Harsh	
		Unripe	
	Flavour	Concentration	
		Activity	
		Lift	
	Acidity	Metallic	
		Steely	
		Sour	
		Soapy	

Overall, the developed wheels mention *body* or *fullness* for beer and white wine and attribute those terms to physical components such as viscosity, density and weight, suggesting that body is a physical, oral-tactile sensation unrelated to aroma, taste or flavour. This contradicts the findings of the later studies, where wine body was reported to be mostly correlated with ratings of flavour and perceived viscosity (Gawel et al., 2007), as well as understood as a holistic multi-sensory perception of flavour using attributes such as *flavour, fullness* and *strength* by regular wine consumers (Niimi et al., 2017a). An earlier study using a trained panel to explore key constituents affecting wine body proposed *viscous mouthfeel* alone as a descriptive term for the panellists during training and used methylcellulose, a widely known thickener, as a reference standard to anchor the attribute (Runnebaum et al., 2011). A major gap exists for scientifically controlled data investigating the impact of flavour, and other compositional factors, such as basic taste, alcohol, phenolic compounds, polysaccharides and carbonation, on the mouthfeel characters of beer and wine.

Previously, researchers have questioned the effectiveness of the mouthfeel wheels regarding trained panellists and consumers. It was highlighted that modification and simplification must be adopted to better understand the product characteristics from the sensory panellists and consumer perspective, pointing out that the mouthfeel wheels were too *complex* and *confusing* (DeMiglio et al., 2002; King et al., 2003).

1.5 Components Attributed to Body Perception in Beer and Wine

Traditionally, beer and wine are alcoholic beverages produced from raw materials by fermentative processes. Beer is obtained from malted cereal grains, such as barley, and in some cases adjuncts, such as corn and rice, by yeast fermentation. Hops (*Humulus lupulus*) and water are added. Similarly, wine is produced from the fermentation of must or juice, traditionally using common grapevines (*Vitis vinifera L.)*, where yeast consumes the grape sugars to yield ethanol and carbon dioxide (CO_2). Fundamental components, namely, ethanol, glycerol, volatiles, organic acids, iron-reactive phenolic compounds, polysaccharides and carbonation, are known to have physicochemical and sensorial effects on beer and wine overall aroma, flavour and mouthfeel sensations, as suggested by the literature (Dietz et al., 2020; Gawel et al., 2016; Ickes & Cadwallader, 2017; Jones et al., 2008; Nolden & Hayes, 2015; Rübsam et al., 2017; Runnebaum et al., 2011).

The key objective of this research was to develop an understanding of the multi-sensory yet poorly defined mouthfeel concept – body. The following sections will examine the emerging role of body perception through an investigation of the literature on compositional factors in beer and wine attributed to mouthfeel and body and its sensory influences, highlighting and addressing the existing research gaps.

1.5.1 Ethanol

The typical alcohol content in beer is between 5-12% ABV, whereas the typical alcohol content generated in wines is 8-14% ABV (Ickes & Cadwallader, 2017). Overall, ethanol is a multi-modal stimulus that alters taste, texture, and hotness and influences flavour and aroma (Clark et al., 2011; Meillon et al., 2009). Understanding the physicochemical properties of ethanol is key to interpreting the change in human perceptual, sensory response when the ethanol is modified or removed from beer and wine.

Previous research acknowledged the importance of ethanol for beer body perception (De Clerck, 1969; Langstaff & Lewis, 1993a); however, an earlier experiment by Langstaff et al.

(1991) found only a weak correlation between various alcohol levels with fullness terms, including *density*, *viscosity*, and after-feel, such as *oily mouth-coat*, *astringency* and *stickiness*, suggesting that in beer, other compositional factors are also responsible for those sensations. More recently, ethanol functionality and palate fullness in beer have been addressed by researchers in many different fields. As a low-molar-mass component of beer, ethanol was reported to strongly correlate with original gravity, which was positively correlated with beer palate fullness (Krebs et al., 2021), which suggests that ethanol is a strong analytical predictor of palate fullness. Furthermore, the study highlighted a positive correlation between ethanol and mouthfeel descriptors, including *viscous*, *full-bodied*, *smooth*, *soft* and *creamy*, whereas a negative correlation was found with the attribute *watery* when explored with experienced panellists (Krebs et al., 2021).

Previous studies used physical viscosity measurements to correlate with and characterise mouthfeel in beverages (Kappes et al., 2007; Stokes et al., 2013). In wine, contrasting findings emerged when using trained panels, and inconsistent associations of ethanol or glycerol contents with wine body were reported. Interestingly, increasing ethanol concentrations in de-alcoholised white wines (0, 3, 7, 10, 12, and 14% ABV) showed a positive correlation with perceived viscosity and density; however, once the ethanol concentration reached 7% ABV, no further increase in perceived intensity of viscosity was observed (Pickering et al., 1998). Perceived viscosity and density were minimally affected by the changes in ethanol concentrations (8, 10, and 12% ABV) in model ice wine solutions, and the changes were mainly attributed to increased sugar concentration (Nurgel & Pickering, 2005). Yanniotis et al. (2007) identified alcohol content and dry extract as the two main factors that influenced measured viscosity of aqueous solutions of ethanol in the range of 0-15% ABV, as well as dry red, white and sweet wines. Another study found a correlation between wine density and viscosity with ethanol levels when measured instrumentally (Neto et al., 2005). The study also noted the importance of serving temperature, as they noted a decrease in physical wine density at higher temperatures (Neto et al., 2005).

Similarly to instrumental measurements, which confirm linear relationships of both glycerol and ethanol concentrations with increased viscosity, an experiment by Gawel et al. (2007) concluded that increased ethanol concentrations (ranging from 11.6 to 13.6% ABV) resulted in increased perceived hotness in Riesling wines, as well as higher body and perceived viscosity. However, it was highlighted that body was not associated with hotness, and increasing ethanol concentration at that level did not affect sweetness, acidity, aroma or flavour intensity ratings. However, the latter positively correlated with the perceived body (Gawel et al., 2007), suggesting that flavour intensity is important for body perception. Interestingly, a recent study found that palate fullness or *'overall impression of weight'* was positively correlated with *dark fruit, flavour intensity, jammy, sweetness* and *hotness*, and negatively correlated with *red fruit* and *confectionery* ('perception of strawberry cream and bubble gum') in Australian Shiraz wines by a trained panel (Li et al., 2017), suggesting that different flavours may be responsible for driving mouthfeel characteristics. Furthermore, Yanniotis et al. (2007) and Gawel et al. (2007) confirmed that glycerol had a negligible effect on dynamic viscosity due to the low concentrations naturally present in wines. It was previously demonstrated that the addition of 6g/L glycerol with masked sweetness did not elicit a sensory response (measured as perceived viscosity) in white wine, suggesting that at narrow ranges that is achievable with traditional winemaking approaches, glycerol is not a contributor to body (Gawel & Waters, 2008).

Further research focused on uncovering the effects of ethanol on olfactory and trigeminal sensations to identify those attributed to higher ethanol concentrations. Commercial and model wines with higher ethanol concentration were rated higher in *hotness, burning, tingling* and *velvet* by the trained sensory panels and negative associations with astringency and mouth-coating were also reported (Demiglio & Pickering, 2008; Fontoin et al., 2008; Jones et al., 2008; Nolden & Hayes, 2015).

In addition to standard ABV beers and wines, many other variants of the beverages exist, including lower alcohol counterparts with generally accepted definitions: low-alcohol, ≤ 1.2% ABV; de-alcoholised, <0.5% ABV; alcohol-free, ≤ 0.05% ABV. King et al. (2013) found that an average wine consumer could detect de-alcoholisation in red wine by as little as 0.4% ABV with training; however, untrained individuals were unable to identify or perceive a reduction lower than 1%. Reduced palate fullness and mouthfeel have been previously reported in beers with lowered alcohol content, along with other attributes that were lost due to the alcohol reduction methods used (Langstaff et al., 1991; Malfliet et al., 2009), suggesting that the altered palate fullness and mouthfeel cannot be conclusively attributed to loss of ethanol alone.

Importantly, ethanol was previously found to significantly impact basic taste. Taste (bitter, sweet, sour, salty, umami) is an oral sensation elicited by the chemoreceptors within the oral cavity and plays an important role in the flavour perception of alcoholic beverages, which may also affect the perception of body. Early research found that ethanol enhances sweetness perception through stimulating and activating sugar-sensitive nerve fibres (Martin & Pangborn, 1970; Hellekant et al., 1997; Scinska et al., 2000), yet contrasting findings of ethanol decreasing sweetness perception were also previously reported. Ethanol increased sweetness perception in beer (Clark et al., 2011) and wine matrices (Nurgel & Pickering, 2006; Zamora et al., 2006). Reduced sourness intensity has been shown as ethanol concentration increased (5, 13, 23% ABV) in binary solutions representing the dominant orosensations elicited in alcoholic beverages (sweet/fructose, bitter/quinine, sour/tartaric acid, astringent/aluminium sulphate) (Thibodeau & Pickering, 2021). Furthermore, increasing ethanol concentrations have been shown to increase bitterness in model wine solutions (Fontoin et al., 2008; Jones et al., 2008; Nolden & Hayes, 2015), yet in a model beer, where hop acids played a role of the bittering agent, the perception of bitterness was not modified by ethanol (Clark et al., 2011). Interestingly, perceived bitterness has been previously reported to modify astringency in beer via cross-modal flavour interactions (Oladokun et al., 2017), which suggests that basic taste perception mediated by ethanol plays a significant role in mouthfeel perception.

1.5.2 Phenolic Compounds

Astringency is perceived by touch via mechanoreceptors, described as drying and puckering of the oral surface (Bate-Smith, 1954; Dinnella et al., 2009) and defined as *'the complex of sensations due to shrinking, drawing or puckering of the epithelium as a result of exposure to substances such as alums or tannins'* (ASTM, 1989). Hydrophobic interactions and hydrogen bonding allow the formation of complexes of proline-rich salivary proteins and polyphenolic compounds, which in turn precipitates the saliva proteins and decreases salivary viscosity (Obreque-Slier et al., 2012; Prinz & Lucas, 2000). Ethanol was also stated to interfere with the hydrogen bonding between proteins and polyphenols (Serafini et al., 1997), therefore decreasing astringency with rising ethanol concentration and enhancing viscosity perception (Demiglio & Pickering, 2008; Fontoin et al., 2008).

The flavonoids and non-flavonoids are the main groups of polyphenols that are distinguished based on the number of phenol aromatic rings that carry one or more hydroxyl groups and the structural elements that bind these rings known to have a considerable effect on taste and mouthfeel (Jackson, 2019; Mayen et al., 1995). Previously, polyphenolic compounds (polyphenols) were found to contribute to the overall flavour, bitterness, colour, mouthfeel, and specifically body, as well as astringency in beer, cider and wine (Oberholster & Titus, 2016; Soares et al., 2018; Symoneaux et al., 2015) and an earlier study, suggested that the levels and type of polyphenols influenced the consumer acceptance rates in beverages, including tea, fruit juices and red wine (Drewnowski & Gomez-Carneros, 2000).

In beer, astringency is caused by polyphenols derived from barley husk or hops (François et al., 2006; Goiris et al., 2014). In wine, it is mainly attributable to the phenolic compounds, commonly known as tannins or proanthocyanidins (Lesschaeve & Noble, 2005), derived from grapes, mainly from the seeds and skins, which chemically precipitate the salivary proteins (Adams & Harbertson, 1999).

In beer, hopping levels and brewing malt contribute a major part of the polyphenols to beer (20-30% and 70-80%, respectively) (Aron and Shellhammer, 2010), including hydroxybenzoic acids, alkylmethoxyphenols, hydroxyphenylacetic acids, hydroxycinnamic acids, flavanols, flavonols, flavones and miscellaneous, such as indole-3-carboxylic acid. Hop polyphenols include α- and β-acids (co-humulone, ad-humulone, n-humulone, iso-α-cohumulone, iso-α-adhumulone, α-nhumulone, lupulone) and prenylflavanoids, such as isoxanthohumol, xanthohumol, desmethylxanthohumol, 8-prenylnaringenin and 6-prenylnaringenin, which contribute up to 30% of beer polyphenols (Quifer-Rada et al, 2015). Particular attention has been paid to the interaction mechanisms of polyphenols with key sensory modalities, including mouthfeel and flavour. The polyphenol bitterness derived from hops interacts with sensory attributes, including sweetness, and components, such as CO_2 and ethanol, which increases carbonation and tingly perception, resulting in interaction with both gustatory and trigeminal stimuli (Clark et al., 2011). It was found that hop acids and ethanol produce a suppressed warming sensation, whereas an increase in warming sensation is evident in the interaction between ethanol and low levels of CO_2 (Clark et al., 2011). Furthermore, it has been reported that at low pH (4.0-4.3), the intensity of astringency in beer is higher; however, it was noted that even greater astringency was observed in beers with pH close to 5 (Francois et al, 2006). This suggests that the pH is noticeable prior to the occurrence of polyphenol and active protein interactions. An intensified astringency was also reported in relation to decreased bitterness, shown by sensory analysis of top-fermented beers stored at different temperatures (Vanderhaegen et al, 2003).

In wine, astringency perception is generated by several stimuli, including phenolic components sourced from grapes (grape-derived tannins (condensed tannins or proanthocyanidins), hydroxybenzoic, hydroxycinnamic acids, flavonol glycosides, flavanal-3-ols (procyanidins) and stilbenes) (Ma et al., 2014), and hydrolysed tannins from the oak barrels or chips (Rodríguez Montealegre et al., 2006). Phenolic compounds contribute to important sensory properties, such as colour, astringency, and bitterness (Ferrer-Gallego et al., 2014). The increase in the intensity of a perceived astringent sensation may be influenced by numerous factors, including lowering pH (Demiglio & Pickering, 2008), alcohol, viscosity (Peleg & Noble, 1999) and sweetness (Fontoin et al., 2008; Smith & Waters, 2012; Payne et al., 2009), and raising the temperature, acidity or repeated exposure (Lyman & Green, 1990). Certain grape cell-derived (as arabinogalactan-proteins) and yeast-derived polysaccharides (from cell walls of yeast (mainly mannoproteins from *Saccharomyces cerevisiae*)) (Quijada-Morín et al., 2014) and volatile fruity extracts reduced the perceived astringency sensation (Sáenz-Navajas et al., 2015). Lower alcohol wines tend to have grippy or puckering astringency (Australian Grape and Wine Authority, 2017; Pickering, 2000). In turn, positively modulated intensity of wine astringency was found to contribute to full-bodied, flavourful and balanced wine (Soares et al., 2018), suggesting that astringency might play a more significant role than hotness (warming) related to ethanol content in wine body perception.

Astringency is generally considered an undesirable element attributed to aged and expired beer (François et al., 2006). Terms such as *stickiness*, *powdery, sappy*, *harsh*, and *gritty* have been used previously to describe astringency in beer (Langstaff et al., 1991; Meilgaard & Muller, 1987). In wine, however, astringency is considered one of the most important sensory attributes related to a hedonic component, attributed to *complexity* defined as *'positive hedonic grouping consisting of an amalgam of pleasing astringency sensations, flavour and balanced acidity'* (Lawless & Civille, 2013). There are extensive classifications of wine astringency sub-qualities, and proposed lexicons (Gawel et sal., 2000), albeit comprehensive for wine experts, have been criticised for their complexity and extraneous nature, particularly when involving consumers (Vidal et al., 2015).

1.5.3 Polysaccharides

Other components that have been reported to impact body and fullness perception include other macromolecular fractions, specifically polysaccharides. Polysaccharides in beer and wine are mainly derived from the yeast cell walls (mannoproteins), cells of the raw materials (arabinogalactan-proteins) and other sources, such as bacteria. Polysaccharides have been found to improve and stabilise flavour, colour, and foaming properties in beer and wine

(Bamforth, 1985; Moreno-Arribas et al., 2000; Sadosky et al., 2002). The positive effects of arabinoxylan (arabinose and xylose) and dextrins (low-molecular-weight carbohydrate) on instrumental viscosity were demonstrated in beer model solutions previously (Sadosky et al., 2002). Investigations into macromolecular profiles of beers have been gaining momentum, linking the intensity of palate fullness to the specific macromolecular fractions (Krebs et al., 2019, 2020), suggesting that palate fullness is influenced by the malting parameter degree of steeping and the resultant modifications. In wine, two fractions of wine major polysaccharides (mannoproteins (MP) and arabinogalactan-protein (ARG); rhamnogalacturonan II (RG II), were found to significantly increase the fullness sensation perceived by a trained sensory panel when compared to base wine (Li et al., 2018; Vidal et al., 2004).

1.5.4 Protein and Protein-derived Components

The sensory properties of beer are highly dependent on the protein and protein-derived content affecting wort and yeast nutrition during the brewing process. These components affect the overall beer quality characteristics, such as foam quantity, formation and stability, colloidal stability and filterability, resulting protein composition, as well as sensory characteristics, such as taste intensity and the overall development of the active flavour compounds (Steiner et al., 2011). Haze stability plays a significant role in relation to turbidity, which gives a first visual impression of the quality of a beverage to the consumer, which is also dictated by different protein groups derived from barley, barley malt and yeast (Robinson et al., 2007). The role of proteins in foam formation and colloidal stability, in turn, influences the perceived body and mouthfeel of the beer (Kato et al., 2021; Krebs et al., 2019; Langstaff & Lewis, 1993b). Currently, the removal of hydrophilic, haze-active proteins, polyphenols or both as a complex held together by hydrogen bonds is considered a preferred method for reducing the propensity for colloidal haze formation. However, it is important to note that the removal of hydrophobic protein complexes that assist foam formation might influence the perception of body and general mouthfeel in beer and wine.

1.6 Concluding Remarks

In this review, studies on beverages, particularly beer and wine, which focused on consumer perception of in-mouth characteristics of beverages with reduced alcohol content, published over the last 20 years were broadly reviewed. These studies included descriptive sensory analysis, consumer evaluation, and available chemical and instrumental analyses. As aforementioned, increased commercial demand for low and no-alcohol beverages has stimulated researchers and alcohol producers to innovate to deliver sensorially acceptable, low-alcohol products to satisfy consumer demand. In summary, various studies suggest a number of different physical and chemical parameters which may contribute to the mouthfeel of low-alcohol beers and wines. Foaming properties, CO_2, polypeptides, phenolic compounds, polysaccharides (dextrins), ß-glucans, ethanol, glycerol, and viscosity are generally believed to impact *fullness*, *roundness*, *body* and overall mouthfeel of beer. In comparison, conflicting evidence suggests a relationship between ethanol, glycerol, polysaccharides and polyphenols and mouthfeel attributes, such as *burning*, *fullness*, *oiliness*, *body* and *astringency* in wine. Numerous publications have conducted instrumental measurements of key mouthfeel parameters in isolation, without correlation with sensory analysis. To date, the definition of the term body for both beer and wine has not been standardised or thoroughly investigated, resulting in a lack of understanding for both scientists and consumers. To understand what contributes to body perception, assessing a concept from the consumer perspective must be investigated, followed by evaluating compositional factors that are thought to contribute to body in both beverage systems.

1.7 Overview of Thesis Content

The aims of this 4-year joint PhD project, involving two research groups; one at the University of Nottingham (UK) and the other at the University of Adelaide (Australia), were to (i) explore consumer language used to describe *body* of two beverage systems: beer and wine, in the UK and Australia; (ii) design beers and wines varying in attributes found to be important for *body* and (iii) evaluate the impact of the varied compositional factors on *body* perception and acceptability. Based on previous research, it is evident that consumer sensory body perception is an understudied, complex and overarching subject. It is hypothesised in this thesis that compositional factors, including ethanol content, viscosity, bitterness, aroma and flavour intensities would contribute to consumers' perception of body in beer and wine matrices, in contrast to previously proposed one-dimensional definitions, including 'viscous mouthfeel'. It is also proposed that consumers would place differing levels of importance on different attributes when it comes to the perception of body in beers and wines with reduced alcohol content.

In the first experimental study, detailed in Chapter 2, UK consumers' understanding of a widely accepted mouthfeel, but an ill-defined concept – body, was investigated. The outputs of this study were published in Food Quality and Preference journal in September 2021. Chapter 3 explored the significance of compositional factors that were found to be important in beer in Chapter 2, on perceived body and overall liking. A consumer-based approach, where British beer consumers evaluated beers with manipulated composition, was adopted. Furthermore, consumers were segmented based on their body perception to explore the importance of the varying factors. This paper is being prepared for submission to Food Quality and Preference. Research in Chapter 4 investigated the significance of modified compositional factors in commercial low-alcohol red wine on Australian wine consumers' perceived body and overall liking. Based on previous findings, research in Chapter 5 explored low-, lower and full-strength alcohol red wines with modified flavour profiles, including flavours that promote and decrease wine body ratings. Participants (experienced tasters, as well as naïve consumers) assessed sensory perceptions of various mouthfeel attributes, including wine body. The final chapter (Chapter 6) summarises the findings and draws conclusions based on the outcomes from all experimental studies and gives an outlook on future perspectives and recommendations for further research to advance our understanding of beer and wine body.

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Chapter 2

Consumer understanding of beer and wine body: an exploratory study of an ill-defined concept

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Abstract

Body or palate fullness is a key beverage sensory characteristic for beverage acceptability, drinkability and when making a purchase decision. Evidence suggests that consumers perceive low-alcohol beverages as lacking in body. Despite the significance of body, little is known about consumers' understanding of the term. This paper used a qualitative approach to gain insights into regular beer and wine consumers' understanding of beer and wine body in the UK. Focus groups and the Free Choice Description (FCD) technique were used to explore the term with frequent beer and wine consumers (n=90) from the UK. In contrast with most research within alcoholic drinks focused on body perception as a one-dimensional component of viscosity, this paper identified other sensory characteristics and compositional factors for both beer and wine that were perceived to contribute to body perception from a consumer perspective. It was evident from the present study that body was a holistic expression constituting several modalities, including flavour, mouthfeel and aroma. Other essential factors for beer and wine body perception included appearance and overall beverage quality. It was also demonstrated that specific flavours, including dark fruit flavours (blackberry, cherry, plum), Maillard reaction and cereal flavours, as well as the barrel-aging flavours (chocolate, coffee, caramel, smoke, grain, oak, roasted malt), and sharp and tangy flavours, such as citrus and tropical fruits were important for body perception. Beverage characteristics, such as velvety, smooth, and creamy, were also found to be responsible for the perception of body in beer and wine.

2.1 Introduction

Body is an essential sensory characteristic of any wine style (Runnebaum et al., 2011) and wine quality (Jackson, 2017) and a desirable attribute for reduced calorie/low alcohol beers (Liguori et al., 2015) that are considered watery, mainly on account of lack of mouthfeel (Malfliet et al., 2009). With the growing low-alcohol beverage market, body is crucial for the drinkability and acceptability of those products. Although the term body is intermittently used by Australian wine consumers (Niimi et al., 2017), concerns have been raised regarding conflicting interpretations of the term (Gawel et al., 2007; Laguna et al., 2019; Vidal et al., 2015). Previous research associated palate fullness with physical properties such as density and viscosity (Langstaff & Lewis, 1993b), non-volatile substances and molar mass fractions in beer (Krebs et al., 2021) and an important contribution to the overall tactile perception in wine along with astringency, heat and carbonation (Jackson, 2002). Numerous studies involving trained panels have defined wine body or fullness as *'viscous mouthfeel'* (Gawel et al., 2007; Laguna et al., 2019; Runnebaum et al., 2011; Skogerson et al., 2009; Vidal et al., 2004) and associated beer body with weight and flow resistance (Langstaff & Lewis, 1993b). Currently, beer body is defined as *'fullness of flavour and mouthfeel'* by the American Society of Brewing Chemists (ASBC, 2011), which includes descriptors proposed by Clapperton et al. (1976) namely thick, satiating, characterless and watery. This definition appears to lack precision regarding what exactly body constitutes. Contradictory findings of ethanol and glycerol contribution to wine body emerged previously (Gawel et al., 2007; Nurgel & Pickering, 2005). Others reported the contribution of various polysaccharide fractions to wine fullness (Vidal et al., 2004) and metabolites, such as proline and lactate, to wine body (Skogerson et al., 2009).

It is likely that there are differences between trained panels, experts and consumers when describing a multi-attribute term like body (Ares & Varela, 2017), highlighting the need to evaluate consumer holistic understanding of the term in commercial beverage samples. Similarly, trained sensory panels and experts demonstrate inconsistencies when describing wine textural sensations (Laguna et al., 2019). Furthermore, existing research is limited in its focus and primarily explores one-dimensional contributors to body, such as viscosity and density, or ethanol and glycerol. Therefore, to create more profound insights into the contributing factors, consumer understanding of the term is required.

Studies investigating consumer perceptions of body in alcoholic beverages are novel and, to date, limited to wine (Niimi et al., 2017), with no qualitative studies specifically exploring consumer understanding of body in beer, as well as comparing and contrasting across beverages. Therefore, it is unclear if the definitions and contributing factors of body found for wine are similar for beer.

The objectives of this study were to (i) gain insights into regular beer and wine consumers' understanding of beer and wine body in the UK; (ii) understand consumer perceptions of differences between light-bodied and full-bodied beers and wines using a qualitative approach; and (iii) investigate the relationship between consumer-generated sensory characteristics and body in commercial beers and wines. Overall, findings from this study will be compared across beverage types to provide direction to researchers and new-product developers on the key factors contributing to body perception from the consumer perspective.

2.2 Materials and Methods

Ethics approval for this study was granted from the University of Nottingham's Medical Ethics Committee (Ref. number: 196-1801). Consumers (n=90) participated in two sessions (Focus group and Free Choice Description session) over a six week period at the Sensory Science Centre, Sutton Bonington Campus, University of Nottingham.

2.2.1 Participants

Consumers were invited to participate via an established consumer database consisting of University of Nottingham students and employees, and members of the public in the Nottinghamshire (UK) area. Consumers were screened to ascertain if they were above the UK legal drinking age (18 years old and above) and determine their beer, red wine and white wine consumption frequencies, self-reported knowledge level and basic demographics, such as age, gender, ethnicity, and occupation. Beer (n=30: 20 male, 10 women; aged 20-65; mean age 29.7±11.4), red wine (n=30: 5 male, 25 women; aged 20-52; mean age 29.2±8.1) and white wine consumers (n=30: 3 male, 27 women; aged 19-63; mean age 28.1±11.9), who self-reported consumption of one of the beverages (beer, red or white wine) at least once a month, were invited to participate. Informed consent was obtained from all participants.

2.2.2 Focus groups

Three alcoholic beverage categories (beer, red wine and white wine) were selected, and 3 focus groups for each category were conducted (9 in total for all three beverage categories). Each focus group comprised 10 consumers of similar self-reported beverage knowledge levels, determined by a previously described method (Flynn & Goldsmith, 1999). Therefore, 3 levels of self-reported subjective knowledge ('less knowledgeable', 'knowledgeable', and 'highly knowledgeable') were formed and equated to 3 focus groups for each beverage category (Figure 2.1). This was to ensure that consumers felt comfortable as they would be discussing alcoholic beverage topics amongst people with a similar knowledge level. Each focus group interview lasted approximately 1.5 h and was held during the daytime.

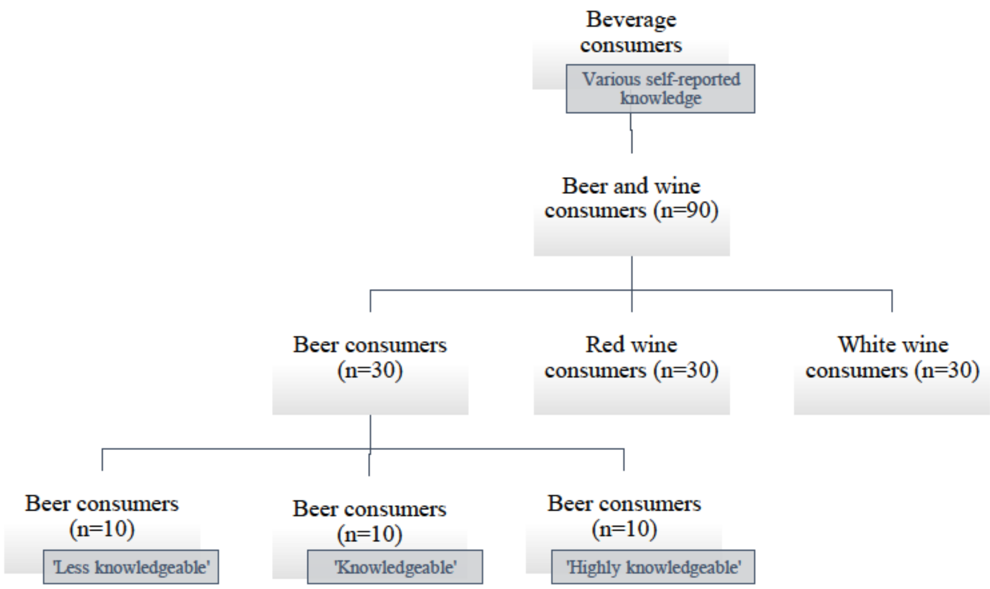

Figure 2.1: From the pool of screened consumers with various self-reported knowledge levels, beer and wine consumers (n=90) were sub-divided into beer (n=30), red wine (n=30) and white wine (n=30) groups, further sub-divided into focus groups, according to preferred beverage category and self-reported knowledge level ('less knowledgeable' (n=10), 'knowledgeable' (n=10) and 'highly knowledgeable' (n=10))

The focus group discussion guide (Table 2.1) was semi-structured and consisted of open-ended questions that were designed to explore (1) consumer definitions of beer or wine body; and (2) differences between consumer groups understanding of the term body, vocabulary usage and the sensory attributes they associate with this concept. The focus groups aimed to consolidate consumers' thoughts, ideas and beliefs into themes that could inform and direct further research. The number of focus groups per beverage category (3, n=30) ensured data saturation (Guest et al., 2017). All focus group discussions were audio-recorded. Extensive notes were taken by the moderator to ensure that consumer responses were accurately captured and allowed subsequent assessment of the non-verbal cues noted.

Table 2.1: Focus group discussion guide

<table>
<tr><th>Event</th><th>Description</th><th>Estimated duration</th></tr>
<tr><td>Opening remarks</td><td>After a short introduction and brief consideration of some housekeeping rules, the moderator initiated the discussion, explained the purpose of the study and encouraged participants to express their opinions freely, as well as ask questions and contribute to the debate respectfully.</td><td>5 min</td></tr>
<tr><td>Warm-up</td><td>The moderator showed illustrations and pictures of different scenarios where alcoholic beverages could be consumed, encouraging associative thinking and engagement. Furthermore, the moderator asked open-ended questions, such as:

PROMPT: "Why do you drink beer/wine?"
PROMPT: "What are your favourite places to have a beverage?"
PROMPT: "Which beer/wine styles do you normally consume?"
PROMPT: "What makes them different?"

The information provided by the participants was carefully noted and used in later stages if required.

In the case of beer groups, supplementary questions were added:

PROMPT: "What different beers do you enjoy? What makes them different?"
PROMPT: "What other beverages apart from beer you would normally drink?" *expect mentioning of 'wine' – expand from there
PROMPT: "What about, for example, 'wine' (mentioned previously) – how do wines differ from each other?" *predicted answers: fullness, complexity, body, region, grape variety
PROBE: If body was not mentioned for beer – e.g. "I could see some similarities; however, for example, the term body was not mentioned for beer? Why do you think that might be?"</td><td>20 min</td></tr>
<tr><td>Topic 1: Body of beer/wine</td><td>After the participants mentioned the term body, an open-ended discussion on the definition of body for the related product was initiated.

PROMPT: "What is body of beer/wine?"</td><td>25 min</td></tr>
</table>

	PROMPT: "What contributes to body?" **PROBE:** "What about the appearance of the drink?" **PROBE:** "Are there any mouthfeel/ flavour terms that you can think of that might be important?"	
Topic 2: Sensory characteristics/ attributes important to body	*Five blind samples for beer and 3 for red and white wine presented to participants in randomised order. Participants were asked to try the samples and make notes on overall characteristics and attributes, including the ones discussed for body earlier.* **PROMPT:** "How would you categorise different body styles?" **PROBE:** "Which aromas would you associate with a full-bodied drink? And light-bodied drink?" **PROBE:** "How does the appearance of those styles of body differ?" **PROBE:** "What texture would you expect of different styles of beer/wine to have?" **PROBE:** "What flavours would you associate with body of an alcoholic drink?" **PROBE:** "What aftertaste would you expect after a light-bodied/ full-bodied beer/wine?"	30 min
Closing remarks	*Moderator closes the sessions by encouraging participants to share any additional opinions or comments and giving thanks.*	2 min

2.2.2.1 Samples

Within each beverage category focus group, a range of either commercial beers (n=5), white (n=3) or red wines (n=3) from the EU and US markets were selected to represent a range of beverage styles. A sample tasting was included to facilitate the discussions, during which consumers communicated their overall impressions of the samples and were then probed for specific attributes related to body. Details of the products selected are shown in Table 2.2 and were chosen to represent a wide range of sensory properties. Samples (50 mL) were served simultaneously in tinted glass vials (100 mL, amber), labelled with random 3-digit codes. Consumers were instructed to cleanse their palates between each sample with water (Evian, France) and unsalted crackers (Ruksens, UK). Red wine samples were kept at ambient temperature (21±2 °C), whereas beer and white wine samples were kept in cold storage at 4±2 °C before focus groups commenced.

Table 2.2: Beer, white wine and red wine samples used to facilitate the focus group discussions, including alcoholic degree, production country and description of the beverage sourced from either the commercial label or the company website

Beverage groups

Beer styles	**Alcoholic degree v/v (%)**	**Country**	**Product Description**
Alcohol-Free Lager	<0.05	Germany	Light, crisp, refreshing
Full-Alcohol Lager	4.8	Germany	Golden, classic German-style pilsner with a robust, distinctive full-bodied taste, a fresh hoppy bouquet, distinct bitterness and rich, full head
Wheat Beer	5.3	Germany	Full-bodied yet elegant character
Stout	4.2	Ireland	Rich and creamy, distinctively black
Bitter	3.6	England	Malty, bittersweet ale with a slight fruitiness and a bitter aftertaste
Red Wines grape variety			
2015 Shiraz	12.5	France	Smooth and fruity red packed with the flavour of ripe damsons and forest fruits, with a hint of bramble on the nose, rich and velvety
2015 Zinfandel	14.5	United States	Full-bodied flavours and elegant spice, bold notes of dark cherry and blackberry jam complement hints of mocha and toasted oak
2017 Gamay	13.5	France	Complex red with blackcurrant, blueberry and sweet spice flavours, smooth, juicy and silky texture
White wines grape variety			
2017 Riesling	9.0	Germany	Medium-dry white packed with zippy citrus, lime and apple flavours, soft and fruity
2017 Sauvignon Blanc	12.5	France	Vibrant aromas of green apple, lime and gooseberry combined with zesty lemon flavours, flavoursome and refreshing
2013 Chardonnay	13.0	France	Full crisp, mineral freshness, pale yellow with a generous nose of nectarine and acacia, citrus and tropical fruit flavours with a long finish

2.2.3 Free Choice Description

In a separate session, consumers' sensory perceptions of 11 different beers, red wines and white wines (Table 2.3) depending on the consumer's focus group assignment were evaluated using the Free Choice Description (FCD) technique. FCD can be described as a free, spontaneous, idiosyncratic, easy and fast methodology that allows the more salient consumer perceptions about the product to be captured (Buck & Kemp, 2017).

All sessions took place in ISO standard (ISO, 2007) isolated sensory booths with controlled temperature (20 ^{o}C), airflow conditions and lightning. Consumers were instructed to taste the samples one by one and spontaneously and freely write down any descriptors or associations that they thought applied to or described the body of the beverage they were evaluating, cleansing their palate with water (Evian, France) and unsalted crackers (Ruksens, UK) in between each sample. The consumers were then asked to review their descriptors, add any missing terms, or remove redundant words, finalising their responses.

2.2.4 Samples

After examining a range of commercial candidate beers and wines from the EU, Australian, US and South American markets, 11 products with a range of flavour and body profiles were selected from each beverage category for consumer testing. Each sample set included an experimental replicate, bringing the overall number of samples evaluated by the consumers in each set to 12 (Table 2.3). Samples were served monadically in tinted glass vials (100 mL, amber), labelled with random 3-digit codes, following the Williams design presentation order. Serving temperature depended on the products served: i.e. chilled for beers and white wines (7±2 ^{o}C) and room temperature for red wines (18±2 ^{o}C).

Table 2.3: Extended list of beer, white wine and red wine samples (depending on consumer group) evaluated by consumers during FCD

Beverage groups			
Beer styles	**Alcoholic degree v/v (%)**	**Country**	**Product Description**
Alcohol-Free Lager (Lager.LowAlc)	<0.05	Germany	Light, crisp, refreshing
*Full-Alcohol Lager (Lager)	4.8	Germany	Golden, classic German-style pilsner with a robust, distinctive full-bodied taste, a fresh hoppy bouquet, distinct bitterness and rich, full head
Wheat beer (Wheat)	5.3	Germany	Full-bodied yet elegant character
Stout (Stout)	4.2	Ireland	Rich and creamy, distinctively black
Bitter (Bitter)	3.6	England	Malty, bittersweet ale with a slight fruitiness and a bitter aftertaste
Craft Red Ale (Craft.Red.Ale)	5.6	England	Full-bodied flavour with subtle cherry and rich fruit overtones
Low-Alcohol Wheat Beer (Wheat.LowAlc)	0.4	Germany	Refreshing isotonic drink, vitamin-rich
Low-Alcohol Craft Beer (Craft.LowAlc)	0.5	Scotland	Fully fruited hoppy ale, resinous notes, citrus fruit, orange, grapefruit, mango, malt
Pale Ale (Pale.Ale)	4.5	England	Pithy bitterness with a malty backbone, citrus flavours
Porter (Porter)	5.0	England	Dark beer with black cherry and plummy aroma, full-bodied, delivering chocolate and prune flavours and a long smoky finish
Craft India Pale Ale (Craft.IPA)	5.6	Scotland	Caramel, tropical fruit, grapefruit, pineapple, lychee with a spiky bitter finish
Red Wines grape variety/ style			
2015 Shiraz (Shiraz.FR)	12.5	France	Smooth and fruity red packed with the flavour of ripe damsons and forest fruits, with a hint of bramble on the nose, rich and velvety
2015 Zinfandel (Zinfandel.US)	14.5	California	Full-bodied flavours and elegant spice, bold notes of dark cherry and blackberry jam complement hints of mocha and toasted oak

2017 Gamay (Gamay.FR)	13.5	France	Complex red with blackcurrant, blueberry and sweet spice flavours, smooth, juicy and silky texture
2015 Malbec (Malbec.FR)	13.0	France	Structured, full-bodied yet elegant red made using super-ripe Malbec grapes, enriched with a hint of oak. This wine is bursting with blackberry and blackcurrant fruit
*2016 Cabernet Sauvignon (Cab.Sav.CL)	13.7	Chile	A smooth, full-bodied Cabernet Sauvignon with cassis and black cherry flavours, complemented by hints of coffee and dark chocolate
2014 Rioja (Rioja.ES)	13.5	Spain	Elegant red spicy bramble aromas and concentrated black fruit flavours combined with a long, savoury finish. Aged in oak barrels
2014 Merlot (Merlot.US)	13.5	California	Packed with the tempting flavours of blackberry, raspberry and chocolate and is silky smooth
2016 Merlot (85%), Cabernet Sauvignon (15%) (Merlot.FR)	12.5	France	Structured, full-bodied yet elegant wine which has been enriched with a hint of oak to give layers of black fruit, ripe plum and toasted spice flavours
2017 Merlot Grenache (Merlot.Grenache.FR)	13.5	France	Juicy easy-drinking and brilliant value wine with strawberry character. The Grenache in the blend adds soft red fruit flavours, and there are hints of chocolate and plum from the Merlot
2017 Pinot Noir (Pinot.Noir.DE)	12.5	Germany	Light and fruity, fresh raspberry and strawberry
2016 Traditional Portugese blend (Portuguese.Blend.PT)	13.0	Portugal	Medium-bodied, red apples and berries
White wines grape variety/ style			
2016 Riesling (Riesling.AU)	12.5	Australia	A vibrant, aromatic, fruit-driven Riesling packed full of bold elderflower and green apple notes with a zesty lime finish
2016 Sauvignon Blanc (Sav.Blanc.FR)	12.5	France	Refreshing grapefruit and citrus flavours with a crisp finish

2017 Chardonnay (Chardonnay.ES)	12.0	Spain	Fruity citrus honeydew melon flavours and underlying richness and intensity from a classic grape variety
*2016 Chardonnay (Chablis.FR)	12.5	France	Crisp, fresh white rich in quintessential mineral characteristics of Chardonnay from the Chablis region, with great acidity, elegant tones of green apples and citrus flavours accompanied by a long, lingering finish
2016 Pinot Grigio (Pinot.Grigio.IT)	12.5	Italy	Elegant and dry, characterised by flavours of peaches, greengages and almonds
2015 Chardonnay (Pouilly-Fuisse.FR)	13.0	France	Rich yet refreshing and mineral scented Chardonnay with ripe peach and pineapple flavours balanced with crisp acidity and a lovely creamy finish
2016 Sauvignon Blanc-Sémillon (Sav.Blanc.Sémillon.FR)	12.0	France	Fresh lemony flavours combined with honeysuckle softness. This well-balanced, crisp and aromatic dry white
2016 Gaglioppo, Cortese (Cortese.IT)	12.5	Italy	The wine is light and fresh, with hints of lemon and grapefruit on the palate and a long, mineral finish
2017 Traditional Portugese Blend (Vihno.Verde.PT)	9.0	Portugal	Zingy white from local grapes, crisp, fresh white with citrus and melon notes and a delicate spritz
2016 Albarino (Albarino.ES)	13.0	Spain	Crisp, fresh, aromatic, tropical fruits, peach, grapefruit
2016 Viognier (Viogner.FR)	13.5	France	Elegant aromas of dried fruit, peach and floral notes, with a hint of vanilla, and a satisfying palate balanced perfectly between richness and freshness

** Alcoholic degree, production country and description of the beverage were sourced either from the commercial label or the company website. Samples marked with the asterisk (*) represent experimental replicate. Abbreviations: LowAlc = Low-alcohol, AU = Australia, CL = Chile, DE = Germany, ES = Spain, FR = France, IT = Italy, PT = Portugal, US = United States

2.3 Data Analyses

2.3.1 Focus groups

Focus group audio recordings were transcribed. Field notes from each session were incorporated into the data analysis to identify participant characteristics, involvement, non-verbal cues and enthusiasm levels, subsequently enriching the data. Personal identifiers, names or consumer interactions were removed from the transcripts to ensure consumers' confidentiality. Qualitative data analysis software (nVivo®, SQR International Pty Ltd.) was used to code responses using a coding framework matrix (Framework Method) (Gale et al., 2013) created to identify key insights, followed by the investigation of the narratives with memoing (reading and note-making). Firstly, structural nodes were applied to each transcript to facilitate the extraction of text within specific discussion questions (Oaks, 2001).

Furthermore, structural nodes were openly coded, which allowed different beliefs to emerge. This initial coding step had no limitations on the number of codes generated; therefore, the second round of coding (i.e., axial/ focused coding) was performed to sort, eliminate, combine, and sub-divide responses to relate the insights to each other. Once the initial analytical framework was developed, transcripts were re-coded, and any new codes and cases that did not fit the existing framework were noted. The initial framework was revised to build a finalised working analytical framework, and new and refined codes were incorporated. All transcripts were then coded using the finalised analytical framework. Overarching categories were applied, where appropriate.

Additionally, sub-group responses were coded separately to highlight similar versus contrasting cases between the knowledge-based consumer groups. The data was organised into the framework matrix using Microsoft Excel (Microsoft Corporation, Washington, US), where summarised data was entered by codes (columns) and cased (rows) and transferred into nVivo® work project. Themes were generated from the data set by reviewing the matrix and making connections within and between participants and categories to interpret the data. The themes were examined with the original research objectives in mind; however, new ideas and concepts generated from the data were also explored. The emerging themes were then brought together based on their similarity, with discrepancies highlighted for each knowledge group, where appropriate.

2.3.2 Free Choice Description

The open comments were first transformed into a list of accurate descriptions by correcting the typing and orthographic mistakes and removing connectors and auxiliary terms. Phrases and terms were identified. Frequency tables of terms per beverage (12 beers, 12 red and 12 white wines) were constructed, grouping the synonyms, and eliminating terms mentioned less than 5% of the time across all beverages. The frequency of mentions was determined for each final term by counting the number of participants that used each term to describe each beverage. The Chi-Square statistic was used to determine significant terms per beverage category, and Correspondence Analysis (CA) was performed to visualise the contributions. To interpret the dimensions of the CA bi-plot, the coordinates of the row/column points and the contribution of the points to inertia were examined. Statistical analyses were performed using XLSTAT (version 2020.5.1, Addinsoft) at a *p*-value of 0.05. CA bi-plots were constructed and visualised with R (R Development Core Team, 2013).

