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The Use of Augmented Reality on Sensory Evaluation of Liked or Disliked Products

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A Dissertation

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Yanyu Dong

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Abstract of a Dissertation submitted in partial fulfilment of the requirements for the Degree of Master of Science in Food Innovation.

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by

Yanyu Dong

Augmented reality (AR) applications in the food industry, are considered innovative to enrich the interactions between consumers and food products, especially for benefitting online retailers. Otherwise, the boosting market of dairy-free foods, alternative proteins and upcycled foods are driven by consumers' pursuit of healthy and functional foods, vegetarian diets and environment sustainability. This study combined and applied these recent food trends in the sensory evaluation of food products. AR HoloLens two headsets were used to set up two product's AR environments: (1) AR coconut view (ARC), and (2) AR dairy view (ARD). Three products were testes: (1) a dairy-free yoghurt based on a vanilla bean-flavoured coconut milk-based yoghurt (coconut yoghurt), and (2) a dairy yoghurt based on a vanilla bean-flavoured cow milk-based yoghurt (dairy-yoghurt), and (3) a transitional yoghurt named "mixed yoghurt" (made by half coconut yoghurt and half dairy yoghurt) to avoid appearance bias. The study aimed to investigate the hedonic ratings, just-about-right (JAR) ratings, check-all-that-apply (CATA) attribute terms, emotional response, purchase intent and consumer shopping behaviours of these three yoghurts (coconut yoghurt, dairy yoghurt and mixed yoghurt) under ARC, ARD and sensory booths (SB) using a 3 x 3 factorial design. The results showed that the liking scores of dairy yoghurt and mixed yoghurt were generally higher than coconut yoghurt regardless of the environments. The interaction effect of yoghurts and environments were statistically significant in terms of appearance, taste/flavour, sweetness, mouthfeel, aftertaste and overall liking. Moreover, AR contextual environments potentially improve the liking scores of the evaluated yoghurt samples. JAR and penalty analysis revealed that most of the consumers rated the sourness, sweetness, and mouthfeel of the dairy and mixed yoghurt to be just-about-right. At the same time, consumers penalized the coconut yoghurt for being "too much" in sourness, "too little" in sweetness, and "too thin" in mouthfeel. For the CATA analysis, attribute terms positively associated with overall liking (such as "sweet", "smooth" and "creamy"), which were selected for coconut yoghurt and dairy yoghurt;

whereas, the attribute terms against overall liking (such as “firm”, “heavy” and “astringent”) were selected for coconut yoghurt. No effects of environments on emotional responses were found among yoghurt types. Regarding purchase intent and the investigations of yoghurt consumption behaviour, the purchase intent of dairy yoghurt and mixed yoghurt were higher than coconut yoghurt, and “taste” and “health” were considered to be the most critical reasons for yoghurt consumption. The use of augmented reality in the sensory evaluation could affect the discrimination of food products. For instance, the significant difference of liking scores between mixed yoghurt and coconut yoghurt was found under SB, but the difference was not significant under ARC. Whether ecological validity could be improved by augmented reality in sensory studies will be investigated in further study.

Keywords: Augmented reality, non-dairy yoghurt, contexts, consumer acceptability, emotional responses.

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Literature Review

1.1 Context in sensory evaluation

1.1.1 Consumer acceptability

Consumer acceptability test belongs to one of the most important sensory analysis, which is commonly used to access the degrees of liking and preference of products by untrained participants using a scaling method (Lawless & Heymann, 2010). Consumer acceptability test gives the essential outcome of the consumer's feedback on the products and enables to build the bridge between customers and manufacturers. The accurate and reliable hedonic results provided by consumer studies help producers to improve and reformulate food recipes (Reis et al., 2017).

Consumer acceptability has been conducted on numerous food products across categories. Traditional commercial food products, like meat (Resurreccion, 2004), bakery (Stantiall & Serventi, 2018), beverage (Lesschaeve & Noble, 2005), and dairy food (Clark et al., 2009), used to be the mainstream in the consumer studies. Consumers tests have also been used for evaluating innovative trends in the food industry, such as plant-based (Fiorentini et al., 2020), fermented (Tangyu et al., 2019), functional (Genevois et al., 2018), upcycled (Grasso & Asioli, 2020), alternative proteins (Karmaus & Jones, 2020) and dairy-free foods (He & Hekmat, 2015), which largely results from the consumers' pursuit of healthy foods, ethical issues and awareness of the environment.

The common methods used in consumer studies include the hedonic scale, just-about-right (JAR) scale, and check-all-that-apply (CATA) method. The 9-points hedonic scale is the most applied scale to assess sensory acceptance, ranging from the dislike extremely (1) to liked extremely (9), where participants evaluate the specific sensory attribute of the products and reflect how much they like or dislike the samples (Lawless & Heymann, 2010). Hedonic scales could evaluate food properties in terms of flavour, texture, appearance, aroma, mouthfeel, aftertaste and overall liking. Other sensory scales, such as the just-about-right (JAR) scale, could measure the sensory attribute's intensities based on consumers' ideal perception, with characteristics like saltiness, sweetness, and sourness, combined with overall liking score to figure out what factors make consumers like or dislike the food. The typical JAR scales consist of verbal, box and line scales, from 3 points to 9 points. For instance, the 3-point line-scale refers to "too little", "just about right" and "too much" for a given attribute (Lawless & Heymann, 2010). The check-all-that-apply (CATA) question is a collection of word items, which either come from previous literature or generated by a trained focus group. Participants were asked to choose the

descriptive items which they think related to the sample. CATA question is considered to be an easy task to complete by consumers (Ares et al., 2011). However, the bias caused by different scaling methods should be noticed before using these methods in sensory studies. Ares et al. (2013) study suggested that the length and the structure of the CATA question could lead to minor bias and affect the conclusion regarding the sample differences. López Osornio and Hough (2010) compared optimum concentration levels on orange juices between 3-point JAR scale and 9-point JAR scale, which revealed that both JAR ratings caused centring bias and the Halo/Horn effect while the 3-point scale was more straightforward and reliable compared to the 9-point scale. All of these sensory methods and techniques are useful to evaluate the novel foods and ingredients in the food industry.

1.1.2 Factors influencing sensory evaluation

Sensory acceptance is highly variable and dynamic among different populations or for the same person in different periods, emotions (Schouteten et al., 2017) and contexts (Jaeger & Porcherot, 2017). Consumer liking of the product could be influenced by food-related factors, person-related factors and context-related factors.

Food-related factors can refer to intrinsic and extrinsic characteristics. For example, colour, aroma, texture and flavour are considered to be the intrinsic characteristics while the extrinsic properties include price, packaging, familiarity and origin (Enneking et al., 2007). The taste or flavour of foods is widely assumed to affect consumers' decision-making and choice (Lawless & Heymann, 2010). For instance, texture characteristics are the key sensory properties that affect yoghurt products' consumer acceptability (Janiaski et al., 2016). Brand loyal consumers gave higher hedonic ratings to their preferred brands in an informed test compared to in a blind test setup (Moreira et al., 2017). Moreover, brand information largely determines the consumer’s liking and purchase intent (Enneking et al., 2007).

Person-related factors refer to human emotions and perception, knowledge, expectation, attitude, education, food habits, ethic and individual psychological and physical conditions (Font-i-Furnols & Guerrero, 2014; Maina, 2018; Saba et al., 1998; Samant et al., 2017). The liking of traditional popular food types, such as ice cream, chocolate and alcohol, decreases among some consumers who expected more healthy food products (Maina, 2018). Consumers who like to challenge and try out new things are used to give positive responses to the acceptance of new food product (Simons & Hall III, 2018).

Context-related factors are linked to the serving environment, such as ambient conditions (e.g. vision, olfaction, temperature, humidity, light), music, serving time, decoration, location, restaurants and social interaction (Hersleth et al., 2005; Piqueras-Fiszman & Jaeger, 2014; Quartier et al., 2014). For example, the recent study investigated consumers’ liking of alcohol-free beers using an immersive

multisensory room to create a “night club” environment and a “beach” environment, which found that consumers had a higher interaction with the nightclub context. Younger participants gave higher hedonic scores of products in the nightclub context than in beach context (Delarue et al., 2019). Overall, the intrinsic and extrinsic of products and contexts could affect hedonic ratings and consumer consumption behaviour.