2.4 Results

2.4.1 Consumers' understanding of beer and wine body explored with focus groups

Consumers most often mentioned flavour attributes when defining body in beer or wine products. Mouthfeel, including but not limited to viscosity (thickness and thinness), mouth-coating, smoothness, astringency, and alcohol warming, were also frequently cited when defining body of all beverages. Aroma and appearance descriptors were also frequently cited; however, some consumers disagreed on appearance and aroma as accurate indicators of full-bodied beers and wines. Nevertheless, they stated they were essential factors for initial body perception prior to tasting the product. Key descriptors and concepts are summarised in Table 2.4.

There was a general consensus across knowledge groups and agreement on the multi-dimensional nature of the term. However, a few consumers disagreed with the rest of the group on carbonation contributing to the body of beer. Basic tastes, namely bitterness, sweetness, and acidity, were considered to play various roles discussed primarily as characteristics defining body intensity.

Interestingly, consumers either perceived body by (i) flavour and flavour intensity; (ii) mouthfeel and texture; or (iii) a combination of flavour and mouthfeel, amongst other concepts, such as aroma, appearance, carbonation, satiety, and quality.

2.4.1.1 Beer

Flavour was most discussed by all knowledge groups, using attributes such as flavour, aftertaste, and flavour intensity. Flavour complexity, flavour carrier, fullness of flavour and juiciness were additionally discussed within the highly knowledgeable beer group.

The majority of the consumers mentioned texture concepts, such as smoothness, thickness, carbonation, mouthfeel, creaminess, and alcohol warming. The highly knowledgeable groups also used the terms astringency, heaviness, density, mouth-coating, viscosity and foaming properties, whilst the less knowledgeable beer group frequently mentioned fullness.

Other concepts mentioned across different knowledge groups were complexity, quality, serving temperature, preference and liking, satiety, expectation, balance, context and enjoyment. Various concepts describing beer characteristics were also frequently cited, including ineffectiveness of flavour, substance, a combination of flavour and mouthfeel, character and distinctiveness.

2.4.1.2 Wine

Wine flavours were often mentioned and discussed in detail within wine focus groups. Flavour and aftertaste were amongst the most frequently mentioned attributes across all knowledge groups, followed by body of flavour, flavour complexity, flavour intensity and sweetness.

Mouthfeel and texture attributes were also frequently mentioned for wine body, with the terms mouthfeel, astringency and heaviness most commonly cited by all knowledge groups across red and white wine consumers. Furthermore, alcohol warming, smoothness, thickness, and mouth-coating were amongst the most discussed sensory attributes. Both knowledgeable and highly knowledgeable groups also used viscosity, sharpness, hotness, carbonation, fullness, and trigeminal sensations to describe the wine body.

Other concepts that consumers deemed necessary for wine body perception were quality, serving temperature, complexity, preference and liking, balance and roundness. White wine consumers also mentioned the importance of wine age, grape variety, region and winemaking processes when describing wine body. The context was mentioned as a consideration when deciding the appropriateness of full-bodied versus light-bodied wine consumption.

Table 2.4: Key descriptors and concepts mentioned by the participants when asked to describe body within the focus groups (including the discussion after sample tasting)

Beverage category	Sensory modality	Key concepts mentioned
Beer	Flavour	flavour ^{H}, aftertaste ^{H}, sweetness ^{H}, bitterness ^{H}, flavour intensity ^{H}, body of flavour ^{H}, flavour complexity ^{M}, flavour carrier ^{L}, fullness of flavour ^{L}, juiciness ^{L}
	Mouthfeel	smoothness ^{H}, thickness ^{H}, carbonation ^{H}, astringency ^{H}, mouthfeel ^{M}, creaminess ^{M}, alcohol warming ^{M}, heaviness ^{L}, density ^{L}, mouth-coating ^{L}, viscosity ^{L}, foaming properties ^{L}, fullness ^{L}
	Aroma/ Appearance/ Other	aroma ^{H}, colour ^{H}, appearance ^{H}, aroma intensity ^{M}, complexity ^{M}, quality ^{M}, serving temperature ^{M}, combination ^{M}, preference/ liking ^{M}, satiety ^{L}, character ^{L}, distinctiveness ^{L}, expectation ^{L}, balance ^{L}, context ^{L}, enjoyment ^{L}, ineffectiveness ^{L}, substance ^{L}, head retention ^{L}, transparency ^{L}
Red wine	Flavour	flavour ^{H}, aftertaste ^{VH}, body of flavour ^{H}, flavour complexity ^{M}, sweetness ^{L}, flavoursome ^{L}, evolution of taste ^{L}
	Mouthfeel	mouthfeel ^{H}, astringency ^{H}, alcohol warming ^{M}, smoothness ^{M}, thickness ^{M}, mouth-coating ^{M}, viscosity ^{L}, sharpness ^{L}, hotness ^{L}, trigeminal sensations ^{L}, heaviness ^{L}, creaminess ^{L}, density ^{L}
	Aroma/ Appearance/ Other	aroma ^{H}, colour ^{H}, appearance ^{H}, context ^{M}, quality ^{M}, serving temperature ^{M}, strength ^{M}, complexity ^{M}, preference/ liking ^{L}, combination ^{L}, balance ^{L}, roundness ^{L}
White wine	Flavour	flavour ^{H}, aftertaste ^{H}, body of flavour ^{H}, flavour intensity ^{M}, sweetness ^{L}
	Mouthfeel	heaviness ^{H}, mouthfeel ^{H}, astringency ^{H}, alcohol content ^{M}, smoothness ^{M}, thickness ^{M}, sharpness ^{L}, carbonation ^{L}, fullness ^{L}, burning/warming ^{L}, numbing sensation ^{L}
	Aroma/ Appearance/ Other	aroma ^{H}, colour ^{H}, appearance ^{M}, combination ^{M}, preference/ liking ^{M}, multi-factorial ^{L}, quality ^{L}, satiety ^{L}, age ^{L}, crispiness ^{L}, grape variety ^{L}, region ^{L}, winemaking process ^{L}, glass coating ^{L}, abstract ^{L}

** Frequency of mentions are represented as: low (≤5 mentions, L); medium (6 – 18 mentions, M); and high (19 – 29 mentions, H)

2.4.2 Consumer understanding of full- and light-bodied products explored within focus groups

2.4.2.1 Full-bodied beers

Beers conceptually identified by consumers as 'full-bodied' were considered more flavoursome, perceptually viscous, astringent, generally being of lower carbonation, or having a different quality of carbonation, namely small, smooth rather than large, coarse bubbles.

Intense, full, rich, associatively dark flavours (blackberry, cherry, plum, chocolate, coffee, caramel, smoke, grain, oak, roasted malt), and sharp and tangy flavours, such as tropical fruit, orange, lemon, pineapple, were related to full-bodied beers. Umami, bitter taste and hoppy flavour were briefly mentioned as being indicative of fuller body.

Also, beer was referred to as full-bodied when the aftertaste matched the initial flavour and persisted. The quality of aftertaste was referred to as *'crucial'*, as beers with an aftertaste that was noticeably different from the initial flavour were considered to be of poor quality and, therefore, of lower body.

Full-bodied beers were associated with alcohol warming. Creaminess, thickness, and smoothness were related to full-bodied beer texture and carbonation quality.

Darker, less transparent, and more aromatic beer styles were also most commonly associated with full-bodied beers. However, several consumers recognised this approach as deceiving and shared experiences in which their expectations did not meet the reality when tasting beers due to visual and aroma cues. They pointed out that flavour and mouthfeel sensations (i.e. flavour intensity, aftertaste, thickness and carbonation properties) play a more significant role in defining full-bodied beer than aroma intensity and overall appearance (such as colour, colour intensity, transparency). Foaming properties, precisely the head appearance, were mentioned as indicative of fuller body in beer.

Interestingly, two distinct opinions emerged when consumers debated beer quality: (i) consumers either related poor beer quality to light body or (ii) agreed that beer quality and beer body were unrelated concepts. When probed to describe differences in quality (unrelated to consumption), at least half of the consumers from less knowledgeable and knowledgeable groups discussed beer packaging (cans, bottles, kegs) concerning quality, emphasising that beer packaged in glass bottles is perceived to be of higher quality.

Furthermore, associations were made with food pairings and context: consumers agreed that it is more appropriate to have full-bodied beers with heavier meals (i.e. various meats, baked bread) during a colder season.

2.4.2.2 Light-bodied beers

Most consumers highlighted the lack of flavour, perceived viscosity (i.e. thinness), and water-like (watery) properties regarding light-bodied beer.

Two distinct perspectives were expressed by consumers when probed on the various flavour, and carbonation characteristics of light-bodied beers: (i) beers with lighter body generally lack flavour characteristics entirely (i.e. they exhibit low-intensity flavour initially, limited flavour diversity and absence of any aftertaste); and (ii) light-bodied beers exhibit flavour characteristics such as sharp, crispy, acidic, hoppy in contrast to the flavour profiles and carbonation quality of the full-bodied beers. The flavours of lower alcohol beers were described as empty and imbalanced.

Common responses related to the aftertaste of light-bodied beers reflected a belief in contrast to that of beers with fuller body: i.e. the aftertaste of light-bodied beers is mild, instant and does not exhibit complexity, as well as lacks flavour development after swallowing. Consumers also mentioned off-flavours, namely, metallic, as a typical characteristic of light-bodied beers, suggesting poor quality.

Furthermore, a debate around the carbonation level of light-bodied beers emerged in all focus groups. High carbonation was generally seen as a characteristic strongly related to beers with lighter body; yet, several discussions supported the idea that low carbonation may correlate with water-like properties in some beers. However, there was a consensus that when combined with perceivably higher viscosity and intense flavour – lower carbonation may impart the opposite effect, in turn allowing the beer to be perceived as being of fuller body.

Lower alcohol beers also emerged within consumers' conversations as being perceived as light in body, thin and highly carbonated.

2.4.2.3 Full-bodied wines

Full-bodied red wines were most commonly associated with strong, intense flavours, namely black cherry, blackberry, plum, chocolate, honey, vanilla, caramel, oak, wood, tobacco, mushroom, earthy, spice, cinnamon and leather notes. Full-bodied white wines were somewhat possibly related to learned associations of flavours perceptually enhancing sweetness, namely, pear, peach, sweet apple, and ripe cherry.

The lingering aftertaste was strongly associated with full-bodied wines. Flavours that remained in the mouth after swallowing and matched the intensity and complexity of the initial sensory profile, rather than acidic and vinegar-like taste, were considered full-bodied.

Consumers agreed that thicker, smoother, creamier, syrup-, liquor- and velvet-like wines, with substantial mouth-coating properties, would be considered full-bodied. Consumers highlighted astringent and tannic red wines as representative of fuller body; however, the majority agreed that a balance with sweetness is required to achieve the desired full-bodied effect. Astringent and acidic white wines were considered less viscous and lighter in body by most consumers, who suggested that the intensity of sweetness predominantly contributes to the perception of viscosity and, therefore, fuller body. Alcohol warming sensation and sweetness were mentioned as important contributors to wine body; however, these were amongst less frequently used attributes when describing full-bodied red wines. Interestingly (and similar to findings for white wine), a considerable number of consumers disagreed or expressed two opposing viewpoints whereby red wine is considered full-bodied with increased viscosity if: (i) it is high in sweetness, or (ii) it is highly astringent, dry and low in sweetness.

Red wines of darker colour (aubergine, plum, purple) were more likely to be considered full-bodied. Similarly, white wines of dark yellow, orange, and gold colours were deemed full-bodied, albeit several consumers disagreed with that statement, suggesting that a paler white wine colour could indicate a fuller body.

Some consumers initiated the debate on quality and its relation to the wine body. Several consumers stated that cheaper, full-bodied, low-quality counterparts lacked balance and roundness in their overall flavour profile compared to expensive, full-bodied, high-quality red wines.

Furthermore, serving temperature was discussed in the context of aroma intensity but was not necessarily related to the body of red wine. Consumers agreed that the appearance of wine, such as a denser coating of the glass and more continual leg distribution, could be indicative of thickness and alcohol content and, therefore, predictive of wine body.

Many conversations emerged regarding context and associative consumption experiences, including the time of day (i.e. consumers considered consumption of full-bodied wines to be more appropriate in the evening), consumption pace (i.e. slower consumption pace was preferable for fuller wines due to their strong, rich and overwhelming flavours), as well as consumption amount (i.e. consumers agreed that relative to the consumption of wine with lighter body, smaller amounts of fuller body wine can be consumed). Some consumers emphasised that a sensation of stomach fullness and sickly feeling after consuming small quantities of wine may indicate its body.

2.4.2.4 Light-bodied wines

Regarding the beliefs for light-bodied red wines, consumers of red wine focus groups agreed that the absence of complex flavours and a strong alcoholic smell, together with a lighter colour and high acidity, gave the strongest correlation with light body perception.

Light-bodied red wines were perceived as watery, diluted, thin, dry, and crisp (sometimes referred to as green flavour). Not all consumers agreed that light-bodied red wines exhibit characteristics, such as dry, astringent, and acidic. Some believed that light-bodied red wines exhibit higher sweetness and red fruit flavours (i.e. strawberry, raspberry, sweet apple). However, some wines have water-like properties similar to grape juice. Interestingly, noticeable alcohol (ethanol) aroma and flavour in red wine indicated to several consumers its light-bodied nature. Light-bodied white wines were mainly perceived as having sharp, crisp, tart attributes and flavours, including green apple, citrus and gooseberry, water-like properties, and low textural presence (thinness). Fewer consumers agreed on the alternative that light-bodied white wines exhibit high sweetness and fruity flavours, namely, lychee, melon, and white peach in combination with absent texture (water-like). The aftertaste of light-bodied red and white wines was considered weak, instant, harsh, and acidic by most consumers.

Low quality and rapid winemaking processes, as well as young wines, were associated with light body.

2.4.3 Consumer understanding of body explored with FCD

2.4.3.1 Beer samples

Over 250 attributes were collated together, and 37 attributes were identified in total. A significant association between attributes was observed from Chi-square analysis (p = 0.021). CA was performed on all attributes that differentiated the beers, resulting in 49.28% of the data variation explained in the first two dimensions. A contribution bi-plot of the beer samples shows the scores and loadings from the CA of the sensory data (Figure 2.2).

The first dimension (Dimension 1, 29.2%) distinguished beer samples on the right-hand side of the bi-plot, which consumers perceived as light-bodied, watery, thin, bitter, crisp, highly carbonated, hoppy, acidic, with weak mouthfeel, weak aroma, and mild overall flavour, from those on the left-hand side perceived as smoky, burnt, malty, thick, smooth, less carbonated, with intense mouthfeel and lingering aftertaste. The second dimension (Dimension 2, 19.7%) separated beer samples in the top half of the bi-plot that consumers perceived as astringent, floral, fruity, full-bodied, with intense aroma and intense overall flavour from flat, creamy, less carbonated samples, with weak aroma and short aftertaste, positioned in the bottom half.

In the upper quadrants, porter (**Porter**) was mostly perceived as smoky, malty, burnt, with intense mouthfeel and lingering aftertaste. In contrast, craft IPA (**Craft.IPA**), low-alcohol craft beer (**Craft.LowAlc**), and American style craft red ale (**Craft.Red.Ale**) were perceived as full- to medium-bodied and together with pale ale (**Pale.Ale**), wheat beer (**Wheat**) and low-alcohol wheat beer (**Wheat.LowAlc**) had a stronger correlation with floral, fruity flavours, as well as intense overall flavour, intense aroma, astringent mouthfeel, carbonation and present aftertaste.

In the lower right quadrant, two lager replicates (**Lager** and **Lager.REP**), and low-alcohol lager (**Lager.LowAlc**) were distinctly perceived as light-bodied, foamy, thin, bitter, watery, with weak aroma, short or absent aftertaste and mild overall flavour. Whereas, in the lower left quadrant, stout (**Stout**) and bitter (**Bitter**) were perceived as flat, creamy, less carbonated, smooth, and thick.

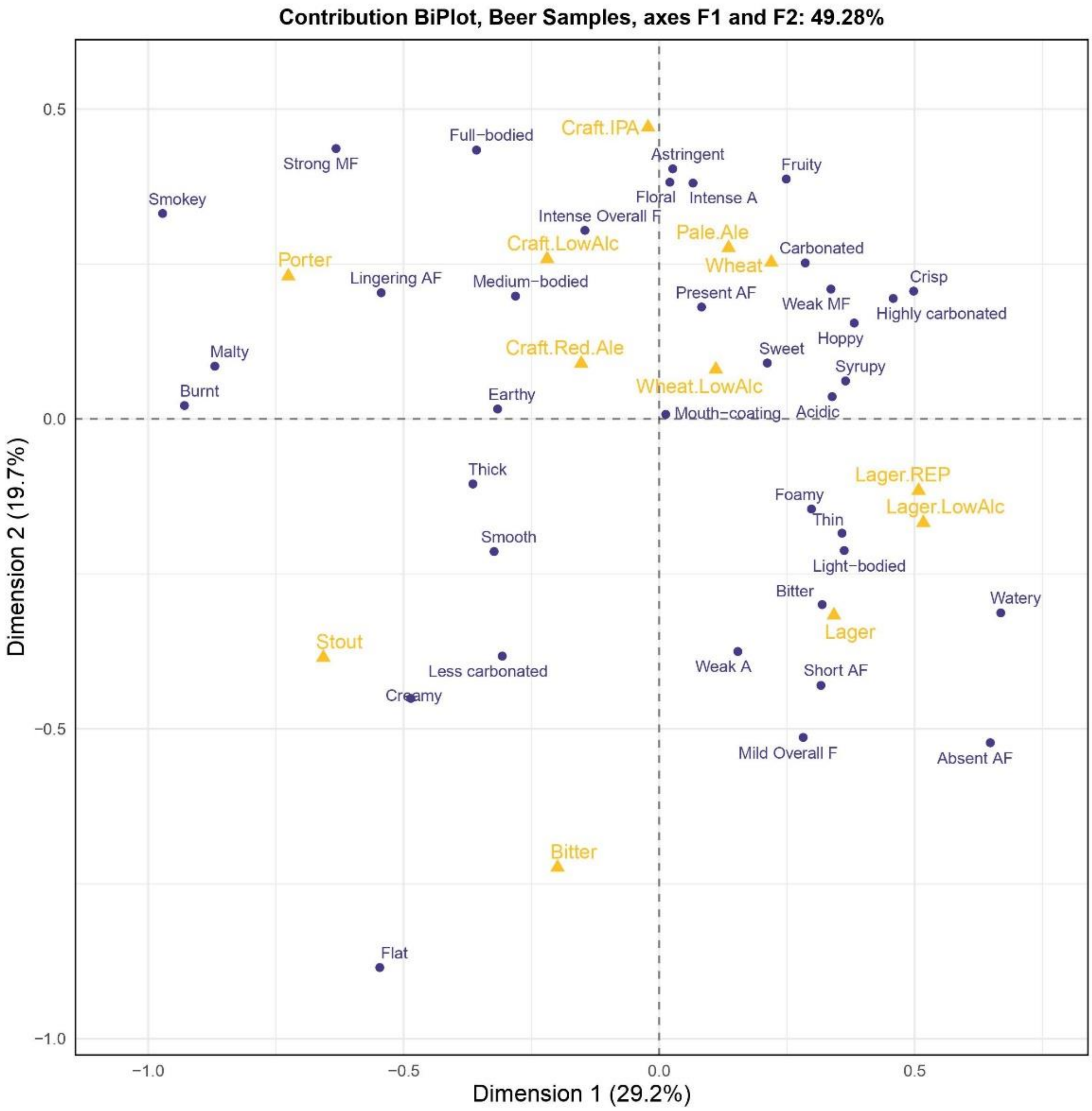

Figure 2.2: Correspondence Analysis bi-plot with attributes (●, n = 37) present on Dimensions 1 and 2 across commercial beer samples (▲, n = 12). Chi-Square test, *p* = 0.021, showing a significant link between the attributes and the samples

2.4.3.2 Red wine samples

Overall, 257 attributes were obtained. A total of 29 collated attributes were identified to differentiate between the red wine samples. A significant association between attributes and samples was observed (Chi-square test, *p* = 0.023). CA was performed on all attributes, resulting in 58.21% of the data variation explained in the first two dimensions. A contribution bi-plot of the red wine samples shows the scores and loadings from the CA of the sensory data (Figure 2.3).

The first dimension (Dimension 1, 43.9%) distinguished red wine samples on the right-hand side of the bi-plot, which consumers perceived as thin, acidic, red fruit-forward, astringent, watery, medium to light-bodied, with mild overall flavour, weak aroma, and short aftertaste, from the left-hand side samples that were perceived as oaky, creamy, thick, smooth, dense, dark fruit-forward, full-bodied, with intense overall flavour and lingering aftertaste. The second dimension (Dimension 2, 14.3%) separated red wine samples in the top half of the bi-plot that consumers perceived as fruity from samples that were more driven by attributes, such as syrupy, light-bodied, and bitter.

In the upper and lower left quadrants, Californian, Chilean and Portugese wines, namely Zinfandel (**Zinfandel.US**), Merlot (**Merlot.US**), Cabernet Sauvignon (**Cab.Sav.CL**), and Portugese blend (**Portugese.Blend.PT**) were perceived by the red wine consumers as oaky, creamy, thick, smooth, mouth-coating, sweet, spicy, full-bodied, with intense aromas, intense overall flavour, lingering aftertaste, and alcohol taste. French wines, namely Malbec (**Malbec.FR**), Merlot-Grenache blend (**Merlot.Grenache.FR**), Shiraz (**Shiraz.FR**) and Gamay (**Gamay.FR**), were mainly perceived as medium-bodied, red fruit-forward, watery, with weak aromas and short aftertaste. In contrast, German Pinot Noir (**Pinot.Noir.DE**) and French Merlot (**Merlot.FR**) were perceived as acidic, thin, and astringent, with mild overall flavour. Finally, Spanish Rioja (**Rioja.ES**) was associated with light body and bitter taste.

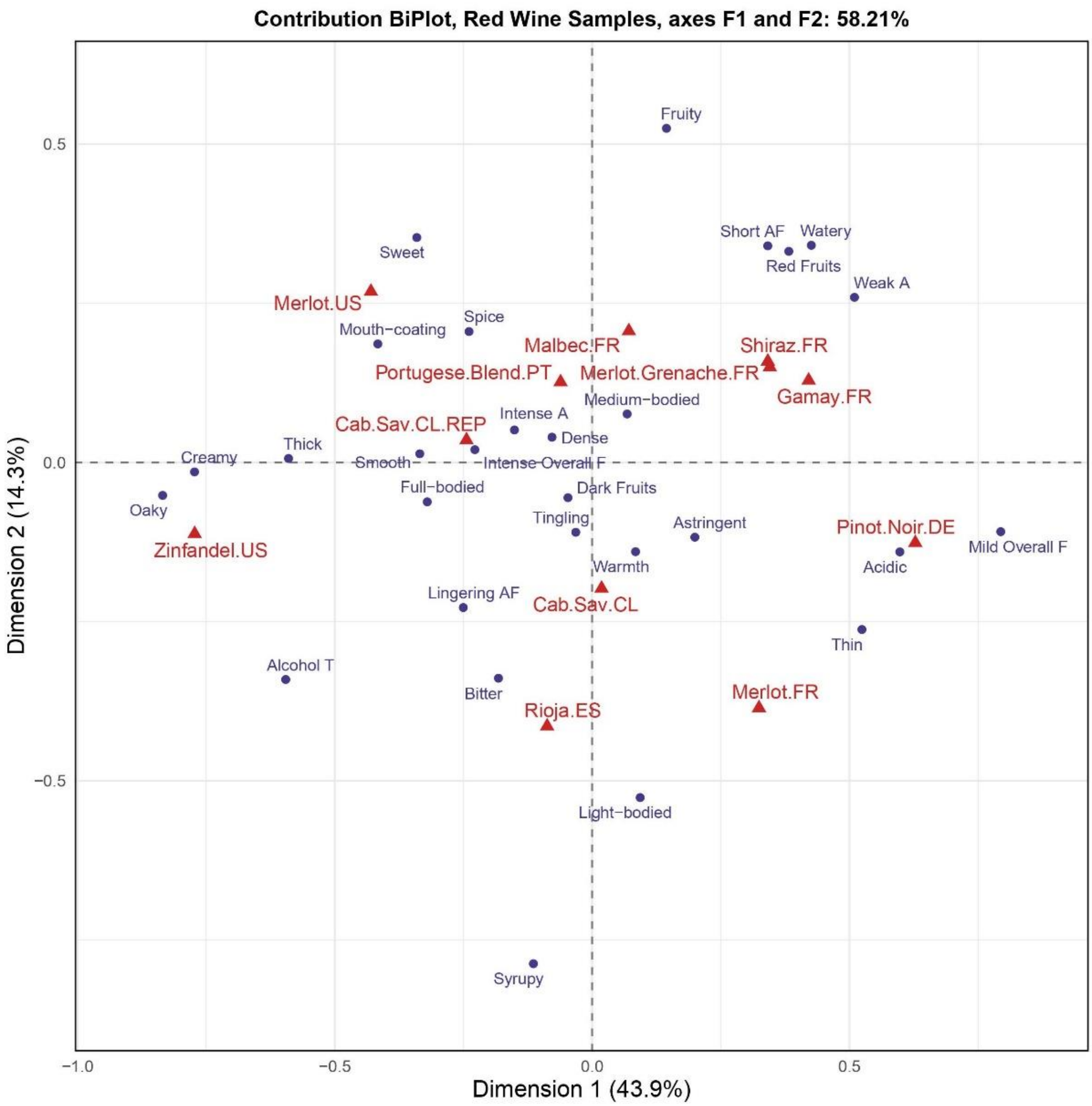

Figure 2.3: Correspondence analysis (CA) bi-plot with attributes (●, n = 29) present on dimensions 1 and 2 across commercial red wine samples (▲, n = 12). Chi-Square test, $p = 0.023$, showing a significant link between the attributes and the samples

2.4.3.3 White wine samples

In total, 22 attributes were generated after the sorting of 211 attributes provided by the consumers. In contrast to beer and red wine samples, the Chi-Square statistic produced a *p*-value higher than 0.05 ($p = 0.652$); therefore, no significant association between attributes and samples was observed, indicating these samples and attributes are likely to be independent.

2.5 Discussion

The understanding of wine and beer body was explored with consumers, and consumer perception of differences between light-bodied and full-bodied beers and wines was investigated as a concept and in commercial samples using focus groups and FCD, respectively.

Similar terms were used for both beer and wine according to the focus group responses. The consumer understands body by the following characteristics: (i) flavour, taste and aftertaste; (ii) mouthfeel, including viscosity, astringency, alcohol warming, and carbonation, and; (iii) overall aroma and appearance (such as opacity or beverage colour intensity). This highlights body is perceived as a multimodal term by the consumers rather than a one-dimensional viscosity characteristic. Consumers also associated body with quality in both beer and wine. Beer body was additionally described by beer consumers using carbonation and foaming properties.

2.5.1 The influence of flavour on the perceived body in beer and wine

In this study, consumers indicated flavour as the major contributor to wine and beer body during focus groups. Overall flavour intensity was also highly correlated with full-bodied wines and beers investigated with FCD. Consumers also indicated light- and full-bodied wines and beers can be distinguished by specific flavours. Previously, higher ratings of flavour (defined as the wine's fruitiness) were commonly associated with higher ratings of the perceived body in Riesling wines (Gawel et al., 2007). Holistic perception of flavour and intensity was also previously described as a key attribute when exploring Australian consumer understanding of wine body (Niimi et al., 2017).

Consumers associated full-bodied red wines with strong, intense, dark fruit flavours, as well as oak-derived and aged flavours, such as chocolate, vanilla, spice, tobacco, and leather, during focus groups. Spice and oaky flavours were also associated with fuller wine styles during FCD, which supports data from previous studies that found palate fullness (defined as *'the overall impression of weight or substantiveness of the wine in the mouth'*) associated with dark fruits, jammy flavour, flavour intensity, hotness and sweetness attributes in late harvest Australian Shiraz wines (Li et al., 2017), and body was related to sweetness, hotness and flavour intensity in early harvest wines (Li et al., 2018).

Light-bodied red wines were associated with red fruit flavours during focus groups. Red fruits, watery, short aftertaste and weak aroma attributes were associated with French Shiraz, Gamay, and Merlot/Grenache blend in the present study, explored with FCD. This finding is similarly supported by Li *et al*. (2017), who found palate fullness was also negatively correlated with red fruit and confectionery flavours.

Oak flavour was one of the major drivers for body in red wine identified with FCD, which is not surprising as *cis*-oak lactone has been found to contribute to spicy, woody and smoky attributes, which also correlated with the perceived body (Koussissi et al., 2009). Similarly, for beer, the FCD results found flavours such as smoky, malty, burnt, earthy and floral correlated with consumer perceptions of full-bodied and medium-bodied beers. In contrast, acidic and bitter tastes were associated closely with light-bodied beers. Liking was not explored in this study, but it should be noted that these attributes might also impact consumer liking as a study that characterised 42 commercial non-alcoholic beers found a correlation of low consumer preference towards flavours such as coffee, burnt, ash, spicy and grassy (Lafontaine et al., 2020). This highlights specific flavours that might increase body perception; however, they may not necessarily increase overall liking, which should be explored further.

During focus groups, consumers associated full-bodied beers with dark fruit flavours, roast-specific flavours, such as chocolate, caramel, coffee, and smoke, as well as citrus, hoppy and tropical flavours. In support of this finding, Romero-Medina et al. (2020) explored sensory profiles of craft beers made with pigmented corn and found palate fullness closely associated with aromas, such as brown sugar, caramel, apple, pineapple, fruity, hoppy, and malty. Beers made with blue corn and barley malts scored higher in fullness than those made with red corn malt (Romero-Medina et al., 2020), highlighting an apparent influence of cereals on body intensity ratings. In contrast, Ramsay et al. (2018) observed lower body perception with beer samples that scored higher in maltiness. However, different beer styles and approaches to create beers with varying alcohol concentrations were used in these studies, explaining this discrepancy.

2.5.2 The influence of mouthfeel on the perceived body in beer and wine

2.5.2.1 Viscosity

In this study, consumers used textural terms, such as thickness and viscosity, to describe body with or without combining it with flavour and flavour intensity terms during focus groups. Attributes such as thick, creamy, and smooth had a stronger correlation to full-bodied wines than beers during FCD, suggesting that texture might be a more substantial contributing factor to body perception in wine.

Contrasting results can be found regarding perceived thickness and astringency to the perceived body in beers and wines. FCD results highlighted that perceptually thicker and more astringent beers were associated with fuller body, whereas thicker and less astringent wines were correlated with fuller body. Similarly, instrumental, and sensory work by Gawel et al. (2014) showed perceived viscosity positively associated with higher phenolics; however, wines with higher total phenolics also scored less in astringency/drying in that study, suggesting perceived viscosity correlated with less astringent wines. Furthermore**,** Laguna et al. (2019) found wine samples with added tannin had the highest measured viscosity and were perceived as more astringent, suggesting that was due to the formation of complexes between the model-wine and salivary proteins; however, no correlation between dynamic viscosity and body (defined as *'viscosity sensation when swishing'*) perception was found, suggesting body perception cannot be explained by viscosity alone.

Perceived acidity negatively correlated with the perceived thickness of beer and wine in the present study explored with FCD. In the same way, some consumers agreed that acidic wines and beers associate with lighter body during focus groups. Similarly, Gawel et al. (2014) observed a strong correlation between wine pH and perceived viscosity, where higher pH increased perceived viscosity. Interestingly, Danner et al. (2019) found no correlation between pH, residual sugar and dynamic viscosity measured across red and white wines. This suggests that despite not significantly affecting the typical dynamic viscosity ranges in commercial wines, wine pH and subsequent perceived acidity play a significant role in perceived viscosity and wine body. An example of this is the study carried out by Hranilovic et al. (2021), in which bio-acidified Merlot wines scored lower in perceived hotness, bitterness and body.

Consumers in the present study also mentioned that density/weight might be correlated with body perception; however, it appeared quite challenging for consumers to define perceived density or palate weight. This is likely due to the narrow viscosity ranges that are characteristic of lagers and non-alcoholic alternative beer products, resulting in no significant correlation between viscosity and sensory perception of palate fullness, mouthfeel or sweetness (Krebs et al., 2019). However, in de-alcoholised wines, the perceived body has been correlated with density when measured instrumentally (Laguna et al., 2017). Further research could benefit from trained panel work to explore contributors of this factor to body perception that consumers find difficult to define.

2.5.2.2 Astringency

The consumers noted astringency in both beer and wine as an important contributor to mouthfeel and body perception. Focus group discussions centred around the impact of sweetness on astringency and body revealed that a group of consumers identified sweet, high in viscosity and low in astringency wines as full-bodied. This was supported by the results of the FCD, where perceived sweetness and thickness were associated with fuller body. In contrast, perceived astringency had a weaker correlation with fuller body in red wine. Another group of consumers suggested full-bodied wines are low in sweetness, dry and highly astringent. According to the beer group results using FCD, astringency was associated with fuller body, but not for red wine. Similarly, Vidal et al. (2004) were able to identify a significant increase in fullness as a result of two fractions of wine major polysaccharides (mannoproteins (MP) and arabinogalactan-protein; rhamnogalacturonan II) added to the wine-like medium. A reduced rating of astringency was also associated with rhamnogalacturonan II, suggesting an association of fullness with less astringent wines (Vidal et al., 2004). In contrast, a recent study investigated the influence of MP supplementation on perceived body and astringency and found no effect on perceived astringency or body in wine (Li et al., 2018), suggesting that other interactions might be at play.

Astringent beers were perceived as more flavoursome, floral, and fuller in body by consumers during FCD. In contrast, a study that defined total mouthfeel in beer as a balanced sensation of fewer negative sensations, such as roughness; decreased astringency; and improved positive sensations such as smoothness, found the removal of high molecular weight compounds such as bitter compounds, polyphenol, maltodextrin, and free amino nitrogen to yield improved softness, smoothness and decreased astringency (Kato et al., 2021). Interestingly and in contrast, total nitrogen was previously positively correlated with palate fullness in another study (Krebs et al., 2021). This highlights the gap for an accurately defined classification for sensory attributes such as palate fullness, body, and mouthfeel. In this study, smoothness, creaminess, and thickness were among the common attributes describing stout beer during FCD; however, a weaker correlation was found with fuller body, and a negative correlation was observed with astringency. Stout was also less carbonated than other beer samples, suggesting that carbonation might play a role in body perception.

2.5.2.3 Ethanol warming

The consumers mentioned the alcohol content as a contributor to body perception, in beer and wine, with lower alcohol beers and wines considered to have a lower body. Alcohol taste was associated with fuller body for red wine during FCD; however, the same finding was not confirmed for beer, suggesting that ethanol might have a stronger correlation with body for wine. Conflicting evidence is reported by the studies investigating the influence of ethanol on body. The addition of ethanol was found to enhance viscosity perception and decrease astringency in wine by interfering with the hydrogen bonding between proteins and polyphenols (Demiglio & Pickering, 2008; Fontoin et al., 2008; Gawel, 1998). This was not consistent with other studies that used a trained sensory panel to evaluate the effect of ethanol on body/viscosity perception, as little to no effect was observed in higher alcohol wines (Pickering et al., 1998). In a white wine-like model, wine with higher ethanol was found to enhance bitterness, hotness and increase palate dryness; however, no significant effect on perceived viscosity was reported when explored with a trained panel (Jones et al., 2008). In contrast, another study found that increased ethanol levels affected perceived viscosity and body, as well as hotness. Still, perceived hotness was not an important component of body (Gawel et al., 2007). Neto et al. (2005) found a correlation between wine density and viscosity with ethanol levels when measured instrumentally. It may be concluded from the previous research that, despite ethanol concentration influencing instrumental density and viscosity, the impact of different ethanol levels on body perception remains unclear.

In contrast with the present findings, ethanol is believed to contribute strongly to beer body (Meilgaard et al., 1979). It was suggested previously that light-bodied beers lack flavour characteristics compared to full strength beers (Malfliet et al., 2009). It was also reported that ethanol contributes to the complexity of flavour in beer (Clark et al., 2011). Collectively, and, as indicated by the consumers in the present study, this might suggest that despite the low alcohol content, perception of a lighter body might occur mainly due to undesirable alterations to flavour and flavour intensity.

2.5.2.4 Carbonation

In the present study, a group of beer consumers did not reach a consensus during focus groups regarding the importance of carbonation for body perception, irrespective of knowledge level. Furthermore, consumers, who agreed that carbonation affected body, associated beers with low carbonation levels to be full-bodied. This was supported by the results from FCD, where lower carbonation correlated with fuller body. A comprehensive review by Bamforth (1985) analysed the foaming properties of beer, and compositional factors, such as proteins, polyphenols, glycerol, carbohydrates, namely dextrins and ß-glucans, ethanol and CO_2, that are important for foam formation. It was reported that nitrogenated beers with improved foam stability have less carbonation and enhance smoothness, consistent with the findings from the present study. Previous research reported various effects of compositional factors on carbonation perception and foam formation in beer and sparkling wine (Viejo et al., 2019); however, research on the impact of those factors on body perception is limited.

2.5.3 The influence of aroma and appearance on the perceived body in beer and wine

Unsurprisingly, most consumers in the present study associated fuller body with beverages appearing darker. It is well known that visual appearance plays a significant role in perception (Morrot et al., 2001) and influences the drinking experience (Reinoso-Carvalho et al., 2019b). Visual appearance cues were previously reported to have an inconsistent influence on perception in beer (Van Doorn et al., 2019). Furthermore, aroma was indicated to influence consumer expectations, subsequently influencing body perception. In contrast, previous research found no effect of aroma on palate sensations and mouthfeel perception in red wine (Sáenz-Navajas et al., 2020). In white wine, it was reported that volatile fractions play a role for some mouthfeel terms (Sereni et al., 2016). Hop aroma was reported previously to modify perceived bitterness by taste-aroma interactions in beer (Oladokun et al., 2016); however, influence on mouthfeel is less understood. These concepts may play an important role when exploring an idea or defining sensory attributes with consumers.

2.5.4 Relating preference to the perceived body

This study shows some consumers related body to abstract concepts, including a strong link between body perception and personal preference. When exploring the idea, consumers who stated they preferred more flavoursome beers and wines were more inclined to associate body with flavour. This notion can be explained by the contribution of sensory attribute liking to overall liking. Moskowitz and Krieger (1995) tested several food categories, and the relative importance of sensory inputs was identified as flavour/taste, followed by texture and appearance. However, when looking at individual responses, substantial differences were found in sensory liking inputs driving overall liking (Moskowitz & Krieger, 1995). It was noted, based on the individual responses in the present study, the consumers who were more reactive to flavour or texture as the main driver for overall liking gravitated towards statements where flavour or texture, respectively, was the central concept in defining body perception.

2.5.5 Relating quality to perceived body

Overall, mouthfeel, including attributes such as thick, mouth-coating, smooth and astringent (dry), was reported by the consumers as one of the main contributors to body perception. Texture and mouthfeel are considered the major contributors to quality and consumer acceptance and preferences for food and beverages (Guinard & Mazzucchelli, 1996). Balance, volume/body, round/smooth tannins, persistency, and fatty mouthfeel were linked to high-quality perception. In contrast, excessive astringency, excessive sourness, imbalance, light, short, green, bitterness and coarse tannins were linked to low quality in wine by experts (Jackson, 2017). It was demonstrated previously that hedonic liking and perceived quality correlate positively for wine experts and consumers (Hopfer & Heymann, 2014). The consumers in the present study mentioned that body correlates with the quality of wine and beer, suggesting that light-bodied products have lower quality; however, not all consumers supported that belief. This observation shows the importance of communicating beverage characteristics to consumers to prevent negative associations and explain the attribute correctly.

It was previously shown that consumers perceive flat carbonated beverages as low in quality, as consumer acceptability and assessment of carbonated beverages is based on carbonation, foam and bubble formation (Viejo et al., 2019). In contrast, consumers from the present study considered low-quality beers to have a lighter body; however, low carbonation levels were linked to full-bodied beer styles. This suggests higher carbonation affects quality but might have a negative effect on the perceived body.

2.6 Conclusion

It is evident from the present study that body is a holistic expression, and it constitutes several modalities, including flavour, mouthfeel, and aroma. According to the consumers in the UK, other important factors for beer and wine body perception include appearance and quality. It was demonstrated with focus groups and FCD that specific flavours and characteristics are responsible for the perception of body. When exploring factors to increase body perception, technical teams and beverage producers must be aware of the term's multifaceted nature and consider a variety of combinational factors. Consumers within different groups who communicated to have a stronger preference for flavoursome beverage products are likely to understand body as a holistic, multisensory perception of flavour. In contrast, consumers more attentive to the textural properties of a beverage are likely to evaluate body according to the textural stimuli. Consumers are also expected to perceive body as a combination of flavour (intensity, balance) and texture (perceived viscosity, trigeminal sensations). Despite being important for the initial evaluation of body, aroma and appearance of the beverage might not play a key role in overall body perception for everyone. Depending on consumer beliefs, the perception of quality may be negatively affected for products with lighter body styles, suggesting a substantial difference between communicating the appeal of different body styles to the consumer and what contributes to its perception. In an attempt to define beer and wine body, consumers of beer, red and white wine groups called the facilitators' attention to the complexity of the concept. There currently appears to be no agreed position on the conditions for fullness in wine or other alcoholic beverages. Further research could benefit from exploring consumer understanding from other geographical locations, as well as directly measuring the impact of compositional factors within beer and wine on the resulting body.

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Chapter 3

The impact of varying compositional factors on consumer perception of beer body

Manuscript

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Abstract

Beer body remains a poorly defined term, and although technical brewing experts currently describe it as the fullness of flavour and mouthfeel, little is known regarding the compositional factors driving its perception. Previous studies have linked consumer understanding of beer body with viscosity (e.g. thickness, smoothness), alcohol warmth and flavour intensity. Therefore, modifications to these attributes in a base beer were explored. In order to assign realistic levels for a sensory experimental design, viscosity, bitterness and ethanol measurements were obtained from a wide range of beers of different styles. A commercial 0.05% lager beer was used as the beer base, with ethanol additions at two levels to yield 2.8 and 4.5% alcohol by volume (ABV). Viscosity, bitterness and hoppy aroma were each increased to perceivably different levels by the addition of carboxymethyl cellulose (CMC), iso-α-acids, and hop oil extract, respectively. A D-optimal experimental design was used to reduce the number of samples (n=18) for consumer testing. Beer samples were evaluated by naive UK beer consumers (n=100) for overall liking, the intensity of perceived body and consumer-derived attributes using the Rate-All-That-Apply (RATA) technique. A 4-way ANOVA revealed significant positive effects of all four factors ($p<0.05$) on body intensity ratings and significant impacts of ethanol, bitterness and aroma on overall liking. Furthermore, cluster analysis was conducted on the body intensity ratings revealing three distinct consumer clusters based on compositional factors. This research suggests that beer consumers are not a homogenous group when it comes to body perception, and they place different levels of importance on different compositional factors and their associated sensory attributes.

3.1 Introduction

Body, palate fullness, and mouthfeel are sensory attributes widely used in the literature to describe beer. Technical experts and consumers frequently use body as an umbrella term to describe multiple mouthfeel characteristics in alcoholic beverages (Gawel et al., 2007; Krebs et al., 2021; Niimi et al., 2017; Ramsey et al., 2018; Runnebaum et al., 2011; Sugrue & Dando, 2018). Mouthfeel is a complex sensory characteristic elicited by interactions between haptic, tactile, trigeminal sensations and temperature-induced impressions in the mouth that relate to the physical or chemical properties of a stimulus (DIN 10950-1 - Sensorische Prüfung - Teil 1: Begriffe, 1999; DIN EN ISO - 5492 Sensorische Analyse - Vokabular, 2009; Sarkar et al., 2019). Pioneering work by Clapperton (1974), Meilgaard et al. (1979), and Langstaff et al. (1991, 1993) explored terms used to describe beer mouthfeel, aroma and flavour and made important contributions to the beer terminology wheel. As a result of those studies, the modality of texture/mouthfeel was divided into three main categories, namely: carbonation (sting, bubble size, foam volume and total carbon dioxide), fullness (density and viscosity), and after-feel (oily mouth-coating, astringency and stickiness). However, a later modification proposed by Schmelzle (2009) suggested that mouthfeel should be added as a category of texture for benefit of the consumer and defined it by tingly, warming, astringent and pungent attributes, with two further categories, including body (viscosity and density) and foam (volume and structure), implying that body is a one-dimensional characteristic of texture (Schmelzle, 2009). Interestingly, the term fullness was replaced with the term body to describe density and viscosity. Throughout the literature, these terms often appear to be used interchangeably, or as an aspect of each other, e.g. body and watery used as bipolar scale anchors for the rating of beer palate fullness (Brown & Clapperton, 1978). The American Society of Brewing Chemists (ASBC, 2011) has expanded the technical definition of beer body to include flavour, defining beer body as *'fullness of flavour and mouthfeel'*. Furthermore, the definition includes descriptors resulting from Clappertons' work, namely thick, satiating, characterless and watery (Clapperton et al., 1976); however, reference standards for those sensory terms are not provided, making sensory panel training on these attributes difficult. Previously, concerns were also raised about the term interpretation in wine research (Gawel et al., 2007; Laguna et al., 2017; Vidal et al., 2015). In wine, the term body is used within red and white wine mouthfeel wheels to define weight, distinct from viscosity, yet the same reference standard (carboxymethyl cellulose, CMC) is proposed for both body and viscosity evaluation (Pickering & Demiglio, 2008).

In a previous exploratory study (Chapter 2), consumer perception of beer body was investigated qualitatively, and consumers were found to understand beer body as a multi-sensory term of flavour (intensity, complexity), texture (smoothness, creaminess, thickness, alcohol warming, mouth-coating, astringency and carbonation), as well as other multi-faceted sensory concepts, such as complexity, balance, quality, preference and satiety. It was clear that olfactory, gustatory and haptic sensory perceptions overlapped when discussing beer body with consumers, suggesting that beer body is not a one-dimensional sensory characteristic, which agrees with previously conducted consumer research in wine (Niimi et al., 2017).

Other studies that included beer body in their lexicons investigated the influence of ethanol concentration on sensory attributes, including body (Ramsey et al., 2018) and the effect of macromolecular distribution, including polysaccharides, proteins and protein-polyphenol complexes on palate fullness (Krebs et al., 2021). Ramsey et al. (2018) presented beer body in their consumer-defined lexicon as a *'feeling of thickness/ fullness as beer is moved around the mouth'* and reported that sweetness, beer body and alcohol warming sensations were cited more frequently as the ethanol concentrations increased, suggesting that ethanol is an important contributor to beer body perception. Krebs et al. (2021) reported that original gravity was the highest influencing factor affecting the perception of palate fullness, as well as other parameters such as viscosity, total nitrogen content, and ß-glucan concentration.

The individual components that contribute to body in beer are not fully understood. Dextrins, polypeptides and ß-glucans (Kato et al., 2021; Krebs et al., 2019, 2021; Langstaff et al., 1991; Langstaff & Lewis, 1993b; Ragot et al., 1989) have been separately explored in the context of mouthfeel evaluation with trained sensory panels, and each of the individual components was found to affect beer fullness. The previous study that explored consumer perception of beer body (Chapter 2) revealed that basic tastes and certain flavours were also admissible as drivers of body perception, including bitterness, malty, and hoppy flavours that have not been reported previously and require further investigation. However, there was some disagreement regarding drivers of body perception, suggesting that consumers may attribute different factors to body perception, which could be based on their past experiences. Studies exploring consumer body perception in alcoholic beverages are beginning to gain traction (Niimi et al., 2017) as body is a desirable attribute for reduced-alcohol beverages that consumers currently perceive as flavourless, empty, unbalanced and lower quality (Chrysochou, 2014; Shemilt et al., 2017). Reduced-alcohol beer is one of the fastest-growing segments within the market, with health consciousness and wellness trends identified among the major drivers of change in alcohol consumption (Ledovskikh, 2017). In order to develop low-alcohol beers that are acceptable to consumers, thereby lowering the risk of long-term health conditions associated with alcohol overconsumption and reducing caloric intake from the regular-alcohol beer counterparts, the perception of beer body and the compositional factors contributing to its perception must be understood.

This study adopted an experimental design investigating the individual impact of four key compositional factors on consumers' perception of beer body and the hedonic response. To manipulate beer composition: ethanol was varied to explore the impact of different alcohol levels; carboxymethyl cellulose (CMC) was added as a viscosity enhancer; iso-α-acids were included to investigate the impact of bitterness, and hop oil extract was used to enhance the hoppy aroma.

The proposed hypothesis was that increasing alcohol, viscosity, bitterness and beer-related aroma intensity would positively contribute to consumers' perception of body in beer, with each compositional factor positively or negatively driving the perception of body depending on consumer segmentation. Furthermore, this study provided an opportunity to gain further insights into a consumer definition of body and explore to what extent different compositional factors drove consumers' perceptions of beer body.

3.2 Materials and Methods

Ethical approval was granted from the University of Nottingham's Medical Ethics Committee (Ref. number: 256-1903). Informed consent was collected from all participants prior to study commencement. An appropriate inconvenience allowance was offered to the participants on study completion.

3.2.1 Participants

Regular beer consumers from the UK who consumed beer at least once a week (n=100: 40 men, 60 women; aged 18-71 (mean age: 30)) were invited through an established consumer database at the Sensory Science Centre (University of Nottingham, UK) to participate in this study. Exclusion criteria included being under the UK legal drinking age (18+), having any medical (including potential pregnancy), religious, allergy or lifestyle reasons that prevent participants from alcohol consumption or any oral sensory impairment.

3.2.2 Instrumental analyses

Prior to sample development, ethanol concentration (EtOH, ABV%), volumetric mass density (ρ, g/cm^3), specific gravity (*SG*) and dynamic viscosity (η, mPa·s) of different commercially available beers sourced from various European countries were measured in triplicate, to establish realistic levels that could be applied within the consequential sample design (data not shown). Furthermore, instrumental analyses were conducted to investigate the impact of modified compositional factors on experimental beer samples' chemical and physical characteristics. The ethanol concentration, density and specific gravity of the 18 experimental samples were measured in triplicate with an Anton Paar Alcolyzer and DMA4500 (Graz, Austria). Bitterness units of the base beer were determined according to the ASBC method Beer-23A (ASBC Method of Analysis., 2011). Analysis of variance (ANOVA) was performed to determine if differences existed between the experimental samples with comparisons of means calculated by Tukey's Honest Significant Difference (HSD) post-hoc test (p=0.05) (XLStat 19.3.2, Addinsoft, New York, USA).

Furthermore, the experimental samples' dynamic viscosity (η) was measured in triplicate according to the EBC Analytica (Method 9.38 - Viscosity of Beer: Glass Capillary Viscometer) method using a calibrated glass capillary Ostwald viscometer (Fisher Scientific, UK) at 20±0.01 C. An aliquot (3 mL) of degassed beer was drawn into the upper bulb of the capillary viscometer via suction once the sample temperature was equated to the setup. It was then allowed to flow down through the capillary into the lower bulb. The time (δt) taken for the sample to pass through the capillary and between the two marks (upper and lower) was recorded in triplicate. The mean time (δt_{mean}), instrumental constant (K) and sample density (ρ) were then used to calculate dynamic viscosity (η) using the following formula:

$$\eta = K \, \delta t_{mean} \, \rho$$

Mean values for alcohol by volume, density, specific gravity and dynamic viscosity for each experimental sample are summarised in Supplementary Table 3.1.

3.2.3 Beer samples

Experimental design software (Design Expert 11, Stat-Ease Inc., Minneapolis, MN, USA) was used to create a design space varying in four compositional factors: ethanol (EtOH: 0.5%, 2.8% and 4.5% alcohol by volume (ABV)), carboxymethyl cellulose (CMC: 'low' and 'high'), iso-α-acids (IαA: 0 and 60 µL/L), and hop oil extract (HopOE: 0 and 280 µL/L). 'Low' corresponded to the viscosity of the samples prior to the modification with CMC (1.7±0.03 mPa•s) and 'high' to 0.16% CMC concentration (3.5±0.06 mPa•s). Levels of all compositional factors were chosen to be perceivably different from the untreated control and tested with a sub-set of naïve assessors (n=12) using Triangle tests (data not shown). A D-optimal design was selected to minimise the sample number for sensory assessment whilst maintaining the ability to produce reliable predictive models resulting in 18 samples, (including one experimental replicate), which are detailed in Table 3.1.

Table 3.1: Custom D-optimal design based on four compositional factors (ethanol (EtOH, E), viscosity (CMC, V), bitterness (IαA, B) and aroma (HopOE, A) at different levels)

Experimental design					
Sample Number	**EtOH (%)** **E** (Ethanol)	**CMC** **V** (Viscosity)	**IαA (μL/L)** **B** (Bitterness)	**HopOE (μL/L)** **F** (Aroma)	**Sample Code**
1	0.05	Low	0	0	$E_0V_0B_0A_0$
2	0.05	Low	0	280	$E_0V_0B_0A_1$ Rep[1]
3	0.05	Low	0	280	$E_0V_0B_0A_1$ Rep[2]
4	0.05	Low	60	0	$E_0V_0B_1A_0$
5	0.05	High	0	280	$E_0V_1B_0A_1$
6	0.05	High	60	280	$E_0V_1B_1A_1$
7	0.05	High	60	0	$E_0V_1B_1A_0$
8	2.8	Low	0	280	$E_1V_0B_0A_1$
9	2.8	Low	60	0	$E_1V_0B_1A_0$
10	2.8	Low	60	280	$E_1V_0B_1A_1$
11	2.8	High	0	0	$E_1V_1B_0A_0$
12	2.8	High	60	280	$E_1V_1B_1A_1$
13	4.5	Low	0	280	$E_2V_0B_0A_1$
14	4.5	Low	60	0	$E_2V_0B_1A_0$
15	4.5	Low	60	280	$E_2V_0B_1A_1$
16	4.5	High	0	0	$E_2V_1B_0A_0$
17	4.5	High	0	280	$E_2V_1B_0A_1$
18	4.5	High	60	280	$E_2V_1B_1A_1$

Sample 1 shows an unmodified sample ('base'); Samples 2 and 3 show the 2 experimental replicates, and Samples 12 and 18 show samples with all compositional factors modified ('extreme')

Samples codes: Ethanol (E, E_0 = 0.05% (Low); E_1 = 2.8% (Medium); E_2 = 4.5% (High) v/v), viscosity (V, V_0 = no addition (Low); V_1 = addition (High) of CMC), bitterness (B, B_0 = no addition (Low); B_1 = addition (High) of iso-α-acids) and aroma additive (A, A_0 = base beer (Original), no addition; A_1 = addition of hop oil extract (Hoppy))

3.2.4 Preparation of experimental beer samples

To create samples with the various compositional factors detailed in Table 3.1, a 0.05% ABV commercial lager beer (Leça do Balio, Portugal) with a mild, neutral flavour profile was used as a base beer to prepare samples with manipulated ethanol (EtOH), carboxymethyl cellulose (CMC), iso-α-acids (IαA), and hop oil extract (HopOE) composition. Firstly, the viscosity of the samples was adjusted by adding 80 mL of 1%wt aqueous CMC (sodium salt, low viscosity, Sigma-Aldrich, Dorset, UK) stock solution prepared in advance or 80 mL of Evian still water (Danone, Paris, France) to 370 mL base beer to achieve 'high' (0.16%, 3.5±0.06 mPa·s) or 'low' viscosity (0%, 1.7±0.03 mPa·s) samples, respectively. For 0.5, 2.8 and 4.5% ethanol samples, 0, 12.6 and 20.5 mL of 96% food-grade ethanol (VWR International, Lutterworth, UK) and 30, 17.4 and 9.5 mL of Evian still water (Danone, Paris, France) were added, respectively, to 470 mL of base beer/water ('low' viscosity samples) or base beer/CMC ('high' viscosity samples) mixture. Furthermore, 30 µL iso-α-acid product (IsoHop®, BarthHaas GmbH & Co, Nurnberg, Germany, density: 1000-1200 kg/m^3, pH: 7.5-10.5, 30% *w/v*) was added to 500 mL base beer/water/ethanol or base beer/water/water mixtures to achieve ~42 International Bitterness Units (IBUs) in samples with intensified bitterness. The base beer bitterness unit level was determined under the ASBC method Beer-23A (ASBC Method of Analysis., 2011) to be at ~12 IBUs. Lastly, for samples with modified aroma, 140 µL of 5% hop oil extract (Totally Natural Solutions, Kent, UK) dissolved in propylene glycol (Fisher Scientific, Loughborough, UK) was added to the final sample mixtures. An equivalent volume of propylene glycol was added to samples with base levels of bitterness (~12 IBUs) and aroma (0 µL/L hop oil extract) to ensure consistency amongst samples. When the desired concentrations of all compositional factors were obtained, samples were degassed completely by sonication and mixed on a roller mixer for at least 6h at room temperature to aid solubilisation. All samples were then refrigerated (5±1 C) before re-carbonation.

3.2.4.1 Re-carbonation of experimental beer samples

After sample preparation, a batch carbonation system manufactured in-house (Medical Engineering Unit, University of Nottingham, UK) was used to re-carbonate the experimental beer samples. The well-mixed, degassed samples were aliquoted into 1 L Duran Pressure Plus+ bottles (Scientific Laboratory Supplies Limited, Nottingham, UK) in duplicate. External plastic meshing was used to protect bottles from accidental breakage when pressure was applied. The caps were tightly secured by placing a silicone sealing ring (RS Components, Corby, UK) inside the cap to prevent any gas leakage. Bottle caps (Fisher Scientific, Loughborough, UK) were modified in-house with a one-way connecting valve (RS Components, Corby, UK), which fitted to the coupling connector (RS Components, Corby, UK) upon initiation of CO_2 delivery. The one-way connecting valve ensured a steady flow until the desired level of CO_2 (controlled by the batch carbonator system) was achieved upon connecting to the coupling connector and isolation of the CO_2 flow upon disconnection (controlled by a shut-off valve). Two pressure gauges fitted on the batch carbonator system allowed close monitoring of the pressure delivered to and dispersed inside each bottle. To speed up the dispersion of CO_2 into the sample mixture, the bottle was disconnected and gently shaken. The steps were repeated as required until the equilibrium was achieved. Once CO_2 flow was isolated from the sample bottle, the bottles' correct pressure (2.5 volumes or 5 g/L) was confirmed, and the sample bottle was disconnected from the carbonator system. The samples were then stored overnight in the cold room (4±2 °C), with sensory evaluation commencing the next day. All samples maintained a fixed CO_2 level (2.5 volumes or 5 g/L) selected as a representative carbonation level found in draught lager style beer (Briggs et al., 2004). Prior to each sensory session, samples were tested for pressure level to ensure no gas leakage had occurred overnight.

3.2.5 Sensory evaluation

3.2.5.1 Session protocol

Eligible consumers (n=100) participated in three evaluation sessions (45 min each) held over six weeks at the Sensory Science Centre, Sutton Bonington Campus, University of Nottingham, UK. All sessions were performed in the ISO standard (ISO 8589:2007) isolated sensory booths with controlled temperature (23±1 C) and airflow conditions. At the beginning of the first session, a short presentation (10 min) was given to participants to explain the session protocol and to provide an opportunity to ask questions. All 18 experimental samples were evaluated across three sessions, i.e., 6 samples per session, presented in a randomised order. Each sample was served in two aliquots (each labelled with a random 3-digit code), which were dispersed from the pressurised bottle upon request to account for the loss of carbonation during evaluations.

All samples were served at 5±1 C and presented monadically, following a blocked, randomised, balanced design according to the William Latin Square. No more than 1 unit of alcohol (8 g) was consumed in any one test session. Consumers were given a forced 1-min break between samples and a 2-min break after the first aliquot set to minimise fatigue and carryover effect. Unsalted crackers (Rakusens, Leeds, UK) and Evian still water (Danone, Paris, France) were provided for palate cleansing. The test was designed, and data was captured using Compusense© Cloud software (Guelph, Ontario, Canada). For the first aliquot (20 mL), consumers evaluated overall liking using a 9-point hedonic scale (Peryam, 1998) to measure consumer acceptability, after which they were asked to define beer body with an open-ended question. Once the first aliquot of all six beer samples presented in the session had been evaluated for overall liking, a fresh aliquot of the same 6 samples (30 mL), each labelled with a different random 3-digit code, was presented, again in a randomised order. Consumers were instructed to take a sip (~10 mL) and rate their perceived body intensity for each sample on a 7-point scale (1 = 'extremely low', 7 = 'extremely high').

Finally, consumers evaluated 11 consumer-generated sensory attributes (Table 3.2) using Rate-All-That-Apply (RATA) (Ares et al., 2014) with a 'not selected' option (equated to 0 for data analysis) with the remaining 20 mL. The attributes were randomised within the modality-specific block for each consumer, with 'overall aroma' always appearing first and 'overall flavour' and 'overall aftertaste' appearing last to ensure consistent sample evaluation. Consumers were asked to rate the intensities of the applicable attributes using a 7-point scale (1 = 'extremely low', 7 = 'extremely high') using the RATA question format (Ares et al., 2014).

Consumer-generated sensory attributes were developed with a subset of 10 naïve consumers who participated in a dedicated attribute generation session prior to the main test (Table 3.2). During the attribute generation session, naïve consumers were presented with a sub-set of 5 samples chosen from the design space to ensure the similarities and differences between the samples were apparent. Consumers were then asked to evaluate beer samples and record all attributes they perceived in each sample. All descriptive terms generated were then listed and grouped by modality, including aroma, flavour, mouthfeel, texture and aftertaste. The sensory attributes for analysis were selected based on the frequency of mention and relevance to the research question.

Table 3.2: Consumer-generated discriminating attributes and their definitions

Attribute	Definition
Basic Taste	
Bitter Taste	Taste on the tongue associated with caffeine or bitter beer
Sweet Taste	Taste on the tongue associated with sugar/ sucrose
Overall Aftertaste	Perception of taste 15s after swallowing
Flavour Attributes	
Malty/ Biscuity Flavour	Sweet, nutty, malty cereal, biscuit-like flavour
Hoppy Flavour	Fresh hop flavour, including herbal, grassy, flowery and earthy notes
Acidic/ Citrus Fruit Flavour	The flavour associated with citrus fruits/ acids
Overall Flavour	The overall flavour associated with beer
Mouthfeel Attributes	
Watery/ Thin Mouthfeel	Absence of texture, water-like
Astringent/ Dry Mouthfeel	Causing dryness in the mouth and on the tongue
Creamy/ Smooth/ Mouth-coating	The feeling of texture, coating sensation in the mouth
Aroma Attributes	
Overall Aroma	Overall aroma associated with beer

3.2.6 Data analysis

3.2.6.1 Open-ended question

The responses to the open-ended question were analysed with content analysis and word frequency queries using qualitative data analysis software (nVivo®, SQR International Pty Ltd.). All responses were considered valid and were used for data analysis. Pre-processing of the collected raw text responses began with data cleaning, which included correcting the typing and orthographic mistakes and removing extra spaces, punctuation, and numeric digits. The raw text was then converted to lowercase. The matrix of content codes was developed manually from the raw text based on the principles of quantitative content coding (Krippendorff, 2010) and in line with the descriptive approach to thematic analysis (Braun et al., 2019). The codes were further grouped into categories, and the frequency of mention was calculated.

3.2.6.2 Effects of compositional factors on hedonic and body intensity responses

To investigate and explain the effects of modified compositional factors (ethanol, viscosity, bitterness and aroma) on variations in body intensity and hedonic score, a 4-way ANOVA with interaction was performed. The models included ethanol at three levels and viscosity, bitterness and aroma at two levels and were partitioned into main effect and two-way interactions, three-way and four-way interactions. The full model was fitted to check assumptions. Four- and three-way interactions were not found significant due to the complex model fit, therefore, only main effect and second-order interactions were considered. A subsequent post-hoc test (Fisher's Least Significant Difference (LSD)) was performed to compare all possible pairs of means with a predetermined significance level of $p<0.05$.

3.2.6.3 Consumer segmentation

To assess whether patterns of body rating varied across consumers, a cluster analysis using k-means with ‘Trace W’ as the clustering criterion, pooled within the covariance matrix, as a classification criterion was performed. To determine the appropriate number of clusters the clustering algorithm (k-means clustering) was computed for different values of k (1-10). For each k, the total within-cluster sum of squares (WSS) was calculated and the curve of WSS was plotted according to the number of clusters k. K-means clustering algorithm was run multiple times (k^100) to minimise the chances of local minima. One-way ANOVAs and a post-hoc test (Fisher's LSD) were subsequently applied to examine differences between clusters and samples within each cluster.

3.2.6.4 Comparison of sample discrimination based on RATA analysed with parametric methods

Previously, *F*- and *t*-tests based on ANOVA were found to be suitable for the analysis of RATA data (Meyners et al., 2016). Therefore, RATA data were analysed using parametric methods, including ANOVA, post-hoc tests (Fisher’s LSD), and Principal Component Analysis (PCA).

PCA was conducted for the experimental beer sample set (n=18) with mean consumer RATA responses for 11 attributes and supplementary quantitative variables, including overall hedonic score, overall body intensity rating, consumer clusters and instrumental measurements (ABV% and dynamic viscosity) to increase the interpretation quality. Furthermore, compositional factors (ethanol, viscosity, bitterness and aroma) were added as supplementary qualitative variables.

All data apart from the open-ended question were analysed using XLSTAT (XLStat 19.3.2, Addinsoft, New York, USA).

3.3 Results

3.3.1 Instrumental analyses

Instrumental analyses were considered with respect to the beer samples with manipulated composition. Significant differences (p<0.05) were observed for ABV (%) levels and dynamic viscosity (mPa•s) of the experimental beer samples, confirming that the ethanol and CMC additions resulted in the increase of measured alcohol levels and instrumental viscosity, respectively (Supplementary Table 3.1).

3.3.2 The consumer definition of body in beer

The consumer definition of beer body was explored via consumer responses to the open-ended question during their first sensory session. Content analysis revealed 32 different content codes from the concepts that consumers used to describe beer body, namely, texture, thickness, silkiness and viscosity, smoothness, flavour and intensity of flavour, aroma, taste (including bitterness), aftertaste, heaviness and weight, mouthfeel, fullness, balance/ whole experience, mouth-coating, sensation, strength, complexity, density, satiety, carbonation and foaminess, lightness, ease of drinking, caloric density, appearance, volume and richness. It also included certain flavours mentioned in association with beer body, including hoppy, citrus, caramel, and earthy. Furthermore, content codes and attributes were collated into 10 categories, with mouthfeel having the highest percentage of mentions, followed by flavour, viscosity and intensity (Table 3.3).

Table 3.3: Categories identified in the open-ended question in which beer consumers (n=100) were asked to define body of beer in their own words, and the percentage of mentioned responses within each category

Category	Examples	Percentage of mention *(%)*
Mouthfeel	mouth, feel, feeling, feels, mouthfeel, sensation	87
Flavour	taste, flavour, flavours, aftertaste	80
Viscosity	thick, thickness, thin, viscosity, texture, watery, wateriness	40
Intensity	intense, intensity, strength	26
Fullness	full, fullness	20
Depth	deep, depth	16
Heaviness	heaviness, heavy, weight	15
Mouth-coating	coated, coating, coat, coats	7
Balance	balance, whole, combination, combined	5
Complexity	complex, complexity	5

3.3.3 Effect of compositional factors on hedonic and body intensity responses

ANOVA revealed a significant impact of ethanol, bitterness and aroma on overall liking ($p<0.001$). Hedonic response was positively driven by the addition of ethanol ($p<0.001$), with higher alcohol beers scoring significantly higher in overall liking (Figure 3.1A). For bitterness and aroma, beers with higher bitterness or higher hoppy aroma scored lower in overall liking, making bitterness and hoppy aroma negative drivers for overall liking (Figure 3.1B and 3.1C).

Furthermore, a significant interaction between ethanol*bitterness was found (Figure 3.1D, $p<0.05$), where ethanol presented as a positive driver for overall liking in samples with higher bitterness level (added iso-α-acids), but no such trend was found for the low bitterness level. Moreover, a significant interaction between bitterness level and aroma was also found (Figure 3.1E, $p<0.05$), where the addition of hop oil extract to beer samples with higher bitterness (added iso-α-acids) had a more substantial negative effect on overall liking, in contrast to when no hop oil extract was added. Interestingly, viscosity levels did not have a significant effect (p>0.05) on the hedonic response.

The majority of the beer samples were perceived by consumers as acceptable (scoring 5 and above on the 9-point hedonic scale), with three samples ($E_0V_1B_1A_1$, $E_1V_0B_1A_1$, $E_1V_1B_1A_1$) receiving a mean liking score of less than 5 (Supplementary Table 3.2).

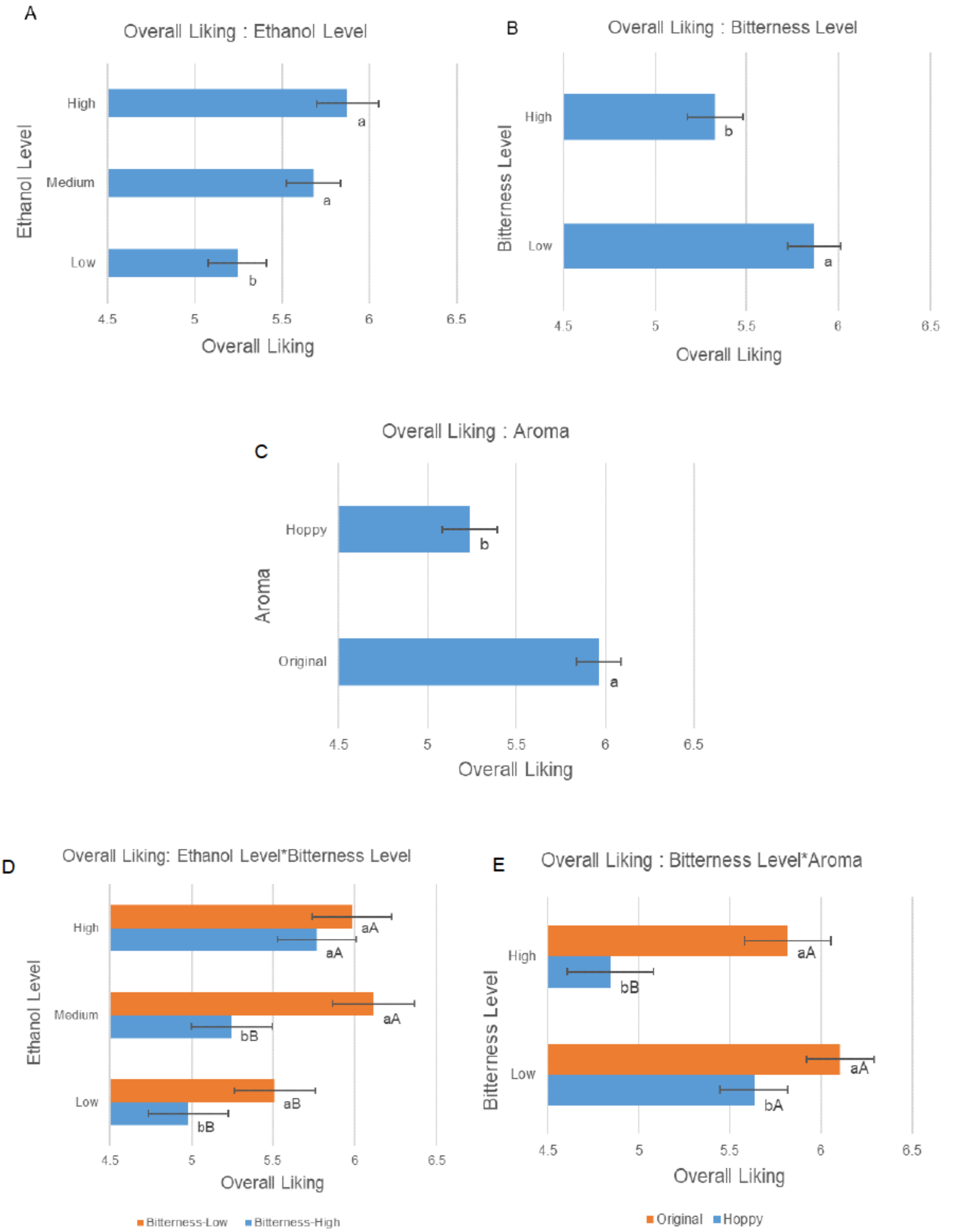

Figure 3.1: Estimated marginal means of ethanol (A), bitterness (B), aroma (C), ethanol*bitterness (D) and bitterness*aroma (E) interaction and effects on overall liking. Different letters (^{abAB}) represent a significant difference between levels of the same compositional factor (A, B, C) and between levels within the interactions (D, E).

For body intensity, ANOVA revealed statistically significant differences for ethanol, viscosity, bitterness levels at $p<0.001$ (Figures 3.2A, 3.2B and 3.2C) and aroma at $p<0.05$ (Figure 3.2D), with each positively contributing to body intensity ratings. Beer samples that included all four modified compositional factors ($E_2V_1B_1A_1$ and $E_1V_1B_1A_1$) scored highest in body intensity (Supplementary Table 3.2).

Moreover, there was a significant interaction between the ethanol and bitterness levels (Figure 3.2E, $p<0.001$), where a positive ethanol impact on beer body intensity at low bitterness but limited ethanol impact at high bitterness level was observed. Whilst not significant ($p=0.08$), a similar interaction trend was observed between ethanol and viscosity, where higher ethanol induced greater body intensity at low viscosity but not at higher viscosity level (Figure 3.2F). Overall, results showed strong evidence accepting the hypothesis that ethanol, viscosity, bitterness and aroma positively contribute to consumers' perception of body in beer.

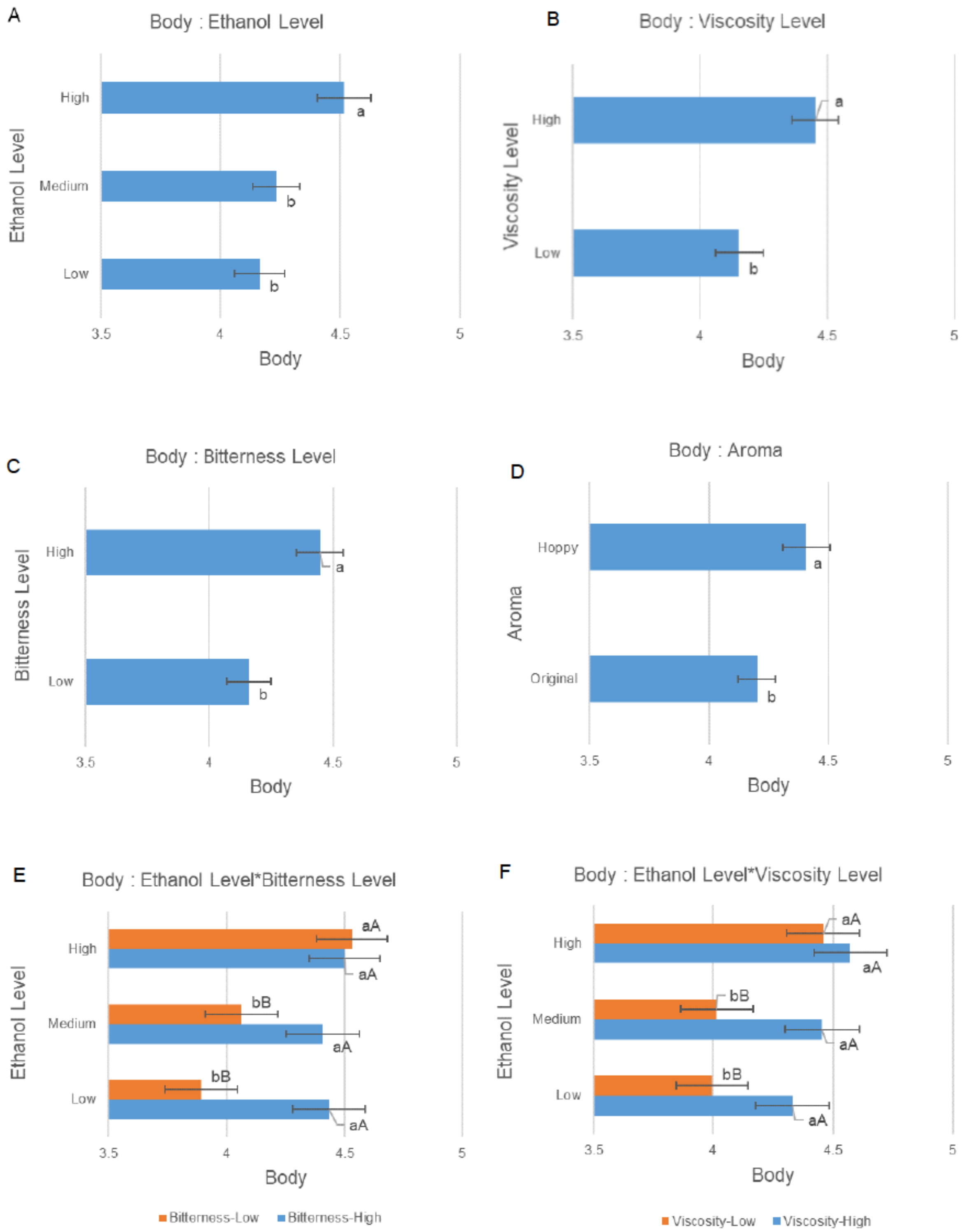

Figure 3.2: Estimated marginal means of ethanol (A), viscosity (B), bitterness (C), aroma (D), and ethanol*bitterness (E) and ethanol*viscosity (F) interactions and effects on consumer beer body perception. Different letters (^{abAB}) represent a significant difference between levels of the same compositional factor (A, B, C, D) and between levels within the interactions (E, F).

3.3.4 Consumer clustering on beer body perception

Cluster analysis (k-means) on body intensity scores was performed to explore if different groups of consumers had different drivers of body perception, as suggested by previous research (Chapter 2). Subsequently, three consumer clusters were identified. Consumer clusters were defined based on the trends they showed when rating the body intensity of the experimental samples. Fisher's LSD test (columns^{abcdefgh}) indicated that Cluster 1 (n=34) rated beer samples with higher viscosity as higher in body regardless of alcohol concentrations, and this cluster was therefore named the Viscosity Driven Cluster. Cluster 2 (n=34) perceived samples with modified bitterness and hoppy aroma as higher in body, so this cluster was named the Flavour Driven Cluster, whereas Cluster 3 (n=32) rated beer samples with higher alcohol concentration as higher in body and was named the Alcohol Driven Cluster. In addition, it was found that the Alcohol Driven Cluster also provided lower body intensity ratings than the other two clusters (Table 3.4).

ANOVA yielded significant differences in body intensity ratings for most beer samples (Table 3.4) across (row^{ABC}) and within each consumer cluster (column^{abcdefgh}). This suggests that the effect of compositional factors on body perception is dependent and varies by different consumer segmentation.

Table 3.4: Overall mean body scores for experimental beer samples (n=18) by cluster (n=3)

Beer Samples	Viscosity Driven Cluster *(n=34)*	Flavour Driven Cluster *(n=34)*	Alcohol Driven Cluster *(n=32)*
$E_2V_1B_1A_1$	4.64^{cB}	5.26^{bA}	4.31^{abcB}
$E_2V_1B_0A_1$	4.91^{bcA}	4.55^{defA}	4.03^{abcdeB}
$E_2V_1B_0A_0$	5.38^{aA}	4.79^{bcdB}	3.59^{efgC}
$E_2V_0B_1A_1$	3.94^{dC}	5.21^{bcA}	4.46^{aB}
$E_2V_0B_1A_0$	4.0^{dB}	4.85^{bcdA}	$4.0^{abcdefB}$
$E_2V_0B_0A_1$	4.55^{cA}	4.55^{defA}	4.37^{abA}
$E_1V_1B_1A_1$	5.08^{abA}	5.26^{bA}	4.18^{abcdB}
$E_1V_1B_0A_0$	4.02^{dB}	4.73^{cdeA}	3.56^{efgB}
$E_1V_0B_1A_1$	3.64^{defB}	5.21^{bcA}	3.59^{efgB}
$E_1V_0B_1A_0$	3.79^{deB}	4.64^{defA}	$4.0^{abcdefB}$
$E_1V_0B_0A_1$	3.5^{efB}	4.38^{defA}	$3.84^{cdefgAB}$
$E_0V_1B_1A_1$	4.73^{bcB}	5.82^{aA}	3.78^{defgC}
$E_0V_1B_1A_0$	4.91^{bcA}	4.61^{defA}	3.37^{gB}
$E_0V_1B_0A_1$	5.08^{abA}	4.29^{efgB}	3.53^{fgC}
$E_0V_0B_1A_0$	3.97^{dB}	4.73^{cdeA}	3.91^{bcdefB}
$E_0V_0B_0A_1$ Rep[1]	3.35^{fA}	3.85^{ghA}	3.71^{defgA}
$E_0V_0B_0A_1$ Rep[2]	3.67^{defB}	4.21^{fgA}	3.87^{cdefAB}
$E_0V_0B_0A_0$	3.32^{fB}	3.71^{hAB}	3.81^{defgA}

Different letters within a row (cluster^{ABC}) or column (beer sample^{abcdefgh}) represent a significant difference in body ratings (Fisher's LSD, $p > 0.05$)

Samples codes: Ethanol (E, E_0 = 0.05%; E_1 = 2.8%; E_2 = 4.5% v/v), viscosity (V, V_0 = no addition; V_1 = addition of CMC), bitterness (B, B_0 = no addition; B_1 = addition of iso-α-acids) and aroma additive (A, A_0 = base beer, no addition; A_1 = addition of hop oil extract)

3.3.5 Effects of compositional factors on sensory properties and body perception

Significant differences were found between samples for all sensory attributes evaluated using the RATA method (ANOVA, $p<0.0001$). PCA resulted in 78.2% of the variation in the data being explained in the first two dimensions. A bi-plot of the beer samples shows the scores and loadings from the PCA of the sensory data (Figure 3.3).

The first dimension (F1, 46.3%) separated beer samples on the right-hand side with intense overall flavour (OverallF), hoppy flavour (HoppyF), overall aroma (OverallA), aftertaste (OverallAf), bitter taste (BitterT) and astringent mouthfeel (AstringentMF) from those perceived as sweet (SweetT) on the left-hand side of the bi-plot. The second dimension (F2, 31.9%) separated beer samples in the top half of the bi-plot perceived as smooth (SmoothMF) and malty (MaltyF) from those perceived to be watery (WateryMF) in the bottom half of the bi-plot.

Overall liking (**Overall Liking**) was positively correlated with sweet taste (SweetT, 0.625) and malty flavour (MaltyF, 0.549), and negatively correlated with bitter taste (BitterT, (-0.627)), overall aroma (OverallA, (-0.616)), hoppy flavour (HoppyF, (-0.538)) and astringent mouthfeel (AstringentMF, (-0.533)).

According to the Pearson correlation matrix ($p<0.05$), overall beer body rating (**Body**) was positively correlated with sensory attributes, including smooth (SmoothMF, 0.796), overall flavour (OverallF, 0.785), overall aftertaste (OverallAf, 0.662), hoppy flavour (HoppyF, 0.627) and negatively correlated with watery mouthfeel (WateryMF, (-0.913)). Furthermore, a weaker yet significant correlation was observed with instrumental measurements of dynamic viscosity (DViscosity, 0.598) and alcohol (ABV%, 0.477).

The Viscosity Driven Cluster was positively correlated with dynamic viscosity (DViscosity, 0.821) and sensory attributes, including smooth mouthfeel (SmoothMF, 0.934) and malty flavour (MaltyF, 0.560), and negatively correlated with watery mouthfeel (WateryMF, (-0.898)). The Flavour Driven Cluster rated samples with more intense overall aftertaste (OverallAf, 0.789), hoppy flavour (HoppyF, 0.754), overall flavour (OverallF, 0.743), bitter taste (BitterT, 0.695) and overall aroma (OverallA, 0.597) as higher in body, and negatively driven by watery mouthfeel (WateryMF, (-0.659)). This cluster also did not significantly correlate with measured alcohol level (ABV%) or dynamic viscosity (DViscosity). Furthermore, the Alcohol Driven Cluster was positively correlated with higher alcohol (ABV%, 0.567), as well as sensory attributes such as overall flavour (OverallF, 0.674). A weaker yet significant positive correlation was also found between aftertaste (OverallAf, 0.501) and hoppy flavour (HoppyF, 0.488).

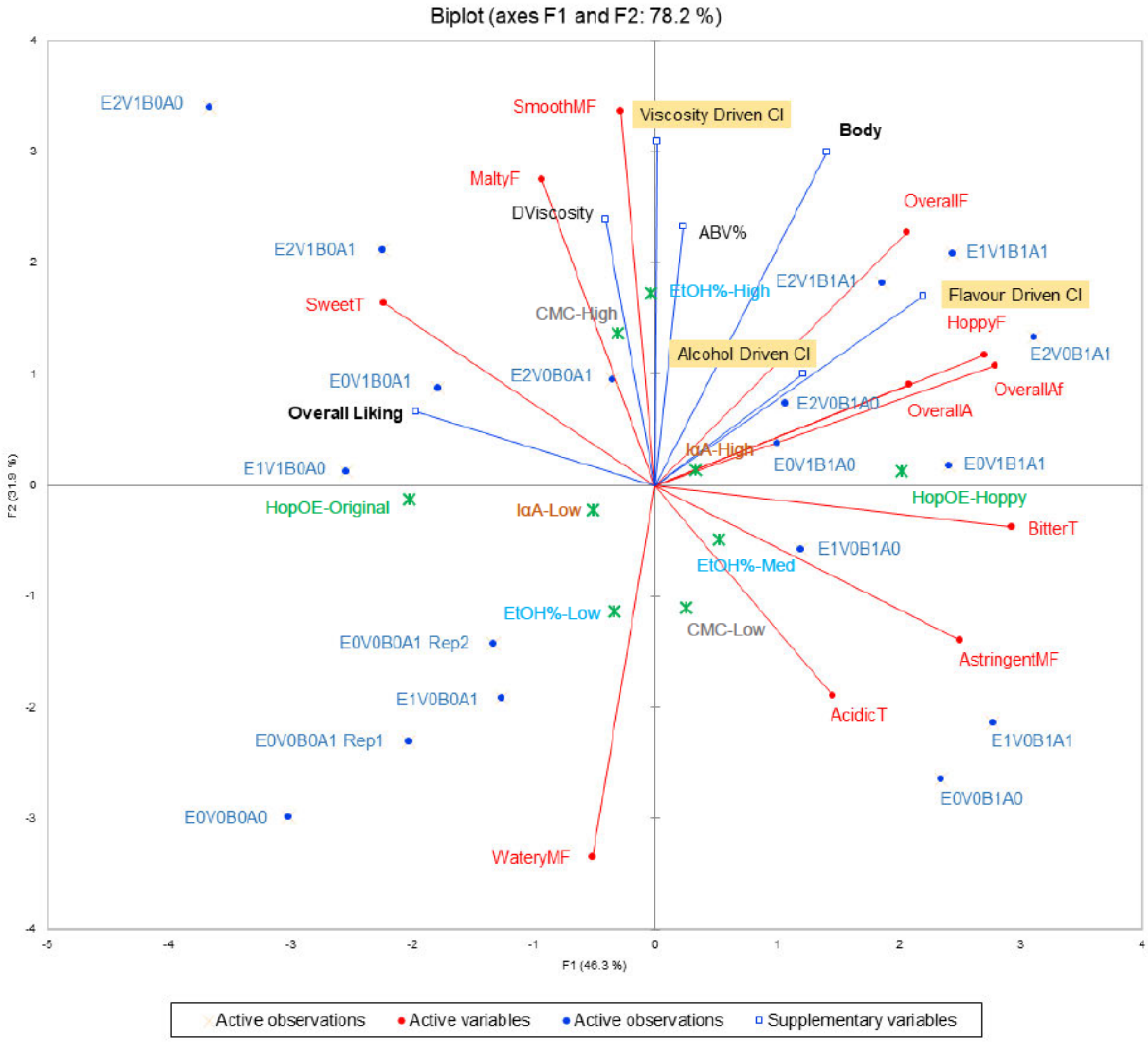

Figure 3.3: Principal component analysis plot (F1 & F2: 78.2%) of the sensory attributes that differentiated 18 experimental beer samples by the consumer panel (n=100) using RATA, overlaid with the supplementary variables (body intensity ratings, overall liking, compositional factors, instrumental measurements and consumer clusters)

Beer samples (●), sensory attributes (●) and supplementary variables (□ & ✶). **Sample codes:** Ethanol (E, E_0 = 0.05%; E_1 = 2.8%; E_2 = 4.5% v/v), viscosity (V, V_0 = no addition; V_1 = addition of CMC), bitterness (B, B_0 = no addition; B_1 = addition of iso-α-acids) and aroma additive (A, A_0 = base beer, no addition; A_1 = addition of hop oil extract). **Attributes:** A = Aroma, T = Taste, F = Flavour, MF = Mouthfeel, Af = Aftertaste. **Compositional Factors**: E = Ethanol (EtO%-Low, EtO%-Med, EtOH%-High), V = Viscosity (CMC-Low, CMC-High), B = Bitterness (IαA-Low, IαA-High) and A = Aroma (HopOE-Original and HopOE-Hoppy). **Clusters by body:** Cluster 1 = Viscosity Driven, Cluster 2 = Flavour Driven, Cluster 3 = Alcohol Driven

Figure 3.4 shows the sample distribution according to the compositional factors modified in each beer sample. A clear separation was seen for samples of different ethanol levels, viscosity and bitterness, whereas samples with modified aroma (addition of hop oil extract) were distributed across the plot without forming distinct groups.