1.1.3 Context effects and biases in human judgment

Context effect means that the judgment of the product could shift depending on different contextual conditions. Biases refer to the inaccurate responses in judgment caused by the contextual changes (Lawless & Heymann, 2010). In the sensory evaluation test, a frame of reference to make the judgment of the product is usually used. For example, participants may found it difficult to estimate the exact sugar content of given juices, but it is easier for them to judge the sweetness according to a given reference. In other words, they evaluate the sweetness of juice samples depending on the previous sensory judgment of the reference. However, people can see things differently, even using the same physical stimulus or the same framework. The visual afterimage effect is a good example of it. Otherwise, the sample's judgment could be influenced by nearby items in time or space (Lawless & Heymann, 2010). The stimulus can be perceived as more intense in the presence of a weaker stimulus and vice versa. People think the red colour is redder compared to the black colour rather than the pink colour, which is called the colour contrast effect. Similarly, quinine with added sugar is more bitter than tasted it alone. The sequence of samples also influences human judgment, which is confirmed by (Font-i-Furnols & Guerrero, 2014). Context effects include contrast effects (adaptation level, intensity shift, hedonic shift and quality shift), range and frequency effects, dumpling effect and the centring effects (Lawless & Heymann, 2010). Overall, the context effects could not be avoided and exist in all scaling methods, but the sensory test goal is to minimize the biases properly and try to get the accurate result as much as possible.

1.1.4 Context in sensory evaluation

Consumer tests in sensory evaluation play an important role in building the bridge between consumers and food manufactures. The higher hedonic ratings of the evaluated food may predict the potential higher popularity in the market. The traditional highly controlled sensory booth has its advantages in terms of highly-repeatability, easily-implemented, time-saving and reliable data. However, failed marketing examples still exist even though the food products had already high liking scores in the consumer tests. After rethinking about the sensory evaluation, scientists raised the concept of ecological validity (Stelick & Dando, 2018). The general-used highly controlled hedonic tests, such as sensory booth tests or central location tests, lack ecological validity, which may not reflect the real consumption contexts. Alternatively, field tests and home-use tests have more ecological validity, but

the drawbacks of these tests are the low repeatability and the possible uncontrollable conditions of the test, which may result in establishing wrong relations and lead to unreliable conclusions. However, the precise and easily implementable lab tests remain the popular way of evaluating sensory acceptance of food products. The study Schouteten et al. (2017) tested consumer liking and emotion of yoghurts (with/without brand information) in home-use location and the central location (lab). Although emotion profiling was different between lab tests and home-use test, no difference was observed in sensory properties. Brand information affected some specific sensory properties but less influence on overall liking and emotion. The study suggested that sensory booth could give more accurate results than a home-use test (Schouteten et al., 2017).

To improve ecological validity as well as maintain the precise result, efforts have been made to bring real-time consumption contexts to the lab tests. One method is to evoke consumption situations using scenario-based cues, which primarily depends on memory and imagination. The research of hedonic ratings on evaluating blackcurrant juices used three written scenarios (having breakfast, watching movies and drinking some beverages to refresh) to instruct consumers to imagine consumption contexts. The hedonic ratings were significantly different between evoked contexts and no-evoked context, which suggested that consumer acceptance was affected by the product and the type of evoked context (Hein et al., 2012).

Another method is to add contextual information to the central location (e.g. sensory booth, café shops, restaurants) by using multiply techniques, furniture, facilities to imitate a real-time consumption environment. A total of 45 participants joined the study conducted by Zandstra et al. (2020), which set up three contextual scenarios in terms of one control (in the lab), an immersive café environment (using audio and visual cues) and the real café shop. Participants were asked to evaluate four tomato soups in each setting randomly. Although the results of liking scores and JAR ratings on sensory properties showed no significant difference among the three contextual settings, consumers felt more engaged in the café shop and immersive café than in the laboratory. However, playing with physical means can only create one specific context, whereas a given food could be served in various contexts. The implementation of this immersive physical method is not flexible. On the contrary, advanced digital technologies, like virtual reality (VR) and augmented reality (AR), could concurrently evaluate samples in different contexts or quickly switch from one environment to another (Jaeger et al., 2017). The new generation VR/AR technologies are more mature, and the headsets are affordable to most research groups. The combination of AR technologies with pictures, videos, auditory and other sensory stimuli could create different contexts, which contributes to the sensory studies (Crofton et al., 2019).

1.2 The use of augmented reality in sensory evaluation

1.2.1 What is augmented reality?

Augmented Reality (AR) is one of the immersive technologies, which overlays computer-generated virtual information (currently mostly vision, hearing and touching) in the real world (Chylinski et al., 2020). Unlike Virtual Reality (VR) which creates a total 3D immersive world to substitute the real environment, AR technology aims to seamlessly blend interactive digital content into a person's view of the physical environment. AR technologies enable to provide contextual information to enhance the interactive experience in terms of appearance, usability, and enjoyment (Li & Fang, 2020). AR can bridge this gap between consumer, product and product content (Kim & Dey, 2016).

The quality of the VR/AR experience is correlated with the high resolution of display with the extensive degree of view field, the freedom of manipulating the virtual objects and interact with simulations, the individual physical adaption capable of virtual environments (Flavián et al., 2019). A recent study used a computer-based HMD (Head Mounted Device) system with a GoPro helmet to create two mixed reality environments to investigate the older adults' liking on the eating environment. However, the stimulation system's low quality made the participants criticized the unrealistic colour scheme and cleanliness of the presented mixed reality environment (Korsgaard et al., 2019).

Otherwise, the high price of immersive headsets and the inconvenience of carry-around challenged the commercialization of AR. Along with the development of AR technology and the continuous launching of affordable headsets, more sophisticated levels of information could be delivered in a relatively convenient way, which reattracted industries and the public's attention and interests. Advancements in smartphone technologies have opened a new era, which enables consumers to easily access virtual worlds in daily life by simply scanning quick-response codes besides products (Flavián et al., 2019; Wedel et al., 2020).

1.2.2 The market of augmented reality

The world retail market is moving to online business, which is an unavoidable tendency. However, consumers are unable to imagine the real quality or the user experience of products and services. Mental intangibility remains one major problem for online sales. The good news is the problem could be improved by using AR technologies. The study reported the effect of HoloLens headset on creating contexts of online retailing, which showed positive feedback on reducing mental intangibility and increasing the feeling of decision comfort (Heller et al., 2019).

Researches and applications for VR and AR have been showing rapid progress across a number of industries, such as automotive, healthcare, manufacture, education, tourism, online shopping, and

entertainment. Products and retail locations may still be static, but its content must extend beyond the physical space to attract the attention of potential and returning buyers. Companies can use AR technologies to educate consumers on nutritional information and product composition or even make healthy, but bland-looking foods appear more appealing (Chylinski et al., 2020). AR ads on websites or mobile allow consumers to virtually try on the products (jewellery, makeup, sunglasses) before buying. Besides, consumers can use AR mobile applications to add the real-sized furniture in their home or explore the AR menu to know the real dishes before ordering.

1.2.3 Recent researches on immersive technologies in the food industry

Consumer engagement in the sensory evaluation could be enhanced by VR and AR technologies, which simulate environments similar to the "real world" (Flavián et al., 2019). The relatively controllable environments created by VR and AR are easy to replicate under experimental conditions. Sensory perception of food products results from multisensory integration of visual, olfactory, auditory, gustatory and tactile stimuli. To date, the majority of sensory studies using VR/AR have involved the stimulation of one or two sensory modalities at a given time, typically vision and audition, and less haptics (Crofton et al., 2019).

Gutiérrez et al. (2019) with their team designed the application, named Personal Health Augmented Reality Assistant (PHARA), which could be deployed in the Microsoft HoloLens and used to support decision-making about the products. When consumers put on the headset, they can use PHARA to scan the interesting food product. The product's information could pump up like different cards in terms of nutrition levels, calorie breakdown, calorie intake, nutrition guide, and healthy alternative. Consumers read the 3D hologram cards to make the best choice of foods. Kim and Dey (2016) reported that AR technology improved people’s ability to perceive information by augmenting senses in terms of visual, auditory and haptic experiences. However, overloading the sensory innervation could affect cognitive capabilities and cause sensory fatigue, especially for elderly populations.

A study conducted by Liu et al. (2019) investigated the use of immersive technologies to explore the effect of different contextual cues (visual, auditory and olfactory) on consumers recall memory, coffee preference and liking during sensory evaluation testing. In the study, six congruent and incongruent context conditions were designed, and the real coffee shop environment was used as the control group. Each participant was randomly exposed to the six contextual settings and evaluated three different brand coffees in each environment. The finding showed that participants preferred to depend on visual or auditory information rather than olfactory information to recall product details in the immersive environment. Interestingly, although the overall liking score was lower in the immersive conditions compared to the real coffee shop (control group), the difference was not significant.