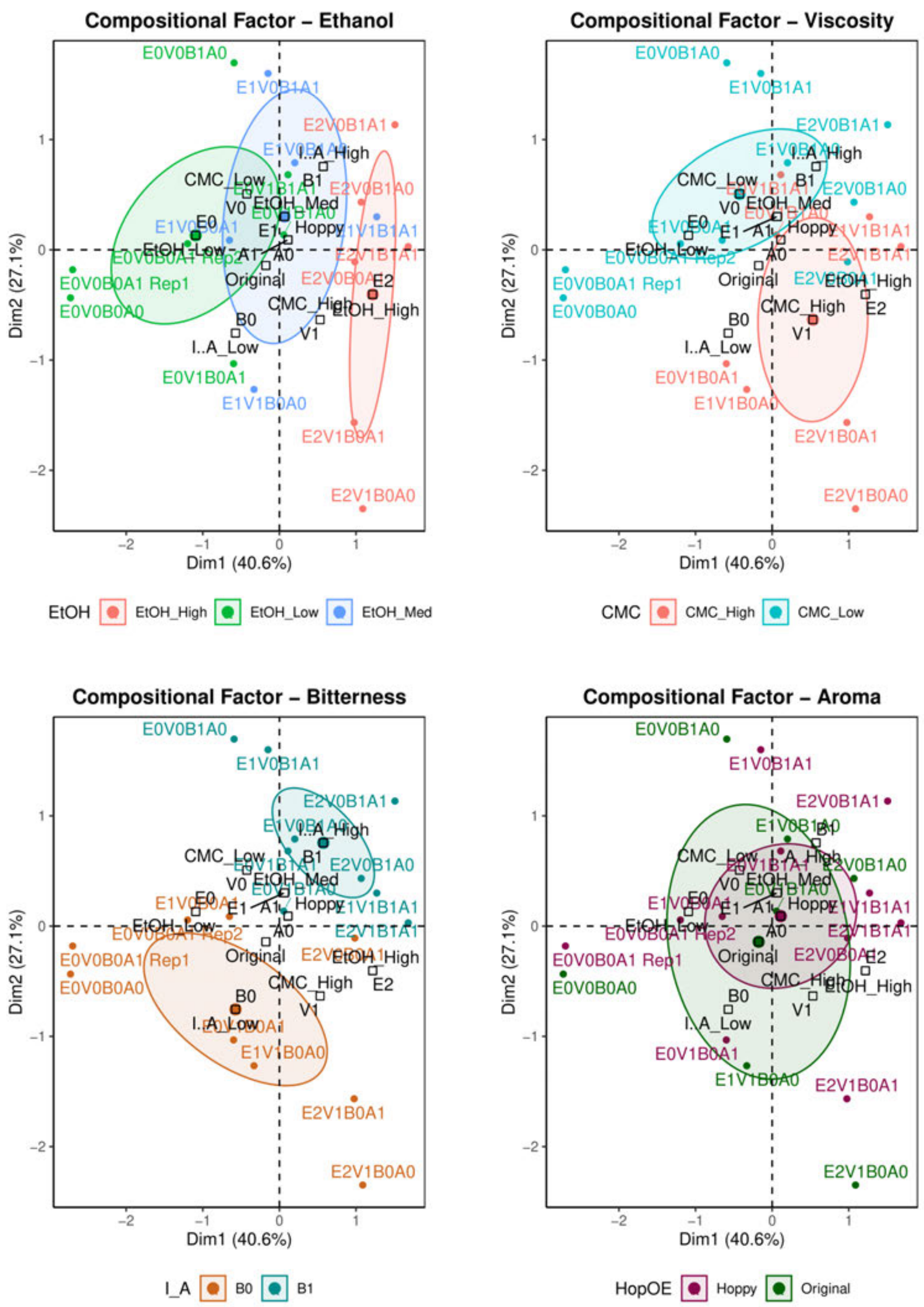

Figure 3.4: Sample distribution by its compositional factors with 95% confidence ellipses. **Sample codes**: Ethanol (E, E_0 = 0.05%; E_1 = 2.8%; E_2 = 4.5% v/v), viscosity (V, V_0 = no addition; V_1 = addition of CMC), bitterness (B, B_0 = no addition; B_1 = addition of iso-α-acids) and aroma additive (A, A_0 = base beer, no addition; A_1 = addition of hop oil extract). **Compositional Factors**: E = Ethanol (EtOH_Low, EtOH_Med, EtOH_High), V = Viscosity (CMC_Low, CMC_High), B = Bitterness (I_A_Low, I_A_High) and A = Aroma ('Original' and 'Hoppy')

3.4 Discussion

3.4.1 The impact of ethanol

Ethanol was one of the main compositional factors that positively influenced the perception of body and overall liking of the experimental beer samples. Interestingly, beer consumers did not mention alcohol or alcohol-related attributes, such as warming or burning, as a defining characteristic of beer body in the open-ended question, supporting earlier findings demonstrated by wine consumers when exploring wine body (Niimi et al., 2017). However, consumers mentioned alcohol warming as a contributor to beer body perception in a focus group setting (Chapter 2). The impact of alcohol on beer's taste, flavour, and mouthfeel characteristics has been previously researched. Studies have shown ethanol contributes to the perception of warming mouthfeel, sweetness, and complexity of beer flavour (Blanco et al., 2016; Clark et al., 2011) and enhances alcohol warming sensation and greater perception of fullness/body (defined as *'feeling of thickness/fullness as beer is moved around the mouth'*) (Ramsey et al., 2018). In this study, experimental samples with higher ethanol concentrations (ABV%) were perceived to have a greater body and enhanced overall flavour (OverallF). It is evident from previous research that ethanol plays a key role in aroma partitioning and release in alcoholic beverages. It was shown that increasing ethanol concentration in model beer results in an in-breath volatile increase, including ethyl acetate, isoamyl alcohol and phenylethyl alcohol, measured after consumption (Clark et al., 2011a). The increased volatility was attributed to changes in surface tension affecting how the beverage coats the mouth during consumption, thereby resulting in increased volatile release (Clark et al., 2011a) which could explain the increase in perceived overall flavour at higher ethanol levels found in the present study. It should be noted that alcohol removal has a significant, detrimental effect on beer flavour and mouthfeel, showed in de-alcoholised lager beer (0.05% ABV) exhibiting maltier flavour, with reduced fruitiness, sweetness, fullness/body and alcohol warming sensation (Ramsey et al., 2018), which highlights a more significant impact on the overall flavour, aroma release and mouthfeel profile than effect of ethanol concentration (0.05 – 4.5 ABV) on aroma release.

However, it is yet unclear if the effect found instrumentally in these previous is capable of an increased sensory effect. Peltz (2015) found that ethanol concentration had a minor effect on hop compounds sensory detection thresholds, whereas Clark et al. (2011b) found ethanol to increase the perceived complexity of beer flavour with a trained sensory panel.

Furthermore, in contrast with other studies, where ethanol enhanced sweetness perception (Clark et al., 2011b; Ramsey et al., 2018, 2020), the sweetness was not correlated to higher ethanol concentration and mainly contributed to overall liking.

3.4.2 The impact of viscosity

In the present study, the thickness of the samples was modified with CMC to increase viscosity whilst not impacting any taste or flavour properties and was found to be a significant driver for beer body perception. The intensity of the watery attribute (WateryMF) was negatively correlated with beer body (**Body**), in agreement with previous research (Krebs et al., 2021), suggesting that experimental beer samples perceived as less viscous were recognised as being low in body. The samples that were perceived to be watery in this study either had one or no compositional factors modified, suggesting that the addition of more of the selected compositional factors influenced the consumer perception away from perceiving samples as watery. Terms describing mouthfeel were mentioned by consumers most frequently when qualitatively defining beer body using the open-ended question and the quantitative consumer ratings show a positive correlation between the addition of CMC (CMC-High) and smooth mouthfeel (SmoothMF). However, viscosity was not the only compositional factor impacting perceptions of smooth mouthfeel (SmoothMF); ethanol (EtOH%-High) was also correlated with smooth mouthfeel (SmoothMF), suggesting that it could be an important sensory attribute for beer body perception, despite it being mentioned less than 5% in relation to consumers definition of beer body in response to the open-ended question. This agrees with previous research where smoothness perception was found to increase with viscosity (thickness) as a function of both suspension viscosity and particle modulus (Shewan et al., 2020) but was not supported by earlier research where decreased smoothness did not affect beer body with a trained panel (Kaneda et al., 2002).

According to the PCA results, beer body ratings were significantly correlated with higher alcohol content (EtOH%-High) and dynamic viscosity (DViscosity). Similarly, a recent study explored macromolecular profiles and palate fullness in lager beers and demonstrated a significant correlation between palate fullness and analytically measured ethanol concentration and viscosity (Krebs et al., 2021). In another study, Krebs et al. (2019) explored non-alcoholic lager beers and showed no significant correlation between viscosity and the sensory perception of palate fullness, suggesting that within the common range of viscosities, the correlation between the thickness of the beer and palate fullness is less apparent. Krebs et al. (2019) noted that sensory attributes that are often mentioned to describe beer, including palate fullness, body and mouthfeel, are currently used indiscriminately due to the absent or inaccurate definition of those terms. Similar interchangeable terminology can be found in the wine literature (Lemos Junior et al., 2019) and requires further investigation.

3.4.3 The impact of bitterness and hoppy aroma

Significant differences were found amongst experimental beer samples containing iso-α-acids, where these samples were perceived as greater in overall flavour (OverallF), overall aftertaste (OverallAf), hoppy flavour (HoppyF), bitter taste (BitterT), overall aroma (OverallA) and astringent mouthfeel (AstringentMF). In comparison, samples without the addition of iso-α-acids (low in bitterness) were perceived as sweet (SweetT) and malty (MaltyF). Unsurprisingly, the addition of iso-α-acids caused a negative effect on the overall liking of the experimental beer samples, which agrees with the previous research (Carvalho et al., 2017). The presence of hop oil extract in the experimental beer samples also caused a decrease in the overall liking. This notion might be explained by the fact that the majority of the consumers (45%) in the present study identified as lager drinkers (compared with other beer style preferences: IPA (16%), pale ale (14%), craft (13%)), which might explain a significant drop in their acceptance when consuming beer samples with enhanced bitterness and hoppy aroma as lager beer style beers tend to contain low levels of both.

Perceived bitterness drove body perception for the Flavour Driven cluster. This cluster was also correlated to sensory attributes such as hoppy flavour (HoppyF) and overall flavour intensity (OverallF), suggesting that the addition of iso-α-acids may have also contributed to the perception of these attributes. Furthermore, in addition to bitterness, hoppy aroma (addition of hop oil extract) also drove beer body perception, explored with 4-way ANOVA, suggesting that the presence of expected beer flavours may positively influence body intensity and highlighting the importance of having congruent flavours in beer matrix on beer body. However, it is unclear if this effect is specific to hoppy aroma/flavour, as previous qualitative research (Chapter 2) suggested dark fruit (blackberry, cherry, plum), citrus and tropical fruit (lemon, orange, pineapple), roast-associated flavours (chocolate, coffee, caramel, smoke, grain, oak, roasted malt), as well as hoppy, to be important for beer body perception. Similarly, Liguori et al. (2018) explored beers produced by osmotic distillation and reported a strong positive correlation between beer body and fruity/esters, fruity/citrus, malty, hoppy and alcoholic/solvent flavour attributes. Therefore, various beer flavours may drive body perception depending on the consumer. This study only explored the impact of the generic hoppy aroma; however, further research should examine the impact of a range of flavours on beer body perception.

Furthermore, as displayed in Figure 3.4, samples with different bitterness levels (B0: IαA-Low and B1: IαA-High) showed clear separation on the plot, unlike samples with modified hoppy aroma (A0: HOE-Original and A1: HOE-Hoppy). It was previously reported that hop aroma could modify perceived bitterness by taste-aroma interactions (Oladokun et al., 2016b). Oladokun et al. (2016b) observed that the addition of hop aroma extract caused an increased bitterness intensity perception and demonstrated that the effect was driven by volatile hop aroma compounds stimulating receptors via the retronasal route. In this study, hop oil extract addition exhibited a significant effect when measuring body intensity of the experimental beer samples, suggesting that volatile hop aroma may have acted indirectly by enhancing bitterness perception and, subsequently, body. This may be attributed to the combined input from the sense of taste and smell that are well-studied in relation to enhanced flavour perception (Auvray & Spence, 2008; Small & Prescott, 2005).

3.4.4 The impact of compositional factor interaction

The nature of the interaction between two compositional factors can be characterised as an additive, suppressive and synergistic (enhancement) using psychophysical curves (Keast & Breslin, 2003), where, respectively, the effects of combined perceived intensity are equal ($AB = A + B$), lower ($AB > A + B$) or greater ($AB < A + B$) than the intensity of each compound individually.

Whilst ethanol was found to contribute to the body of beer, it is interesting that varying viscosity, bitterness and hoppy aroma also exhibited a significant effect on body when explored with 4-way ANOVA. This adds further evidence that body is not a simple one-dimensional characteristic but rather a multi-faceted term, where enhancement can be achieved in beers with low and no alcohol. The results highlighted this notion as an experimental beer sample with modified viscosity, bitterness and hoppy aroma, but no alcohol ($E_0V_1B_1A_1$) scored second-highest for body intensity and was not perceived to be significantly different in body from samples with both 2.8% and 4.5% ABV ($E_1V_1B_1A_1$ and $E_2V_1B_1A_1$, respectively) (Supplementary Table 3.2). In support of the present findings, it was previously noted that body and the alcoholic/solvent descriptors decreased after the removal of ethanol; however, the addition of hop extract and pectin solution improved the body of the beer samples (Liguori et al., 2018). This highlights that high alcohol content is not a necessity for body perception, assuming that other factors can be modified to compensate.

When exploring significant compositional factor interaction effects on the overall beer body ratings, synergistic effects of ethanol and bitterness, as well as ethanol and viscosity, were found. Figure 3.4 shows a clear separation of samples with added iso-α-acids driving overall body perception, supporting that bitterness is one of the main compositional drivers of beer body (Leskosek-Cukalovic et al., 2010). Similarly, the addition of iso-α-acids (high bitterness) to beer samples with different alcohol concentrations increased overall body rating, in contrast with the overall liking score, suggesting that bitterness elicited by iso-α-acids may have enhanced effects of ethanol bitterness, similar to findings of other studies that explored the perception of binary mixtures containing quinine (Thibodeau & Pickering, 2021), in turn enhancing beer body perception through increasing bitterness. Likewise, the addition of CMC (high viscosity) to beer samples with different alcohol concentrations promoted overall body ratings. It was also demonstrated that adjusting the bitterness and viscosity of experimental beer samples at low alcohol concentration (0.05% ABV) had a similar effect on overall beer body ratings as at higher alcohol concentration (4.5% ABV). No further increase in body perception was found after the addition of iso-α-acids or CMC to beer samples, suggesting that similar body ratings can be achieved in lower alcohol products.

It was previously reported that ethanol elicits bitterness (Nolden et al., 2016; Nolden & Hayes, 2015; Small-Kelly & Pickering, 2020), among other tastes and sensations, including astringency (Nolden & Hayes, 2015), warming, irritation or burning (Allen et al., 2014; Clark et al., 2011; Ramsey et al., 2018), suggesting that ethanol is a complex stimulus capable of eliciting multiple taste and chemesthetic sensations. In this study, ethanol addition positively influenced the overall liking of the samples at the higher bitterness level but not at the low bitterness level. Because bitterness was a negative driver of liking, this result suggests that ethanol was capable of reducing bitterness to acceptable levels. Therefore, ethanol may be capable of *rounding out* undesirable attributes in beer. Furthermore, an interaction effect between bitterness (addition of iso-α-acids) and hoppy aroma (addition of hop oil extract) (bitterness level*aroma) was observed when exploring the effects of compositional factors on overall liking. Previously the contribution of hoppy aroma to bitterness and mouthfeel was studied in Pilsner beer, and it was reported that hop aromatisation impacted bitterness and enhanced fullness perception (van Opstaele et al., 2010), suggesting a synergistic effect between hop aroma and bitterness for those parameters. It is likely that the perception of bitterness was increased with the addition of hop oil extract due to that synergistic effect, subsequently driving the hedonic response down, potentially related to the negative emotions elicited in response to beers with higher bitterness concentration explored previously (Viejo et al., 2020). In this study, the highest liking score was achieved at medium alcohol concentration (2.8% v/v) with no iso-α-acid addition, suggesting that reducing the bitter components in beer would likely increase its palatability through enhancement of the established sweet-like component in the taste of ethanol reported previously (Lemon et al., 2004).

With higher bitterness having a negative effect on overall liking but a positive effect on overall body perception, it is important to consider that improving beer body in the final product by modifying the compositional factors might negatively impact consumer acceptance.

3.4.5 The impact of consumer clustering

One of the interesting findings of this study was that three clear clusters were identified based on the perceived beer body intensity ratings. Results revealed that consumers rated body according to different compositional factors present in the samples, including viscosity, flavour (hoppy aroma and bitter taste) and ethanol, suggesting that individual differences within a population for beer body perception are based on different dominant attributes. This highlights the relevance of compositional factors explored within this study and provides direction for the brewing industry and new product developers to consider a combinational approach.

The Viscosity Driven consumer cluster asserted the perceived thickness of the beer samples to beer body perception, suggesting that viscosity was important when assessing body intensity for this consumer cluster. Furthermore, the addition of iso-α-acids (IαA-High) and hop oil extract (HOE-Hoppy) drove the body perception for the Flavour Driven consumer cluster. It is evident from the results of both the present study and previous research that whilst beers with higher alcohol and viscosity are perceived to have greater beer body, there is a different consumer focus on taste and flavour. Furthermore, according to the PCA, body ratings of the Flavour Driven cluster (Flavour Driven Cl) and Alcohol Driven cluster (Alcohol Driven Cl) were driven by the hop-oil-extract-associated sensory attributes, including overall flavour intensity (OverallF), hoppy flavour (HoppyF) and overall aftertaste (OverallAf) of the experimental beer samples. This is not surprising as the addition of ethanol was previously attributed to enhancing flavour intensity, as well as eliciting bitter and sweet tastes when explored with ethanol/water mixtures (Mattes & DiMeglio, 2001; Scinska et al., 2000).

The three-cluster solution revealed different term interpretation patterns based on sensory characteristics, which suggests that beer consumers cannot be seen as a homogenous group when attempting to define and evaluate a multi-sensory attribute such as beer body as they place different levels of importance on different compositional factors and their associated sensory attributes. Therefore, whilst all four compositional factors may be considered important for body in beer, results suggest that reduction or removal of one factor, such as ethanol, can still result in body intensity ratings comparable to their full strength counterparts, provided the other factors are increased. Despite compositional factors having a positive effect on consumer beer body perception, the acceptability of a manipulated final product will likely depend on the individual consumer clusters. Consumer clusters may also differ depending on the explored beer and beverage market in general, which is acknowledged as a limitation of the study.

3.5 Conclusion

Previous research associated beer body with viscosity and density as contributing sub-qualities, as well as palate weight and flow resistance, which suggested that beer body is a one-dimensional characteristic of texture. As seen in the present study, viscosity is not the single characteristic that influences beer body, as all four factors explored (ethanol concentration, viscosity, bitterness, and hop aroma) were all important drivers of body perception.

However, with regard to flavour, only certain tastes and aromas may be responsible for creating a fuller-bodied beverage, highlighting the importance of congruence and taste-aroma interactions. Therefore, further work needs to address the impact of different flavour profiles on the perceived beer body. This study has made a major contribution to research on the effects of beer compositional factors on beer body perception by demonstrating that ethanol, viscosity, bitterness and aroma have the ability to drive beer body ratings, suggesting that factors besides ethanol can contribute significantly to body enhancement. However, new product developers should pay close attention to the fact that despite the explored compositional factors having a positive effect on body perception, not all will promote acceptability. Cluster analysis revealed that consumers are not homogenous when assessing body perception, and they place differing levels of importance on different compositional factors.

The findings obtained only apply to one beer style and consumers selected from the UK. Exploring different beer styles and extending the generalisation of the findings to other consumer and beverage markets will broaden the understanding of the contribution of each compositional factor to the perception of beer body.

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3.7 Supplementary Materials for Chapter 3

Supplementary Table 3.1: Mean (triplicates) chemical/ physical profile of the experimental beer samples

	Beer Sample	**Alcohol by volume** (ABV %)	**Density** (g/cm3)	**Specific Gravity** (*SG*)	**Dynamic Viscosity** (mPa•s)
1	$E_0V_0B_0A_0$	0.53^{a}	1.018^{abc}	1.020^{abc}	1.77^{b}
2	$E_0V_0B_0A_1$ Rep[1]	0.52^{a}	1.023^{a}	1.025^{a}	1.79^{b}
3	$E_0V_0B_0A_1$ Rep[2]	0.51^{a}	1.019^{abc}	1.021^{abc}	1.78^{b}
4	$E_0V_0B_1A_0$	0.55^{a}	1.022^{ab}	1.024^{ab}	1.76^{b}
5	$E_0V_1B_0A_0$	0.51^{a}	1.019^{abc}	1.021^{abc}	3.56^{a}
6	$E_0V_1B_0A_1$	0.51^{a}	1.020^{abc}	1.022^{abc}	3.57^{a}
7	$E_0V_1B_1A_0$	0.51^{a}	1.022^{ab}	1.024^{ab}	3.56^{a}
8	$E_1V_0B_0A_1$	2.88^{b}	1.017^{abc}	1.019^{abc}	1.73^{b}
9	$E_1V_0B_1A_0$	2.80^{b}	1.020^{abc}	1.022^{abc}	1.74^{b}
10	$E_1V_0B_1A_1$	2.82^{b}	1.017^{abc}	1.019^{abc}	1.75^{b}
11	$E_1V_1B_0A_0$	2.85^{b}	1.018^{abc}	1.020^{abc}	3.52^{a}
12	$E_1V_1B_1A_1$	2.87^{b}	1.019^{abc}	1.021^{abc}	3.51^{a}
13	$E_2V_0B_0A_1$	4.51^{c}	1.015^{bc}	1.017^{bc}	1.69^{b}
14	$E_2V_0B_1A_0$	4.54^{c}	1.014^{bc}	1.016^{bc}	1.71^{b}
15	$E_2V_0B_1A_1$	4.42^{c}	1.014^{bc}	1.016^{bc}	1.72^{b}
16	$E_2V_1B_0A_0$	4.58^{c}	1.015^{bc}	1.017^{bc}	3.49^{a}
17	$E_2V_1B_0A_1$	4.55^{c}	1.014^{bc}	1.016^{bc}	3.49^{a}
18	$E_2V_1B_1A_1$	4.55^{c}	1.013^{bc}	1.015^{c}	3.51^{a}

Sample 1 shows an unmodified sample ('base'); Samples 2 and 3 show the 2 experimental replicates, and Samples 12 and 18 shows samples with all compositional factors modified ('extreme'). Samples codes: Ethanol (E, E_0 = 0.05%; E_1 = 2.8%; E_2 = 4.5% v/v), viscosity (V, V_0 = no addition; V_1 = addition of CMC), bitterness (B, B_0 = no addition; B_1 = addition of iso-α-acids) and aroma additive (A, A_0 = base beer, no addition; A_1 = addition of hop oil extract)

Supplementary Table 3.2: UK beer consumer (n=100) mean hedonic scores and mean body intensity scores of 18 experimental beer samples

Beer Samples	Mean Hedonic Scores	Mean Body Scores
$E_2V_1B_1A_1$	5.36^{fghi}	4.75^{abc}
$E_2V_1B_0A_1$	5.79^{bcdef}	4.51^{cd}
$E_2V_1B_0A_0$	6.31^{a}	4.61^{abc}
$E_2V_0B_1A_1$	5.23^{hij}	4.54^{bcd}
$E_2V_0B_1A_0$	6.09^{abc}	4.29^{de}
$E_2V_0B_0A_1$	5.61^{defgh}	4.50^{cd}
$E_1V_1B_1A_1$	4.82^{jk}	4.86^{a}
$E_1V_1B_0A_0$	6.23^{ab}	4.12^{ef}
$E_1V_0B_1A_1$	4.54^{k}	4.16^{ef}
$E_1V_0B_1A_0$	5.84^{abcde}	4.15^{ef}
$E_1V_0B_0A_1$	5.96^{abcd}	3.9^{fg}
$E_0V_1B_1A_1$	4.64^{k}	4.8^{ab}
$E_0V_1B_1A_0$	5.45^{efghi}	4.32^{de}
$E_0V_1B_0A_1$	5.31^{ghi}	4.32^{de}
$E_0V_0B_1A_0$	5.36^{fghi}	4.21^{e}
$E_0V_0B_0A_1$ Rep[1]	5.12^{ij}	$3.64g^{h}$
$E_0V_0B_0A_1$ Rep[2]	5.6^{defgh}	3.92^{fg}
$E_0V_0B_0A_0$	5.75^{cdefg}	3.61^{h}

Beer samples sharing a letter within the column are not significantly different (Fisher's LSD $p > 0.05$). Samples codes: Ethanol (E, E_0 = 0.05%; E_1 = 2.8%; E_2 = 4.5% v/v), viscosity (V, V_0 = no addition; V_1 = addition of CMC), bitterness (B, B_0 = no addition; B_1 = addition of iso-α-acids) and aroma additive (A, A_0 = base beer, no addition; A_1 = addition of hop oil extract)

Chapter 4

Effects of wine compositional factors on the sensory properties and consumer body perception of commercial low-alcohol red wine

Manuscript

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Abstract

Wine alcohol levels have risen on average by 2% ABV primarily due to worldwide temperature surging, as a consequence of higher grape sugars, resulting in greater alcohol concentration during fermentation. Therefore, the wine industry faces financial pressure as increased alcohol levels incur higher tax rates and retail prices. Furthermore, consumer demands underpin winemaking decisions, driving the production of different wine styles. The health consciousness concern around alcohol-induced harm has spurred interest in reduced alcohol wines, yet consumers associate them with reduced quality, lacking in flavour and perceived viscosity. Therefore, this study aimed to understand the consumers' perception of body and sensory properties of commercially available low-alcohol red wine with modified compositional factors.

Wines varying in alcohol were created from a commercial, de-alcoholised red wine. Carboxymethyl cellulose (CMC), grape seed extract (GSE) and natural flavourings were added at two levels each, resulting in wines (n=18) for consumer trials. Body definition, hedonic and Rate-All-That-Apply (RATA) responses for various sensory attributes, including different aromas, flavours and mouthfeel attributes, and body, were collected from red wine consumers (n=116) using a Home Use Test. A multi-factorial design allowed the main and interaction effects of the compositional factors and their effect on sensory response to be studied in detail. Consumers positively correlated wine body with liking and defined it with flavour and taste attributes (*spicy, woody, green, bitter*, and *acidic*) and mouthfeel characteristics (*mouth-coating, alcohol, heat* and *thick)*. Results suggest that common wine industry terms used to describe wine body might be insufficient to communicate wine characteristics to consumers. Furthermore, increasing the ethanol concentration of the de-alcoholised red wine (from 0.5 to 5.5% ABV) positively affected consumer hedonic response and body perception. The hedonic response was also positively affected by the addition of CMC, yet this viscosity modification did not affect wine body perception. In contrast, perceived mouth-coating sensation and thickness were positively correlated with wine body, and mouth-coat sensation, thick, hot mouthfeel, bitter taste, alcohol flavour and lingering aftertaste were positive wine body predictors. The addition of GSE to increase perceived astringency was not a factor on its own for the wine samples' overall liking or body perception. Flavour enhancement with a berry flavour negatively influenced both hedonic and body intensity responses, suggesting that some flavour profiles might negatively affect body in wine.

4.1 Introduction

In the last three decades, the average alcohol level for Australian wines has risen from 12.4% up to 14.4% v/v due to worldwide temperature increasing, leading to higher fermentable grape sugars (Varela et al., 2015). Consequentially, the industry faces negative financial implications, as rising alcohol levels result in adjusted tax rates and increased retail prices. Furthermore, consumer demand for well-structured wines significantly impacts produced wine styles, driving the international production of higher alcohol wines (Godden & Muhlack, 2015; Wilkinson & Jiranek, 2013). On the contrary, the health consciousness trend, addressing the harmful effects of alcohol, in particular, has led to increased interest in reduced alcohol beverages (Bruwer et al., 2014; Grønbæk, 2009).

Previous research has explored different compositional factors in wine (Gawel et al., 2007; Runnebaum et al., 2011; Skogerson et al., 2009). Consumer demand for lower alcohol products is a factor in shaping the current wine market (Wine Intelligence, 2022), yet consumer perceptions of lower alcohol and alcohol-free wines appear to vary (Bruwer et al., 2014; Bucher et al., 2018, 2020). Bucher et al. (2020) reported that Australian consumers perceived lower alcohol white wines (8% v/v) positively. In contrast, British consumers reported that low-alcohol wines were perceived as lower in quality, tasteless and lacking alcohols' after-effect via an online survey (Bruwer et al., 2014). This could be due to several sensory defects that occur as a consequence of their altered production process (Sam et al., 2021). However, it is not yet clear which compositional factors are responsible for this reduction in acceptability – ethanol alone or the reduction of other compounds (e.g. tannins, flavour compounds) limited by arrested fermentation or removed post-production by membranes (Mangindaan et al., 2018).

Wine body has sparked particular interest amongst researchers, as lower alcohol wines are often described as lacking body (Chapter 2) and texture by wine consumers (Niimi et al., 2017). Previously, studies noted a moderate contribution of ethanol to the instrumental viscosity of wines (Neto et al., 2005; Yanniotis et al., 2007). In contrast, ethanol addition in model wines (from 0% to 8% v/v) decreased instrumental viscosity (Laguna et al., 2017). Furthermore, some reports highlighted that the effects of ethanol on wine body (defined as 'viscous mouthfeel') or perceived viscosity (defined as 'pressure required for liquid foods to flow between the upper surface of the tongue and palate') were negligible (Nurgel & Pickering, 2005; Pickering et al., 1998). Increased alcohol concentration resulted in higher perceived wine body and viscosity in white table wines (Gawel et al., 2007; Jones et al., 2008). Whilst previous studies have observed a positive correlation between ethanol and instrumentally measured viscosity and density in wines, others have not (Laguna et al., 2017; Runnebaum et al., 2011). Therefore, it would be interesting to explore the impact of ethanol as well as a viscosity modifier on wine body in an attempt to decouple the two.

Higher alcohol levels have previously been shown to alter other wine sensory characteristics, including a positive enhancement of bitterness (Demiglio & Pickering, 2008; Fischer & Noble, 1994; Fontoin et al., 2008; Jones et al., 2008; Nurgel & Pickering, 2005; Vidal et al., 2004), negative effects on sourness (Ickes & Cadwallader, 2017; Zamora et al., 2006), but enhanced perception of sweetness (Nurgel & Pickering, 2006; Zamora et al., 2006) and hotness (Gawel et al., 2007; Jones et al., 2008; Nurgel & Pickering, 2006). Furthermore, high ethanol levels in wine were previously shown to mask important volatile aroma and flavour attributes (Robinson et al., 2009) and lower oligomeric tannin astringency (Fontoin et al., 2008; Vidal et al., 2004), amongst other characteristics, such as wine viscosity and body (Jordão et al., 2015; King et al., 2013; King & Heymann, 2014).

Astringency is considered a complex perceptual phenomenon involving several simultaneously perceived sensations (Pires et al., 2020). Yet, research has shown that consumers are able to correctly define wine astringency referring to it as *a rough and dry sensation occurring in the mouth and on the palate and tongue when/or after consuming wine* (Vidal et al., 2015). Astringency has been previously reported to positively correlate with viscosity ($r = 0.855$, $p = 0.030$) in the wine-saliva mixtures (Laguna et al., 2019), but less astringent wines were found to be associated with fuller body in Chapter 2. Therefore, as contradictory evidence exists, it would be beneficial to explore the impact of astringency on body perception in wine.

Flavour profiles of higher ethanol wines are affected by the ability of ethanol to mask the perception of esters, suppressing the fruitiness of the wine (Escudero et al., 2007; Goldner et al., 2009). Reduction in alcohol content plays an important role in wine sensorial characteristics, including modified wine taste, mouthfeel, and olfactory wine properties, including loss of volatile and polyphenolic compounds. The removal of alcohol from red wine by reverse osmosis also resulted in reduced fruity aromas (Meillon et al., 2010) and enhanced vegetative, musty and sweaty aromas explored in white wines (Fischer & Berger, 1996). Ethanol affects flavour perception and contributes to the sensory profile of wine with alcohol-related attributes, including warming and ethanol flavour, which consumers attribute to wine (Reynolds, 2010). Therefore, the lack of alcohol flavour in wines with reduced alcohol results in decreased consumer wine appreciation (Meillon et al., 2010). Flavour intensity was previously reported to enhance perception of body in wine (Gawel et al., 2007; Niimi et al., 2017), and Chapter 2 found full-bodied red wines to be associated with strong, intense dark fruit flavours, as well as oak-derived and aged flavours such as chocolate, vanilla, spice, tobacco and leather. Therefore, it would be interesting to explore the impact of flavour on body perception.

Despite being a key attribute for perceived quality (Runnebaum et al., 2011), wine body lacks consistent definition and classification (Laguna et al., 2017). Recently, a study explored different consumer segments based on consumer knowledge and involvement with Fine Wine Instrument (FWI) (Johnson & Bastian, 2015) and showed differences in consumer preferences for different flavours in wines produced from non-traditional red grape varieties (Mezei et al., 2021). The FWI uses a multi-dimensional scale, incorporating different wine-related consumer behaviours based on attitudes, interests, and opinions, to measure consumers' level of involvement across three dimensions: Connoisseur, Knowledge and Provenance. Cluster analysis results in three clusters: Wine Enthusiasts (WE, highly knowledgeable and involved consumers), Aspirants (ASP) and No Frills (NF, novice, less knowledgeable consumers). As research in Chapter 3 found different consumer clusters in relation to body perception, the FWI could prove a powerful tool when exploring consumer perception of body in wine.

This paper seeks to further expand on the current understanding of wine body from a consumer perspective by exploring the effects of compositional factors in commercially available low-alcohol red wine samples on wine body and mouthfeel perception. Therefore, this study aimed to investigate (i) consumer understanding and definition of wine body, including the effect of consumer segmentation based on wine knowledge and involvement; (ii) the impact of compositional factors (ethanol, CMC, GSE and a flavour blend) on consumer hedonic response, body perception and other sensory characteristics in a commercial de-alcoholised red wine.

4.2 Materials and Methods

4.2.1 Overview

Australian wine consumers (n = 116) over 18 years of age and who drank red wine no less than once per month were recruited through the University of Adelaide's wine consumer database to participate in a Home Use Test (HUT). The HUT involved completing a questionnaire and three sensory sessions over one week in their own homes. Experimental wine samples were generated by varying four compositional factors, namely; three ethanol concentrations, and two levels each of CMC, GSE and a berry flavour blend additions, resulting in 18 wines. Samples were assigned to three sensory sessions (randomised within each session). Ethics approval for this study was granted by the University of Adelaide Human Research Ethics Committee (Ref. number: H-2020-080). Informed consent was obtained from all assessors before the trial.

4.2.2 Experimental wine samples

4.2.2.1 Preparation of the experimental wine samples

A commercially available, de-alcoholised (0.5% v/v) red wine (Garnacha/ Syrah, 2019, Spain) with low residual sugar content (3.6 g/100 mL) was used as the base wine. This base was selected to resemble a standard dry table wine. Experimental wine samples were prepared by modifying the base wine's ethanol concentration (EtOH: 0.5, 3.0 and 5.5% v/v), viscosity (CMC: 1.455 ± 0.03 mPa·s ('low) and 1.961 ± 0.02 mPa·s ('high'), astringency (GSE, 0 or 1.5 g/L) and flavour intensity by enhancing red and dark fruit intensity (Base or Berry), as outlined in detail below. All compositional factors were combined with base wine according to the D-optimal experimental design using Design Expert (Design Expert® 12, Stat-Ease Inc., Minneapolis, US) to maintain a lower number of experimental samples suitable for consumer testing (Table 4.1). D-optimal design is constructed to minimise the overall variance of the predicted regression coefficient by maximising the value of determinant of the information matrix. The benefits of D-optimal configuration, the experimental region is not simple but it is irregular. As compared with other designs, the D-optimal design has a smaller number of runs and thus the cost of the experimentation can be optimised.

Table 4.1: Experimental wine samples varying in ethanol, CMC, GSE and flavour profile (base and berry flavour blend) prepared following a D-optimal experimental design

Experimental Design					
	EtOH (%) **E** (Ethanol)	**CMC** **V** (Viscosity)	**GSE (g/L)** **T** (Tannin)	**Flavour blend** **F** (Flavour)	**Sample Code**
1	0.5	Low	0	Base	$E_LV_LT_LF_B$ Base
2	0.5	Low	0	+Berry	*$E_LV_LT_LF_{+\ Rep\ 1}$
3	0.5	Low	0	+Berry	*$E_LV_LT_LF_{+\ Rep\ 2}$
4	0.5	Low	1.5	Base	$E_LV_LT_HF_B$
5	0.5	High	0	+Berry	$E_LV_HT_LF_+$
6	0.5	High	1.5	Base	$E_LV_HT_HF_B$
7	0.5	High	1.5	+Berry	$E_LV_HT_HF_+$
8	3.0	Low	0	+Berry	$E_MV_LT_LF_+$
9	3.0	Low	1.5	Base	$E_MV_LT_HF_B$
10	3.0	Low	1.5	+Berry	$E_MV_LT_HF_+$
11	3.0	High	0	Base	$E_MV_HT_HF_B$
12	3.0	High	1.5	+Berry	$E_MV_HT_HF_+$
13	5.5	Low	0	+Berry	$E_HV_LT_LF_+$
14	5.5	Low	1.5	Base	$E_HV_LT_HF_B$
15	5.5	Low	1.5	+Berry	$E_HV_LT_HF_+$
16	5.5	High	0	Base	$E_HV_HT_LF_B$
17	5.5	High	0	+Berry	$E_HV_HT_LF_+$
18	5.5	High	1.5	+Berry	$E_HV_HT_HF_+$

Factors: Ethanol (EtOH, E_L = 0.05% (Low); E_M = 3.0% (Medium); E_H = 5.5% (High) v/v), viscosity (CMC, V_L = no addition (Low); V_H = addition (High) of CMC), tannin (GSE, T_L = 0 g/L (Low); T_H = 1.5 g/L (High) of GSE) and flavour additives (Flavour blend, F_B = Base wine (Base), no addition; F_+ = addition of Berry flavour mix (Berry)). Samples marked with an asterisk (*) represent experimental replicates.

Firstly, the base wine was modified to create two viscosity levels. Various viscosity agents were considered for this study, including CMC, polydextrose, high-methoxyl pectin, 0.75%

hydrolysed guar gum, xanthan gum and sodium alginate. To make an informed decision on which viscosity agent to use, candidate agents were tested at different levels, representing 'low', 'medium' and 'high' viscosities of commercial wines (Danner et al., 2019). In this study, candidate viscosity agents were evaluated in the base wine by experienced sensory scientists (n=4) within the research group, and CMC was selected as, perceptually, it appeared odourless, tasteless and did not change the flavour of the base wine. Once selected, the levels of CMC addition required to produce a perceivably different viscosity level were calculated by the generation of a calibration curve showing the effects of added viscosity agent on the dynamic viscosity of the sample. Five CMC concentrations in base red wine were presented to a panel of experienced wine tasters and sensory scientists (n=22) for evaluation. A Triangle test was used to select the viscosity concentration where a perceptibly significant difference occurred (data not shown).

The base wine was transferred from its original commercial bottles into 7.5 L glass vessels to make up 10 base wines with 'low' (V_L: 1.455 ± 0.03 mPa·s) viscosity level (6,450 mL of base wine + 1,050 mL of water) and 8 base wines with 'high' (V_H: 1.961 ± 0.02 mPa·s) viscosity level (6,450 mL of base wine + 1,050 mL of 5%wt aqueous CMC (Sigma-Aldrich, Saint Louis, USA) stock solution prepared in advance).

To create wine samples with different ethanol concentrations, neutral grape alcohol (food grade, Spirit Neutral, Ultra-Premium, ≥96% v/v) was obtained from Tarac Technologies Pty., Ltd. (Nuriootpa, South Australia, Australia). For samples with an ethanol content of 0.5, 3.0 and 5.5%, 0 mL, 195 mL and 390 mL of grape alcohol, and 390 mL, 195 mL and 0 mL of distilled water were added, respectively, to the 7,110 mL of base wine/water (V_L) or wine/CMC (V_H) mixtures.

In this study, GSE (1.5 g/L, Tarac Technologies, Nuriootpa, SA, Australia) was added to adjust the perceived astringency. The GSE concentration was selected based on previously established levels found to modify perceptual astringency in red wine (Niimi et al., 2017).

In order to explore the impact of flavour on body perception, four natural flavour additives (raspberry (product code: 1375), blackberry (2253), butter (2061) and custard (2108)) sourced from The Product Makers Pty., Ltd (Melbourne, Australia) were diluted 1:100 in a 20% aqueous food-grade ethanol solution (Tarac Technologies Pty., Ltd, Australia). A prototype flavour blend was created by mixing the flavour solutions based on previously identified concentrations of similar natural flavourings (Saltman et al., 2017). To evaluate the prototype flavoured wines, a focus panel consisting of experienced sensory scientists (n = 4) skilled in flavouring wine was assembled. Based on the feedback from the focus panel, the composition of the flavour blend was refined. The final flavour blend consisted of raspberry (0.3 g/L), blackberry (0.2 g/L), butter (0.2 g/L) and custard (0.007 g/L) natural flavourings. The wine samples were spiked with the flavour blend, according to the experimental design, creating samples with modified berry flavour intensity.

Finally, potassium metabisulfite (Sigma-Aldrich, Saint Louis, USA) (20 mg/L) was added to prevent the oxidation of the samples. Well-mixed samples were then transferred into 30 mL glass vials with a plastic screwcap closure (Rowe Scientific, Pty., Ltd, Australia) with additional padding for a tighter seal. Food-grade nitrogen blanketing was used to prevent further oxidation. The vials were flushed with nitrogen prior to filling, and any ullage was blanketed. The vials were labelled with a random 3-digit code and sorted into sets. Three sets of six samples corresponding to the sensory evaluation sessions were labelled and packaged. Furthermore, leftover wine samples were manually transferred to 750 mL wine bottles with plastic screwcap closures with no ullage and nitrogen blanketing for further chemical analysis. Bottles were stored at 4°C (± 1°C) until analysis.

4.2.2.2 Chemical analyses

The fundamental wine chemical analyses as reported by Iland et al. (2004) were followed. The pH, titratable acidity (TA, as g/L tartaric acid) by titration to pH 8.2 (Mettler Toledo T50 Autotitrator), alcohol (% v/v) and density (Anton Paar Alcolyzer Wine ME and DMA 4500M, North Ryde, NSW, Australia), volatile acidity (VA, as g/L acetic acid), residual sugar measured enzymatically as total glucose and fructose (Boehringer-Mannheim/R-BioPharm) were measured in control and experimental samples. The dynamic viscosity was measured with a glass capillary Ostwald viscometer at 20 °C (± 0.01°C) according to the EBC Analytica (Method 9.38 - Glass Capillary Viscometer). All measurements were conducted in triplicate. Chemical and physical measures' means are summarised in Supplementary Table 4.1.

4.2.3 Home-Use-Test

4.2.3.1 Consumers

Australian regular red wine consumers (n = 116: 53 men, 63 women) were invited through an established wine consumer database. The consumer inclusion criteria included drinking red wine at least once a month, being over the Australian legal drinking age (18+), not pregnant and having no medical, religious, allergic or lifestyle-related reasons to abstain from alcohol. Participants who reported impaired sensory ability were also excluded. Furthermore, participants from states other than South Australia (SA, Australia) were excluded to ensure same-day delivery of the wine samples. Participants were recruited via email sent through the consumer database (i.e. those who have already given consent to be contacted). The email included the Participant Information Sheet and Electronic Consent Form. After participants agreed to participate and returned the electronically signed Consent Form, they were asked to complete an electronic Address Form. Participants were also recruited via an advertisement on the University of Adelaide and Waite Research Institute websites. Participants were free to contact the researchers to express interest. An inconvenience monetary allowance was offered to the participants upon study completion.

4.2.3.2 Packaging and delivery

The wines were dispatched and delivered by an independent courier service to the participants' homes on the same day. The package delivered included experimental wine samples sorted into three sets for each separate sensory session, detailed instructions (including session log-in, set-up and tasting instructions), clear wine glasses (Försiktigt, IKEA, height: 13 cm, volume: 16 cl), crackers (Captain's Table Classic Water Crackers, Malaysia) and sample mats, indicating the wine sample codes, corresponding to the randomised design of each session. The contents of the package were padded to ensure a low risk of breakage and were securely sealed.

4.2.3.3 Consumer wine tasting procedure

Participants completed three home-based tasting sessions using their own computers, tablets or smartphones to input their responses via an online link (CompuSense©, Guelph, Ontario, Canada). Prior to sample distribution, participants received an e-mail containing the link to access their three sessions. Participants each evaluated all 18 samples over the three sensory sessions. Each session corresponded to the evaluation of one sample set (containing 6 experimental wine samples) and lasted approximately 45 minutes. Participants were instructed to complete the three evaluations within one week and have at least a 24h break between sessions.

For each session, participants were instructed to pour the entirety of each sample (30 mL each, labelled with a random 3-digit code) into the supplied wine glasses and place them on the corresponding coded tasting mat. All samples presented within each session followed a randomised, balanced design following William Latin Square. A one-minute break between samples, enforced with a digital timer, ensured minimal fatigue and a carryover effect. Consumers were instructed to cleanse their palate with still water and plain crackers provided (Figure 4.1). At the commencement of the first session only, participants were asked to provide demographic information (e.g. gender, age) and complete the Fine Wine Instrument (FWI) questionnaire (Johnson & Bastian, 2015).

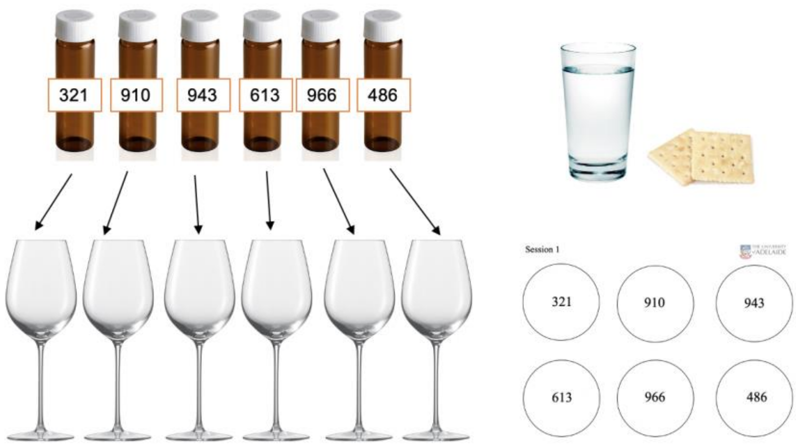

Figure 4.1: Instructions for setting up each Home Use Test sensory session. This involved pouring the wine samples into provided wine glasses and placing them on the correspondingly coded sample mat, as well as cleansing the palate with provided crackers and water.

The psychographic Fine Wine Instrument questionnaire (Johnson & Bastian, 2015) was used to measure the fine wine behaviour of red wine consumers (n=116) and to segment the consumers in order to understand the cognitive factors driving their wine liking and wine body conceptual and perceptual responses. The segmentation was based on the measurements using a multi-dimensional scale, which incorporated different wine-related consumer behaviours based on attitudes, interests and opinions to measure consumers' level of involvement. In brief, 18 statements were presented to the consumers in randomised order, consisting of three dimensions, namely, connoisseur, knowledge and provenance, with seven, five and six statements, respectively. The importance of each statement was measured by the consumers using a 9-point category scale, where 1 = 'strongly agree' and 9 = 'strongly disagree'.

An open-ended question *('In your own words, how would you describe wine body?'*) was included in the first sensory session to explore consumer understanding of the term body and investigate the language consumers used to interpret this attribute. Consumers were instructed to provide an answer and were assured that all answers were acceptable. Consumers were also instructed to type *'I don't know'* when unsure.

Consumers were instructed to take their first sip of the wine and assess the overall liking of the sample using a 9-point hedonic Likert scale, where 1 = 'dislike extremely'; 5 = 'neither liked nor disliked', and 9 = 'liked extremely'.

Consumers then rated the perceived body intensity of the samples on a 7-point scale (1 = 'extremely low', 7 = 'extremely high') and profiled the samples using Rate-All-That-Apply (RATA) with a pre-defined attribute list (n = 37), commonly used to evaluate red wine with naïve consumers (Danner et al., 2018). For each experimental wine sample, the RATA task was carried out by sensory modality in the following order: olfactory (aroma, n=15), gustatory (basic tastes, n=3), somatosensation (mouthfeel, n=5), flavours (n=14) and aftertaste (n=1). All attributes were randomised within the modality for each participant.

4.2.4 Data analyses

All data analyses were performed in XLSTAT® software (Version 2020.5.1, New York, USA) in Microsoft Excel™. Content analysis was performed using nVivo® software (Version 12, SQR International Pty Ltd.).

4.2.4.1 Content analysis

The qualitative data obtained from the open-ended question was pre-processed for content analysis. The raw text was converted to lowercase; typographical and orthographical mistakes were corrected; extra spaces, punctuation, and numeric digits were removed. The content analysis was performed in four stages: (i) de-contextualisation, (ii) re-contextualisation, (iii) categorisation, and (iv) compilation. During de-contextualisation, the data was considered as a whole and broken down into smaller meaning units, known as the open coding process (Hillebrand & Berg, 2000). The coding process was performed repeatedly to increase the stability and reliability of the analysis. The codes were generated inductively, and the coding list, including explanations of the codes, was used to minimise a cognitive change during analysis, securing additional reliability. Furthermore, all responses were checked against the coding list to ensure all aspects of the content were covered concerning the aim during re-contextualisation. During categorisation, themes and categories were identified. The codes with similar meanings or synonyms were grouped together. Lastly, the final categories were compiled and analysed with frequency analysis, and categories mentioned by less than 5% of the consumers were removed (Guerrero et al., 2010).

4.2.4.2 Consumer segmentation with the Fine Wine Instrument (FWI)

The data were analysed with a combination of descriptive statistics, one-way ANOVA with Fisher's Least Significant Difference (LSD) post-hoc test, Pearson's correlation, discriminant analyses and Agglomerative hierarchical clustering (AHC), using Euclidean distance and Ward's method of the three variables of the FWI, as described in Johnson & Bastian (2015).

After the FWI segments were established, Pearson's Chi-squared test was used to determine whether statistically significant differences existed between the frequencies of category mentions within each FWI cluster. Body definition categories mentioned by the consumers (concluded by the content analysis) and mean body ratings for each cluster were used to identify emerging trends for each wine sample analysed with ANOVA, post-hoc tests.

4.2.4.3 Hedonic and body intensity scores

A mixed model analysis of variance (ANOVA: sample, consumer), with the consumer as a random effect, was applied to hedonic and body intensity scores of the experimental wine samples with a subsequent post-hoc test (Fisher's LSD) to investigate the overall existing differences between the samples and compare all pairs of means with a predetermined significance level of 0.05, respectively.

4.2.4.4 Effects of compositional factors on sensory responses

A 4-way ANOVA with interactions was conducted to interpret the effects of modified compositional factors (ethanol, viscosity, tannin, flavour) on consumer hedonic response and perceived body intensity. The total variance was partitioned into variance assigned to particular sources. The among-sample means variance was compared to the within-sample variance (random experimental error). If the samples were not different, the among-sample means variance was similar to the experimental error. The variance due to panellists or other blocking effects was tested against the random experimental error. The model included levels detailed in Table 4.1 and included three levels of ethanol (Low, Medium, High), two levels of viscosity (Low, High), tannin (Low, High) and flavour (Base, Berry).

4.2.4.5 RATA analyses with the parametric method

RATA data were analysed using parametric methods, including mixed model two-way ANOVA with consumers as random and wine samples as fixed factor effects and subsequent post-hoc analysis (Fisher's LSD), where $p<0.05$ was considered significant. Furthermore, Principal Component Analysis (PCA) was performed using the significant mean sensory attribute intensity data generated by ANOVA. Mean hedonic scores, body intensity rating, instrumental measurements and compositional factor design centroids were added to the PCA as supplementary variables.

Partial Least Squares (PLS) regression was used further to explore relationships between body and other sensory characteristics. Two sensory characteristics of interest, namely body and thickness, were evaluated following Tenenhaus et al. (2005). To test the predictive capabilities of the PLS model, a bootstrapping procedure was implemented by dividing the data into calibration (65–75%) and validation (25–35%) sets replacing the data of these sets n=1000 times. After each separation, the models were calibrated and then validated using root mean square error of prediction ($RMSE_P$). The mean coefficient of determination (R^2) and cumulative predictive ability ($Q^2(cum)$) were also reported for validation.

4.3 Results

4.3.1 Chemical analyses

Measured alcohol level and dynamic viscosity were found to be significantly different ($p<0.05$) between the wine samples with modified composition (i.e. addition of ethanol and CMC, respectively), demonstrating that these parameters were modified accordingly. Measures of density, pH, TA, VA and residual sugars were not found significantly different ($p>0.05$) between the samples, irrespective of ethanol, CMC, GSE or flavour blend additions.

4.3.2 Red wine consumers' understanding of wine body

Following the content analysis, red wine consumers (n=116) used attributes from several sensory modalities to describe wine body. Consumers used concepts such as *Flavour* (51.1% of citations) and *Mouthfeel* (48.6%) to define wine body, which were the most frequently used terms, followed by *Fullness*, *Texture*, *Weight* and *Palate*, all above 15% of citations. Other terms cited were *Alcohol*, *Colour*, *Aroma*, *Intensity*, and attributes that appeared texture-related: *Thickness* and *Density*. Some descriptors used to define wine body were multi-dimensional, including *Combination*, *Richness*, and *Complexity*.

4.3.3 Contributory effects of model factors on consumer hedonic response and perceived wine body

The overall liking data was captured to determine whether consumers in the present study deemed experimental wine samples (n=18) with various compositional factor modifications sensorially acceptable. Significant differences were found between the samples ($p<0.001$), and in general, low acceptability was observed (mean = 4.02, range: 3.50 to 4.54 on a 9-point hedonic scale) (Supplementary Table 4.2). Low acceptability was unsurprising, as the wines created for this study were low-alcohol model wines.

The results of a 4-way-ANOVA showed a significant impact of ethanol (F=6.76, p=0.001), CMC (F=7.34, p=0.007) and flavour (F=8.77, p=0.003) on the overall hedonic scores. A significant interaction effect was also found between GSE and flavour (F=4.52, p=0.034) (Supplementary Table 4.3).

Figure 4.2 illustrates the significant effects of main factors and factor interactions on consumer hedonic response. It was found that ethanol concentration and CMC level positively drove the overall liking of the experimental wine samples (Figure 4.2A & 4.2B). The addition of the berry flavour blend negatively drove overall liking (Figure 4.2C). Interestingly, a significant interaction effect was observed between GSE and the berry flavour (Figure 4.2D). At low GSE concentration, there was no significant change in overall liking irrespective of flavour (base or modified berry flavour); however, the addition of GSE significantly decreased overall liking when coupled with enhanced berry flavour.

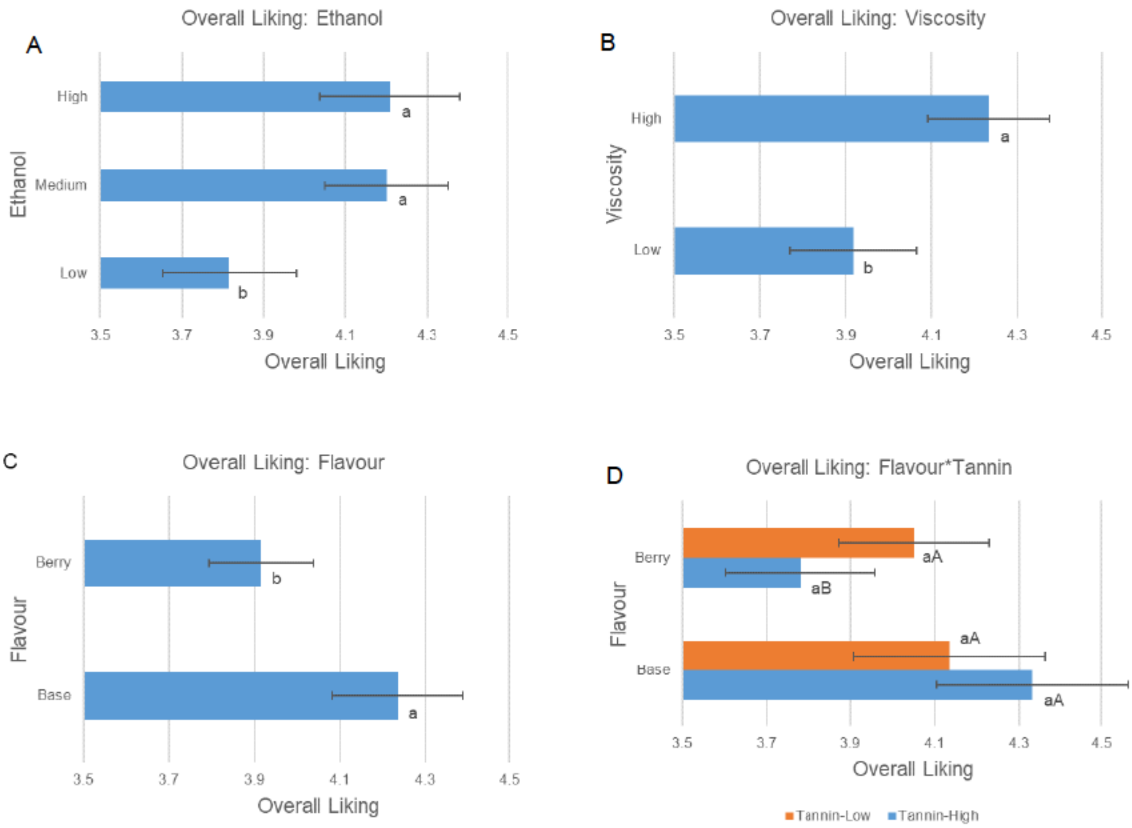

Figure 4.2: Estimated marginal means of ethanol (A), viscosity (CMC) (B), flavour (C), flavour*tannin (GSE) interaction (D) and effects on consumer overall liking. Different letters (^{abAB}) represent a significant difference between levels of the same compositional factor and within the interactions

When exploring the compositional factor ability to drive wine body ratings, 4-way-ANOVA revealed a significant effect of ethanol concentration (F=21.85, p<0.001) and flavour blend addition (F=18.10, p<0.001). The addition of CMC (F=0.14, p=0.706) and GSE (F=0.40, p=0.527) was not found to be significant drivers for wine body perception. This highlights the negligible influence of increased viscosity and astringency on wine body perception from a consumer perspective (Supplementary Table 4.4). Significant interaction effects were found between ethanol and GSE (F=2.90, p=0.055) and CMC and GSE (F=3.74, p=0.053).

Perceived wine body was positively driven by the ethanol concentration (Figure 4.3A) and negatively driven by the flavour blend addition (Figure 4.3B). Furthermore, a significant interaction was observed between ethanol concentration and GSE addition (Figure 4.3C). Moreover, a significant interaction was observed between CMC and GSE addition (Figure 4.3D). Interaction plots show the main impact on wine body perception is due to ethanol concentration, with only marginal differences in body perception dependant on the GSE level (Figure 4.3C). In contrast, the interaction with CMC shows a greater impact on wine body perception where both GSE and CMC are at a low level (no addition of GSE and CMC, respectively). This impact of GSE on body perception showed enhancement when CMC was at a higher level (Figure 4.3D).

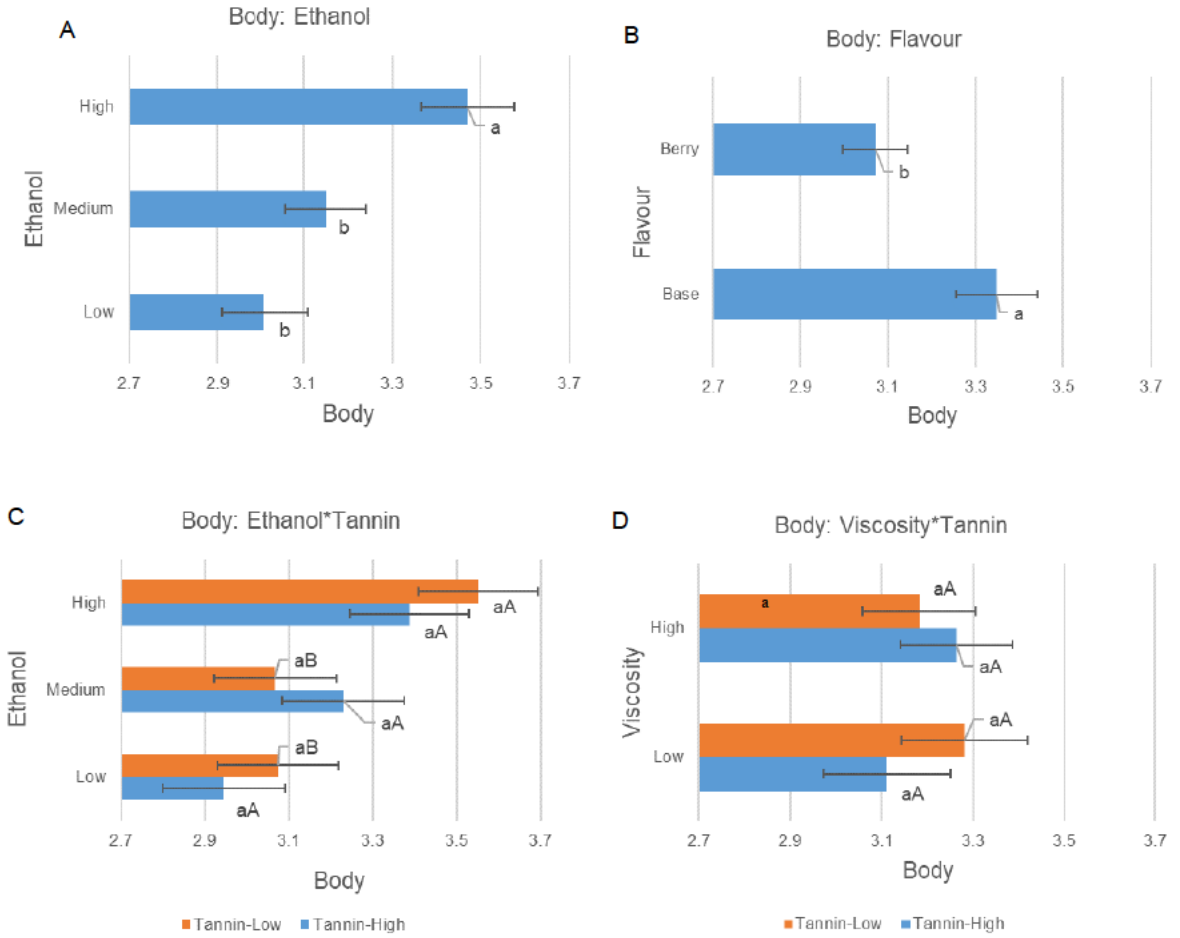

Figure 4.3: Estimated marginal means of ethanol (A), flavour blend (B), and ethanol*tannin (GSE) (C) and viscosity (CMC)*tannin interaction (D) and effects on consumer overall wine body perception. Different letters (^{abAB}) represent a significant difference between levels of the same compositional factor and within the interactions

4.3.4 Relationship between consumer perceived sensory properties, compositional factors and wine body

To understand the relationship between sensory attributes and overall body perception, the RATA responses evoked by 18 experimental wine samples were analysed. ANOVA results showed that all sensory attributes differed significantly between the experimental samples ($p<0.001$). PCA was performed to visualise sensory RATA attributes with quantitative supplementary variables (overall liking, overall body rating, ethanol concentration (ABV%) and dynamic viscosity) and qualitative supplementary variables (compositional factors) added in relation to the wine samples. Compositional factors were presented as qualitative variable centroids and included three levels of ethanol concentrations (EtOH-Low, EtOH-Medium and EtOH-High) and two levels of each viscosity (CMC-Low, CMC-High), astringency (GSE-Low, GSE-High), and flavour (Flavour-Base, Flavour-Berry) additions. Figure 4.4 shows the PCA bi-plot, representing the first two dimensions (F1 and F2), which explained 68.7% of the data variance. F1 (51.1% of the data variance) divided the experimental wine samples on the right-hand side with sensory attributes, including sweet taste, jammy, dark fruit, floral, grapey, confectionery and red fruit aromas and flavours from negatively correlated with attributes on F1; namely, alcohol flavour, woody, peppery, earthy, green aromas and flavours, bitter taste, mouth-coat and aftertaste. Furthermore, F2 explained 17.6% of the data variance and was positively correlated with attributes, including alcohol aroma, hot, thick, silky mouthfeel, spicy, dried fruit aromas and flavours, and dairy flavour. F2 was negatively correlated with attributes such as astringent, acidic and chemical aroma and flavour attributes.

Wine body (Body) ratings were positively correlated with mouth-coating (0.840), thick (0.809), hot mouthfeel (0.728), alcohol (0.795), peppery flavour (0.735), bitter taste (0.717) and overall aftertaste (0.786). Other weaker yet significant correlations included instrumental ethanol concentration (ABV%, 0.635), peppery aroma (0.526), woody (0.591), earthy flavours (0.497) and overall liking (0.477). Wine body showed a weaker negative correlation with red fruit aroma (-0.549) and flavour (-0.498), dark fruit aroma (-0.486), confectionery (-0.515; -0.478), jammy (-0.538; -0.495) aromas and flavours, grapey (-0.517), dairy (-0.478) and floral (-0.478) aromas.

Similarly to the overall wine body score, ethanol concentration (ABV%) strongly correlated with hot (0.727), thick (0.676), mouth-coating (0.650) mouthfeel attributes, alcohol flavour (0.658) and aftertaste (0.642), as well as spicy flavour (0.678) and negatively correlated with acidic taste (-0.516).

High hedonic scores (Overall Liking) correlated with wine sample $E_HV_HT_LF_B$ and attributes such as silky (0.703) and dried fruit flavour (0.763). A weaker but still significant correlation was also found between Overall Liking and dairy (0.531), spicy (0.586) and high alcohol concentration (ABV%, 0.477), with acidic taste being negatively correlated (-0.682).

Dynamic viscosity did not correlate with mouthfeel attributes, such as thickness or mouth-coating but had a weaker correlation to dairy flavour (0.636), silky mouthfeel (0.586), and negatively correlated with astringent mouthfeel (-0.681).

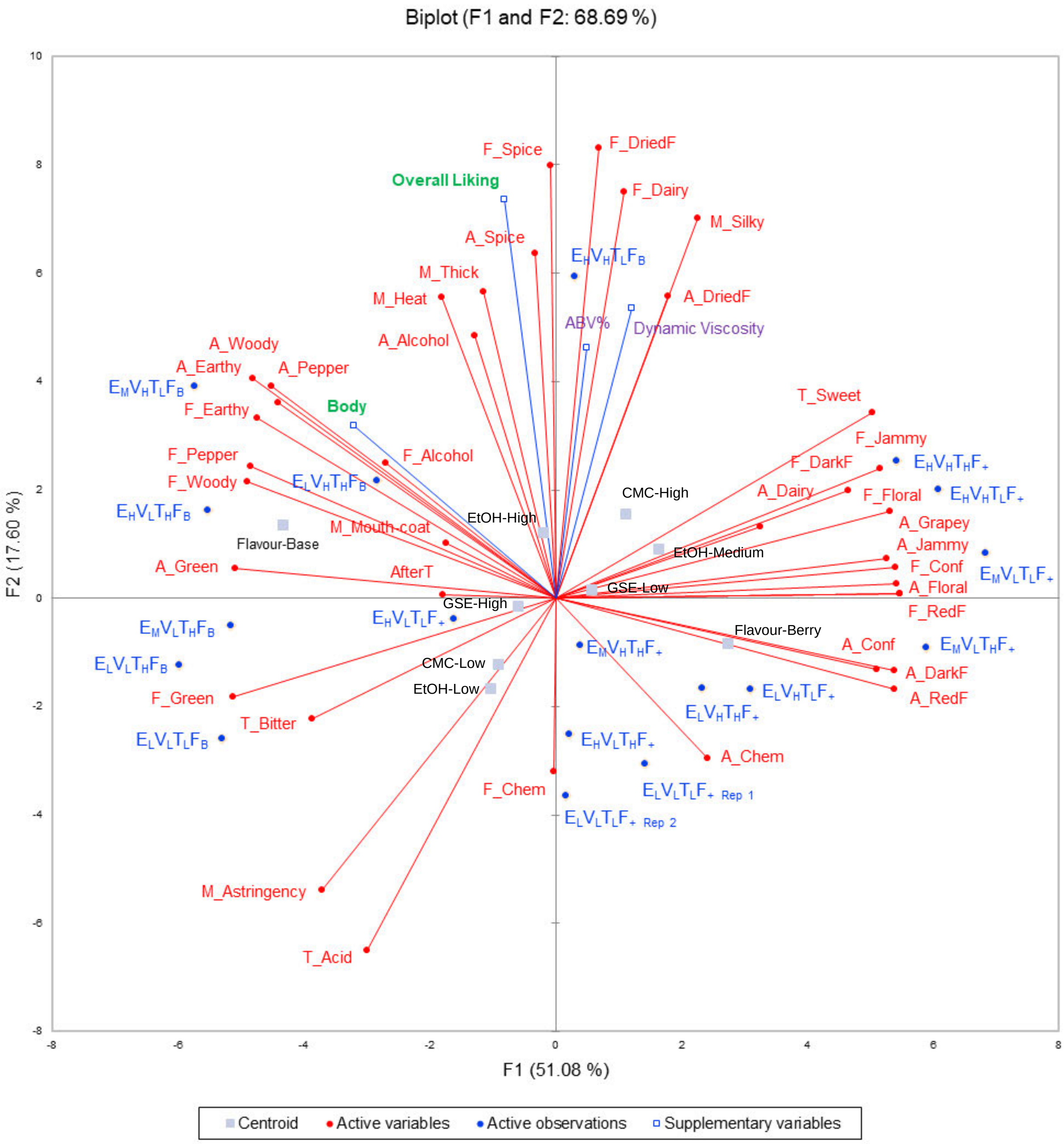

Figure 4.4: Principal Component Analysis bi-plot visualisation of the experimental wine samples (active observations) and varied compositional factors, including qualitative variable centroids (ethanol (EtOH-Low, EtOH-Medium, EtOH-High), viscosity (CMC-Low, CMC-High), GSE (GSE-Low, GSE-High), and flavour (Flavour-Base, Flavour-Berry)) and quantitative supplementary variables (Overall Body rating (Body), overall hedonic response (Overall Liking), ethanol concentration (ABV%) and dynamic viscosity (Dynamic Viscosity); as well as Rate-All-That-Apply responses (active variables).

Samples codes: Ethanol (E, E_L = 0.05%; E_M = 3.0%; E_H = 5.5% v/v), viscosity (V, V_L = no addition; V_H = addition of CMC), tannin (T, T_L = 0 g/L; T_H = 1.5 g/L of GSE) and flavour additives (F, F_B = Base wine, no addition; F_+ = addition of berry flavour blend)

In addition, a PLS regression of the PLS component ‘body’ on the characteristics of the experimental wine samples (R^2=0.858, Q^2(cum)=0.859) indicated the significant characteristics, as shown in Figure 4.5A. Positive wine body predictors included sensory characteristics with standardised regression coefficient absolute values of 0.1 and higher, including bitter taste, mouth-coating, hot, thick mouthfeel, and lingering aftertaste; whereas negative wine body sensory predictors included characteristics with negative values: red fruit, confectionery, jammy, floral aromas and flavours, as well as dark fruit and grapey aromas.

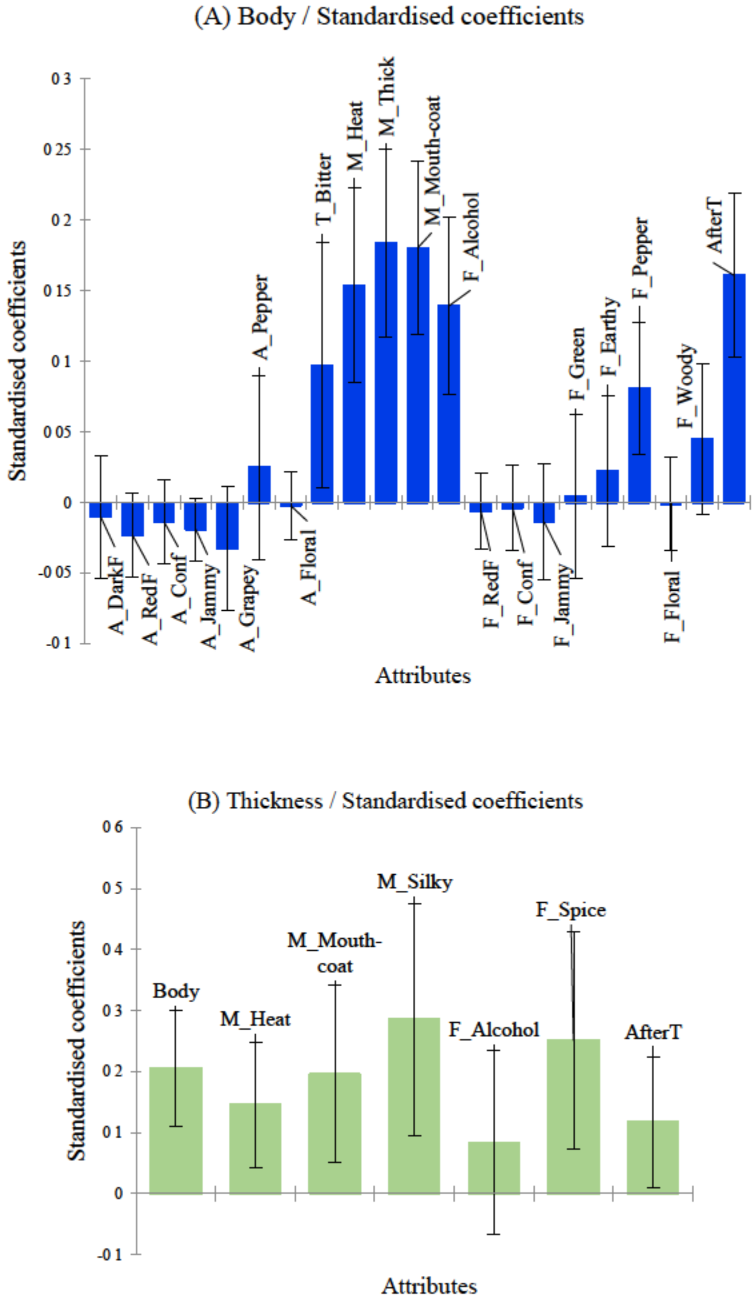

Figure 4.5: Partial Least Squares (PLS) regression output, including standard errors; Standardised coefficients of the PLS by (A) body and (B) thickness intensity scores as Y-variables, and sensory attributes as X-variables

Thickness (R^2=0.817, Q^2(cum)=0.806) was predicted by wine characteristics with positive values, including wine body, hot, mouth-coating, silky mouthfeel, and spicy flavour (Figure 4.5B).

4.3.5 Segmentation of consumer sample

Firstly, the consumer's FWI answers were scored within the three dimensions of statements labelled Connoisseur, Provenance and Knowledge, and three segments labelled Wine Enthusiasts (WE; n=54), Aspirants (ASP; n=46) and No Frills (NF; n=16), were identified. Discriminant analysis showed that 95% of the respondents were correctly classified by the AHC. WE scored significantly higher in all three dimensions, whereas NF scored significantly lower. The cluster centroids are displayed in Table 4.2. As a majority of consumers were within the WE and ASP clusters, this suggests that most participants in this study were considered more knowledgeable and involved wine consumers.

Table 4.2: Cluster centroids following Agglomerative Hierarchical Clustering (AHC)

	Variable			
Cluster	**Connoisseur**	**Knowledge**	**Provenance**	**Segment name**
1	74.2^a	76.4^a	76.1^a	Wine Enthusiasts (WE, n=54)
2	58.6^b	57.6^b	60.0^b	Aspirants (ASP, n = 46)
3	37.3^c	47.2^c	51.0^c	No Frills (NF, n=16)

Values sharing a letter within a column are not statistically different (p<0.05, Fisher's LSD)

According to the Chi-Squared test, the scores of the content analysis further segmented into FWI categories revealed that *Flavour* and *Fullness* were used by a greater proportion of NFs than WEs. In contrast, the terms *Mouthfeel, Texture and Alcohol* were used by a greater proportion of WEs than NFs, suggesting alcohol seemed to play a more significant role in wine body perception for WEs. Consumers in the ASP segment seemed to perceive wine body as a combination of *Flavour*, *Fullness, Colour* and *Mouthfeel*, as they cited those attributes as equally frequent as NEs and WEs (Table 4.3).

Table 4.3: Consumer responses to the open-ended question '*In your own words, how would you describe wine body?*' collated into categories and frequency of mention, calculated using frequency analysis, converted into percentages for each FWI segment

Category	Examples	Percentages of mention (%)			
		Overall (n=116)	NF (n=16)	ASP (n=46)	WE (n=54)
Flavour	flavour, flavours, flavor, flavors	**51.1**	**28.4[a]**	**14.2[ab]**	**8.5[b]**
Mouthfeel	mouthfeel, mouth, feel, feeling	**48.6**	**7.5[a]**	**15.9[b]**	**25.2[b]**
Fullness	full, fullness, depth	**26.2**	**15.2[a]**	**8.8[ab]**	**2.2[b]**
Texture	texture, textural	**21.2**	**2.1[a]**	**3.5[ab]**	**15.6[b]**
Weight	weight, heaviness, heavy, heavier	21.1	7.6[a]	5.2[a]	8.3[a]
Palate	palate, structure	16.2	2.5[a]	6.7[a]	7.0[a]
Alcohol	alcohol, alcohol content	**13.7**	**0.8[a]**	**1.3[a]**	**11.6[b]**
Colour	colour, dark, light colour	**11.2**	**7.6[a]**	**2.2[ab]**	**1.4[b]**
Aroma	aroma, aromas	11.1	5.6[a]	3.3[a]	2.2[a]
Intensity	intensity, intense	10.0	0.7[a]	4.5[a]	4.8[a]
Thickness	thickness, thick, viscous, viscosity	8.7	0.5[a]	1.6[a]	4.1[a]
Combination	combination, combined, related	7.5	2.3[a]	1.6a	3.6[a]
Density	density, dense	7.4	0.7[a]	1.6[a]	5.1[a]
Richness	richness, rich	6.2	0.7[a]	1.0[a]	4.5[a]
Complexity	complexity, complex	5.1	0[a]	0.8[a]	4.3[a]

Segments: No Frills (NFs, n = 16), Aspirants (ASPs, n = 46) and Wine Enthusiasts (WEs, n = 54). Terms sharing a letter in the rows are not significantly different (Pearson's Chi-squared Test, $p < 0.05$).

Consumer segmentation with the FWI showed differences in consumer segment definitions of wine body; however, mean body ratings of the experimental wine samples were compared between the consumer segments and no significant interaction was found (p=0.412).

4.4 Discussion

The present study investigated the impact of ethanol, GSE, CMC level and flavour enhancement on consumer wine body perception and the hedonic response. Body perception positively correlated with an overall liking in this study; however, the compositional factors did not impact both liking a body perception in the same way. Ethanol was consistent across the two measures, with higher hedonic and body intensity scores resulting from its addition. Interestingly, CMC addition only impacted perceived liking, whilst GSE addition did not impact hedonic or body ratings, but flavour addition had a negative impact on both. Based on the consumer segmentation using the FWI methodology, identified consumer segments conceptually defined wine body differently, suggesting that not all consumers will perceive body similarly, but this was not reflected in the body intensity scores as no significant difference between segments was found.

4.4.1 Ethanol

The main effects of ethanol concentration on perceived wine body in the de-alcoholised red wine model were evident. Higher ethanol concentration enhanced the perceived wine body and positively drove the overall hedonic response for the experimental wine samples. Interestingly, overall liking did not change when comparing 3.0% v/v and 5.5% v/v ethanol concentrations, whereas wine body rating increased significantly between these concentrations.

Ethanol concentration, perceived alcohol flavour and heat (alcohol warming/hotness) played significant roles in wine body perception in this study. This finding partly agrees with Gawel et al. (2007), who found that increased ethanol concentration (within the standard alcohol concentrations typically found in Riesling wine (11.6 - 13.6% v/v)) influenced wine body perception, yet attribute *hotness* was related to ethanol concertation alone and not to wine body (Gawel et al., 2007). Jones et al. (2008) also found an increase in hotness perception attributed to a 2% v/v change in ethanol concentration in the model white wine system. In contrast, PCA and PLS results in the present study revealed that hotness (heat) was a driver and a predictor of wine body. The percentage increase in alcohol in the study by Gawel et al. (2007) and Jones et al. (2008) (2% v/v) was lower than used in the current study, suggesting that it was not sufficient to elicit perceived hotness and correspondingly increase wine body ratings. It was previously shown that within the typical ethanol concentrations for red wines (14, 14.5, 15%

v/v), no significant effect on aroma, taste, or mouthfeel was detected by a descriptive sensory panel (Frost et al., 2017), suggesting that a higher alcohol increase is required for perceivable flavour, aroma or mouthfeel changes. Yu and Pickering (2008) reported an ethanol difference threshold of 1% v/v on average across different wine styles, which was lower than reported previously (4% v/v) in table wine (Fillipelo, 1955; Hinreiner et al., 1955) and concluded that individuals vary greatly in their sensitivity to differences in ethanol. Importantly, this study used commercially available de-alcoholised red wine and examined an ethanol concentration increase by 5% v/v (0.5% to 5.5% v/v), which is different to the ethanol concentrations used in the previous studies.

Furthermore, results of the present study showed that samples with 5.5% v/v alcohol concentration were perceived as having more dried fruit, woody, earthy, spicy, alcohol flavours, and hot and thick mouthfeel; whereas samples with lower two ethanol concentrations correlated with perception of dark, red fruit, floral, confectionery flavours and aromas. Similarly to the findings of the present study, increasing ethanol concentration (0, 8, 10, 12, 14 and 16% v/v) was linked to enhancing the perception of flavour and mouthfeel attributes, namely, woody, spicy, bitter taste and burning sensation, and decrease the perception of fruity, floral and caramel aromas and flavours in model red wines (Villamor et al., 2013). At higher levels of alcohol (14.5 – 17.5% v/v) evaluated in Malbec wines, the sensorial aroma perception of fruity characters was diminished and instead described as predominantly herbaceous, in contrast with fruity aromas perceived at lower alcohol levels (10.0 – 12.0% v/v) (Goldner et al., 2009), which is similar to the findings in the present study with lower ethanol concentrations (an increase of 5% v/v). Results suggest that as the ethanol concentration increases, primary fresh fruit flavours may diminish, whereas secondary riper fruit flavours may dominate in the red model-like wine. Previously an increase in ethanol concentrations (10 – 18% v/v) was attributed to suppressing the fruit aroma attributes in wine, as increasing ethanol concentrations significantly reduced the headspace concentration of volatile aroma compounds (Robinson et al., 2009).

Moreover, experimental wine samples with a base ethanol level (0.5% v/v) in the present study were perceived as acidic, astringent and bitter, lower in body, and had the lowest acceptance scores. In another study, higher sourness intensity has been shown as ethanol concentration decreased (23, 13, 5% v/v) in binary solutions representing the dominant orosensations elicited in alcoholic beverages (sweet/fructose, bitter/quinine, sour/tartaric acid, astringent/aluminium sulphate) (Thibodeau & Pickering, 2021), similarly to the results of the present study.

In contrast, earlier studies investigated the impact of ethanol concentration on sourness and bitterness of the de-alcoholised white wine concentrate and reported that the bitterness intensity increased significantly by raising ethanol concentration, whereas no effect on sourness was found unless a pH of 3.2 was achieved (Cretin et al., 2018; Fischer & Noble, 1994). Bitter taste in this study was a positive predictor of wine body by PLS; however, it should be noted that wine samples exhibiting higher bitterness received low hedonic scores. Previously, bitterness was noted to modulate the perception of mouthfeel in wines (Gawel et al., 2018). Bitterness can be elicited by several major components in wine, including (i) ethanol, which is known to stimulate the bitter taste receptor TAS2R13 (Allen et al., 2014); (ii) phenolic compounds (non-flavonoids, flavonoids, flavanoids), that also have an overarching effect on other aspects of wine mouthfeel, including astringency, viscosity, oiliness and hotness; (iii) bitter hydrophobic peptides that were previously proposed to impact fullness of white wine (Skogerson et al., 2009). In this study, three experimental samples, namely, $E_MV_LT_HF_B$, $E_LV_LT_HF_B$, and $E_LV_LT_LF_B$ were perceived as high in bitterness, suggesting that GSE addition may have contributed to the increased bitterness, as GS tannin tends to have a lower degree of polymerisation, which would explain the elicited bitterness sensorial response (Fischer & Noble, 1994). Yet, GSE was not found to be a significant driver of wine body on its own. At typical wine ethanol levels (11 – 15 % v/v), ethanol contributed to perceived astringency and bitterness in red wine (Fontoin et al., 2008). In the present study, enhanced ethanol level (to 5.5% v/v) negatively correlated with perceived acidity, bitterness and astringency. The model system in this study compared ethanol levels added to de-alcoholised base wine that are not typical for standard wines, suggesting that results may differ in model systems that explore typical ethanol concentrations of wine.

Furthermore, wine aftertaste duration was previously related to wine body in an exploratory study with wine consumers (Chapter 2). Aftertaste intensity was correlated with higher ethanol wine samples in the present study; therefore, could be considered an important contributor to wine body. An increase in 6% v/v ethanol in Shiraz wines was previously found to increase the finish intensity of coconut and floral flavours (Baker & Ross, 2014). Consumers in this study did not specify the precise aspect of the aftertaste; however, it was closely related to mouth-coating, which suggests it was more related to mouthfeel than flavour. Similarly, it was reported previously that extended perception of mouthfeel attributes, including heat/irritation, tingle/prickle, smoothness, mouth-coat and overall astringency, could be linked to genetic sensitivity (i.e. sensitivity to 6-propyl-2-thiouracil (PROP)) (Pickering & Robert, 2006), which requires further investigation.

4.4.2 Viscosity

In this study, the addition of CMC and subsequent viscosity enhancement (confirmed by the instrumental analyses) of the experimental wine samples positively affected hedonic scores but did not impact body perception. In contrast, Niimi et al. (2017) found no impact of modifying wines with xanthan gum (0.5 g/L) on liking or emotional response. Interestingly, as shown in the PCA, dynamic viscosity in this study significantly correlated to the instrumental measurements of ethanol, as well as mouthfeel attributes, including thick, hot mouthfeel and alcohol, dry fruit and spicy aromas and flavours. This agrees with the work by Pickering et al. (1998), where perceived intensity (by a trained panel) and physical measurements of viscosity and density in de-alcoholised white wine were found to be highly correlated with ethanol (Pickering et al., 1998). More recently, significant correlations between dynamic viscosity and ethanol concentration (but not pH and residual sugar) were observed in commercial dry Chardonnay and Shiraz wines (Danner et al., 2019), indicating that ethanol may have been the main compositional factor that increased dynamic viscosity in those wines. Therefore, whilst CMC was chosen to be the main physical viscosity modifier, ethanol also appears to have an impact.

Collectively, and based on the previous research and the PCA presented in the present study, dynamic viscosity and perceived thickness are strongly correlated with consumer wine body perception and also appear to be a strong predictor of wine body for consumers, according to the PLS. However, the addition of CMC as a physical viscosity modifier was not found to drive consumer body perception, which suggests that other compositional factors, presumably ethanol, modified the sensory characteristics (including thickness, hotness, mouth-coating) of the experimental wine samples, thus positively effecting consumer wine body perception. Similarly to the findings of the present study, Rinaldi et al. (2020) found that wines exhibiting richness, velvety, silky and mouth-coating qualities were perceived as fuller in body.

4.4.3 Astringency

In this study, the addition of GSE to the experimental wine samples did not have a direct significant effect on consumer hedonic response or wine body ratings. In contrast, Niimi et al. (2017) reported that the addition of GSE to wines significantly decreased the liking and elicited an increase in the intensity of negative emotions. Whereas Valera and Gambaro (2006) found that body was positively correlated with astringency in wines. The contradictory results may depend on the wine style tested (i.e. wines with reduced alcohol versus standard ABV wines) or could be the result of variation across consumers, as suggested by the work of Michon & Lesschaeve (2001), where two groups of consumers emerged when exploring the temporal changes in bitterness, astringency and overall aroma during the repeated wine consumption. Hedonic responses were found to be either negatively or positively influenced by astringent wines (Michon & Lesschaeve, 2001). However, segmentation by the FWI in this study did not find differences based on the GSE addition.

According to the PCA, astringent sensory characteristics of the experimental wine samples were most apparent at low ethanol and low CMC levels, which is in agreement with previous research where increasing wine viscosity with CMC whilst adding grape seed tannin (GST, 2.5 g/L) was shown to decrease the maximum intensity and total duration of astringency (Smith et al., 1996). Since tannins have a high affinity toward proteins, polysaccharides contained in CMC could interfere with the CMC-protein precipitation by interacting with proteins and polyphenols, stabilising them or competing for binding sites (Sommer et al., 2019). This would reduce the ability of GST to bind to salivary proteins and oral cells, counteracting the reduction in salivary lubrication produced by tannin binding to the salivary proteins (Payne et al., 2009). Whilst GSE did not significantly influence body perception in this study, less astringent experimental wine samples (e.g. those without the GSE addition) were perceived as higher in body, suggesting that other characteristics, such as perceived thickness and flavour, play a more significant role as a driver for body perception within the lower ABV wine matrix. It was reported previously that the addition of tannin extracts to wines could modulate aroma perception in a compound-dependent manner (Munoz-Gonzales et al., 2020). In the present study, the addition of GSE prolonged the aftertaste of the experimental wine samples and contributed to mouth-coat sensation, spicy aroma, alcohol aroma and flavour.