Torrico et al. (2020) investigated the effects of the traditional booth, real restaurants (bright- or dark-rooms) and VR environments (bright- or dark-rooms) on the wine tasting experience, acceptability, and emotional responses of consumers. It was found that the emotional responses under dark-VR were different compared with under traditional booths. Kong et al. (2020) studied three contextual environments (traditional sensory booth and two VR-based immersive environments) on chocolate products' sensory perception. During the test, VR headsets created two 360-degree video environments ("a pleasant sightseeing tour and "a live music concert"). The results showed that participants tended to show positive emotions in both VR environments than traditional sensory booths. However, although VR technology can provide a full immersive experience when serving food, one of the drawbacks is not showing the product. This cannot allow participant to assess the appearance of the product. In contrast, AR is an approach that can include the observation of the sample in a simulated context.

1.3 Non-dairy yoghurt

1.3.1 The market of non-dairy foods

The increasing market of plant-based foods is driven by the needs of special populations who avoid the consumption of cow milk foods (Mäkinen et al., 2016). The reasons are various, including allergy to cow milk proteins, lactose intolerance, cholesterol issues, loving animals, environmental sustainability and a vegan or vegetarian diet (Karmaus & Jones, 2020; Mäkinen et al., 2016; Panghal et al., 2018). Lactose intolerance is a prevalent phenomenon among Asian populations, nearly 100% (Mäkinen et al., 2016; Sahi, 1994). This could be a reason to explain why soy milk-based products emerged in ancient China and still popular in Asian countries.

Soy products in terms of soy milk, tofu, are traditional foods of origins in Asian countries, which have been widely accepted by consumers (e.g. vegetarians) in western countries who avoid eating meat or dairy food for ethical or health reasons (Kundu et al., 2018). Moreover, public awareness of environmental-friendly and upcycled foods also influence the consumers' purchase behaviours (Grasso & Asioli, 2020).

The common plant-based milk and their foods in the market include soybean milk, almond milk, coconut milk, rice milk, coca milk and oat milk. They all have advantages and disadvantages. For example, soybean milk and soy milk-based foods took up approximately 58% market share in 2017 due to their various food products and high nutrition values. Soy milk contains nearly 3.6 g / 100g proteins, which is comparable to cow milk (Krans, 2017). However, people may be bored with soy and soy foods and expect more new plant milk products. Almond milk and almond foods have a good reputation as one of the "brain-foods", which promotes concentration, memory and good sleep. But consumers

complained about the taste of the almonds foods and described as watery and less creamy. A study from Kundu et al. (2018) compared cow milk's sensory properties, almond milk, soy milk, and mixed soy and almond milk, which reported that soy milk was the most popular product, cow milk gained second place, and almond milk was the last one. Coconut milk is used world widely for cooking dishes, confectioneries, beverage, bakery products, ice creams, biscuits, yoghurt, and others. Unlike other non-dairy beverage, coconut milk contains high fat, high fibre, moderate minerals and vitamins, and low proteins. Coconut milk is not a good alternative source of dairy proteins, but it is a good substrate to make yoghurt. Fat and proteins act as natural emulsifiers to make the coconut yoghurt good textural and stable (Patil & Benjakul, 2018).

Flavour and taste have a key impact on food selection. However, the natural flavour and fibres of plant-based milk negatively influence the product's sensory properties. For example, the oxidation of lipids could produce the violate compounds, which result in the off-flavour taste; phenols (e.g. tannins and saponins) and flavonoids are responsible for the bitter or astringent tastes (Drewnowski & Gomez-Carneros, 2000). In this regard, sensory acceptance of plant-based milk products are obstacles to the western market. Fortunately, fermentation, an old existing method, enables improving sensory, nutritional properties and extending foods' shelf life. It can reduce the level of anti-nutrients and enhance mineral extractability in plant-based food (Tangyu et al., 2019). It also helps to increase the bioavailability of photochemical compounds as the lactic acid bacteria could break down the complex proteins to peptides or amino acids (Sanjukta et al., 2015).

1.3.2 The role of sensory evaluation in non-dairy yoghurt

Yoghurt is the most popular fermented food around the world and almost welcomed by all generations. It has been considered as the dominant food type for carrying mass live probiotics (Capela et al., 2006). Yoghurt selling accounted for approximately 80% of the global probiotic business (Bis-Souza et al., 2019). From the health point, the regular consumption of yoghurt contains several therapeutic benefits, such as enhancing the immune system, controlling intestinal infection, reducing lactose intolerance, lowering serum cholesterol levels, maintaining internal pH balance and increasing anticarcinogenic activity (Bonifait et al., 2009; Lourens-Hattingh & Viljoen, 2001; Rivera-Espinoza & Gallardo-Navarro, 2010).

Sensory acceptance test enables to assess the main properties of products that drive the consumer liking (Lawless & Heymann, 2010). The role of some sensory properties may be more important than others for forming positive expectations during consumption. For yoghurt products, taste and texture were considered the major driver of the preference and yoghurt purchase intent. Janiaski et al. (2016) compared different strawberry flavoured yoghurts with various fat contents on hedonic ratings. They reported that consumers preferred the low-fat yoghurt than the non-fat yoghurt, suggesting that the

viscosity and smoothness of mouthcoating were the key sensory properties to affect yoghurt's consumer acceptability. However, there are lack of studies to compare the alternative yoghurt with the traditional yoghurt only based on sensory attributes. Moreover, the effects of different environments on the liking scores of non-dairy yoghurt have not been fully explored. Therefore, the integration of sensory evaluation data, advanced instrumental measurements and different contexts could provide a comprehensive evaluation of the yoghurt products, which drive successful marketing.

Chapter 2

Introduction

Efforts of sensory science have helped understand how food products' sensory attributes drive consumers' liking and decision-making. Consumer tests play a vital role in sensory science. Unlike the descriptive tests that focus on profiling the sensory characterization of products, consumer tests analyse products' liking and preference using a scaling method (Lawless & Heymann, 2010). Untrained participants are welcomed to join the consumer tests. Consumer studies have been conducted in various research directions in terms of consumer acceptability, emotional responses, purchase intent, perception and ethical studies. The direct market feedback help producers to economically reformulate their products for improving the hedonic scores. Successful food products are based on consistency with consumer expectations and liking (Maina, 2018). Different foods have the different main attributes determining consumer acceptability of the products. For instance, a sensory study aimed to investigate the attributes for meat-lover to refuse alternative protein-based meat, which illustrated that flavour and texture were the main reasons to affect consumer acceptability (Resurreccion, 2004). Although meat-lover recognized the health issues of the overconsumption of meat, most of them still refused to accept the plant-based meat because of lacking meat flavour (Font-i-Furnols & Guerrero, 2014; Resurreccion, 2004).

Human perception and judgment of the food are highly variable and individually dependent (Lawless & Heymann, 2010). The person could make the different judgments of the same food depending upon time, location, emotion and social interaction. Different populations may possess contrast judgment about the same food. Sensory perception could be influenced by the intrinsic and extrinsic attributes of the products, contextual factors, experience, beliefs, food habits, emotions, well-being, and expectations. It is widely believed that contextual factors, such as serving locations, music and environmental conditions (normally lighting, humidity and temperature), can shape consumers' emotional and hedonic responses when serving foods. Undoubtedly, sensory data possess high value for evaluating new products or improving the quality of original products. However, with the emergence of some past failed cases (Liu et al., 2019) of products in the marketplace, there has been some evidence that something may be missing in the traditional sensory tests.

For every well-designed scientific research, controlling variables in the experiment is essential to acquire precise and accurate data. The traditional sensory evaluation is highly controlled using isolated sensory booths with constant temperature, light and humidity, which aims to minimize or eliminate the external influence (such as odours and noises) on sensory perception (Stelick & Dando, 2018). However, the obvious disadvantage of a highly controlled sensory booth is the lack of ecological validity

(Stelick & Dando, 2018). The real-time tasting experience is more complex and variable than in the sensory booth. Environmental factors influence one's perception of foods, even if the influence is subtle. The impact of contextual information on sensory perception and acceptance should not be neglect (Jaeger & Porcherot, 2017).

To overcome the disadvantages of using immersive rooms or fields / home-use locations to increase engagement, advanced immersive technologies, such as Virtual Reality (VR) and Augmented Reality (AR), bring more sensory studies possibilities. It enables to build the different contexts quickly, and shift from one context to another context immediately. The effect of immersive technologies on improving ecology validity and engagement has been proved by previous studies (Kong et al., 2020; Sinesio et al., 2019; Zandstra et al., 2020). Sinesio et al. (2019) reported that similar results of emotions and hedonic scores were acquired in real-life environments, immersive room and virtual reality conditions (Sinesio et al., 2019). The delivery of AR experience could be achieved by using AR HMD devices (e.g. the head-mounted display headsets) and mobile phones capable of controlling users' visual and auditory experiences (Wedel et al., 2020). AR menus have been used in some restaurants to make the consumers see the real-size 3D model of the dishes which they would like to order (Das et al., 2015). Recent interests of sensory AR systems mostly focus on engaging human-computer interaction or enrich intuitions by facilitating engagement with multisensory information from both the physical space and virtual information space (Crofton et al., 2019). Therefore, more vivid and realistic contexts could be created by immersive technologies in sensory studies. Moreover, AR could increase interactivity to food products, such as modifying food texture or colour (Ammann et al., 2020) and add digital nutrition information (Gutiérrez et al., 2019). Complicated global food competition demands high-quality products. If VR/AR technology could be appropriately used to enhance interaction and engagement during sensory evaluation tests, the more reliable consumption contextual data would be obtained.

Plant-based proteins have become an important direction of functional foods when the major public health issues, like obesity, heart and cardiovascular disease, have been disclosed to correlated with overconsumption of meat or dairy foods (Panghal et al., 2018). Moreover, non-dairy foods are considered to be good alternatives for consumers who are allergic to milk proteins or have lactose intolerance (Gupta & Abu-Ghannam, 2012). However, the sensory characteristics of non-dairy yoghurt may be the main obstacle to the consumer's liking and preference for plant-based foods. In this regard, yoghurt has a good reputation for its desirable taste and healthy benefits (probiotics). Moreover, the fermentation process could add more nutrition values, such as minerals, phytochemicals and vitamins (Tangyu et al., 2019). In comparison with other plant-based foods, plant-based yoghurts have the higher potential to be accepted by general populations rather than special groups (e.g. vegan/vegetarian.)

So far, there are few studies about the use of immersive technologies on creating contexts in the sensory evaluation of food products. Although some previous VR-immersive studies revealed that contexts had a marginal effect on sensory acceptability (Kong et al., 2020; Torrico et al., 2020), either AR or VR sensory study is still at early stages of research. In this experiment, vanilla bean-flavoured cow milk-based yoghurt (dairy yoghurt), vanilla bean-flavoured coconut milk-based yoghurt (coconut yoghurt), and mixed yoghurt (50% dairy yoghurt and 50% coconut yoghurt) were chosen to be the stimuli, and HoloLens 2 headsets (Microsoft) were used to create immersive AR environments. Three contextual environments referred to the traditional sensory booth (SB), AR dairy view (ARD) and AR coconut view (ARC) were used for consumers. This study aimed to investigate three environments' effects on sensory acceptance, emotional responses, purchase intent, and yoghurt consumption behaviours among three yoghurt samples using augmented reality as a contextual factor of the evaluation.

Chapter 3

Materials and Methods

3.1 Participants

A total of N=63 untrained participants (23 males and 40 females) with 92% of them ageing from 21 to 40 years were recruited voluntarily for this study at Lincoln University. The number of participants showed accuracy, which was verified by the power analysis. All work involving human participants was approved by the Lincoln University Human Ethics Committee (Approval No: 2019-68). A brief introduction was given to each participant. All participants should claim not allergic to yoghurt ingredients involved in the study and were asked to sign the consent form before the sensory evaluation. This study included three sensory sessions (sensory booth session, AR dairy view session and AR coconut view session) and all sessions were conducted in the sensory labs or focus group rooms of the Replacement For Hilgendorf (RFH) building located in Lincoln University, Lincoln, New Zealand. Each participant was required to complete the three sessions at once. The duration of all sessions was approximately 30 to 40 minutes. Besides, the order of three sessions for each participant was random.

3.2 Stimuli

A focus group (N=7) from Lincoln University aimed to select dairy and dairy-free yoghurt for the study. Five coconut-milk based yoghurts and five dairy yoghurts with different flavour and brands were pre-selected from the local supermarket. After assessing sensory attributes in terms of appearance, flavour, mouthfeel, texture and overall liking, a cow-milk based vanilla bean yoghurt (the brand name is Yoplait) and a coconut milk-based vanilla bean yoghurt (the brand name is Raglan) were decided as the product stimuli for this experiment. The ingredients of dairy yoghurt include skim milk, milk solids, sugar, water, cream, thickener (modified starch), gelatine, natural flavours, acidity regulators (citric acid, sodium citrate), preservative (potassium sorbate), vanilla bean seeds (0.01 %), cultures. The ingredients of coconut yoghurt contain organic coconut cream, apple juice concentrate, natural starch, vanilla paste, live vegan cultures (*acidophilus* and *bifidobacterium*). To avoid the appearance bias, a mixed vanilla bean yoghurt (50% cow milk-based vanilla bean yoghurt and 50% coconut milk-based vanilla bean yoghurt) was used as the transitional stimulus in the study. Yoghurt products were purchased and kept in the refrigerator when they were not in use. The preparation and sampling process were conducted within one hour before the sensory session to prevent stale. About 15ml samples were poured into 30 ml cups with lids. Samples were coded with 3-digital random numbers. Participants were randomly attended sensory sessions. For each sensory session, participants were balanced-randomly served three samples to avoid position bias. The experiment aimed to measure the

effect of AR headset environments (HoloLens 2, Microsoft) on consumers' liking of the yoghurt products.

3.3 Sensory procedure

A brief explanation of the experimental procedures was given to each participant at the beginning of three sensory sessions, including the proper wearing and operation of AR headsets, the duration of the experiment and how to fill the questionnaire (Appendix A) of the RedJade Sensory Solutions (Martinez, CA, USA) platform. Each participant was instructed to evaluate three yoghurt samples in one of three sensory sessions. There were three contextual environmental settings (SB, ARC and ARD). For each environment, the participant was asked to rate the acceptability of sensory characteristics of each yoghurt sample based on the 9-point hedonic scale where 0 means "dislike extremely" and 9 means "like extremely" with a neutral response at 5 (Lawless & Heymann, 2010). Sensory attributes contained appearance, colour, aroma, taste/flavour, sweetness, sourness, mouthfeel, viscosity, aftertaste and overall liking. The intensity of the sweetness, sourness, dairy flavour, coconut flavour and mouthfeel were assessed by the JAR scale, where 1 = not at all sweet/sour enough or much too weak/thin; 2 = just about right; 3 = much too sweet/sour or much too strong/thick (Li et al., 2014). A set of CATA terms were listed to be selected all sensory attributes which could be applied for the sample. Those terms were referenced to the previous studies (Chetachukwu et al., 2019; Jaeger et al., 2019; Janiaski et al., 2016), included fruity flavour, dairy flavour, coconut flavour, vanilla flavour, sweet, sour, plain, smooth, creamy, astringent, homogeneous, cohesive, thick, thin, light, firm, compact, heavy. The purchase intent of each yoghurt sample was also investigated in the questionnaire (1=No, 2=Yes).

The CATA methods assessed the emotional responses generated by the yoghurt-tasting experience. The 33 emotional terms were pre-selected, and all originated from the previous literature (Gutjar et al., 2015; Schouteten et al., 2017) and the EsSense Profile™ (Nestrud et al., 2016), including 24 positive terms (adventurous, satisfied, active, affectionate, energetic, enthusiastic, free, friendly, glad, good, happy, interested, joyful, loving, merry, nostalgic, pleased, pleasant, secure, warm, daring, eager, polite, understanding), 4 neutral terms (calm, peaceful, steady and wild) and 5 negative words (bored, disgusted, worried, aggressive and guilty).