4.4.4 Flavour

As expected, in this study, experimental wine samples with the berry flavour profile (F_+) were perceived by the attributes red, dark fruit, confectionery, floral but also exhibited low wine body; whereas wines with the base flavour profile (F_B) were perceived as woody, peppery, green and earthy and had higher body ratings, suggesting that certain flavour profiles might enhance perceived body in wine. These results also agree with those in Chapter 2, where specific wine flavours (namely, wood, spice, and earthy amongst others) were important in wines described as fuller-bodied. However, it appears that further work is required to understand the impact of red and dark fruit flavours on body perception, as results in Chapter 2 suggest that black cherry, blackberry and plum flavours are associated with full-bodied wines, whereas red and dark fruits induced by the berry flavour profile in this study were associated with low wine body. Furthermore, Valera and Gambaro (2006) found that body (as a quality parameter) positively correlated with berry, dried fruit, caramelised, spice, and alcohol-related characteristics, similarly to the overall body perception in this study. There may be a connection between consumer perception of quality and specific flavour attributes, as previously it was reported that consumer acceptance and quality scores decreased for red wines exhibiting higher acidity, jammy, vegetable and leather aromas (Frøst & Noble, 2002), which may, in turn, contribute to body perception. This is further supported by the finding in this study that commercially available de-alcoholised red wines were perceived as lower in quality by more knowledgeable and involved red wine consumers.

Furthermore, in this study, perceived acidity did not appear to be modified by the enhanced berry flavour, but the sweetness was, which was unsurprising as those wines also exhibited associatively sweet aromas and flavours (Arvisenet et al., 2016; Symoneaux et al., 2015), including red fruit, floral, confectionery and jammy. The effects of wine matrix on wine flavours were previously studied. Volatile aroma compounds derived from grapes and fermentation were previously shown to contribute to orthonasal aroma and retronasal flavour perception, as well as mouthfeel perception. The addition of volatile reconstitution mixture (ethyl acetate, ethyl butanoate, 2-methyl butyl acetate, 3-methyl butyl acetate, hexyl acetate, ethyl hexanoate, ethyl octanoate, acetic acid, ethyl decanoate, phenylethyl acetate, 2-phenylethanol, hexanoic acid, octanoic acid, beta-damascenone), which included volatiles derived and quantified from the 2003 unoked Chardonnay wine positively drove hotness and acidity, and the higher concentration of volatiles 130% w/v) increased the ‘overall aroma’ ratings (Jones et al. 2008).

4.4.5 Interactions

Flavour*tannin interaction was found to affect overall liking, suggesting that the addition of GSE significantly decreased overall liking when coupled with enhanced berry flavour. It was previously shown that interactions between aroma compounds and different components of the wine non-volatile matrix could affect odorant volatility, aroma release and overall perceived aroma intensity (Polaskova et al., 2008). Specifically, grape seed tannin in admixture with wine polysaccharides was previously attributed to flavour retention (Mitropoulou et al., 2011), suggesting that the volatility decreased possibly due to the ability of GSE to form colloidal size particles.

The addition of GSE did not significantly affect the perceived wine body; however, a significant interaction effect with ethanol (ethanol*tannin) was observed. Villamor et al. (2013) reported an interaction effect between ethanol concentration and tannin having an impact on drying sensation. Similarly, it was reported previously that high ethanol concentrations decrease the perception of astringency in model wines (Fontoin et al., 2008; Vidal et al., 2004), as well as alter astringent sub-qualities in wine (Obreque-Slier et al., 2010). In lower alcohol wines, the understanding of wine body as a notion of the interaction between ethanol and tannin is limited. This study's results suggest that the addition of the GSE can help reduce the required alcohol level in order to achieve the same body rating. The impact of ethanol concentration (9% and 14% v/v), tannin and single-flavour compounds, including (2-PEtOH [floral], IBMP [bell-pepper] and oak lactone [coconut], on finish in de-alcoholised Syrah wine, was previously investigated. Wine samples with higher ethanol content (14% v/v) exhibited a prolonged duration of the bell pepper, coconut and floral flavours on the finish, with bell pepper also lasting longer when a higher concentration of tannin was present (Baker & Ross, 2014).

Viscosity*tannin interaction was also observed, suggesting that GSE showed enhancement of body perception when CMC was at a higher level. It was previously demonstrated with the trained panel that the maximum intensity and total duration of perceived astringency were significantly decreased as viscosity rose in aqueous solutions of grape seed tannin and CMC (Smith et al., 1996). As suggested previously, the increase in viscosity may also decrease the protein-tannin interactions (Demiglio & Pickering, 2008; Hagerman et al., 1998; McRae & Kennedy, 2011). In this study, wine body did not correlate with perceived astringency, nor was astringent mouthfeel found to be a predictor of wine body, suggesting that the astringency perception might have been negatively impacted by the GSE addition to the viscous wine matrix.

4.4.6 Consumer segmentation

Consumers in the present study fell into ASP and WE segments, suggesting that the level of wine-related knowledge and involvement of these consumers was higher, and they were able to use more information about the products, including assessing the wider variety of sensory characteristics and making more confident decisions in their evaluations (Johnson & Bastian, 2015). In this study, consumer wine knowledge and high involvement level also explained why some consumers (WE) described body using mostly texture and mouthfeel characteristics, as texture terms are more widely used in the peer-reviewed and industry-aligned technical definition of wine body (Runnebaum et al., 2011). Similarly, consumers' knowledge and involvement can predict quality perception, as more knowledgeable consumers are able to interpret more extrinsic and intrinsic cues (Sáenz-Navajas et al., 2014).

Flavour has been previously linked to consumers' conceptual notion of wine body. In a study by Niimi et al. (2017), consumers ranked wine body as one of the most important concepts in relation to wine purchase, together with wine flavour, balance of flavours and wines' ability to match the food, and subjectively understood wine body as a holistic multi-sensory perception of flavour. In this study, consumers predominantly used flavour attributes in relation to a wine body definition with lower overall wine knowledge and involvement (NF), suggesting that responses may vary significantly between the wine consumer segments. It is worth mentioning that consumers in this study mostly fell into ASP and WE clusters; therefore, more consumer studies with a larger population and distinct knowledge and involvement scores must be used to confirm this finding.

4.5 Conclusion

In this study, consumer understanding and definition of red wine body were consumer-segment dependent. Consumers were segmented into more knowledgeable and involved segments (ASP and WE), with WE consumers emphasising the textural characteristics of wine to describe the wine body. In comparison, NF cluster members defined red wine body as flavour, fullness and colour. Consumer segmentation is an effective tool that can be used to understand the different liking patterns amongst consumers and explore different types of consumer preferences based on a specific sensory attribute, to enhance their targeting techniques.

This study has uncovered the important factors positively driving consumer conceptual and perceptual body in de-alcoholised red wine. Increasing the ethanol concentration of the de-alcoholised red wine (from 0.5 to 5.5% v/v) positively affected consumer hedonic response and body perception. The hedonic response was also positively affected by the addition of CMC, yet this viscosity modification did not affect wine body perception. In contrast, perceived mouth-coating sensation and thickness were positively correlated with wine body, and according to PLS, mouth-coat sensation, thick, hot mouthfeel, bitter taste, alcohol flavour and lingering aftertaste were positive wine body predictors. The addition of GSE to increase perceived astringency was not a factor for the overall liking or body perception of the wine samples. Flavour enhancement with a berry flavour negatively drove both hedonic and body intensity responses, suggesting that some flavour profiles might negatively affect body in wine. Adjusting the content of ethanol, fruit flavour (through grape maturity), astringency (through phenolic management) and texture will allow winemakers to construct wines with desirable mouthfeel, and flavour attributes that will modulate the overall body style that is linked with altered purchase decision and enhanced hedonic response of the wine. Further research is required to establish the ability of different flavour profiles and flavour intensities to influence consumer wine body perception.

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4.7 Supplementary Materials for Chapter 4

Supplementary Table 4.1: Basic chemical composition of the 18 experimental wine samples.

Sample Code	Alcohol by Volume (ABV %)	Density (g/cm3)	Dynamic Viscosity (mPa·s)	pH	Titratable Acidity (TA)	Volatile Acidity (VA)	Residual sugar (g/L)
$E_LV_LT_LF_B$ Base	0.58[a]	1.019[a]	1.455[a]	3.43[a]	4.51[a]	0.77[a]	2.88[a]
*$E_LV_LT_LF_+$ Rep 1	0.58[a]	1.019[a]	1.454[a]	3.34[a]	4.82[a]	0.72[a]	2.84[a]
*$E_LV_LT_LF_+$ Rep 2	0.52[a]	1.022[a]	1.461[a]	3.29[a]	5.06[a]	0.43[a]	3.07[a]
$E_LV_LT_HF_B$	0.58[a]	1.019[a]	1.458[a]	3.8[a]	4.5[a]	0.39[a]	2.93[a]
$E_LV_HT_LF_+$	0.53[a]	1.019[a]	1.961[b]	3.7[a]	4.6[a]	0.57[a]	2.95[a]
$E_LV_HT_HF_B$	0.48[a]	1.022[a]	1.979[b]	3.71[a]	4.63[a]	0.55[a]	2.97[a]
$E_LV_HT_HF_+$	0.58[a]	1.021[a]	1.963[b]	3.77[a]	4.54[a]	0.51[a]	2.91[a]
$E_MV_LT_LF_+$	2.93[b]	1.016[a]	1.454[a]	3.3[a]	5.14[a]	0.52[a]	2.87[a]
$E_MV_LT_HF_B$	3.03[b]	1.018[a]	1.458[a]	3.3[a]	5.1[a]	0.68[a]	2.81[a]
$E_MV_LT_HF_+$	2.9[b]	1.016[a]	1.433[a]	3.64[a]	4.67[a]	0.47[a]	3.06[a]
$E_MV_HT_HF_B$	3.01[b]	1.018[a]	1.988[b]	3.56[a]	4.9[a]	0.51[a]	3.05[a]
$E_MV_HT_HF_+$	3.02[b]	1.016[a]	1.957[b]	3.53[a]	4.56[a]	0.65[a]	2.79[a]
$E_HV_LT_LF_+$	5.47[c]	1.016[a]	1.462[a]	3.61[a]	4.81[a]	0.66[a]	2.94[a]
$E_HV_LT_HF_B$	5.43[c]	1.016[a]	1.467[a]	3.37[a]	5.0[a]	0.45[a]	2.91[a]
$E_HV_LT_HF_+$	5.36[c]	1.015[a]	1.455[a]	3.71[a]	4.72[a]	0.48[a]	2.84[a]
$E_HV_HT_LF_B$	5.29[c]	1.013[a]	1.968[b]	3.4[a]	4.92[a]	0.49[a]	2.82[a]
$E_HV_HT_LF_+$	5.44[c]	1.013[a]	1.966[b]	3.45[a]	4.71[a]	0.51[a]	2.87[a]
$E_HV_HT_HF_+$	5.40[c]	1.012[a]	1.959[b]	3.34[a]	5.4[a]	0.53[a]	2.81[a]

Wine samples sharing a letter in the columns are not significantly different (Tukey HSD $p < 0.05$). Samples were measured in triplicate.

Compositional factors: Ethanol (EtOH, E_L = 0.05%; E_M = 3.0%; E_H = 5.5% v/v), viscosity (CMC, V_L = no addition; V_H = addition of CMC), tannin (GSE, T_L = 0 g/L; T_H = 1.5 g/L of GSE) and flavour additives (Flavour mix, F_B = Base wine, no addition; F_+ = addition of Berry flavour mix)

Supplementary Table 4.2: Australian red wine consumers (n=116) mean hedonic scores of 18 experimental wine samples

Wine Samples	Mean Hedonic Scores
$E_HV_HT_LF_B$	4.54[a]
$E_HV_LT_LF_+$	4.39[ab]
$E_HV_LT_HF_B$	4.34[abc]
$E_HV_HT_LF_+$	4.19[abcd]
$E_LV_HT_HF_B$	4.19[abcde]
$E_MV_LT_LF_+$	4.13[bcdef]
$E_MV_LT_HF_B$	4.11[bcdef]
$E_MV_HT_HF_+$	4.08[bcdefg]
$E_LV_LT_LF_{+\ Rep\ 2}$	4.05[bcdefg]
$E_HV_HT_HF_+$	4.04[bcdefg]
$E_MV_LT_HF_+$	3.99[cdefgh]
$E_HV_LT_LF_+$	3.92[defgh]
$E_LV_HT_LF_+$	3.85[defghi]
$E_LV_LT_LF_B$ Base	3.81[efghi]
$E_LV_LT_LF_{+\ Rep\ 1}$	3.78[fghi]
$E_LV_LT_HF_B$	3.73[ghi]
$E_HV_LT_HF_+$	3.65[hi]
$E_LV_HT_HF_+$	3.50[i]

Supplementary Table 4.3: A 4-way ANOVA of compositional factor effects on consumer overall liking

Factors	DF	Sum of squares	Mean squares	F	Pr > F
Ethanol	**2**	**52.43**	**26.21**	**6.76**	**0.001**
Viscosity	**1**	**28.48**	**28.48**	**7.34**	**0.007**
Tannin	1	0.41	0.41	0.11	0.745
Flavour	**1**	**34.02**	**34.02**	**8.77**	**0.003**
Ethanol*Viscosity	2	4.29	2.15	0.55	0.575
Ethanol*Tannin	2	5.57	2.79	0.71	0.488
Ethanol*Flavour	2	9.01	4.51	1.16	0.313
Viscosity*Tannin	1	0.87	0.87	0.22	0.636
Viscosity*Flavour	1	9.02	9.02	2.33	0.127
Tannin*Flavour	**1**	**17.55**	**17.55**	**4.52**	**0.034**

Supplementary Table 4.4: A 4-way ANOVA of compositional factor effects on consumer overall wine body rating

Factors	DF	Sum of squares	Mean squares	F	Pr > F
Ethanol	**2**	**61.95**	**30.98**	**21.85**	***p*<0.001**
Viscosity	1	0.20	0.20	0.14	0.706
Tannin	1	0.57	0.57	0.40	0.527
Flavour	**1**	**25.66**	**25.66**	**18.10**	***p*<0.001**
Ethanol*Viscosity	2	7.37	3.69	2.60	0.074
Ethanol*Tannin	**2**	**8.22**	**4.11**	**2.90**	**0.055**
Ethanol*Flavour	2	1.74	0.87	0.61	0.542
Viscosity*Tannin	**1**	**5.29**	**5.29**	**3.74**	**0.053**
Viscosity*Flavour	1	0.08	0.08	0.06	0.807
Tannin*Flavour	1	2.79	2.79	1.96	0.161

Chapter 5

The impact of enhanced flavour on sensory properties and perception of body in red wine

Manuscript

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Keywords: consumer, expert panel, rate-all-that-apply, sensory assessment

Abstract

Consumer lifestyle choices and preferences are evolving, and more relevance is given to sustainability linked to nutritional, health-related properties of foods and beverages. Indeed, the frequency and amount of consumed alcohol are directly related to health. Wine producers are faced with major challenges when producing high quality, full-bodied, flavoursome wines with decreased alcohol content as highly demanded but criticised for loss of flavour and mouthfeel attributes by consumers. This study compared the perceived sensory properties, including body and other mouthfeel attributes, of flavoured red wines and their lower alcohol counterparts. To achieve this, commercial no-alcohol (0.05% alcohol by volume (ABV)), lower alcohol (9% ABV) and full alcohol-strength (14.5% ABV) base Shiraz wines were modified with food-grade, natural flavourings to create different flavour enhancements: red fruit, dark fruit, floral, green, vanilla, woody and savoury. Two sensory panels comprising (i) experienced wine tasters (n=42) and (ii) naïve red wine consumers (n=110) evaluated the flavour-enhanced wines using the Rate-All-That-Apply (RATA) technique. Experienced wine tasters evaluated no-alcohol (0.05% ABV, n=8) and lower alcohol (9% ABV, n=8) reference and flavoured wines in two blocks. The consumer panel subsequently evaluated a subset of flavoured 9% ABV (n=5) and full-strength alcohol Shiraz wines (14.5% ABV, n=5). All flavour additions significantly changed the sensory profile of the wines, but these differences did not impact body perception for the no- and lower alcohol wines. Experienced wine tasters perceived no significant differences ($p>0.05$) in body in wines within the same alcohol strength block (i.e. 0.05% or 9% ABV). However, the lower alcohol wines (9% ABV) were perceived to be significantly fuller in body ($p<0.05\%$) than no-alcohol wines, irrespective of flavour enhancements. Similarly, the consumer panel found no significant differences in body ($p>0.05$) for wines of lower alcohol content (9% ABV) despite flavour additions. In contrast, full-strength alcohol wines (14.5% ABV) with enhanced savoury and woody flavours were perceived as fuller in body, thickness and mouthfeel complexity than wine with enhanced red fruit flavour ($p<0.05$). Furthermore, different consumer clusters were identified based on hedonic responses, and three distinct consumer clusters emerged: (i) Like All, (ii) Complex Body Likers, and (iii) Low Alcohol Likers. This study demonstrated the ability of natural flavours to enhance wine sensory properties, including aroma, flavour, and mouthfeel characteristics, identifying the flavour drivers for enhanced wine body.

5.1 Introduction

Changing consumption habits and global health consciousness trends (Zhang et al., 2018) influence beverage markets. Therefore, beverage producers are witnessing an increasing demand in the low-alcohol beverage category in existing and emerging markets. This has been attributed to new policies, changing demographics, and improved low-alcohol product production methods (Bellut & Arendt, 2019). A recently proposed initiative (WHO SAFER) aims to alert governmental bodies to problems related to excessive alcohol consumption and encourages officials to strengthen restrictions on alcohol availability; advance and enforce drinking and driving countermeasures; enforce bans and restrictions on alcohol advertising, sponsorship, and promotion; and increase alcohol prices by imposing higher taxes and pricing policies (WHO, 2020). Currently, wine producers are faced with major challenges when producing high quality, perceivably fuller in body yet flavoursome wines with decreased alcohol content. Various methods have been employed for the production of wines with reduced alcohol levels: (i) viticultural practices (early harvest, reduced leaf area, and increased irrigation) (Bindon et al., 2013; Di Vaio et al., 2020); (ii) winemaking practises (water addition (Schelezki et al., 2020), non-*Saccharomyces* yeast co-inoculation and gene modification techniques) (Zamora, 2016) and; (iii) post-fermentation practises (vacuum distillation, reverse osmosis, pervaporation and spinning cone technologies) (Pham et al., 2020). It was previously reported that wine alcohol reduction ≥ 2% alcohol by volume (ABV) negatively impacts sensory attributes, including wine colour, polysaccharides, and volatile composition (specifically higher alcohols and esters), which in turn can result in a significant loss of aroma and flavour (Aguera et al., 2010; Gil et al., 2013; Liguori et al., 2018; Pham et al., 2020; Rolle et al., 2018).

Early research suggested that wine experts conceive wine body as a one-dimensional texture attribute linked to viscosity (Nurgel & Pickering, 2005; Runnebaum et al., 2011; Skogerson et al., 2009; Yanniotis et al., 2007) and that body often considered to be lacking in lower alcohol beverages. However, research focused on end-user perceptions revealed that body is understood to be a multi-sensory perception of flavour and texture (Chapter 2; Niimi et al., 2017) and is associated with both quality and complexity (Parr et al., 2020). Body, in part, appears to represent a component of mouthfeel in wine that is important for consumer wine choice (Niimi et al., 2017) and often appears on wine bottle labels, which is a primary mean of communication of wine sensory attributes between wine producers and consumers and are important for initial assessment of wine taste, quality and value (Dobele et al., 2018). Thus, the constituents that contribute to the wine body must be understood to support strategies designed to achieve public health and well-being benefits while meeting consumer demand for lower alcohol beverages (with sensory acceptability maintained). Previous research sought to explore the contribution of ethanol, glycerol, polysaccharides, proteins and phenolic compounds on perceived wine body (Jones et al., 2008; Runnebaum et al., 2011; Vidal et al., 2004; Yanniotis et al., 2007) but despite flavour previously being attributed to wine body perception (Gawel et al., 2007), limited attention has been paid to flavour as a driver of body. Previous research conducted in this thesis (Chapters 2, 3 and 4) suggested that flavour could play an important role in body perception, especially in no- and low-alcohol products. Whilst research conducted by others demonstrated that olfactory cues involved in olfactory-oral cross-modal sensory interactions, including flavour-texture, can modulate the perception of wine in-mouth sensations, namely harsh, unripe, dynamic, complex, surface smoothness, sweet, bitter (Pittari et al., 2020), and astringent sensations (Niimi et al., 2017).

Aroma and flavour are the key factors in determining the quality of the wine (Aleixandre-Tudo et al., 2015; Mihnea et al., 2015), and wine body, plays an important role in the overall mouthfeel and perceived quality, according to experts (Runnebaum et al., 2011). Volatile flavour compounds are perceived at far lower concentrations (i.e., ng/L and µg/L concentrations) than the other wine constituents (acids, sugars, ethanol and phenolic compounds) and impart distinct aroma profiles to wine. Despite the routine use of flavour additives to enhance the aroma and flavour of commercial products in most food and beverage industries, the addition of flavour-enhancing substances in winemaking is strictly prohibited (Standard 2.7.3, 2.7.4 and 4.5.1; Food Standards Australia New Zealand, 2015, 2016, 2017) but are used in controlled studies to investigate their impact. For example, Saltman et al. (2017) found that the addition of natural flavourings resulted in red wines acceptable to different consumer segments, thereby demonstrating how winemakers can target specific flavours for specific consumer segments.

Given that body incorporates several important sensory characteristics and is linked to the quality of wine by experts (Etaio et al., 2010; Runnebaum et al., 2011), and consumers rate it as an important factor in their wine choice (Niimi et al., 2017), it is essential for the industry to determine how best to communicate body characteristics to consumers. Etaio et al. (2010) found that parameters such as balance, body and aroma complexity contributed most to the overall quality of young red wines, where body was defined as *the intensity of taste and* *mouthfeel sensations, including consistency, density and volume*. The terms proposed contain too many technical and abstract terms and may not be appropriate to effectively communicate the body characteristics of wine to both experts and consumers. Terms such as *consistency, density* and *volume*, albeit coherent and recognisable to wine experts, present a serious challenge for sensory professionals, as reference standards are not available to assist with the evaluation of body. The interpretation of the concept of sensory attributes that are not adequately defined (including body, balance, harmony, complexity) greatly depends on the expertise and experience (Etaio et al., 2010; Guinard et al., 1998; Jackson, 2000). Consumer preference and perceived quality have also been demonstrated to differ among consumers with varying levels of involvement, expertise and wine-related knowledge (de-la-Fuente-Blanco et al., 2017; Johnson et al., 2017; 2018; Sáenz-Navajas et al., 2015; Urdapilleta et al., 2011, 2021). Consumer segmentation methodologies result in homogenous groups of consumers within a heterogeneous market (Danner et al., 2020; Johnson et al., 2017, 2018). A multi-dimensional, psychographic segmentation tool customised for the Australian wine market - the Fine Wine Instrument (FWI) (Johnson & Bastian, 2015), is based on Attitudes, Interests and Opinions (AIO). The FWI provides enriched and robust insights into consumer wine knowledge and involvement of identified consumer segments, permitting the design of targeted marketing communication tools and products to meet the needs of these consumer groups. The FWI consists of 18 scale statements covering three dimensions, labelled Connoisseur, Knowledge and Provenance. These three dimensions then form the segmentation base for a cluster analysis that usually identifies and characterises three fine wine-related segments, labelled Wine Enthusiasts, Aspirants and No Frills in the Australian wine market (Danner et al., 2020; Johnson & Bastian, 2015). In conjunction with their hedonic or attribute intensity responses, consumer segmentation and clustering based on their wine-related knowledge can provide additional insights into consumers' perceptions and product-related behaviour.

Therefore, the main aims of the current study were: (i) to compare wine body understanding between experienced wine tasters and naïve Australian red wine consumers; (ii) to measure the ability of flavour enhancement to manipulate sensory attributes, including mouthfeel and body in no- (0.05% ABV), lower (9% ABV) and full-strength alcohol (14.5% ABV) wines; and (iii) to segment consumers based on their fine wine behaviour, including wine knowledge and involvement, hedonic responses and body intensity scores to identify and define consumer segments and clusters.

5.2 Materials and Methods

Ethics approval for this study was granted by the University of Adelaide Human Research Ethics Committee (Ref. number: H-2020-080). Informed consent was obtained from all participants before the sensory trials.

5.2.1 Experimental wine samples

Three different base wines, a non-vintage no-alcohol South Australian Shiraz (0.05% v/v), a 2020 lower alcohol Australian Shiraz (9% v/v), and a 2019 full-strength alcohol South Australian Shiraz (14.5% v/v), sourced from retail outlets (Clearmind, Dan Murphy's, Australia), were chosen for this study and aimed to represent red wines of the same grape variety and similar flavour profile. Different flavour blends, summarised in Table 5.1, were prepared from natural flavour additives that were sourced commercially from Product Makers Pty. Ltd. (Melbourne, Vic., Australia), Symrise Pty., Ltd. (North Rocks, NSW, Australia), StaVin Inc. (Sausalito, CA, USA) and Continental (Unilever, Epping, NSW, Australia). The final flavour blends (Table 5.1) were diluted in a 20% aqueous ethanol solution (food-grade, Tarac Technologies Pty. Ltd., Nuriootpa, SA, Australia), and the resulting stock solutions were stored at 4 °C. The developed flavour profiles were chosen based on consumer responses in earlier studies where consumer understanding of wine body was investigated (Chapter 2; Niimi, Danner, et al., 2017).

Table 5.1: Composition of flavourings added to base wines

Flavour Blends	Flavour Additives
Red Fruit	30.0 mg/L raspberry[a], 9.2 mg/L blackberry[a], 1.0 mg/ L passionfruit[a], 1.0 mg/ L honey[a]
Dark Fruit	20.2 mg/L blackberry[a], 0.5 mg/L honey[a], 4.5 mg/L date[b]
Floral	1.2 mg/L cis-3-hexenol[b], 0.5 m/L ethyl phenyl acetate[b]
Vanilla	24.6 mg/L vanilla[a], 2.3 mg/L honey[a]
Green	2.5 mg/ L *cis*-3-hexenol[b]
Woody	1.2 mg/L whiskey lactone[b], 1.1 mg/L cinnamon[a], 1.2 mg/L chocolate[a], oak[c] (20 cubes/L)
Savoury	200 mg/L beef stock[d]

[a]Flavour additives sourced from The Product Makers (raspberry[1375]; blackberry[2253]; passionfruit[2196]; cinnamon[1525]; vanilla[0723]; honey[2408]; chocolate[2269])

[b]Flavour additives sourced from Symrise (date[760919]; whiskey lactone[105630]; *cis*-3-hexenol[131104]; ethyl phenyl acetate[105951])

[c]Products sourced from StaVin (medium toasted French oak barrel head cubes, 1x1cm)

[d]Products sourced from Unilever (salt reduced beef stock powder)

Bench-top tastings were first performed to optimise the flavour blends and the intensity of the overall sensory properties of the flavoured base wines. This involved the addition of stock solutions containing various combinations of flavourings to base wines at different concentrations that were subsequently evaluated by a focus panel of three experienced sensory professionals, highly experienced in red wine sensory evaluations, to identify prototype flavoured wines. The focus panel evaluated the prototype wines and provided recommendations that enabled flavour refinement resulting in the formulation of seven flavour blends (Table 5.1). These blends were used to prepare flavour-enhanced versions of the 0.05% and 9% ABV base wines (n=14). The sensory profiles of these wines were evaluated as part of Trial 1, which directed the formulation of four flavour-enhanced versions of the 14.5% ABV base wine for use in a subsequent trial (Trial 2). The flavour-enhanced wines used in sensory evaluations are summarised in Table 5.2.

Table 5.2: Flavour additions of three base wines (0.05%, 9% and 14.5% v/v) used in experienced taster and consumer trials

Wine/ Flavour Target	**Code**	**Stock Solution/ Flavour Blend** *(g/L)*	**Used In***
0.05% Shiraz			
Reference wine	0REF	-	Trial 1
Red fruit	0RF	9.5 g/L red fruit blend	Trial 1
Dark Fruit	0DF	9.5 g/L dark fruit blend	Trial 1
Floral	0FL	4.5 g/L floral blend	Trial 1
Vanilla	0VN	6.3 g/L vanilla blend	Trial 1
Green	0GR	8.2 g/L green blend	Trial 1
Woody	0WD	2.5 g/L woody blend	Trial 1
Savoury	0SV	2.3 g/L savoury blend	Trial 1
9% Shiraz			
Reference wine	9REF	-	Trial 1 & 2
Red fruit	9RF	9.0 g/L red fruit blend	Trial 1 & 2
Dark Fruit	9DF	12.2 g/L dark fruit blend	Trial 1
Floral	9FL	4.3 g/L floral blend	Trial 1
Vanilla	9VN	8.0 g/L vanilla blend	Trial 1 & 2
Green	9GR	10.1 g/L green blend	Trial 1
Woody	9WD	4.5 g/L woody blend	Trial 1 & 2
Savoury	9SV	4.8 g/L savoury blend	Trial 1 & 2
14.5% Shiraz			
Reference wine	14REF	-	Trial 2
Red fruit	14RF	9.5 g/L red fruit blend	Trial 2
Vanilla	14VN	8.5 g/L vanilla blend	Trial 2
Woody	14WD	4.8 g/L woody blend	Trial 2
Savoury	14SV	5.2 g/L savoury blend	Trial 2

*Trial 1 = Experienced wine tasters (n=42), Trial 2 = Red wine consumers (n=110)

A reference wine (base wine with no flavour addition) was added to each sample set for Trial 1 and Trial 2 with the addition of 20% aqueous ethanol solution to ensure the reference samples were treated the same as the flavoured wine samples and to account for the dilution factor.

5.2.2 Wine chemical analyses

Basic wine chemistry analyses were conducted on base and flavoured wines (in triplicate), according to published methods (Iland et al., 2004), and included measurement of pH, titratable acidity (TA, as g/L tartaric acid) by titration to pH 8.2 (Mettler Toledo T50 Autotitrator), alcohol (% v/v) and density (Anton Paar Alcolyzer Wine ME and DMA 4500M, North Ryde, NSW, Australia), volatile acidity (VA, as g/L acetic acid), free and total sulphur dioxide and residual sugar measured enzymatically as total glucose and fructose (Boehringer-Mannheim, R-BioPharm, NSW, Australia). Chemical and physical data for reference wines are summarised in Supplementary Table 5.1.

5.2.3 Sensory evaluation

5.2.3.1 Panellists

Experienced wine tasters (n=42; 23 men, 19 women; between 23 – 58 years of age) were recruited from the School of Agriculture, Food and Wine at the University of Adelaide to participate in the sensory session (Trial 1). The panel was selected following the criteria proposed by Parr et al. (2002, 2004) and included: (i) established winemakers, (ii) wine-science researchers and teaching staff regularly involved in wine-making and wine evaluation, (iii) wine professionals, and (iv) students and graduate students in Viticulture and Oenology who had relevant professional experience (including participation in vintages and wine-tasting classes).

Naïve Australian red wine consumers (n=110; 47 men, 63 women; between 18 – 66 years of age) were recruited through an in-house consumer database (University of Adelaide Sensory Laboratory) and participated in one sensory session (Trial 2) at a central location. Consumers were selected based on the inclusion criteria: being of legal drinking age in Australia (18 years old and above); no formal training in wine evaluation, winemaking or wine industry experience; and red wine consumption frequency (at least once a month). Exclusion criteria were applied and included having any medical (including potential pregnancy), religious, allergy or lifestyle reasons that prevent participants from alcohol consumption or any oral sensory impairment. An appropriate inconvenience allowance was offered to the participants on session completion.

5.2.3.2 Procedure

The sensory panels comprising experienced wine tasters (n=42, Trial 1) and red wine consumers (n=110, Trial 2) each completed a single sensory session in a purpose-built sensory laboratory. Data were collected with CompuSense© Cloud Software (Guelph, Ontario, Canada).

Experienced wine tasters evaluated 16 wine samples, including seven flavoured versions of the 0.05% ABV Shiraz, seven matching flavoured versions of the 9% ABV Shiraz (detailed in Table 5.2) and the two reference wines (0.05% and 9% ABV). Wines were served following a blocked randomised experimental design: The first block comprised flavour-enhanced wine samples with 0.05% alcohol content (n=8), and the second block comprised experimental wine samples with 9% alcohol content (n=8). Consumers, on the other hand, evaluated 10 wine samples in a single block, with wine samples randomised for each consumer, including four flavoured versions of the 9% ABV Shiraz, four flavoured versions of the 14.5% ABV Shiraz (detailed in Table 5.2) and 2 control wines (14.5% and 9% ABV).

At the commencement of the sensory session, experienced wine tasters were asked to provide some general demographic information, including age and gender, whereas consumers were asked to provide more in-depth demographic information, including age, gender, income, education and frequency of red wine consumption. An open-ended question (*'In your own words, how would you describe wine body?'*) was included for both panels to explore each cohorts' understanding of the term *body* and investigate the language used to interpret this sensory attribute. Furthermore, consumers were asked to complete the FWI questionnaire (Johnson & Bastian, 2015) for subsequent psychographic-based consumer segmentation, exploring their wine knowledge and involvement.

The sensory evaluation for both trials was conducted in individual sensory booths equipped with a computer terminal under white fluorescent lighting and ambient temperature (22 ± 1 °C). Experimental wine samples (30 mL) were served in clear wine glasses coded with a random 3-digit code and covered with a glass petri dish to ensure minimal loss of volatile compounds. Unsalted, plain crackers (Captain's Table Classic water crackers, Malaysia) and de-ionised water were served to panellists for palate cleansing, and a 1 min break was imposed between samples. For experienced wine tasters, a 5 min break was also enforced between blocks.

During the tasting, all panellists were first asked to provide their overall liking scores using a 9-point scale (where 1 = 'dislike extremely'; 9 = 'like extremely') (Peryam, 1998) for the monadically and randomly presented wines. The preliminary liking responses that the experienced tasters provided informed the choice of four flavour blends to progress to the consumer acceptance and evaluation trial (Mezei et al., 2021). Furthermore, all panellists were asked to evaluate the wine samples following the RATA procedure. In total, 51 sensory attributes commonly used to evaluate red wine (Danner et al., 2018) were presented to the experienced wine tasters, including aroma, basic taste, flavour, mouthfeel (including *body*) and aftertaste; whereas consumers were presented with a refined attribute list (37 sensory attributes). All attributes were randomised within the modality across participants to minimise the influence of term order. Both panels characterised wine samples by rating sensory attributes on a 7-point scale (where 0 = not selected; 1 = 'extremely low; 7 = 'extremely high').

5.2.4 Data analyses

Content (Krippendorff, 2010) and frequency analysis for the open-ended question was carried out using nVivo® software (Version 12, SQR International Pty Ltd.). Pearson's Chi-Squared test determined whether statistically significant differences existed between the frequencies of category mentions between experienced tasters and consumer panels.

Instrumental data were analysed with analysis of variance (ANOVA) and a post-hoc test (Fisher's Least Significant Difference (LSD)) to examine the differences between the wines with different alcohol levels.

Analysis of liking and tasting intensity data were performed using XLSTAT® software (Version 2020.5.1, NY, USA) in Microsoft Excel™. Two-factor analysis of variance (ANOVA: sample, panellist), with panellist as a random effect, was performed on tasting data. A subsequent post-hoc test (Fisher's LSD) was carried out to investigate the existing differences between the samples with pre-determined significance levels ($p<0.05$). Furthermore, Principal Component Analysis (PCA) was performed to visualise the RATA data, using the significantly different mean sensory attributes from the ANOVA, with sensory attributes as main variables and overall liking and body ratings added as supplementary variables.

FWI data was analysed following Johnson and Bastian (2015) using the Agglomerative Hierarchical Clustering (AHC) with Euclidean distance and Ward's clustering method. Consumer clustering analysis based on the hedonic and body responses was also performed using k-means analysis with 'Trace W' as a clustering criterion. Furthermore, two-factor ANOVA (wine, consumer) was performed to examine the differences between wine samples within each cluster. Demographics and the composition of Fine Wine segments in each hedonic cluster were explored using post-hoc pairwise comparison with SPSS (IBM SPSS Statistics, Armonk, NY). Hedonic clusters were also added as supplementary variables to the PCA for the consumer panel.

5.3 Results

5.3.1 Comparison of experienced tasters' and consumers' conceptual understanding of wine body

The content analysis of the open-ended question revealed that experienced wine tasters most frequently used the term *palate weight* (70.4% versus 36.1% of mentions from consumers) to define wine body. Other attributes used to define wine body by experienced tasters were: *alcohol level, tannin (astringency), mouthfeel, texture* and *heaviness,* with fewer panellists mentioning *flavour, acidity* and *aroma,* among other attributes (Figure 5.1A).

On the other hand, consumers used *flavour* (74.4% versus 17.6% of mentions from the experienced tasters) to define wine body, which was the most frequently used term, followed by fullness, texture, taste, and weight *viscosity* and *heaviness* (Figure 5.1B). A small percentage of consumers (12% of mentions) associated *alcohol levels* with wine body (Supplementary Table 5.2).

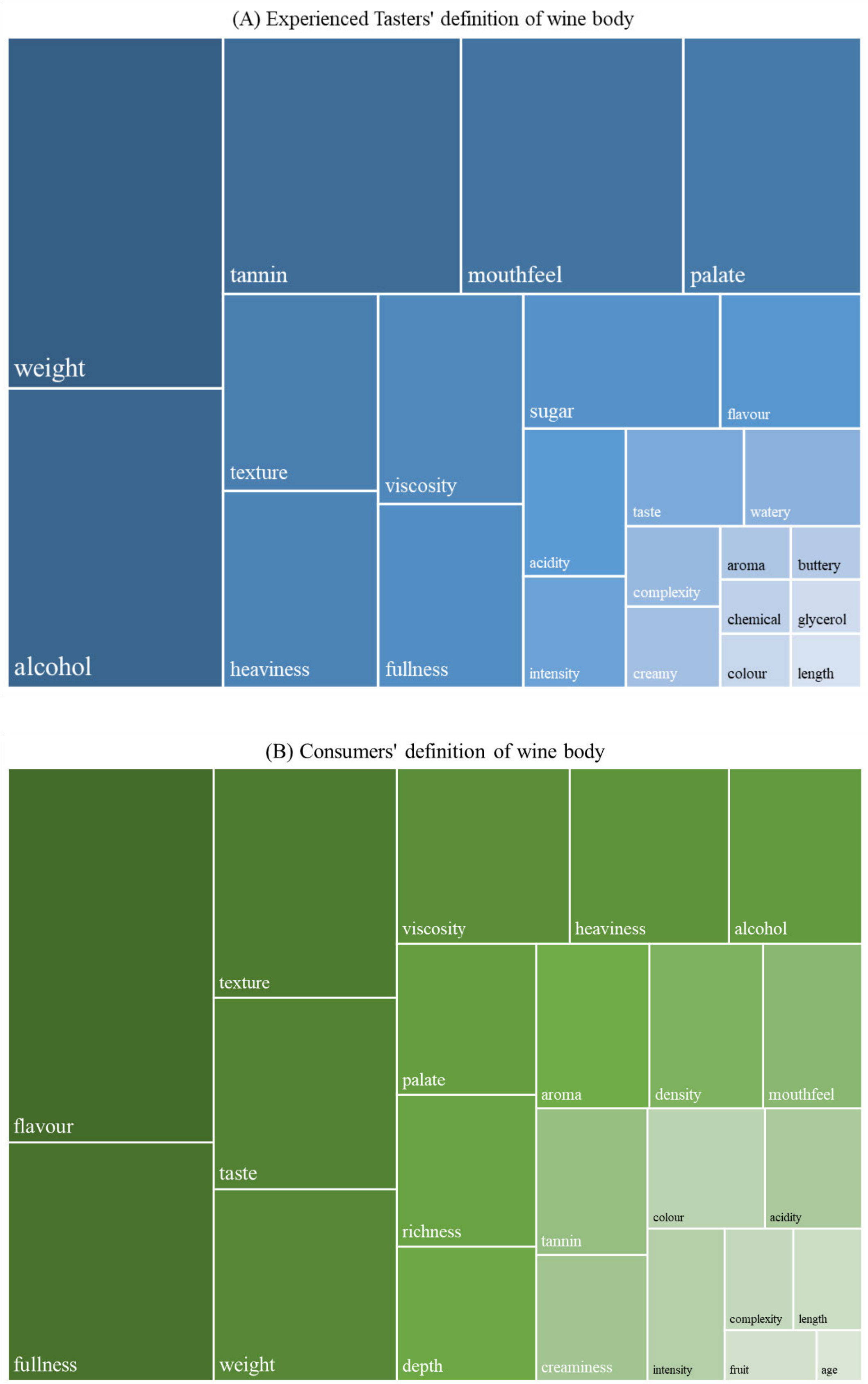


Figure 5.1: Tree maps of identified and collated categories used by (A) experienced wine tasters (n=42) and (B) consumers (n=110) to define wine body in an open-ended question (*'In your own words, how would you describe wine body?'*). The intensity of colour gradient relates to categories frequency of mention (74.4 – 0.03% range).

5.3.2 Experienced wine tasters

5.3.2.1 Sensory evaluation of no- and lower alcohol red wine with Rate-All-That-Apply

Flavour-enhanced Shiraz wines (0.05% and 9% ABV) were compared. In total, 45 out of 51 sensory attributes encompassing various sensory modalities, including aroma, flavour and mouthfeel, were statistically significant ($p<0.05$) (Appendix Table 5.1).

Body attribute was not found to be significantly different ($p>0.05$) between wines within a single block; however, body ratings showed significant difference ($p<0.05$) between blocks, with the lower alcohol wines (9% ABV) perceived to be fuller in body, irrespective of flavour modifications (Table 5.3). *Body* ratings for no-alcohol wines (0.05% ABV) with enhanced woody (WD), vanilla (VN), savoury (SV) and green (GR) flavours were no significantly different from lower alcohol wines (9% ABV) with enhanced WD, dark fruit (DF), floral (FL) and red fruit (RF) flavours.

Table 5.3: Mean body ratings of 16 flavoured wines (including reference wines) assessed by the experienced wine tasters

Wine Code	Mean Body Ratings
9SV	4.00^{a}
9VN	3.81^{a}
9REF	3.76^{a}
9GR	3.74^{a}
9WD	3.69^{ab}
9DF	3.60^{abc}
9FL	3.55^{abcd}
9RF	3.45^{abcde}
0WD	2.71^{bcdef}
0VN	2.67^{cdef}
0SV	2.57^{def}
0GR	2.48^{ef}
0DF	2.45^{f}
0FL	2.45^{f}
0RF	2.40^{f}
0REF	2.36^{f}

Wines sharing a letter are not significantly different (Fisher's LSD, $p<0.05$). **Codes:** REF = Reference wine, DF = Dark Fruit, RF = Red Fruit, FL = Floral, GR = Green, SV = Savoury, WD = Woody, VN = Vanilla

Between blocks, mouthfeel attributes such as *astringent*, *thick*, *warming* and *body* were rated significantly lower (p<0.05) in the 0.05% ABV wines compared to the 9% ABV wines. However, the 0.05% ABV base wine with enhanced WD flavour received a similar mean score for perceived *thickness* as 9% ABV base wines with enhanced GR, RF, DF, WD and FL flavours, suggesting that the WD flavour enhancement positively influenced perceived *thickness* in the 0.05% ABV base wine. Moreover, a significant modification (p<0.05) to *creamy mouthfeel* was achieved with VN and WD enhancements in no-alcohol and lower alcohol base wines.

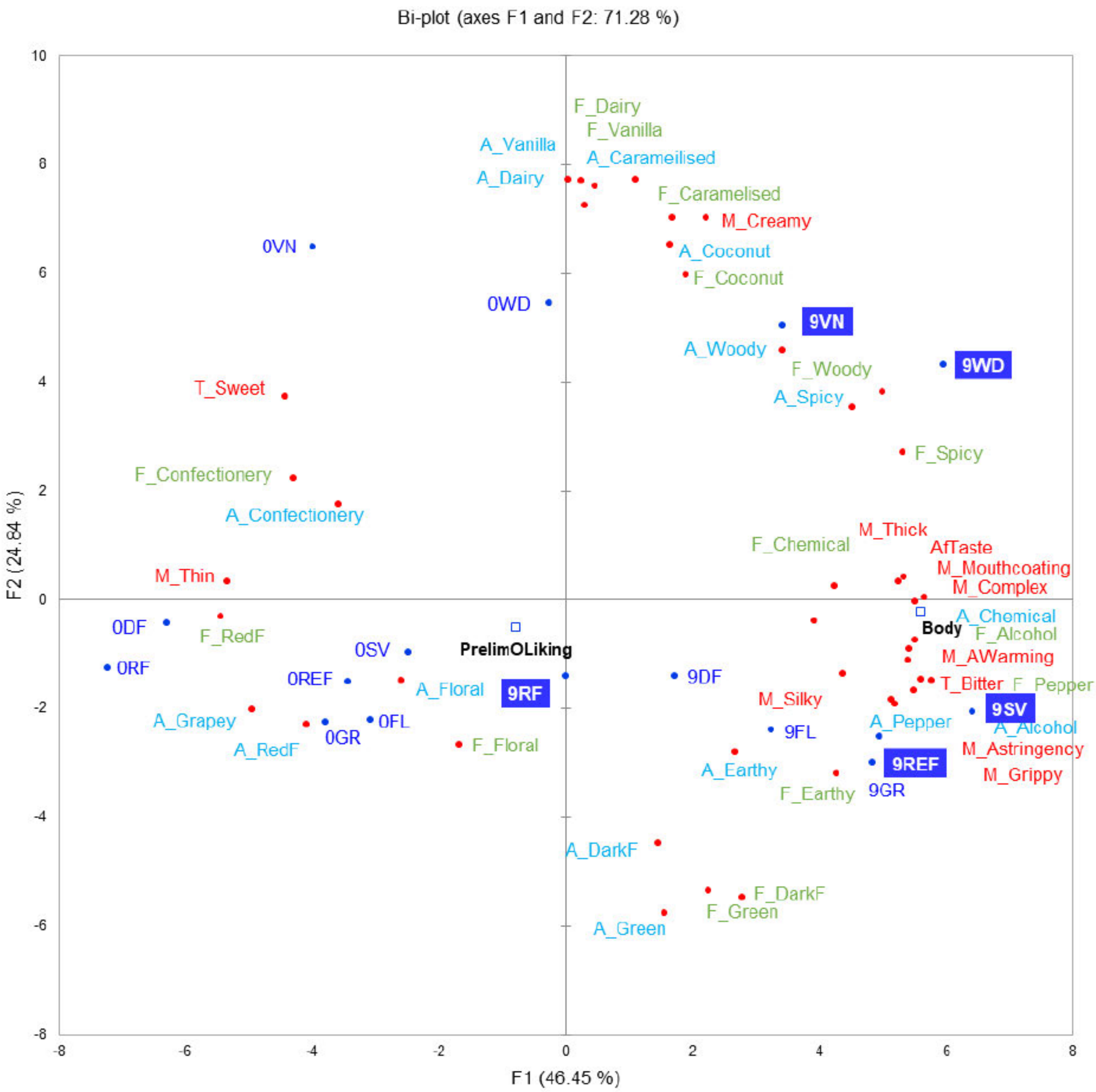
No- and lower alcohol wine samples did not show any significant difference (p>0.05) for the intensity of *bitter* and *acidic* tastes; however, significant differences (p<0.05) in sweetness perception were found within and amongst blocks. The addition of DF, RF and VN flavours to each base wine induced significantly higher (p<0.05) scores for sweetness. Lastly, aftertaste was not found to significantly differ (p>0.05) within the 0.05% ABV wine block.