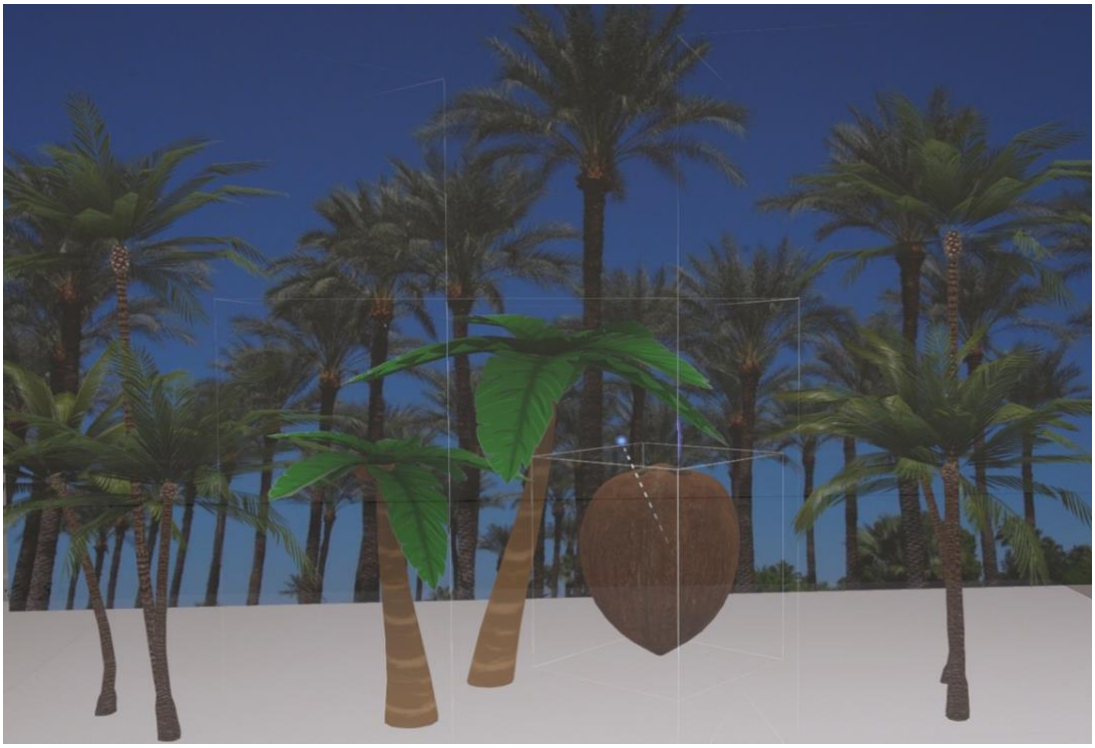
For each participant, the demographic information (gender, age and ethnicity) and consumer yoghurt consumption behaviour were collected once at the beginning of the sensory booth session. Each participant was asked to multi-select the reasons for the yoghurt consumption (nutritional, taste, probiotics, health, as a habit, emotional pleasant and other), what factors that consider most when purchasing yoghurt (flavour/taste, price, brand, plant-based yoghurt/dairy-based yoghurt, organic,

locally produced, packaging, other/explanation). Participants were asked to use crackers (Arnott's Water Cracker) or waters between samples to remove the carryover effect.

3.4 Environmental settings

Figure 1 shows the experiment's three environmental settings, including the traditional sensory booth (the control setting), AR dairy view setting, and AR coconut view setting. The sensory testing booth (1.5m width × 2.1m height) was individual and isolated, located at RFH building, Lincoln University, Lincoln, New Zealand. The room temperature were controlled around 20°C. Both incandescent light and the white-colour fluorescent light were constant during the whole evaluation process. There was a window-door within each booth unit, which connected the testing booth with the food preparation room for easily placing samples and tablets.

(a)



(b)

(c)

(d)

Figure 1. Environmental settings for sensory evaluation of yoghurt samples. (a) Sensory booth, (b) AR coconut view, (c) AR dairy view, (d) HoloLens 2 headset.

HoloLens 2 headset (Microsoft, Washington, USA) was applied for two AR testing settings to generate the two AR environments. So far, HoloLens 2 headset has been considered to be the most advanced AR headset in the market. Participants can see the appearance of the samples through the transparent visor. The headset is friendly to the participants with glasses - the headset slides right over them. While assessing samples in the AR sessions, participants were asked to wear the VR headset for viewing the pre-settled contextual setting. When it's time to fill the sensory questionnaire after tasting the sample, easily flip the visor up (no need to take off the headset) to step out of the AR environment. Participants should repeat the process until finishing evaluating all samples. Moreover, participants were required not to touch the 3D models to avoid the setting bias for each participant.

Two AR contextual settings were conducted in the isolated focus room at RFH building and displayed by the 3D Viewer application, which was run by the HoloLens 2 headset. Two HoloLens 2 devices were put on the table in the sensory focus group room, where one was used for the ARC and another for ARD. Both AR contextual settings included 3D models, photos and music. The criterion for creating the AR settings was based on the actual environment and perceptions of milk or coconut production. One instructor helped participants properly wear the headsets and explain the operation procedure while another instructor could set the table. When participants understood the entire process and saw the right contextual settings, instructors left the focus room to give participants the private space for sensory evaluation.

For ARC (figure 1 b), the coconut photo was used as the background while 3D-palm trees and one 3D coconut displayed in front of the photo companying with the beach sounds. 3D models used for ARC were from the Sketchfab 3D model's platform, where consumers are able to free download non-commercial used 3D models and purchase business purposed 3D models. Free 3D models used in ARC included palms trees (Sketchfab, 2017) and one coconut (Sketchfab, 2020). The palm-tree photo comes from the Pixabay photo platform (*Palm Trees*, 2020). The beach sound for the ARC was originated from the beach view video on YouTube (*Calming Sea - Relaxing 2 Hour - Birds Singing*, 2015, 03:15-05:21), which gave a natural beach sound with sea wave and bird sounds.

The ARD settings were presented in Figure 1 c, including the background photo of the cow farm view, two 3D cow models, one 3D milk model, and the farm's natural cow sounds. All 3D models were free downloaded from the Sketchfab platform, including cow model (Sketchfab, 2015) and milk model (Sketchfab, 2018). The background photo of farm view was free downloaded from Pixabay platform (*Cow*, 2018). The cow sounds with a slight bird sounds were used from a cow farm video on YouTube (*COW VIDEO | COWS MOOING | COMPILATION*, 2019, 03:15-05:21) which displayed the natural peaceful farm sound with cows' mooing.

3.5 Statistical analysis

The normality of hedonic data of sensory attributes was assessed by the Shapiro-Wilk test in XLSTAT Statistical Software 2019 (Addinsoft, New York, NY, USA). The result showed that all attributes data were not normality distributed. Therefore, the non-parametric Freidman's test followed by a *post-hoc* Nemenyi test in XLSTAT Statistical Software 2019 was performed to assess if there were significant differences in hedonic ratings among the combinations of 3 yoghurt types $\times$ 3 environments. The *H0* assumption of the Friedman's test is that at least one treatment significantly differs from the rest treatments. If *H0* is approved, the Nemenyi test will be applied for the multiple comparisons. Penalty analysis performed on JAR data was used to determine the effects of the sensory attributes on the yoghurt samples' liking scores. Cochran's *Q* test, Correspondence Analysis (CA) and Principal Coordinate Analysis (PCoA) were applied to assess the CATA emotional responses and the CATA attributes of yoghurt under different contexts settings. Principal Component Analysis (PCA; Correlation Biplot) was applied to investigate the correlations of liking scores of attributes and yoghurt samples under SB, ARC and ARD. Agglomerative Hierarchical Cluster (AHC) analysis was performed to categorize the nine yoghurt environment combinations. The dissimilarity of these treatments was analysed, relying on the Euclidean distance and Ward's method for investigating the difference between yoghurt's sensory attributes against the overall liking. Purchase intent frequencies were analysed by the Cochran's *Q* test and simultaneously confidence interval test with multiple comparisons. A PCA test was performed to analyse the CATA demography data. Data from all participants were collected

automatically by RedJade Sensory Software (Martinez, CA, USA) and analysed by Minitab 18 software (Minitab, LLC, State) or XLSTAT Statistical Software 2019 (Addinsoft, New York, NY, USA).

Chapter 4

Results

4.1 Hedonic results

Consumer acceptability results were analysed by non-parametric Friedman analysis, followed by multiple pairwise comparisons using Nemenyi's procedure. Table 1 shows the Friedman analysis results of sensory acceptance of three yoghurt types (coconut vanilla yoghurt, dairy yoghurt and mixed yoghurt) under three contextual settings (SB, ARC and ARD) as well as the interaction effect between yoghurt and environment. The data of acceptability was auto-sorted and analysed for mean ranks in XLSTAT Statistical Software. The result revealed the liking scores of all evaluated attribute were significant differences ($p < 0.05$) among yoghurt types, including appearance, colour, aroma, taste/flavour, sweetness, sourness, mouthfeel, viscosity, aftertaste and overall liking. However, *p*-values of attributes under different environments did not show significantly different ($p \geq 0.05$). For the nine treatments (yoghurt × environment), the significant differences in hedonic ratings were appearance, taste/flavour, sweetness, mouthfeel, aftertaste and overall liking. Generally, dairy yoghurt and mixed yoghurt had higher liking scores than coconut yoghurt regardless of environments. However, there was no significant difference in liking between dairy yoghurt and mixed yoghurt.

Table 1. The summary of *p*-value ($\alpha = 0.05$) of Friedman analysis of sensory attributes on yoghurt samples under different environments.

Treatments	**Acceptability Attributes**				
	Appearance	Colour	Aroma	Taste/Flavour	Sweetness
Yoghurt	0.017	0.002	0.021	*p*<0.001	0.001
Environment	0.097	0.782	0.548	0.979	0.362
Yoghurt*Environment	0.033	0.060	0.139	0.001	0.005
Treatments	Acceptability Attributes				
	Sourness	Mouthfeel	Viscosity	Aftertaste	Overall Liking
Yoghurt	0.027	0.003	0.002	*p*<0.001	*p*<0.001
Environment	0.395	0.662	0.479	0.452	0.331
Yoghurt*Environment	0.211	0.011	0.060	0.004	0.002

Table 2. Results of Nemenyi analysis at significant level (α = 0.05) on four attributes under 9 treatments (critical difference: 1.5274).

Treatments	Appearance	Taste/Flavour	Sweetness	Overall liking
C-SB	4.08 ^{a}	4.06 ^{a}	4.06 ^{a}	4.08 ^{a}
C-ARD	4.88 ^{ab}	4.22 ^{ab}	4.28 ^{ab}	4.13 ^{ab}
C-ARC	4.89 ^{ab}	4.60 ^{ab}	4.90 ^{ab}	4.87 ^{ab}
D-SB	5.03 ^{ab}	5.71 ^{b}	5.15 ^{ab}	5.12 ^{ab}
D-ARC	5.22 ^{ab}	4.98 ^{ab}	5.08 ^{ab}	5.24 ^{ab}
D-ARD	5.06 ^{ab}	5.29 ^{ab}	5.44 ^{ab}	5.62 ^{b}
M-SB	4.90 ^{ab}	5.65 ^{b}	5.37 ^{ab}	5.25 ^{ab}
M-ARC	5.15 ^{ab}	5.37 ^{ab}	5.64 ^{b}	5.58 ^{ab}
M-ARD	5.79 ^{b}	5.10 ^{ab}	5.10 ^{ab}	5.11 ^{ab}

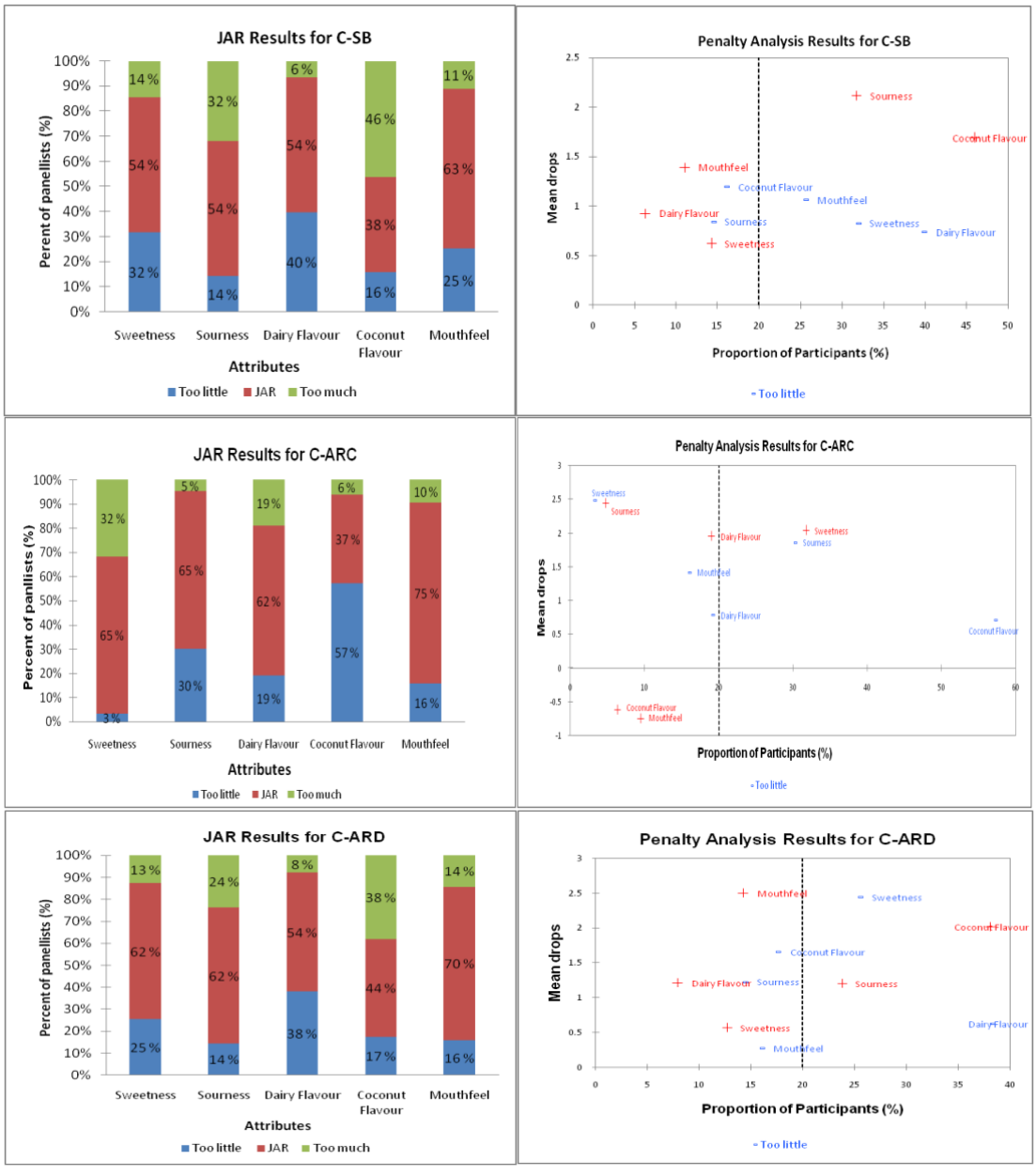
Data displayed as “mean ranks”; the different letters in the same column means significantly difference (p < 0.05). D-SB: dairy yoghurt in sensory booth; C-SB: coconut milk-based yoghurt in sensory booth; M-SB: Mixed yoghurt (50% dairy yoghurt and 50% coconut milk-based yoghurt) in sensory booth; D-ARC: dairy yoghurt in AR coconut view; C-ARC: coconut milk-based yoghurt in AR coconut view; M-ARC: mixed yoghurt in AR coconut view; D-ARD: dairy yoghurt in AR dairy view; C-ARD: coconut milk-based yoghurt in AR dairy view; M-ARD: mixed yoghurt in AR dairy view.

Table 2 shows the Nemenyi test results comparing mean ranks at significant value alpha 5% for sensory attributes, including appearance, taste/flavour, sweetness and overall liking. Only attributes which presented significantly different (α = 0.05) by the Nemenyi test among 9 treatments were summarized in Table 2. The liking score of dairy yoghurt under ARD significantly differed with the coconut yoghurt under SB for the overall liking. Regarding appearance and sweetness, mixed yoghurt under ARD acquired the higher liking scores than coconut yoghurt under SB. Besides, the hedonic ratings of taste/ flavour of mixed yoghurt under SB and dairy were significantly higher than coconut yoghurt under SB. However, there was no difference in liking scores on M-SB and D-ARD. Overall, the coconut-based yoghurt was the most disliked yoghurt among three yoghurt types under three contextual settings.