PCA was performed to visualise statistically significant attributes, including aromas and flavours, and differentiate the combined flavoured wine samples from both blocks, resulting in 71.28% data variance being explained by the first two dimensions (F1 and F2). Figure 5.2 shows the bi-plot of the wine samples and sensory attribute scores and the loadings from the PCA of the sensory data.

Principal components F1 and F2 showed a clear separation between samples with 0.05% and 9% ABV, with no-alcohol wine samples perceived as *sweet*, *confectionery*, and *thin*, with *red fruit* and *floral* flavours and aromas, whereas 9% ABV wine samples were perceived as *thick*, *mouth-coating*, *complex* and *warming*. The flavour additions were reflected in the experienced wine tasters' perceptions of the aroma and flavour attributes.

Wine body had a strong positive correlation to mouthfeel attributes, including astringency (r = 0.956), warming sensation (r = 0.984), thickness (r = 0.977), mouth-coating (r = 0.947), silky (r = 0.843), grippy (r = 0.936) and complex mouthfeel (r = 0.955), and a negative correlation to thin mouthfeel (r = -0.980). Aromas and flavours that positively correlated to wine body included alcohol (r = 0.950, 0.985), peppery (r = 0.733, 0.918), spicy (r = 0.557, 0.846), and to a lesser extent flavours, such as dark fruit (r = 0.567), earthy (r = 0.607), and woody (r = 0.712). Lingering aftertaste (r = 0.941) was also positively correlated with wine body. Strong negative correlations with wine body were found with red fruit (r = -0.748) and confectionery (*r* = -0.502) flavours. Bitter taste had a strong positive correlation with wine body (*r* = 0.961), whereas sweet taste (*r* = -0.611) had a significantly negative correlation with wine body.

Modified wine samples with VN and WD flavour additions were situated in the upper left (0.05% v/v) and right (9% v/v) quadrants, and their positioning was primarily driven by aroma, flavour and mouthfeel attributes, including vanilla, dairy, caramelised, coconut, woody, spicy, and creamy mouthfeel. Wines (9% v/v) with modified SV, GR, FL and DF flavour profiles corresponded to attributes such as body, complex, warming, bitter, peppery, astringent, grippy, silky, with alcohol and earthy flavours and aromas, and were located in the lower right quadrant.



Wine samples (●), sensory attributes (●) and supplementary variables (□)

Figure 5.2: Principal Component Analysis (PCA) biplot of the significant sensory attributes of the experimental wine samples combined between Bracket 1 and Bracket 2 (n=16) profiled by the experienced wine panel (n=42) using RATA technique. **Sample codes:** REF = Reference wine, DF = Dark Fruit, RF = Red Fruit, FL = Floral, GR = Green, SV = Savoury, WD = Woody, VN = Vanilla. **Attributes:** A = Aroma, T = Taste, F = Flavour, M = Mouthfeel, Af = Aftertaste. **Wines:** Wines used in Trial 2 are highlighted

5.3.2.2 Preliminary hedonic responses

In addition to RATA evaluation, the experienced wine tasters were asked to provide liking scores for the flavoured wines to identify sample acceptability. The preliminary hedonic data and body ratings were used to inform the selection of the suitable base wines and flavour profiles for the subsequent consumer trial. All wine samples scored less than 4 on the 9-point hedonic scale (Supplementary Table 5.3), with the no-alcohol wines being rated less acceptable than the lower alcohol wines. Based on the data, no-alcohol wines were excluded from the consumer trial, and an additional base wine with a higher alcohol percentage (14.5% ABV), compared with 9% ABV base wine, was chosen to represent a more realistic matrix. Wines with enhanced flavours that positively (9% ABV SV, WD and VN) and negatively (9% ABV RF) affected body and mouthfeel perception and included a greater range of preliminary hedonic scores were selected for Trial 2.

5.3.3 Red wine consumer panel

5.3.3.1 Sensory evaluation of lower and full-strength alcohol red wine with Rate-All-That-Apply

Two flavoured base wines (9% and 14.5% ABV with RF, VN, SV, and WD flavour enhancements), including the two reference wines (n=10), were presented to the consumer panel (n=110) for RATA evaluation (Trial 2). ANOVA revealed significant differences for attributes when comparing flavour treatments between the two base wines (Appendix Table 5.2). Mouthfeel attributes were significantly different between wines with different alcohol content. All 9% ABV flavoured wine samples scored significantly lower (p<0.05) in mouthfeel attributes in comparison with the 14.5% ABV wines, and no significant differences were found between 9% ABV wines. In contrast, significant differences were found between the 14.5% ABV samples, where body was perceived significantly higher (p<0.05) in wines with enhanced SV and WD flavours in comparison with the RF flavour (Table 5.4).

Table 5.4: Mean body ratings of 10 flavoured wines (including reference wines) assessed by the consumer panel

Wine Codes	Mean Body Ratings
14SV	4.03^{a}
14WD	3.87^{a}
14VN	3.80^{ab}
14REF	3.79^{ab}
14RF	3.59^{b}
9VN	2.79^{c}
9SV	2.75^{c}
9WD	2.72^{c}
9RF	2.70^{c}
9REF	2.66^{c}

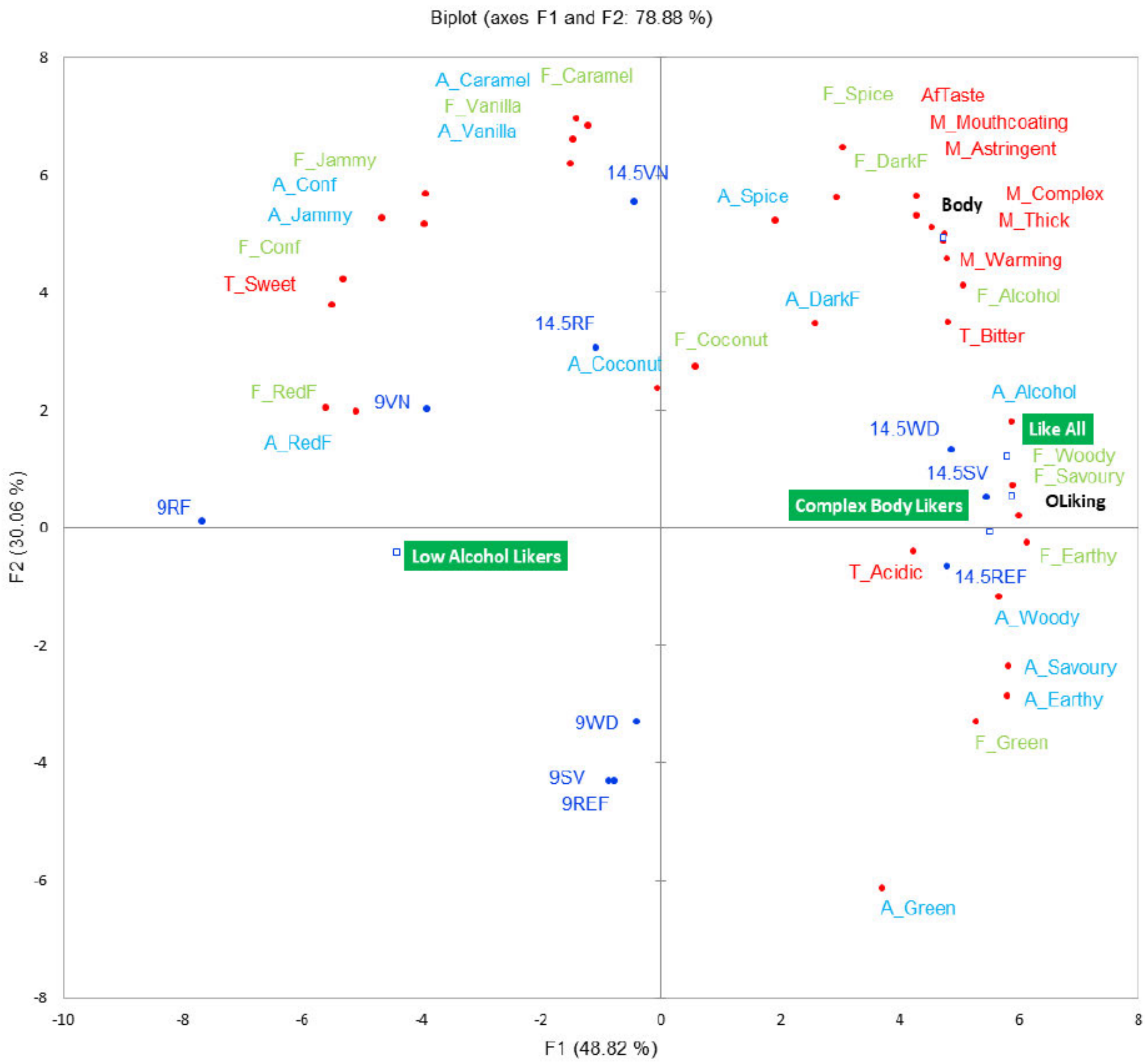
Wines sharing a letter are not significantly different (Fisher's LSD, p<0.05)

Furthermore, wine (14.5% ABV) with enhanced VN flavour received a significantly higher ($p<0.05$) mouth-coating score than the REF wine. *Thickness* and *mouthfeel complexity* were perceived significantly higher in 14.5% ABV wines with enhanced SV flavour than RF, suggesting that enhanced SV flavour influenced body, thickness and complexity attributes in the 14.5% ABV wine. Moreover, sweetness perception was significantly enhanced ($p<0.05$) in RF (9% ABV) and RF and VN (14.5% ABV) flavoured wines.

RATA data was visualised as a PCA plot, with the first two PC dimensions explaining 78.88% of the variation amongst Shiraz wines (Figure 5.3). Similarly to experienced wine tasters, when tasting the experimental wine samples, consumers correlated wine body with perceived thickness (r = 0.997), astringency (r = 0.970), mouth-coating (r = 0.975), warming sensations (r = 0.987), as well as strong correlation with aromas and flavours such as dark fruit (r = 0.729, 0.828) and alcohol (r = 0.876, 0.976). A weaker correlation of wine body with earthy (r = 0.487, 0.698), woody (r = 0.490, 0.695), savoury (r = 0.527, 0.769), and spicy (r = 0.472, 0.781) aromas and flavours was found. Consumers also rated wine body similarly to mouthfeel complexity (r = 0.971), and length of aftertaste (r = 0.986). Furthermore, wine body was strongly correlated to bitter taste (r = 0.906) and a significant negative correlation was found for red fruit aroma and flavour attributes (r = -0.348, -0.433).

Additionally, enhanced WD and SV flavours and REF (14.5% ABV) wines had similar sensory profiles and were closely positioned on the bi-plot, driven by alcohol aroma, woody, savoury, earthy and green aromas and flavours. RF and VN flavoured wines were situated on the opposite side of the bi-plot due to the influence of red fruit, confectionery, jammy, vanilla and caramel flavours and aromas, as well as sweet taste. Samples with higher alcohol, enhanced WD and SV flavours were perceived as fuller in body, whereas higher and lower alcohol wines with enhanced RF and VN flavours were perceived as lighter in body. Lower alcohol wines with enhanced WD and SV flavours were also perceived to be lighter in body in comparison to 14.5% ABV wines and similar to the lower alcohol REF wine.

Consumer hedonic clusters (section 5.3.3.2) were also overlaid on the PCA plot (Figure 5.3). Both Like All and Complex Body Likers were situated in close proximity to the wines they liked most (14.5% WD, SV and REF), while the Low Alcohol Likers cluster was located among the wines that they significantly liked the most, including 9% ABV wines with enhanced flavours of vanilla, wood, red fruit and savoury attributes (9% VN, WD, RF and SV).



Wine samples (●), sensory attributes (●) and supplementary variables (□)

Figure 5.3: Principal Component Analysis (PCA) of the significant sensory attributes of the experimental wine samples (n=10) showing the consumers' (n=110) mean liking scores of each wine sample by consumer cluster. **Sample codes:** REF = Reference wine, DF = Dark Fruit, RF = Red Fruit, FL = Floral, GR = Green, SV = Savoury, WD = Woody, VN = Vanilla. **Attributes:** A = Aroma, T = Taste, F = Flavour, M = Mouthfeel, Af = Aftertaste

5.3.3.2 Segmentation of the consumer sample based on hedonic responses and fine wine behaviour

Based on the consumer FWI responses, the AHC classified consumers into three psychographic segments (FWS). The FWI allows identifying consumer segments based on three dimensions labelled Connoisseur, Provenance and Knowledge (Johnson & Bastian, 2015). The mean score in each dimension determined consumer FWS, which were labelled No Frills (NF), Aspirants (ASP) and Wine Enthusiasts (WE). WEs scored highly on all three dimensions and were described as highly involved and knowledgeable, whereas NFs scored comparably lower and were classified as less knowledgeable and involved consumers. ASP ranged in between, scoring close to the midpoint of the scale. The values of the cluster centroids were in agreement with the original study (Johnson & Bastian, 2015). Supplementary Table 5.3 shows the results of each of the identified segments against the three FWI dimensions, demonstrating the significant mean scores for each dimension. No significant differences were found for segment demographics (data not shown).

Since ANOVA revealed no significant differences in consumer perception of wine body or liking of the samples based on their fine wine behaviour, consumers were clustered using k-means based on both their body and overall liking scores to assert if liking or body perception patterns varied across the consumer sample as a whole. Clustering analysis did not reveal any identifiable patterns for body perception. However, three consumer clusters based on the hedonic responses were identified (Table 5.5). Cluster 1 (n=48) scored all the wines above 5 on a 9-point hedonic scale, and the mean scores were not found significantly different ($p>0.05$) between the wine samples with the exception of 14SV, which was significantly liked more; therefore, this cluster was labelled ‘Like All’. Cluster 2 (n=29) showed significant hedonic differences ($p<0.05$) between wines with enhanced SV and WD and wines with enhanced RF flavour, which negatively drove body perception in both 14.5% and 9% ABV base wines. Higher alcohol wines (14.5% ABV) also scored significantly higher ($p<0.05$) in liking for this cluster than lower alcohol (9% ABV) wines, therefore, the cluster was labelled ‘Complex Body Likers’. Cluster 3 (n=33) rated flavoured wines with lower alcohol content (9% ABV) significantly higher ($p<0.05$) than full-strength alcohol (14.5% ABV) wines, irrespective of flavour enhancement, therefore being labelled ‘Low Alcohol Likers’.

Table 5.5: Overall mean liking scores for experimental wine samples by hedonic cluster

	14REF	14RF	14SV	14VN	14WD	9REF	9RF	9SV	9VN	9WD
Like All (n=48)	6.63^{Ba}	6.40^{Ba}	7.06^{Aa}	5.96^{Ba}	6.90^{ABa}	5.83^{Ba}	5.58^{BCa}	5.90^{Ba}	5.54^{BCa}	6.02^{Ba}
Complex Body Likers (n=29)	5.10^{Ab}	3.37^{BCc}	5.93^{Ab}	4.28^{ABb}	5.00^{Ab}	4.14^{ABb}	2.83^{Cb}	4.41^{ABb}	2.83^{Cb}	2.97^{Cc}
Low Alcohol Likers (n=33)	4.76^{Ab}	4.61^{Ab}	4.24^{Ac}	4.88^{ABb}	3.94^{Ac}	4.55^{Ab}	5.18^{Ba}	5.09^{Bb}	6.00^{Ba}	5.30^{Bb}

Segments not sharing a letter within a row (^{ABC}) and within a column (^{abc}) are significantly different (Fisher's LSD, p<0.05)

The data revealed insightful trends when the consumer composition between hedonic clusters was compared (Table 5.6). Like All cluster (n=48) comprised WE, ASP and NF members in the following proportions: 35.4%, 47.9% and 16.6%. Complex Body Likers cluster (n=29) comprised 48.8%, 31% and 20.6% members. Low Alcohol Likers cluster (n=33) comprised 24.4%, 42.4% and 33.3%, respectively, with significantly (p<0.05) more NF members in this hedonic cluster.

Table 5.6: Cross-tabulation of consumer hedonic clusters and Fine Wine segments

		Wine Enthusiasts (n=39)	**Aspirants** (n=46)	**No Frill** (n=25)
Like All	Count	17^{a}	23^{a}	8^{a}
(n=48)	% within hedonic cluster	35.4	47.9	16.7
	% within FWI	43.6	50.0	32.0
	% of total	15.5	20.9	7.3
Complex Body Likers	Count	14^{a}	9^{a}	6^{a}
(n=29)	% within hedonic cluster	48.3	31.0	20.7
	% within FWI	35.9	19.6	24.0
	% of total	12.7	8.2	5.5
Low Alcohol Likers	Count	8^{b}	14^{ab}	11^{a}
(n=33)	% within hedonic cluster	24.2	42.4	33.3
	% within FWI	20.5	30.4	44.0
	% of total	7.3	12.7	10.0

Each subscript letter denotes a subset of Fine Wine segments whose column proportions do not differ significantly from each other at the 0.05 level

5.4 Discussion

This study explored the potential for natural flavourings to manipulate the perception of wine sensory properties, specifically wine body. The flavour profiles were selected based on previous data (Chapters 2 and 4) that showed the potential for specific flavours to contribute to body perception whilst maintaining wine style by enhancing existing varietal characteristics.

5.4.1 Comparison of experienced wine tasters' and consumers' understanding of wine body

Content analysis revealed that experienced wine tasters use technical terms frequently mentioned in professional and scientific literature to describe body, such as weight, texture, mouthfeel, viscosity (Gawel et al., 2007; Jackson, 2019; Runnebaum et al., 2011; Skogerson et al., 2009) suggesting that the concept of wine body perception is a function of expertise, similar to the terms such as complexity and quality (Parr et al., 2011; Sáenz-Navajas et al., 2015). Despite experts using the terms body and fullness frequently and interchangeably, there appears to be little agreement on a proper definition of body in earlier studies on wine (or beer) (Clapperton, 1973; Gawel et al., 2007; Langstaff et al., 1991; Langstaff & Lewis, 1993a; Nurgel & Pickering, 2005; Pickering et al., 1998). Gawel et al. (2007) investigated the term body in Riesling wines with an experienced sensory panel and reported that panellists considered perceived viscosity as a concrete sensory attribute and a compositional factor of wine body. Experienced tasters in the present study provided precise terms related to texture, including palate weight, viscosity, mouthfeel, and fullness, as well as attributes associated with physical sensations of warming, hotness and astringency (alcohol and tannin, respectively). According to the experienced tasters' responses, wine body can be understood as a complex of related orally perceived sensations, including mouthfeel attributes related to texture. This is similar to the definition used in the literature by the trained sensory panels (Runnebaum et al., 2011); however, it is disparate from the definition currently used for beer body. According to the American Society of Brewing Chemists (ASBC, 2011), beer body is defined *as fullness of flavour and mouthfeel,* in agreement with findings reported by Gawel et al. (2007) that viscosity and flavour were perceived to be positively associated with body in Riesling wines. In contrast, red wine consumers described wine body with flavour, mouthfeel, taste and texture terms, indicating that consumers understand body to be a holistic perception of flavour, as well as mouthfeel sensations, consistent with the findings in the earlier studies (Niimi et al., 2017). Consumers also mentioned aroma and colour of the wine as defining factors. Aroma and colour have previously been attributed to body; however, it was argued that aroma and appearance influence consumer expectation rather than body perception (Chapter 2).

This finding further suggests that the previous definitions used by wine experts and researchers to explore body, specifically *viscous mouthfeel* (Runnebaum et al., 2011) and *tactile sensation* (Skogerson et al., 2009), may lack sufficient clarity given that confusion remains regarding the precise meaning of the term body. Furthermore, reference standards previously used to anchor sensory attributes related to body, such as weight and viscosity (i.e. the use of carboxymethyl cellulose as a reference standard for both) (Pickering & Demiglio, 2008), may prove insufficient when engaging with trained sensory panels, if they do not represent what body constitutes for the end-user, as reported in the present study. It was recently reported that there is a risk of misunderstanding when experts communicate with naïve consumers, and in the case of wine, a univocal understanding of sensory descriptors is rare (Bianchi et al., 2021). This suggests that the dimensions (or anchors) experts refer to, often do not match those used by consumers, especially naïve wine consumers.

5.4.2 Effects of enhanced flavours on perceived body and mouthfeel evaluated with experienced wine tasters

Findings of the present study indicate that experienced wine tasters found that the alcohol content of flavoured wines influenced the perception of wine body. Within the same alcohol level (9% ABV), wine body ratings were not significantly different; however, wine samples with enhanced SV and WD flavours had higher mean body scores in comparison to samples with the enhanced RF flavour. According to the PCA plot, wine body strongly correlated with mouthfeel attributes, such as thick, mouth-coating, warming, astringent and grippy, as well as aromas and flavours, including alcohol, earthy, peppery, woody and spicy. Flavoured 9% ABV wines with enhanced SV, GR, WD and VN flavour positively drove body perception. Despite experienced tasters' cognitive understanding of wine body that emerged in the present study emphasising textural characteristics of the wine as defining, this result shows that perceptually different flavours also positively influenced wine body. Wine mouthfeel complexity was also related to body perception by experienced tasters. Previous research found that complexity is associated with oak ageing, which introduces additional dimensions of flavour that are not derived from grapes (Wang & Spence, 2019). Non-fruit, winemaking-related (secondary and tertiary) flavours such as smoke, coconut, toast, pepper, honey, liquorice and meaty have previously been used to distinguish and classify complex wines (Spence & Wang, 2018; Wang & Spence, 2019; Wang et al., 2021; Wang & Spence, 2018), similarly to the findings of the present study concerning body. Interestingly, in the present study, wine body was also expressed via a single dynamic element, length, or aftertaste, as rated by experienced wine tasters, which has previously been associated with wine complexity (Schlich et al., 2015).

No-alcohol wines were perceived as thin and associated with previously reported flavours to negatively affect the wine body, including red fruit, confectionery, and floral (Chapter 2). De-alcoholisation practises, including nanofiltration (NF), reverse osmosis (RO), osmotic distillation (OD), evaporative perstraction (EP), pervaporation (PV), spinning cone column (SSC), as well as the combined approaches such as OD/EP and RO-OD/EP have been previously attributed to numerous sensory changes with various effects depending on methodology and the alcohol reduction levels. According to previous research, the higher alcohol content in wines and anthocyanin concentration were associated with higher intensity of dark fruit aroma and flavour, body, bitterness, hotness and aftertaste (Bowen et al., 2020; Goldner et al., 2009). Whereas the sensory changes in wines with reduced alcohol included lack of body, flavour imbalance, reduced heat sensation, increased astringency, bitterness and acidity, as well as loss of overall sensory quality (Gawel et al., 2007; King et al., 2013; King & Heymann, 2014; Meillon et al., 2009), highlighting that de-alcoholisation and alcohol removal techniques result in significant loses of crucial wine compounds important for body perception.

5.4.3 Effects of enhanced flavours on perceived body and mouthfeel evaluated with consumers

Similar to responses from experienced wine tasters, consumers related wine body to perceived textural attributes when tasting the flavoured wines. This contrasts with the qualitative understanding of body, where flavour was the key term while texture attributes, including alcohol warming and astringency, were used less frequently. Consumers related attributes such as red fruit, confectionery aromas and flavours, and sweet taste to 9% ABV wines and wines with enhanced RF and VN flavours, which they associated with lighter body. In contrast, 14.5% ABV wines with enhanced WD and SV flavours were perceived fuller in body and were positively correlated with spicy, dark fruit, alcohol, woody, savoury aromas and flavours, and bitter taste. This suggests that consumers used wine flavour, texture and alcohol content of samples to distinguish their different body styles, which partly agreed with their cognitive perception of wine body, as alcohol content (warming) was less frequently mentioned as a defining factor.

Similar to the findings of the present study, where enhanced SV and WD flavours influenced body perception in the 14.5% ABV wines, Moran et al. (2018) showed that wines expressing increased dryness, more intense savoury and peppery aromas and flavours, as well as coarser quality tannin mouthfeel made from late-pruned vines, were associated with fuller body. This suggests that viticulture practices could be optimised to elicit flavours congruent with body perception. The taste sensation of umami (savoury) requires protein hydrolysis which renders free glutamic acid. The main components of the nitrogen fraction of musts and wines are amino acids, peptides, proteins and ammonium ions. These are derived from the enzymatic degradation of grape proteins, excretion by living yeasts at the end of fermentation and proteolysis during yeast autolysis. Thus, amino acids are important contributors to the wine's savoury taste and flavour (Vilela et al., 2016).

Conversely, other viticulture techniques such as vine heating (thermal regime) were previously reported to lead to wines with a lighter body, and which were also associated with decreased colour intensity, increased floral and red fruit flavour intensities decreased savoury flavour and low in both tannin intensity and sub-quality (Moran et al., 2021), consistent with the flavours associated with lighter-bodied wines in this study. Collectively, these results further support the suggestion that flavour plays a role in body perception and that flavour has the ability to enhance or reduce perceived body intensity, although it may not be a significant driver on its own.

Sensory properties, including flavour complexity and intensity in complex matrices, such as wine, depend on sensory-active compounds' sensory and chemical interactions (Sáenz-Navajas et al., 2015). In the case of quality, Saenz-Navajas et al. (2015) used chemical and consumer sensory analysis to report that consumers linked higher wine quality to high concentrations of oak-related volatiles, such as eugenol, and *cis*- and *trans*-oak-lactones. In comparison, lower quality was linked to astringent-related compounds such as polymeric proanthocyanidins, *cis*-aconitic acid, certain flavonols and hydroxycinnamic acid derivatives, the most significant volatiles of wines aged in barrels (Díaz-Plaza et al., 2002). This suggests that woody aroma and flavour correlate to higher wine quality, whereas wines exhibiting higher astringency negatively correlate with wine quality for consumers. In this study, wine body was positively associated with higher perceived astringency and wines with enhanced WD flavour, exhibiting woody, dark fruit and spicy aromas and flavours, suggesting that wine body may not directly correlate with wine quality. In a previous study, focus groups were conducted to explore consumer understanding of body in beer and wine, and findings suggested that the perception of body depended on factors other than quality because not all consumers agreed that the concepts were related (Chapter 2).

Other sensory attributes such as tannin (astringency), complexity and length (aftertaste) were also amongst the least mentioned descriptors used by consumers when defining wine body. Nevertheless, astringent, complex mouthfeel, and persistent aftertaste correlated to body perception when tasting wine samples. This suggests that specific differences exist for consumers when cognitively defining and perceptually evaluating complex sensory concepts. Previously, Vidal et al. (2015) asked naïve consumers to list sensations they perceived when drinking an astringent red wine and only a very small percentage of consumers (8%) mentioned body, suggesting that astringency was not a descriptor consumers associated with body. Furthermore, grape seed extract was used in Chapter 4 to increase astringency in no- and low-alcohol wines and a negative effect was found, suggesting that low astringency levels in low-alcohol wine are important for body. Perceived astringency might play a significant role in wine body evaluation, and consumers may attribute fuller body to higher astringency, as well as other textural attributes, such as thickness in red wines. Winemakers can use skin extraction to manage wine phenolics, as wine viscosity, oiliness and coarseness characteristics may be of phenolic origin (Smith & Waters, 2012). Whole bunch pressing can produce juice with low phenolic content, whereas extensive skin contact or the addition of pressings prior to fermentation can produce juice with higher phenolic content and subsequently flavour intensity. Techniques such as fining or micro-oxygenation (controlled addition of small doses of oxygen to wine in tanks) (Gómez-Plaza & Cano-López, 2011) before fermentation can lead to a reduction in phenolic content (Smith & Waters, 2012). Phenolics might play a significant role in providing desired texture to wines with less alcohol, as phenolic extracts were previously reported to increase perceived viscosity. Nevertheless, an important remark was made concerning higher alcohol wines, where adding phenolic extracts had a limited impact on perceived viscosity (Smith et al., 2017).

Discrepancies were seen in the conceptual definition (knowledge-based) and perceptual evaluation (tasting) of wine body for consumers, highlighting the differences in neural processing and brain activity when presented with stimuli. Interestingly, differences in neural activity, where only certain brain regions activate during the after-tasting phase, were previously reported. Pazart et al. (2014) conducted a functional magnetic resonance imaging (fMRI) study and found that the brain regions responsible for sensory integration (chemical, perceptual and visual sensory integration in the cerebral orbitofrontal cortex (Rolls et al., 2010)) were only activated after tasting in naïve wine tasters, in contrast to experienced wine tasters who had a more immediate and targeted sensory reaction. An earlier study demonstrated activation in the primary gustatory cortex and amygdala, responsible for emotional information processing, in response to tasting wine in naïve wine tasters. In contrast, for expert tasters, increased activity was observed in areas of the brain responsible for working memory, including short-term storage and information processing, namely the left insula and adjoining orbitofrontal cortex, as the dorsolateral prefrontal cortex (Castriota-Scanderbeg et al., 2005). This suggests that the changes in neural processing have to be considered when analysing sensory properties with naïve tasters and experts and subsequently using the results to communicate sensory characteristics to consumers. Expertise seemingly allows panellists to better match wines to sensory descriptors (Solomon, 1990), use a higher number of pertinent descriptors (wine-related odorant study) (Zucco et al., 2011) and exhibit better odour recognition (Parr et al., 2002), greater consistency and better descriptor recall (Croijmans & Majid, 2016; Hughson & Boakes, 2002), and overall to perform better than untrained tasters when matching wines to descriptors (Gawel, 1997; Lawless, 1984). This suggests that experienced tasters tend to use a more analytical approach when defining and evaluating sensory characteristics.

5.4.4 Consumer segmentation

In the present study, the Complex Body Likers cluster preferred flavoured wines rated higher in body, including 14.5% and 9% ABV wines with enhanced SV and 14.5% ABV WD flavours, and were also categorised as Wine Enthusiasts, suggesting that consumers are more interested in wine provenance, posses higher wine knowledge and display more fine wine behaviours tend to prefer full-bodied, higher-alcohol wines with dominant secondary and tertiary flavours, including spice, woody and savoury notes. On the other hand, the Low Alcohol Likers cluster was mainly categorised as No Frills consumers and gravitated toward wines with light body and red fruit, confectionery, sweet and jammy flavour profiles that included lower alcohol wines with enhanced RF and VN flavours. Previously, it was found that *flavour* and *fullness* were terms used by a more significant proportion of NF than WE consumers when describing body. In contrast, the terms *mouthfeel, texture and alcohol* were used by a greater proportion of WE than NF consumers, suggesting that alcohol seems to play a more significant role in wine body perception for WE consumers (Chapter 4). Previous studies have also shown that Wine Enthusiast segments consume more wine, spend more money on wine and are more knowledgeable about wine than the other two FWS (Danner et al., 2020; Johnson & Bastian, 2015). Research has also indicated that Wine Enthusiast experience stronger positive emotions when tasting higher quality and more complex wines (Danner et al., 2020), suggesting that quality and complexity may act as non-sensory attributes related to the wine body knowledgeable consumers.

Several studies have examined consumer hedonic responses to sensory drivers and red wine composition and identified consumer clusters with similar preference trends, as seen in the present study. The consumer clusters identified previously included consumers who liked red fruit, confectionery forward and simple wines (similar to the Low Alcohol Likers in the present study) and consumers who prefer more complex wine profiles, including textural, oak-driven wines with green, savoury and spicy notes (similar to the Complex Body Likers in the present study) (Bastian et al., 2010; Lattey et al., 2010; Wang et al., 2016). Taste phenotypes, taste receptor polymorphisms and inter-individual variations were previously reported to influence consumer liking (in turn predicting purchase and consumption behaviours), suggesting that genetic, as well as cultural factors may play a significant role in the individual liking of wine (Carrai et al., 2017; Hayes & Pickering, 2012; Pickering et al., 2013). Since it is argued in the present study that individual flavours and flavour intensity are amongst the defining factors of wine body for consumers, further investigation into consumer taste phenotypes may uncover drivers for the individual body responses of different consumer segments. The consumer cluster identified as Low Alcohol Likers is a novel finding in wine.

Based on the wine sensory characteristics identified above in relation to consumer perception of wine body, the use of different yeast strains (such as *Hanseniaspora vineae*) to promote increased flavour intensity and diversity in wines (Medina et al., 2013). Nonconventional yeasts species are among the main representatives of grape natural microbiota. In general, their pronounced sensitivity to antimicrobial agents (e.g., SO_2) and higher alcohol contents prevent the complete transformation of grape sugars into ethanol during alcoholic fermentation. Therefore, their application in co-inoculation or sequential inoculation with *Saccharomyces cerevisiae* is increasingly getting popular, especially regarding their potential positive effects on wine flavour (Ciani et al., 2016). Furthermore, the intentional addition of mannoproteins derived from *S. cerevisiae* to modulate wine mouthfeel through interaction with phenolic compounds (Rowe et al., 2010), and different oenotannins to impact astringency, colour, bitterness and earthy characters (Harbertson et al., 2012; Versari et al., 2013); oak barrel fermentation, maturation or oak chip addition to promote the higher intensity of colour, coffee, woody, sweet/caramelised characters in the final product (Alencar et al., 2019); amongst other winemaking techniques could be evaluated, if developed flavour and mouthfeel profiles are found to influence individual body intensity responses by consumers.

The comparison of cognitive understanding and perceptual evaluation of wine body between experienced wine tasters and naïve consumers, as well as flavour treatments tested in this study, provide important information to wine communicators, new product developers, marketers, winemakers and viticulturists regarding the potential application of natural wine flavourings, specifically in the current pursuit for sensorially acceptable wines with reduced alcohol content, that are criticised for lacking key sensory characteristics, including aroma, flavour and body.

5.5 Conclusion

Enhanced savoury and woody flavours added to 14.5% ABV base wine positively influenced the perception of body for naive wine consumers, whereas enhanced red fruit flavour negatively influenced the perception of wine body. Other mouthfeel attributes were significantly enhanced in 14.5% ABV wines due to the flavour additions, including thickness and creaminess. Furthermore, these differences affected the consumer acceptance of the experimental wine samples. Three consumer clusters based on the hedonic responses were identified. The Like All cluster scored the wines above 5, and the mean scores were not found significantly different between the wines, with the exception of 14% ABV wine with enhanced savoury flavour. The Complex Body Likers cluster perceived wines with enhanced savoury and woody flavours as positively driving liking and wines with enhanced red fruit flavour as negatively driving liking in both 14.5% and 9% ABV base wines. The Low Alcohol Likers cluster rated flavoured 9% ABV wines significantly higher than 14.5% ABV wines, irrespective of flavour enhancement. Further research will benefit from evaluating wines with enhanced flavours identified to influence the body, produced with conventional winemaking techniques.

5.6 References

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5.7 Supplementary Materials for Chapter 5

Supplementary Table 5.1: Basic wine chemistry of reference wines

Sample Code	Alcohol (ABV%)	Density (g/cm3)	Dynamic Viscosity (mPa·s)	pH	Titratable Acidity (TA)	Volatile Acidity (VA)	Residual sugar (g/L)	Free SO_2 (mg/L)	Total SO_2 (mg/L)
0REF	0.96^{c}	1.019^{a}	1.465^{a}	3.32^{a}	4.20^{a}	0.13^{a}	9.66^{a}	11.2^{a}	94.5^{a}
9REF	9.44^{b}	1.019^{a}	1.484^{a}	3.32^{a}	5.28^{a}	0.26^{a}	8.42^{a}	20.8^{b}	43.2^{b}
14REF	14.61^{a}	1.022^{a}	1.461^{a}	3.53^{a}	5.48^{a}	0.41^{a}	3.07^{b}	23.2^{b}	59.2^{b}

Values are means of triplicate technical measures. Mean values followed by a different letter (within a column) are significantly different (Fisher's LSD, $p<0.05$)

Supplementary Table 5.2: Experienced tasters' panel and consumers' key responses to the open-ended question '*In your own words, how would you describe wine body?*' collated into categories and frequency of mention, calculated using frequency analysis and converted into percentages

		Percentages of mention (%)	
Category	**Examples**	**Experienced Tasters** (n=43)	**Consumers** (n=110)
Weight	weight	70.4^{a}	36.1^{b}
Mouthfeel	mouthfeel, mouth, feel, feeling	45.8^{a}	16.9^{b}
Palate	palate, structure	42.3^{a}	21.7^{b}
Alcohol	alcohol, alcohol content, ethanol	42.3^{a}	12.0^{b}
Texture	texture, textural	28.2^{a}	33.7^{a}
Thickness	thickness, thick, viscous, viscosity	28.2^{a}	21.7^{a}
Heaviness	heavy, heaviness	28.2^{a}	28.9^{a}
Astringency	tannin, tannins, astringent, astringency, phenolics, phenolic compounds	28.2^{a}	12.0^{b}
Fullness	full, fullness	24.6^{a}	50.6^{b}
Flavour	flavour, flavours, flavoured, flavor, flavors	17.6^{a}	74.7^{b}

Sugar	sugar, polysaccharides	14.1^{a}	0.02^{b}
Acidity	acid, acidity, sharp, sharpness	14.1^{a}	12.0^{a}
Intensity	intensity, intense	10.6^{a}	12.0^{a}
Taste	taste, sweet, sweetness, bitter, bitterness	10.6^{a}	36.1^{b}
Complexity	complexity, complex	7.0^{a}	7.2^{a}
Colour	colour, color, dark, light colour	3.5^{a}	12.0^{b}
Aroma	aroma, aromas, smell, smells, bouquet	3.5^{a}	14.5^{b}
Length	length, aftertaste, finish	3.5^{a}	4.8^{a}
Creaminess	creamy, creaminess	3.5^{a}	4.8^{a}
Density	density, dense	0.12^{a}	12.0^{b}
Richness	richness, rich	0.09^{a}	21.7^{b}
Depth	deep, depth	0.03^{a}	19.3^{b}

Terms sharing a letter in the rows are not significantly different (Pearson's Chi-squared Test, $p < 0.05$)

Supplementary Table 5.3: Cluster centroids for the three fine wine segments following the Agglomerative Hierarchical Clustering

FWI Dimension	**No Frills** *(n=25)*	**Aspirants** *(n=46)*	**Wine Enthusiasts** *(n=39)*
Connoisseur	3.474^{a}	4.379^{b}	5.498^{c}
Knowledge	3.256^{a}	4.500^{b}	5.497^{c}
Provenance	3.473^{a}	4.714^{b}	5.491^{c}

Scores followed by a different letter (within a row) are significantly different (Fisher's LSD, $p<0.05$)

Supplementary Table 5.4: Mean preliminary hedonic scores of 16 experimental wines assessed by the experienced wine panel (n=42)

Wine Code	Mean Preliminary Liking Score
9REF	**4.619[a]**
0VN	4.238[ab]
0DF	4.214[ab]
9VN	**4.143[ab]**
9DF	4.048[abc]
0REF	4.024[abcd]
9GR	4.000[abcd]
0RF	3.976[abcd]
9RF	**3.881[abcd]**
0GR	3.81[abcd]
9SV	**3.738[abcd]**
0SV	3.643[bcd]
0WD	3.357[bcd]
0FL	3.167[cd]
9WD	**3.143[d]**
9FL	3.143[d]

Wines sharing a letter are not significantly different (Fisher's LSD, $p<0.05$). Wines highlighted in bold were selected for the subsequent consumer trial (Trial 2).

Supplementary Table 5.5: Mean hedonic scores of 10 experimental wines assessed by the naïve red wine consumer panel (n=110)

Wine Code	**Mean Liking Score**
14WD	5.53^{abc}
14VN	5.21^{cd}
14SV	5.94^{a}
14RF	5.08^{cde}
14REF	5.68^{ab}
9VN	4.98^{de}
9WD	5.02^{de}
9SV	5.28^{bcd}
9RF	4.71^{e}
9REF	5.02^{de}

Wines sharing a letter are not significantly different (Fisher's LSD, $p<0.05$)

5.8 Appendix for Chapter 5

Appendix Table 5.1: Analysis of variance results for overall liking and Rate-All-That-Apply sensory attribute scores of flavoured wine samples assessed by the experienced wine tasters

	O_Liking	A_Alcohol	A_DarkF	A_RedF	A_DriedF	A_Conf	A_Jammy	A_Green	A_Chem	A_Grapey	A_Earthy	A_Dairy	A_Pepper
9VN	4.14^{ab}	1.46^{a}	2.23^{de}	2.64^{def}	1.73^{ab}	3.28^{bc}	2.23^{abc}	0.54^{f}	1.85^{bcde}	1.35^{fgh}	0.92^{fghij}	1.97^{b}	0.85^{cdef}
9REF	4.61^{a}	1.76^{a}	3.52^{a}	2.95^{cde}	2.04^{a}	1.45^{ef}	2.33^{abc}	1.90^{abc}	1.52^{cdef}	1.38^{fgh}	1.76^{bcde}	0.45^{c}	1.57^{ab}
9WD	3.14^{d}	1.76^{a}	2.40^{cde}	2.09^{f}	1.50^{ab}	1.97^{def}	2.02^{abc}	0.81^{f}	2.54^{ab}	0.97^{h}	1.14^{efghi}	1.42^{b}	1.26^{abc}
9DF	4.04^{abc}	1.38^{a}	3.21^{ab}	3.50^{bc}	1.73^{ab}	3.78^{a}b	2.78^{a}	0.92^{ef}	2.00^{bcd}	2.59^{bcd}	0.92^{fghij}	0.40^{c}	1.04^{abcde}
9GR	4.00^{abcd}	1.71^{a}	3.11^{abc}	2.81^{cdef}	1.88^{ab}	2.09^{de}	2.02^{abc}	2.47^{a}	2.07^{bcd}	1.64^{efgh}	1.97^{abcd}	0.40^{c}	1.59^{a}
9SV	3.73^{abcd}	1.73^{a}	2.52^{bcde}	2.09^{f}	1.73^{ab}	1.14^{f}	1.78^{c}	1.76^{bcd}	2.11^{bc}	1.09^{gh}	2.52^{a}	0.64^{c}	1.64^{a}
9RF	3.88^{abcd}	1.35^{ab}	2.88^{abcd}	4.40^{a}	1.26^{b}	3.95^{ab}	2.64^{ab}	1.14^{def}	1.73^{bcdef}	3.00^{abc}	0.71^{ghij}	0.35^{c}	0.71^{cdef}
9FL	3.14^{d}	1.66^{a}	2.50^{bcde}	2.73^{def}	1.35^{ab}	2.50^{cd}	1.73^{c}	2.35^{ab}	3.00^{a}	2.11^{def}	1.38^{cdefg}	0.50^{c}	1.02^{abcde}
0WD	3.35^{bcd}	0.52^{c}	1.90^{e}	2.31^{ef}	1.81^{ab}	2.42^{d}	1.97^{bc}	0.78^{f}	2.21^{abc}	1.85^{defg}	1.50^{cdef}	1.59^{b}	0.95^{bcde}
0VN	4.23^{ab}	0.35^{c}	2.09^{e}	3.31^{cd}	1.81^{ab}	3.95^{ab}	2.21^{abc}	0.52^{f}	1.00^{f}	2.38^{cde}	0.66^{hij}	2.59^{a}	0.42^{ef}
0FL	3.16^{cd}	0.64^{c}	2.07^{e}	3.02^{cde}	1.52^{ab}	2.71^{cd}	2.07^{abc}	2.57^{a}	2.28^{abc}	2.02^{def}	1.31^{defgh}	0.59^{c}	0.57^{def}
0DF	4.21^{ab}	0.35^{c}	3.07^{abc}	4.14^{ab}	1.45^{ab}	4.19^{a}	2.52^{abc}	0.66^{f}	1.09^{ef}	3.23^{ab}	0.50^{ij}	0.69^{c}	0.45^{ef}
0SV	3.64^{bcd}	0.33^{c}	2.19^{de}	2.59^{def}	1.92^{ab}	1.54^{ef}	1.95^{bc}	0.95^{ef}	1.54^{cdef}	1.83^{defg}	2.33^{ab}	0.78^{c}	1.14^{abcd}
0GR	3.81^{abcd}	0.54^{c}	2.57^{bcde}	3.52^{bc}	1.47^{ab}	2.78^{cd}	2.28^{abc}	2.19^{abc}	1.57^{cdef}	3.02^{abc}	1.33^{defgh}	0.47^{c}	0.50^{ef}
0REF	4.02^{abcd}	0.73^{bc}	2.28^{de}	3.19^{cd}	2.07^{a}	2.14^{de}	2.11^{abc}	1.54^{cde}	1.00^{f}	2.59^{bcd}	2.04^{abc}	0.57^{c}	0.95^{bcde}
0RF	3.97^{abcd}	0.31^{c}	2.66^{bcde}	4.71^{a}	1.42^{ab}	4.28^{a}	2.71^{ab}	0.73^{f}	1.23^{def}	3.73^{a}	0.40^{j}	0.40^{c}	0.31^{f}

Appendix Table 5.1 (cont.)