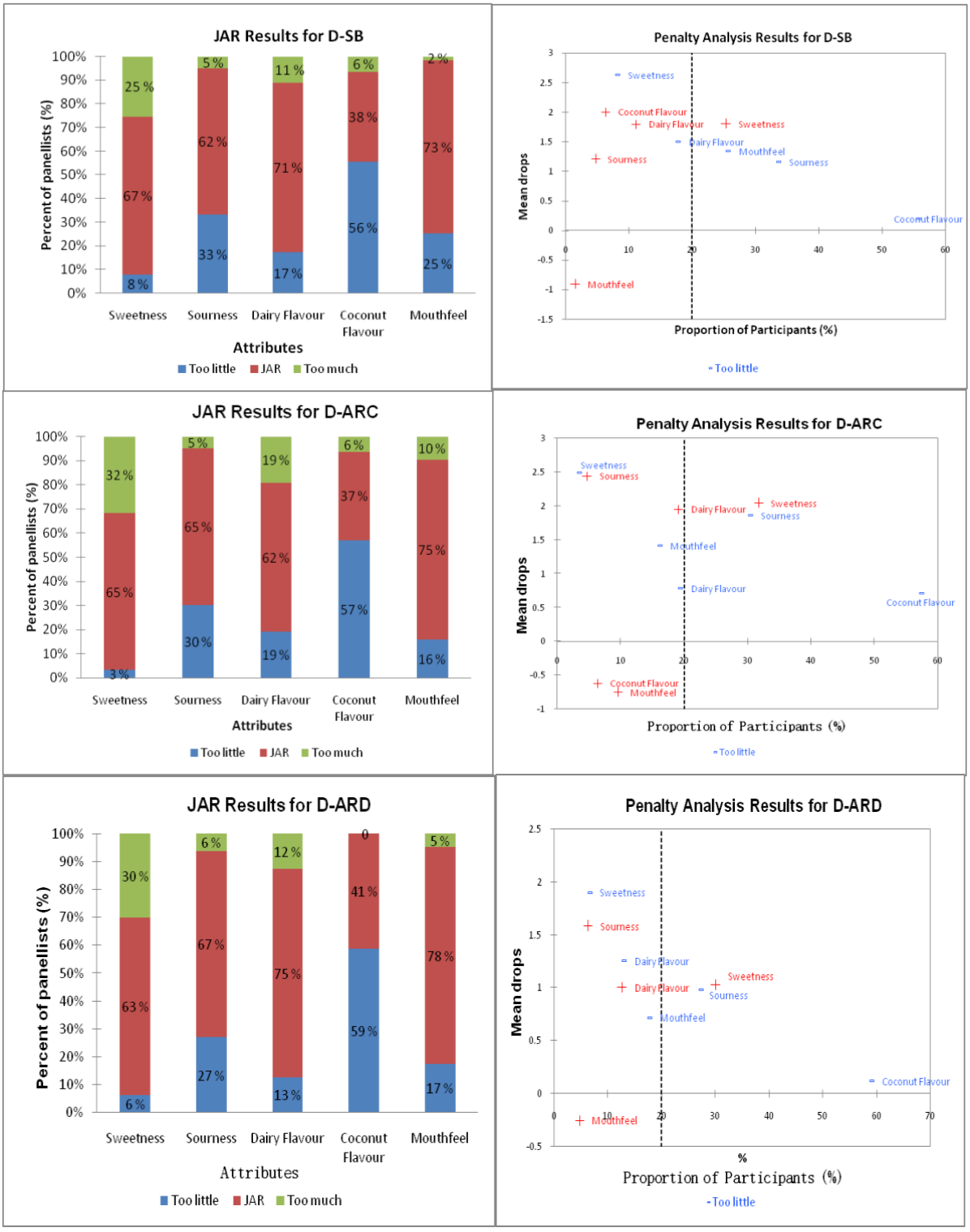
4.2 JAR results and penalty analysis

The JAR frequencies and mean drops based on the penalty analysis for five attributes (sweetness, sourness, dairy flavour, coconut flavour and mouthfeel) of the yoghurt samples (coconut milk-based yoghurt, dairy yoghurt and mixed yoghurt) under three contexts (SB, ARC and ARD) were presented in Figure 2. Coconut milk-based yoghurt under ARC had the highest selections of JAR for sweetness (65%), sourness (65%), dairy flavour (62%) and the mouthfeel (75%). In contrast, the highest selection of JAR for coconut flavour (44) was under ARD. The highest proportions of participants thought that coconut milk-based yoghurt was "too little/weak" sourness and coconut flavour under ARC. Similarly, the frequencies of “too little/weak/thin” sweetness, dairy flavour and mouthfeel were the highest selection under the sensory booths. Coconut yoghurt under sensory booth acquired the highest

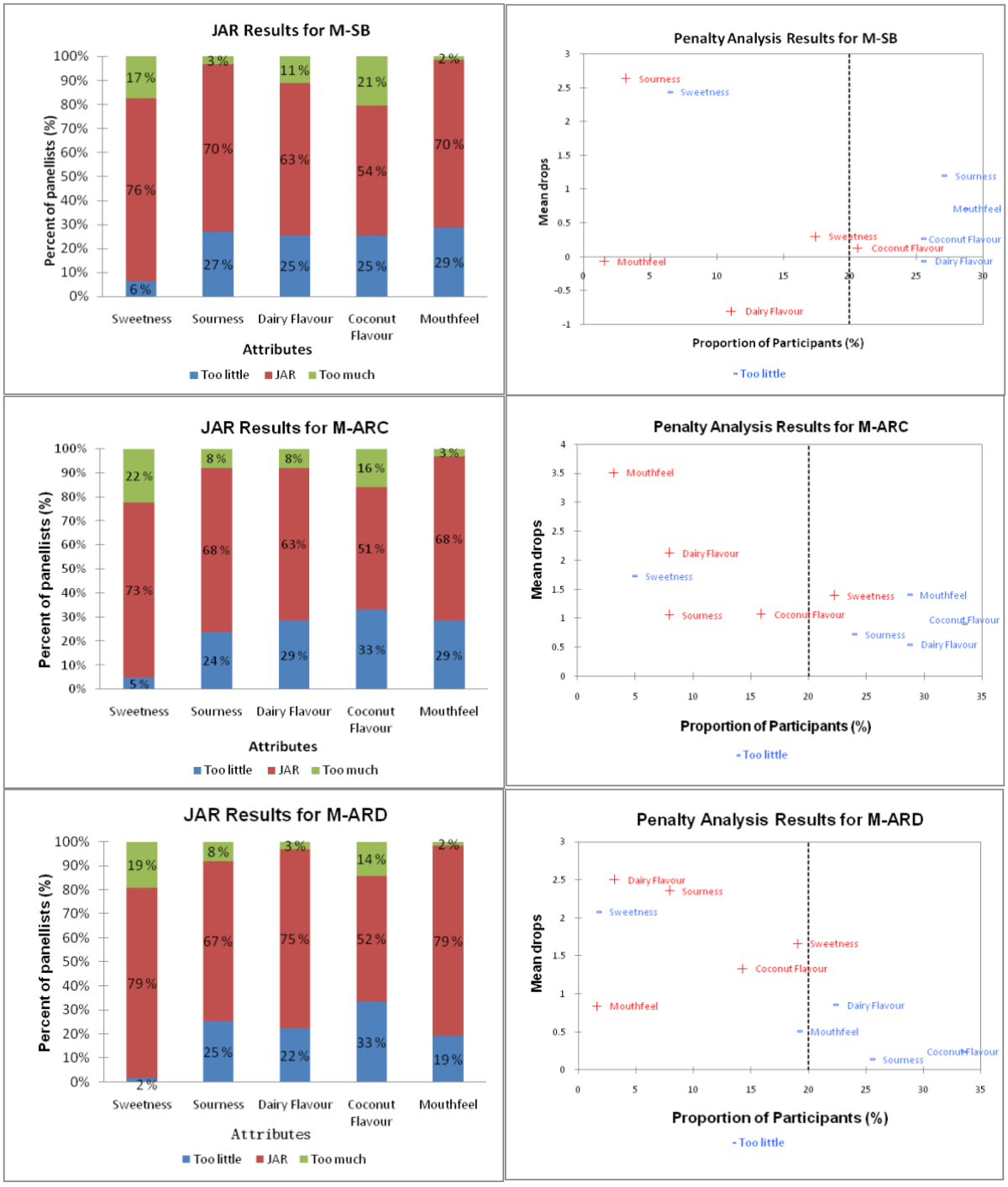
selection of “too much/strong” coconut flavour (46%) and sourness (32%) while the attributes of sweetness (32%) and dairy flavour (19%) were thought to be "too much" under ARC. Regarding dairy yoghurt under all environments, the JAR frequencies of sweetness, sourness, dairy flavour and mouthfeel were not much different under all environments, which varied from 62% to 78%. Approximately 56% - 59% participants selected “too weak” of coconut flavours, and 25-32% thought “too much” sweetness. For mixed yoghurt, JAR was selected most frequently for sweetness (73-79%), sourness (67-70%), dairy flavour (63-75%), coconut flavour (51-54%) and mouthfeel (68-79%) under all contextual settings. The selections of "too little/weak/thin" of all evaluated attributes of mixed yoghurt, except sweetness, were similar under different environments ranging from 19% to 33%. Only 14-22% of participants selected "too much/strong" sweetness and coconut flavour of mixed yoghurt regardless of environments.