	A_Floral	A_Spicy	A_Woody	A_Caramel	A_Coconut	A_Vanilla	T_Bitter	T_Sweet	T_Acid
9VN	1.97^{cde}	2.19^{abc}	2.00^{bc}	2.97^{b}	1.92^{b}	3.57^{b}	3.09^{a}	3.04^{abcde}	3.45^{ab}
9REF	1.66^{def}	2.23^{abc}	2.09^{b}	0.78^{e}	0.47^{c}	0.90^{d}	3.23^{a}	2.23^{f}	3.85^{ab}
9WD	1.28^{efg}	2.78^{a}	3.16^{a}	1.61^{cd}	4.11^{a}	2.73^{c}	3.35^{a}	2.76^{cdef}	3.35^{ab}
9DF	2.21^{cd}	1.69^{cd}	1.31^{cdefg}	0.71^{e}	0.42^{c}	1.02^{d}	3.26^{a}	3.11^{abcde}	3.57^{ab}
9GR	1.69^{def}	1.88^{bcd}	1.88^{bcd}	0.69^{e}	0.42^{c}	0.85^{d}	3.19^{a}	2.50^{ef}	3.47^{ab}
9SV	0.78^{g}	2.28^{abc}	2.02^{bc}	0.97^{de}	0.40^{c}	0.71^{d}	3.19^{a}	2.61^{def}	3.26^{b}
9RF	2.45^{bcd}	1.33^{d}	0.92^{g}	0.71^{e}	0.42^{c}	0.90^{d}	3.35^{a}	3.07^{abcde}	3.71^{ab}
9FL	3.23^{b}	1.92^{bcd}	1.50^{bcdefg}	0.57^{e}	0.50^{c}	0.95^{d}	3.04^{a}	2.54^{def}	3.52^{ab}
0WD	1.66^{def}	2.54^{ab}	3.04^{a}	1.71^{c}	4.31^{a}	2.57^{c}	1.47^{b}	3.23^{abcd}	3.71^{ab}
0VN	2.31^{cd}	1.66^{cd}	1.66^{bcdef}	3.85^{a}	1.40^{b}	4.33^{a}	1.21^{b}	3.61^{ab}	3.73^{ab}
0FL	4.09^{a}	1.83^{bcd}	1.00^{fg}	0.40^{e}	0.40^{c}	1.07^{d}	1.59^{b}	3.00^{bcde}	3.92^{a}
0DF	2.66^{bc}	1.23^{d}	1.21^{defg}	0.88^{e}	0.42^{c}	1.09^{d}	1.02^{b}	3.73^{a}	3.66^{ab}
0SV	1.11^{fg}	1.76^{cd}	1.85^{bcde}	0.66^{e}	0.54^{c}	0.81^{d}	1.42^{b}	3.19^{abcde}	3.66^{ab}
0GR	2.02^{cde}	1.40^{d}	1.14^{efg}	0.52^{e}	0.19^{c}	1.19^{d}	1.54^{b}	2.95^{bcde}	3.92^{a}
0REF	1.90^{cdef}	1.54^{cd}	1.73^{bcde}	0.64^{e}	0.42^{c}	0.71^{d}	1.26^{b}	2.73^{cdef}	3.71^{ab}
0RF	2.45^{bcd}	1.23^{d}	0.83^{g}	0.64^{e}	0.26^{c}	0.88^{d}	1.02^{b}	3.33^{abc}	3.59^{ab}

Appendix Table 5.1 (cont.)

	M_Body	M_Astrin	M_AWarm	A_Thick	M_M-coat	M_SilkyT	M_Thin	M_Oily	M_Compl	M_Creamy	M_Grippy
9VN	3.81^{a}	3.14^{a}	2.78^{a}	2.88^{a}	2.83^{abc}	2.50^{a}	2.61^{b}	1.76^{ab}	2.21^{ab}	2.33^{a}	2.78^{a}
9REF	3.76^{a}	3.47^{a}	2.76^{a}	2.52^{ab}	3.00^{ab}	2.28^{abc}	2.42^{b}	1.31^{abc}	2.42^{a}	1.61^{bcde}	2.92^{a}
9WD	3.69^{ab}	3.11^{a}	2.69^{a}	2.47^{ab}	3.04^{a}	2.26^{abc}	3.02^{b}	1.83^{a}	2.14^{ab}	2.21^{abc}	2.78^{a}
9DF	3.60^{abc}	3.16^{a}	2.52^{a}	2.57^{ab}	2.78^{abc}	2.28^{abc}	2.83^{b}	1.45^{abc}	2.19^{ab}	1.81^{abcde}	2.64^{ab}
9GR	3.74^{a}	3.47^{a}	2.81^{a}	2.61^{ab}	2.95^{ab}	2.52^{a}	2.73^{b}	1.52^{abc}	2.33^{a}	1.50^{de}	2.78^{a}
9SV	4.00^{a}	3.26^{a}	2.71^{a}	2.73^{a}	3.11^{a}	2.47^{a}	2.47^{b}	1.45^{abc}	2.38^{a}	1.73^{abcde}	2.78^{a}
9RF	3.45^{abcde}	3.21^{a}	2.42^{a}	2.59^{ab}	2.52^{abcde}	2.35^{ab}	3.00^{b}	1.35^{abc}	1.97^{abc}	1.76^{abcde}	2.88^{a}
9FL	3.55^{abcd}	3.35^{a}	2.66^{a}	2.45^{ab}	2.69^{abcd}	2.31^{abc}	3.02^{b}	1.35^{abc}	1.83^{abc}	1.52^{cde}	2.85^{a}
0WD	2.71^{bcdef}	2.33^{b}	0.64^{b}	1.95^{bc}	2.31^{bcdef}	1.45^{d}	4.16^{a}	1.47^{abc}	1.57^{bcd}	2.07^{abcd}	1.76^{c}
0VN	2.67^{cdef}	2.00^{b}	0.64^{b}	1.73^{c}	2.23^{cdef}	2.09^{abcd}	3.88^{a}	1.19^{abc}	1.64^{bcd}	2.28^{ab}	1.73^{c}
0FL	2.45^{f}	2.31^{b}	0.59^{b}	1.52^{c}	2.21^{cdef}	1.95^{abcd}	4.33^{a}	1.33^{abc}	1.45^{cd}	1.21^{e}	1.88^{c}
0DF	2.45^{f}	2.02^{b}	0.52^{b}	1.47^{c}	2.02^{def}	1.85^{abcd}	4.28^{a}	1.11^{bc}	1.42^{cd}	1.50^{de}	1.83^{c}
0SV	2.57^{f}	2.16^{b}	0.69^{b}	1.73^{c}	1.81^{f}	1.69^{bcd}	4.61^{a}	1.35^{abc}	1.40^{cd}	1.38^{de}	1.97^{bc}
0GR	2.48^{ef}	2.11^{b}	0.57^{b}	1.42^{c}	2.14^{cdef}	2.04^{abcd}	4.26^{a}	1.31^{abc}	1.35^{cd}	1.52^{cde}	2.00^{bc}
0REF	2.36^{f}	2.16^{b}	0.52^{b}	1.42^{c}	2.16^{cdef}	1.90^{abcd}	4.45^{a}	1.04^{c}	1.40^{cd}	1.31^{e}	2.07^{bc}
0RF	2.40^{f}	1.90^{b}	0.54^{b}	1.57^{c}	1.88^{ef}	1.64^{cd}	4.57^{a}	1.11^{bc}	1.04^{d}	1.42^{de}	1.81^{c}

Appendix Table 5.1 (cont.)

	F_Alcohol	F_DarkF	F_RedF	F_DriedF	F_Conf	F_Jammy	F_Green	F_Chemical	F_Dairy	F_Earthy	F_Pepper	F_Floral	F_Spicy
9VN	2.23^{ab}	2.45^{bcd}	2.81^{fg}	1.73^{abc}	3.04^{bcd}	2.54^{abc}	0.85^{d}	1.54^{bcde}	1.50^{ab}	1.16^{de}	1.16^{abcd}	1.69^{cdef}	2.40^{ab}
9REF	1.97^{ab}	3.28^{a}	3.00^{efg}	2.21^{ab}	2.19^{ef}	2.33^{abc}	1.66^{abc}	1.57^{bcde}	0.35^{d}	1.85^{b}	1.54^{ab}	1.92^{cde}	2.14^{bc}
9WD	2.07^{ab}	2.61^{abcd}	2.64^{g}	2.33^{a}	2.38^{de}	2.14^{bc}	1.19^{cd}	2.54^{a}	1.04^{bc}	1.14^{def}	1.47^{ab}	1.42^{def}	2.92^{a}
9DF	1.97^{ab}	3.16^{ab}	3.50^{cde}	1.85^{abc}	2.90^{cde}	2.76^{ab}	1.33^{bcd}	1.90^{abcd}	0.49^{d}	1.26^{bcde}	1.07^{bcde}	1.88^{cdef}	2.09^{bc}
9GR	2.45^{a}	2.95^{abc}	2.50^{g}	1.92^{abc}	2.11^{ef}	2.28^{abc}	2.43^{a}	1.97^{abc}	0.54^{cd}	1.85^{b}	1.52^{ab}	2.14^{cde}	1.90^{bcd}
9SV	2.33^{ab}	3.31^{a}	2.38^{g}	2.07^{abc}	1.47^{f}	2.28^{abc}	2.00^{ab}	2.02^{abc}	0.42^{d}	2.50^{a}	1.69^{a}	1.14^{f}	2.38^{ab}
9RF	1.76^{b}	2.81^{abc}	3.95^{abcd}	1.78^{abc}	3.54^{abc}	2.97^{a}	1.31^{bcd}	2.23^{ab}	0.64^{cd}	0.88^{def}	0.88^{cdef}	2.19^{cd}	1.81^{bcde}
9FL	2.09^{ab}	2.92^{abc}	2.73^{fg}	1.97^{abc}	2.78^{cde}	2.00^{bc}	2.21^{a}	2.61^{a}	0.66^{cd}	1.47^{bcd}	1.26^{abc}	3.23^{b}	2.28^{ab}
0WD	0.57^{c}	2.28^{cd}	2.97^{efg}	1.90^{abc}	2.73^{cde}	2.33^{abc}	0.92^{d}	2.04^{abc}	1.45^{ab}	1.00^{def}	0.66^{defg}	1.69^{cdef}	2.16^{bc}
0VN	0.54^{c}	2.00^{d}	4.07^{abc}	1.76^{abc}	3.87^{ab}	2.66^{abc}	0.81^{d}	1.40^{bcde}	1.73^{a}	0.71^{ef}	0.31^{g}	2.00^{cde}	1.57^{cde}
0FL	0.57^{c}	2.61^{abcd}	3.50^{cde}	1.37^{c}	2.99^{cde}	1.95^{c}	2.09^{a}	1.83^{abcde}	0.64^{cd}	1.21^{cde}	0.47^{fg}	4.04^{a}	1.52^{cdef}
0DF	0.21^{c}	3.02^{abc}	4.38^{ab}	1.38^{c}	4.43^{a}	2.45^{abc}	0.73^{d}	1.00^{e}	0.63^{cd}	0.64^{ef}	0.26^{g}	2.40^{c}	1.13^{ef}
0SV	0.40^{c}	2.57^{abcd}	3.38^{def}	1.76^{abc}	2.28^{def}	2.35^{abc}	1.38^{bcd}	1.33^{cde}	0.45^{d}	1.83^{bc}	0.69^{defg}	1.66^{cdef}	1.23^{def}
0GR	0.33^{c}	2.57^{abcd}	3.76^{bcd}	1.42^{c}	2.83^{cde}	2.26^{abc}	2.33^{a}	1.57^{bcde}	0.38^{d}	1.04^{def}	0.52^{efg}	2.19^{cd}	1.16^{ef}
0REF	0.35^{c}	2.31^{cd}	3.76^{bcd}	1.54^{bc}	2.45^{de}	2.14^{bc}	1.21^{cd}	1.09^{de}	0.40^{d}	0.97^{def}	0.73^{cdefg}	1.40^{ef}	0.85^{f}
0RF	0.38^{c}	2.69^{abcd}	4.57^{a}	1.42^{c}	3.90^{a}	2.61^{abc}	0.74^{d}	1.09^{de}	0.23^{d}	0.52^{f}	0.35^{fg}	2.14^{cde}	0.85^{f}

Appendix Table 5.1 (cont.)

	F_Woody	F_Caramel	F_Coconut	F_Vanilla	AfTaste
9VN	2.35^{bc}	2.54^{a}	1.23^{b}	3.26^{a}	3.95^{a}
9REF	2.09^{bcd}	1.14^{bcd}	0.57^{d}	1.04^{c}	3.97^{a}
9WD	3.26^{a}	1.54^{bc}	4.16^{a}	2.38^{b}	4.14^{a}
9DF	1.69^{cde}	0.95^{cde}	0.47^{d}	1.21^{c}	4.11^{a}
9GR	1.97^{bcd}	0.78^{de}	0.38^{d}	0.81^{c}	3.95^{a}
9SV	2.26^{bc}	0.90^{cde}	0.64^{cd}	0.88^{c}	3.81^{ab}
9RF	1.40^{def}	0.76^{de}	0.54^{d}	1.26^{c}	3.83^{a}
9FL	1.88^{bcd}	0.97^{bcde}	0.54^{d}	0.76^{c}	3.90^{a}
0WD	2.54^{b}	1.61^{b}	4.09^{a}	2.42^{b}	3.26^{bc}
0VN	1.47^{def}	2.69^{a}	1.21^{bc}	2.90^{ab}	3.02^{cd}
0FL	0.95^{fg}	0.57^{de}	0.23^{d}	0.88^{c}	2.97^{cd}
0DF	1.00^{efg}	0.66^{de}	0.26^{d}	1.07^{c}	2.78^{cd}
0SV	1.50^{def}	0.47^{e}	0.47^{d}	0.73^{c}	2.47^{d}
0GR	0.95^{fg}	0.40^{e}	0.16^{d}	0.85^{c}	2.71^{cd}
0REF	1.16^{efg}	0.45^{e}	0.38^{d}	0.71^{c}	2.83^{cd}
0RF	0.54^{g}	0.45^{e}	0.28^{d}	0.66^{c}	2.83^{cd}

Wines sharing a letter are not significantly different (Fisher's LSD, $p<0.05$)

Appendix Table 5.2: Analysis of variance results for overall liking and Rate-All-That-Apply sensory attribute scores of flavoured wine samples assessed by the consumer panel

	OLiking	A_Alcohol	A_DarkF	A_RedF	A_Conf	A_Jammy	A_Green	A_Earthy	A_Spice	A_Woody	A_Caramel	A_Coconut
14WD	5.52^{abc}	2.91^{ab}	3.25^{ab}	2.39^{e}	2.13^{c}	2.45^{d}	1.91^{a}	2.15^{abc}	2.59^{ab}	2.83^{a}	1.88^{b}	2.09^{a}
14VN	5.20^{cd}	2.67^{bc}	2.94^{bcde}	2.91^{bc}	3.49^{b}	2.86^{bc}	1.29^{b}	1.53^{ef}	2.84^{a}	2.11^{de}	2.90^{a}	1.80^{ab}
14SV	5.93^{a}	3.20^{a}	3.42^{a}	2.58^{cde}	1.68^{d}	2.58^{cd}	1.83^{a}	2.29^{ab}	2.55^{ab}	2.64^{abc}	1.78^{b}	0.86^{c}
14RF	5.08^{cde}	2.67^{bc}	3.32^{a}	3.97^{a}	3.61^{b}	3.21^{ab}	1.43^{b}	1.40^{fg}	2.35^{bc}	1.83^{e}	1.87^{b}	0.88^{c}
14REF	5.68^{ab}	3.18^{a}	3.21^{abc}	2.50^{de}	1.77^{cd}	2.44^{d}	1.81^{a}	2.31^{a}	2.50^{abc}	2.74^{ab}	1.70^{bc}	0.82^{c}
9VN	4.98^{de}	2.36^{de}	2.87^{cde}	3.19^{b}	3.45^{b}	2.98^{ab}	1.43^{b}	1.19^{fg}	2.79^{a}	2.22^{d}	2.59^{a}	1.72^{b}
9WD	5.01^{de}	2.38^{cde}	2.65^{e}	2.62^{cde}	1.92^{cd}	2.25^{d}	1.91^{a}	1.95^{bcd}	2.41^{bc}	2.37^{bcd}	1.72^{bc}	1.96^{ab}
9SV	5.28^{bcd}	2.41^{cd}	2.84^{de}	2.85^{bcd}	1.92^{cd}	2.44^{d}	1.92^{a}	1.92^{cd}	2.19^{c}	2.35^{cd}	1.42^{cd}	1.01^{c}
9RF	4.70^{e}	2.09^{e}	3.16^{abcd}	4.29^{a}	3.99^{a}	3.23^{a}	1.43^{b}	1.08^{g}	2.18^{c}	1.23^{f}	1.85^{b}	1.07^{c}
9REF	5.01^{de}	2.51^{cd}	2.88^{cde}	2.92^{bc}	1.89^{cd}	2.41^{d}	1.81^{a}	1.78^{de}	2.39^{bc}	2.16^{de}	1.32^{d}	0.84^{c}

Appendix Table 5.2 (cont.)

	A_Vanilla	A_Savoury	T_Bitter	T_Sweet	T_Acidic
14WD	2.41^{c}	1.98^{b}	2.64^{ab}	2.59^{c}	3.33^{a}
14VN	4.03^{a}	1.36^{de}	2.30^{bc}	3.35^{b}	3.24^{ab}
14SV	1.57^{f}	2.43^{a}	2.59^{ab}	2.43^{c}	3.22^{ab}
14RF	2.09^{cd}	1.25^{e}	2.74^{a}	3.37^{b}	3.33^{a}
14REF	1.67^{ef}	2.10^{ab}	2.54^{ab}	2.49^{c}	3.17^{ab}
9VN	3.37^{b}	1.18^{ef}	1.72^{d}	3.51^{b}	2.97^{bc}
9WD	2.03^{de}	1.63^{cd}	1.88^{d}	2.72^{c}	3.23^{ab}
9SV	1.52^{f}	1.86^{bc}	1.83^{d}	2.76^{c}	3.18^{ab}
9RF	2.01^{de}	0.86^{f}	1.68^{d}	3.96^{a}	2.83^{c}
9REF	1.49^{f}	1.63^{cd}	2.00^{cd}	2.66^{c}	3.33^{a}

Appendix Table 5.2 (cont.)

	M_Body	M_Astring	M_Warm	M_Thick	M_M-voat	M_Complex
14WD	3.86^{a}	3.46^{a}	3.72^{a}	2.91^{ab}	2.87^{ab}	3.26^{ab}
14VN	3.80^{ab}	3.66^{a}	3.67^{a}	2.94^{ab}	2.98^{a}	3.24^{ab}
14SV	4.03^{a}	3.64^{a}	3.86^{a}	3.04^{a}	2.96^{ab}	3.41^{a}
14RF	3.59^{b}	3.50^{a}	3.65^{a}	2.73^{b}	2.79^{ab}	2.90^{cd}
14REF	3.79^{ab}	3.50^{a}	3.89^{a}	2.90^{ab}	2.68^{b}	3.03^{bc}
9VN	2.79^{c}	2.80^{b}	2.66^{b}	1.86^{c}	2.17^{c}	2.63^{de}
9WD	2.72^{c}	2.81^{b}	2.68^{b}	1.87^{c}	2.14^{c}	2.52^{e}
9SV	2.74^{c}	2.69^{b}	2.63^{b}	1.88^{c}	2.23^{c}	2.52^{e}
9RF	2.70^{c}	2.60^{b}	2.59^{b}	1.77^{c}	2.14^{c}	2.37^{e}
9REF	2.65^{c}	2.85^{b}	2.70^{b}	1.82^{c}	2.20^{c}	2.38^{e}

Appendix Table 5.2 (cont.)

	A_Alcohol	A_DarkF	A_RedF	A_Conf	A_Jammy	A_Green	A_Earthy	A_Spice	A_Woody	A_Caramel	A_Coconut	A_Vanilla	A_Savoury
14WD	3.45^{a}	3.43^{a}	2.61^{f}	1.86^{cd}	2.53^{cd}	1.91^{ab}	2.22^{a}	2.67^{ab}	3.04^{a}	1.76^{bc}	2.08^{a}	2.17^{c}	1.88^{b}
14VN	3.30^{a}	3.09^{bcd}	3.07^{c}	3.15^{b}	2.95^{ab}	1.45^{cd}	1.54^{cd}	2.85^{a}	2.09^{c}	2.60^{a}	1.49^{b}	3.56^{a}	1.38^{c}
14SV	3.56^{a}	3.41^{ab}	2.67^{def}	1.60^{d}	2.46^{d}	1.87^{ab}	1.98^{ab}	2.70^{ab}	2.59^{b}	1.55^{cd}	0.96^{c}	1.65^{def}	2.26^{a}
14RF	3.35^{a}	3.36^{ab}	3.70^{b}	3.08^{b}	3.05^{ab}	1.46^{cd}	1.53^{cd}	2.66^{ab}	1.96^{c}	1.88^{b}	1.02^{c}	1.96^{cd}	1.42^{c}
14REF	3.42^{a}	3.25^{abc}	2.62^{ef}	1.72^{cd}	2.35^{d}	1.98^{a}	2.21^{a}	2.59^{abc}	2.82^{ab}	1.50^{cde}	0.79^{c}	1.56^{efg}	1.94^{b}
9VN	2.40^{bc}	3.15^{abc}	3.49^{b}	3.28^{b}	2.80^{bc}	1.54^{cd}	1.32^{d}	2.69^{ab}	2.08^{c}	2.37^{a}	1.50^{b}	2.84^{b}	1.22^{cd}
9WD	2.36^{bc}	2.78^{de}	2.86^{cdef}	2.00^{c}	2.33^{d}	1.88^{ab}	1.68^{bc}	2.41^{bcd}	2.11^{c}	1.51^{cde}	1.76^{ab}	1.85^{cde}	1.34^{c}
9SV	2.53^{b}	2.72^{e}	2.94^{cde}	1.91^{cd}	2.30^{d}	1.62^{bcd}	1.54^{cd}	2.25^{cd}	1.97^{c}	1.41^{de}	0.84^{c}	1.42^{fg}	1.48^{c}
9RF	2.21^{c}	3.04^{cde}	4.37^{a}	3.98^{a}	3.25^{a}	1.33^{d}	1.00^{e}	2.15^{d}	1.26^{d}	1.64^{bcd}	1.05^{c}	2.00^{c}	0.98^{d}
9REF	2.55^{b}	2.73^{e}	2.96^{cd}	2.00^{c}	2.31^{d}	1.74^{abc}	1.55^{cd}	2.18^{d}	2.02^{c}	1.22^{e}	0.76^{c}	1.29^{g}	1.36^{c}

Appendix Table 5.2 (cont.)

	AT_Aftertaste
14WD	4.13[a]
14VN	4.04[a]
14SV	4.11[a]
14RF	3.98[a]
14REF	3.97[a]
9VN	3.42[b]
9WD	3.32[b]
9SV	3.22[b]
9RF	3.28[b]
9REF	3.15[b]

Wines sharing a letter are not significantly different (Fisher's LSD, $p<0.05$)

Chapter **6**

Conclusions & Future Perspectives

6.1 Conclusions

The main objectives of this research were to explore beer and wine consumer understanding of an ill-defined mouthfeel attribute – *body*, and to evaluate the impact of compositional factors contributing to consumer perception of body in beer and wine, using sensorial and analytical techniques. A literature review was undertaken in Chapter 1, which included an overview of oral physiology, leading into how the brain transforms sensory textural messages into conscious perception, providing examples of available studies on the perception of alcoholic beverages. Furthermore, the classification of mouthfeel, including body, from the perspective of experts in the fields of beer and wine was evaluated. The physicochemical and sensorial effects of key components, compositional factors and associated attributes, including ethanol, viscosity, phenolic compounds, astringency, polysaccharides and proteins on mouthfeel and body perception, were also discussed in detail, which highlighted the gaps arising from previous research.

It was evident from the existing literature on the evaluation and perception of body that prior research lacked robust qualitative sensory data regarding consumer language used when describing body. Additionally, no collection of quantitative sensory intensity or profiling data regarding body and mouthfeel from consumer evaluations of beers and wines with modified compositional factors had been performed. The lack of research concerning consumer perceptions of beer and wine with reduced alcohol content was also addressed by using commercial beers and wines as base beverages for the evaluation of body with consumers.

Research presented in Chapter 2 used a qualitative approach to gain insights into regular British beer and wine consumers' understanding of body and found body to be a holistic expression that constituted several modalities, including aroma, flavour, and mouthfeel. This research involved focus groups and employed the Free Choice Description technique to demonstrate that specific flavours and sensory characteristics are responsible for body perception for beer and wine consumers. Research findings showed that consumers perceive body as a combination of flavour (intensity, balance) and texture (perceived viscosity, smoothness). Furthermore, it was suggested that, despite being important for the initial evaluation of body, the aroma and appearance of a beer or wine might not play a key role in overall body perception for all consumers. Depending on consumer beliefs and potentially their beer- and wine-related knowledge level, the perception of quality varies in importance. This result identified a limitation associated with considering consumers as a homogenous group and a subsequent need to employ consumer segmentation and clustering in future work.

Therefore, research in Chapter 3 aimed to explore consumer perceptions of body further by manipulating the composition of a commercially available, de-alcoholised lager beer, using key compositional factors and attributes found important in Chapter 2. Firstly, ethanol (0.05% to 4.5% v/v) and carboxymethyl cellulose were used to increase the base ethanol level and enhance the instrumental viscosity of the model system, respectively. Furthermore, the flavour of the model system was altered via the addition of iso-α-acids (to increase bitterness) and hop oil extract, to perceivably change the aroma of the base beer to resemble a hoppy beer. Key findings confirmed that viscosity was not the only characteristic that influenced beer body. Each of the factors explored (the concentration of ethanol, CMC (viscosity), iso-α-acids (bitterness), and hop oil extract (hoppy aroma)) were all found to be important positive drivers of body perception. It was also found that ethanol was a positive driver for overall liking, whereas the addition of iso-α-acids or hop oil extract negatively affected hedonic responses. This investigation makes a major contribution to research on beer body perception by demonstrating that ethanol, viscosity, bitterness, and aroma can influence beer body ratings and suggest that factors besides ethanol can contribute significantly to body enhancement. Research findings add weight to the current understanding that beer body is not a one-dimensional characteristic of texture.

Furthermore, different clusters emerged based on consumers' body perception within the modified beer sample set. Combined with the focus group data, it was hypothesised that consumers might place differing levels of importance on different attributes when it comes to the perception of body. Cluster analysis revealed that consumers are not homogenous when assessing body. Three consumer clusters were identified when body responses were evaluated: (i) a Viscosity Driven cluster, who associated the perceived thickness of beer samples with the perception of body, suggesting that viscosity was important when assessing body intensity for this consumer cluster; (ii) a Flavour Driven cluster, for whom the addition of iso-α-acids and hop oil extract influenced the perception of body, and (iii) Alcohol Driven consumers, whose evaluation of body was influenced by adjustment to ethanol concentrations. It is evident from the findings of this study that whilst beers with higher alcohol and viscosity are perceived to have greater body, the focus is also shifted towards taste and flavour for some consumers. These results highlight the importance of consumer clustering regarding the evaluation of complex sensory attributes, which can be used to help beer and wine producers develop and market their products suitable for specific consumer clusters. Furthermore, a combinational approach targeting mouthfeel and flavour might be required when aiming to develop no- and low-alcohol beers with acceptable perceived body.

A model wine system was developed in Chapter 4, following a similar experimental design from Chapter 3, whereby commercially available de-alcoholised red wine was modified by the addition of: ethanol (0.05% to 5.5% v/v), CMC (to enhance instrumental viscosity), grape seed extract (GSE, to increase the perception of astringency) and natural flavour blend (to enhance red and dark berry aroma). Consumers assessed the wines for their perceived body intensity, liking and various sensory attributes using a Rate-All-That-Apply approach. Similarly to the model beer in Chapter 3, increasing the ethanol concentration of the de-alcoholised red wine model system positively influenced consumer hedonic responses and body ratings. GSE was not a significant factor for the wine samples' overall liking or body perception, suggesting that astringency at low alcohol levels does not contribute positively to body perception or indeed liking. The hedonic response was positively affected by the addition of CMC, yet wine body perception was not affected by this viscosity modification, which contradicts the majority of the literature describing body in wine as viscosity driven. In contrast with the beer model system, where the addition of CMC had a positive effect on consumer body perception, this finding indicated that in wine, the addition of CMC did not have a significant effect on body, despite evaluation of similar ethanol levels (0.05% to 4.5% v/v for beer and 0.05% to 5.5% v/v for wine). It is evident that learning from beer cannot be translated to wine, presumably due to their individual sensory characteristics. Moreover, CMC solubility might have been modified, due to differences in the composition of carbohydrates, organic acids, aldehydes, anthocyanins, phenolic compounds, inorganic anions, and metals between the two beverage systems, subsequently affecting perceived viscosity or modified flavour release as it reacted with different components.

Consumer clusters based on hedonic responses and body ratings were explored in Chapter 4; however, no identifiable patterns emerged. Consumer segmentation using the Fine Wine Instrument was also explored to investigate whether body perception was impacted by wine knowledge and level of involvement. Fine Wine Instrument used a multi-dimensional scale, incorporating different wine-related consumer behaviours based on attitudes, interests, and opinions, to measure consumers' level of involvement. Consumers who fell into less knowledgeable and involved segments defined wine body using flavour and texture attributes, while highly knowledgeable and involved consumers emphasised textural characteristics.

Aroma enhancement with a berry flavour blend negatively affected both hedonic responses and body intensity ratings. This suggests that some flavour profiles in wine might affect both body and liking in a negative manner, whereas in beer (Chapter 3), hoppy aroma profile negatively affected liking but positively affected body perception. To explore the potential for different flavours to contribute to body perception in wine, various flavour blends were added to different alcohol strength wines in Chapter 5.

Commercial no- (0.05% v/v), lower (9% v/v), and full-strength alcohol (14.5% v/v) base Shiraz wines were modified with food-grade, natural flavourings to enhance different varietal characters, including red fruit, dark fruit, floral, green, vanilla, woody and savoury. A panel of experienced tasters assessed the no- and lower alcohol flavour-enhanced wines, whilst a consumer panel assessed a subset of the lower alcohol wines and a similarly flavoured set of full-strength alcohol wines. Consumer responses indicated that full-strength alcohol wines with enhanced woody and savoury flavours were perceived to be higher in body. In contrast, the addition of the red fruit flavour negatively influenced the perception of body, confirming the ability to elicit opposing sensory response depending on the flavour profile.

The differences between experienced and naïve Australian consumers' cognitive understanding of body was explored qualitatively and showed similar results to the study reported in Chapter 2 and 4, where a homogenous group of consumers found it difficult to agree upon what body constitutes, which was attributed to knowledge levels in Chapter 4 using the Fine Wine Instrument. In Chapter 5, three distinct hedonic clusters were identified based on their acceptance of the flavoured wines. The so-named, Like All cluster scored the wines above 5, and the mean scores were not significantly different between the wines. A distinct cluster, the Complex Body Likers, perceived wines with enhanced savoury and woody flavours as positively driving liking and wines with enhanced red fruit flavour as negatively driving liking in both 14.5% and 9% ABV base wines. Low Alcohol Likers rated flavoured 9% ABV wines significantly higher in liking than 14.5% ABV wines, irrespective of flavour enhancement. Identifying a consumer cluster comprising consumers with a preference for lower alcohol wines is a novel finding, which provides an important insight for wine producers aiming to meet the needs and acceptance of lower alcohol products among different targeted consumers. These results confirm that consumers not only differ in their physiological perceptions (attributable to inter-individual variation) but also based on individual memories, knowledge, and overall involvement. Furthermore, these findings highlight the need for a diverse range of wines with different alcohol content within the wine sector to suit the expectations and preferences of different consumer clusters and knowledge segments.

6.2 Future Perspectives

Overall, the findings from this thesis revealed that the employment of qualitative techniques (Chapter 2) in consumer research is a powerful tool when exploring complex, multi-dimensional sensory attributes, such as body, and is necessary to provide compelling insights into consumer understanding and language use. Furthermore, it was demonstrated that compositional factors driving consumer body perception differed for beer (Chapter 3) and wine (Chapters 4 and 5); yet cognitively and perceptually, consumers demonstrated similar trends in their understanding and perception of body in beer and wine model systems. More importantly, the clustering techniques and segmentation tools employed in Chapters 3, 4 and 5 showed that consumer body perception varied for different groups of consumers. This was found, in some part, to be dependent on their preferences, beverage-related knowledge and involvement – explored using the Fine Wine Instrument, and liking, which is subjective and can be impacted by a variety of factors. As proposed in Chapter 2, consumers related body to abstract concepts, including a strong link between body perception and personal preference. For example, consumers who stated they preferred more flavoursome beers and wines were more inclined to associate body with flavour. Therefore, future research should explore the factors influencing beer and wine hedonic response and the subsequent effect on body perception. This thesis has offered robust insights into consumers' cognitive and perceptual understanding of an important mouthfeel attribute – body, and further research will benefit from exploring the following:

- The results presented in Chapter 2 explored consumer understanding of body from the UK and Australia. Exploring consumer definitions of desirable sensory attributes, specifically of existing no- and low-alcohol products, within new, growing and emerging markets will broaden the understanding of consumer demands from different geographical locations and contribute further to the cross-cultural element of this research. In turn, this will support the development of products providing the same sensory experience of traditional beers, wines, and other alcoholic beverages that are proposed to enter the low-alcohol product category.
- The findings obtained in Chapters 3, 4, and 5 explored compositional factors applied to specific beer and wine styles. Extending the generalisation of the findings to other traditional styles of beers, namely, wheat, ale, stout, porter, as well as craft beers with an emphasis on novel flavours and varied brewing techniques; and wines, including dry red, white, rosé wines, sparkling, sweet and dessert, fortified wines; as well as other

beverage markets, including ciders and distilled spirits, will promote further understanding by replicating the experimental designs in other beverage styles and beverages where alcohol reduction can be applied.

- When exploring factors that increase body perception, technical teams and beverage producers must be aware of this attributes' multifaceted nature and consider various combinational factors when addressing consumer body perception, as suggested in Chapter 2. Studies outlined in Chapters 3, 4 and 5 demonstrated how different compositional factors in model systems influence sensory characteristics attributed to body, measured with sensory techniques, allowing exploration of the changes from the consumer perspective. Further research could benefit from using analytical methods (GC-MS, HPLC, APCI-MS) to measure the impact of compositional factors, including important macromolecular fractions with molar masses up to 108g mol^{-1} that are classified into polysaccharides, proteins and protein–polyphenol complexes within real beer and wine systems, as well as other alcoholic beverages, on the resulting body to understand if brewing and winemaking techniques can be applied to modulate the attributes that consumers associate with body.
- The findings outlined in Chapters 2, 3, 4 and 5 also showed that certain flavours might be responsible for creating a fuller beverage profile, highlighting the importance of combining basic tastes with congruent aromas. Therefore, the impact of different flavour profiles on the perceived body must be explored. New product developers should also pay close attention to the fact that not all promote acceptability despite the explored compositional factors having a positive effect on body perception.
- Research in Chapters 3, 4 and 5 highlighted that beers and wines with reduced alcohol content are perceivably thin, watery, with weak aroma and short aftertaste, accentuating the negative impacts on flavour and mouthfeel, including body, in these commercially available products, to date. Currently, the production of non-alcoholic beers and wines limits the formation of higher alcohols and secondary metabolites (terpenes, C-3 norisoprenoids, C-6 alcohols), responsible for complete coherent flavours during the fermentation or alcohol removal process (Valera & Valera, 2019). As such, samples produced with different alcohol reducing techniques that increase the retention of volatile compounds and preserve the texture and taste of the beverages must be explored. In beer and wine, these techniques include reducing alcohol production during the fermentation stage, such as using non-*Saccharomyces cerevisiae* or modified

yeast strains, reducing the yeast population during fermentation, arresting/limiting fermentation, or using a combinational approach (Blanco et al., 2021; Canonico et al., 2021; Liu et al., 2022). Certain drawbacks, such as the behaviour of a given species, should be considered strain dependent, including the production of increased concentration of higher alcohols or glycerol, which impart a pungent aroma and higher perceivable sweetness, respectively. Future research should focus on the optimisation of fermentation conditions for each species/strain, and on the selection of appropriate *S. cerevisiae* strains to enhance their effect.

In wine, these also include viticultural techniques that limit alcohol production during the pre-fermentation stage: leaf area reduction, modified irrigation systems, application of growth regulators, and photosynthetic activity reduction (Novello & Laura, 2013). Moreover, pre-fermentation strategies such as harvest date management, dilution/blending of grape must, filtration of grape juice, and addition of enzymes such as glucose oxidase to remove grape must glucose before fermentation. Furthermore, the resulting body alteration must be measured qualitatively and quantitatively to accentuate consumer perceptions in conjunction with chemical composition variation in beverages with reduced alcohol content.

- Since it has been argued in Chapters 3, 4 and 5 that individual tastes, flavours and flavour intensities are amongst the defining factors of body for consumers, further investigation into consumer taste phenotypes, including PROP/PTC tasters and non-tasters, other genetic variations in TAS receptors, sweet-liking phenotype (Thibodeau, 2021), as well as considering genetic traits such as nerve development, tongue structures and individual taste sensitivities (Wooding et al., 2021) may uncover the justification behind individual body responses. This would be highly beneficial, informing the current understanding of individual differences in orosensation, resulting in essential insights for product development and marketing based on market segmentation, taste types and responsiveness.
- Results in Chapter 5 suggested that aromas and tastants might influence textural characteristics in lower alcohol wines. Further work into the multi-modal perception of body from the consumer perspective would be beneficial to understand which other modalities may be involved in increasing or decreasing body. Emerging research shows promising outcomes when exploring visual-texture and auditory-texture multi-modal combinations, which can help promote the body of de-alcoholised beverages.

- The cognitive and perceptual differences in body perception and evaluation, respectively, between experienced wine tasters and naïve consumers demonstrated in Chapter 5, call for an evaluation of mouthfeel in beverages before, during and after product tasting using neuroscientific methodologies, such as functional magnetic resonance imaging (fMRI) that may prove to be powerful tools for understanding the underlying neural circuitry associated with beverage consumption. The use of these techniques could provide insightful new knowledge into consumer brain dynamic processes, underscoring the complex nature of consumer odour and tastant processing evident during consumption, leading to a valuable and substantial contribution to the prediction of consumer behavioural responses to beverages with different alcohol levels and mouthfeel characteristics, focusing on the level of expertise and individual preferences.

6.3 References

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https://doi.org/10.1093/emph/eoab031

6.4 Relevant Conferences, Awards and Other Work

6.4.1 Conferences, Symposiums & Outreach

2018

- Ivanova N. (2018) Focusing on body: Mouthfeel concept in beer and wine products; Poster presentation, *5th International Conference on Food Oral Processing*, Nottingham, UK
- Ivanova N. (2018) Understanding body: Mouthfeel concept in beer and wine products; Oral presentation, *Food Science PhD Symposium*, University of Nottingham, Sutton Bonington Campus, UK
- Ivanova N. (2018) Focusing on body: Consumer understanding of the mouthfeel concept in beer and wine products; Oral presentation, *EuroSense - 8th European Conference on Sensory and Consumer Research*, Verona, Italy
- Ivanova N. (2018) Focusing on body: Consumer understanding of the mouthfeel concept in beer and wine products; Oral presentation, *6th Nursten Postgraduate Flavour Symposium*, University of Nottingham, Sutton Bonington Campus, UK
- Ivanova N. (2018) Focusing on body: Consumer understanding of the mouthfeel concept in beer and wine products; Oral presentation, *Nottingham-Adelaide Postgraduate Symposium*, University of Nottingham Malaysia Campus, Malaysia
- Ivanova N. (2018) Focusing on body: Consumer understanding of the mouthfeel concept in beer and wine products; Oral presentation, *Exploring the Chemistry of Beer*, Canalhouse, Nottingham, UK

2019

- Ivanova N. (2019) Improving body in low-alcohol beer: The effects of ethanol, bitterness, viscosity and aroma on consumer perceptions of body in beer; Poster presentation, *Postgraduate Symposium*, University of Nottingham, Sutton Bonington Campus, UK
- Ivanova N. (2019) Improving body in low-alcohol beer: The effects of ethanol, bitterness, viscosity and aroma on consumer perceptions of body in beer; Oral

presentation, *7th Nursten Postgraduate Flavour Symposium*, University of Reading, UK

- Ivanova N. (2019) Improving body in low-alcohol beer: The effects of ethanol, bitterness, viscosity and aroma on consumer perceptions of body in beer; Poster presentation, *13th Pangborn Sensory Science Symposium*, Edinburgh, UK
- Ivanova N. (2019) Improving body in low-alcohol beer: The effects of ethanol, bitterness, viscosity and aroma on consumer perceptions of body in beer; Oral presentation, *School of Agriculture, Food and Wine Postgraduate Symposium*, University of Adelaide, SA

2021

- Ivanova N. (2021) Focusing on body: Consumer understanding of the mouthfeel concept in beer and wine products; Oral presentation, *CRUSH – Grape and Wine Sciences Symposium*, National Wine Centre, Adelaide, SA
- Ivanova N. (2021) Effects of ethanol, viscosity, tannin and flavour enhancement on sensory properties and consumer perception of body in commercial low-alcohol red wine; Oral presentation, *SenseAsia – the 4th Asian Sensory and Consumer Research Symposium*, Online

2022

- Ivanova N. (2022) Effects of compositional factors on consumer perception of body in commercial low-alcohol red wine; Poster Presentation, *18th Australian Wine Industry, Technical Conference & Trade Exhibition*, Adelaide, SA

6.4.2 Awards & Grants

- Awarded Brewing Research Education Fund (BREF, UK) Grant – operations and consumables (2017)
- Awarded 1st Gold Prize at the 1st Year PhD Symposium Conference, Oral presentation, University of Nottingham, Sutton Bonington Campus, UK (2017)
- Awarded ‘Highly commended presentation’ at the 6th Nursten Postgraduate Flavour Symposium, University of Nottingham, Sutton Bonington Campus, UK (2018)

- Awarded ARC Training Centre for Innovative Wine Production Prize at the School of Agriculture, Food and Wine Postgraduate Symposium, Oral presentation, University of Adelaide, Waite Campus, SA (2019)
- Awarded Wine Australia Scholarship – operations, consumables, stipend (2019)
- Awarded Wine Australia Travel Grant (2020)
- Awarded Turing Grant through Turing Mobility Funding Scheme (2022)

6.4.3 Publications and Other Work

Ivanova N., Yang Q., Bastian S. E. P., Wilkinson K. L., Ford R. (2021). Consumer understanding of beer and wine body: an exploratory study of an ill-defined concept. *Food Quality and Preference*, 98, 104383.
DOI: https://doi.org/10.1016/j.foodqual.2021.104383

Stewart, S., Sanders, R., **Ivanova, N.**, Wilkinson, K. L., Stewart, D. C., Dong, J., Hu, S., Evans, D. E., Able, J.A. (2022). The influence of malt variety and origin on wort flavour. *Journal of the American Society of Brewing Chemists*, 1-17.
DOI: https://doi.org/10.1080/03610470.2022.2041156

In extension to the original research plan and as a fall-back strategic response to circumvent being unable to conduct human research due to the global pandemic in 2020, an additional study was designed and cross-cultural surveys developed and administered in four countries were completed by 5,528 beer and wine consumers. These surveys aimed to examine consumer perceptions of body in beer and wine measured qualitatively and quantitatively across established (UK, Australia), emerging (China) and new-emerging (India) markets to explore cultural differences (subsequently not included in the thesis due to time constraints).