(a)


JAR Results for D-SB
Percent of panellists (%)
Sweetness
Sourness
Dairy Flavour
Coconut Flavour
Mouthfeel
Attributes
Too little
JAR
Too much
Penalty Analysis Results for D-SB
Mean drops
Proportion of Participants (%)
Too little
JAR Results for D-ARC
Penalty Analysis Results for D-ARC
JAR Results for D-ARD
Penalty Analysis Results for D-ARD
Proportion of Participants (%)

(b)



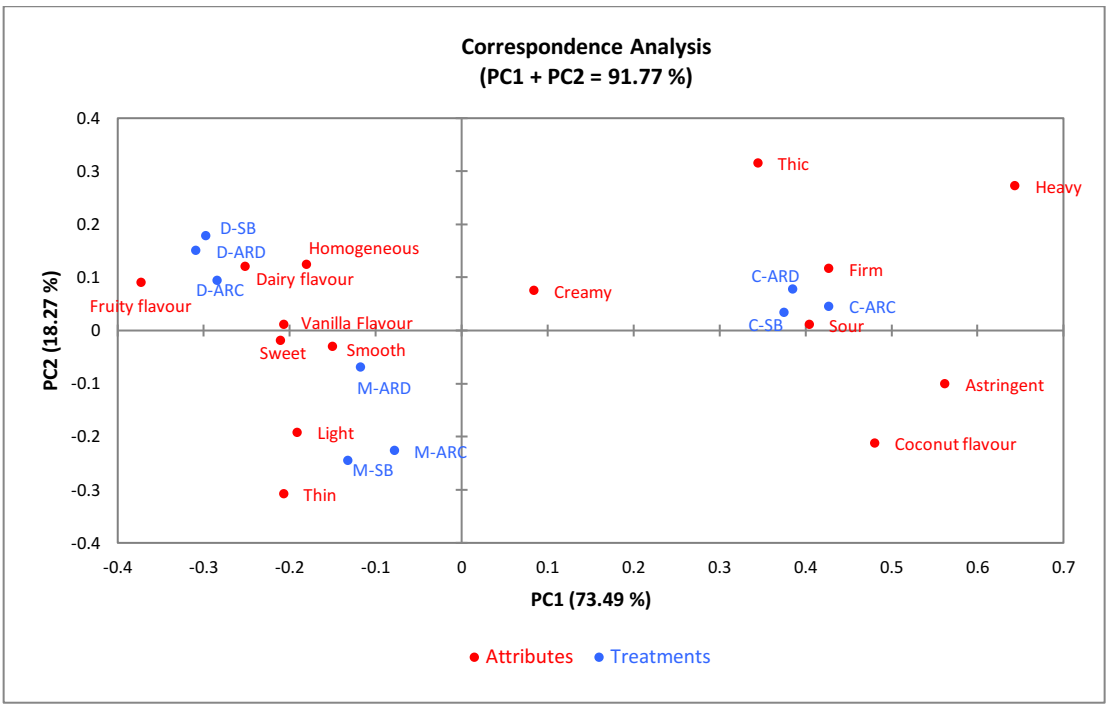
(c)

Figure 2. Just-About-Right (JAR) frequencies and penalty analysis results of sensory attributes (+) of coconut yoghurt (a), dairy yoghurt(b) and mixed yoghurt (c) under SB, AR1 and AR2.

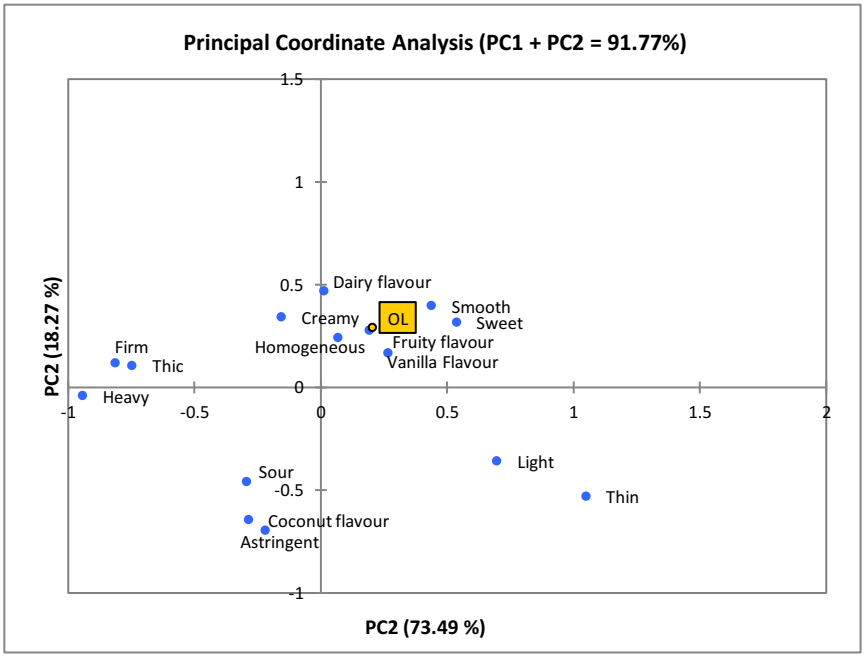
Penalty analysis was based on the JAR frequencies and the hedonic scores of yoghurt samples under different contexts. Setting the threshold population size as 20% was usually considered to be the significant level in penalty test (Meullenet et al., 2008; Pagès et al., 2014). According to the explanation of the penalty plots (Meullenet et al., 2008), more than 20 % participants penalized coconut yoghurt for being “too much/strong” sourness and “coconut flavour” and “too little/weak” sweetness and dairy flavour under SB and ARD, whereas “too much” sweetness and “too little/weak” sourness and coconut flavour were penalized under ARC. Dairy yoghurt under all environments was penalized by lacking sourness and coconut flavour and “too much” sweetness. For mixed yoghurt, “too little/weak” sourness and coconut flavour affected the liking scores regardless of environments. “Too thin” mouthfeel under SB and ARC, as well as “too much” sweetness under ARC and “too weak” dairy flavour under ARD, were penalized by over 20% consumers. In addition, "too thin" mouthfeel influenced the hedonic scores of dairy yoghurt under all contexts.

4.3 CATA analysis of attribute terms of yoghurt samples in different environments

Figure 3 shows the correspondence analysis of the CATA attribute terms for the yoghurts in different environments and principal coordinate analysis of the CATA attribute terms with the overall liking score. The principal component one (PC1) of correspondence analysis accounted for 73.47%, and the principal component two (PC2) was 18.27, which explained 91.77% of data viability. According to the Cochran's *Q* test results, 15 terms were significantly different, including “fruit flavour”, “dairy flavour”, “coconut flavour”, “vanilla flavour”, “sweet”, “sour”, “smooth”, “creamy”, “astringent”, “homogeneous”, “tick”, “thin”, “light”, “firm” and “heavy”. The participants elicited attribute terms toward the dairy yoghurt samples under all environments, such as “homogeneous”, “fruity flavour”, “dairy flavour”, “vanilla flavour”, “sweet”, “smooth” and “creamy”. The mixed yoghurt sample was related to the terms “thin”, “light”, “sweet” and “smooth”. Besides, the mixed yoghurt under ARD was associated with “creamy” and “vanilla flavour”. On the contrary, coconut yoghurt was linked with “coconut flavour”, “thick”, “firm”, “sour” and “astringent”. According to the results of the correspondence analysis of the descriptive terms against the overall liking of all samples in different contexts, the liking score was positively associated with “sweet”, “smooth”, “dairy flavour”, “fruity flavour”, “vanilla flavour”, “creamy”, “light” and “homogeneous”, whereas negatively associated with “firm”, “heavy” and “astringent”.



(a)



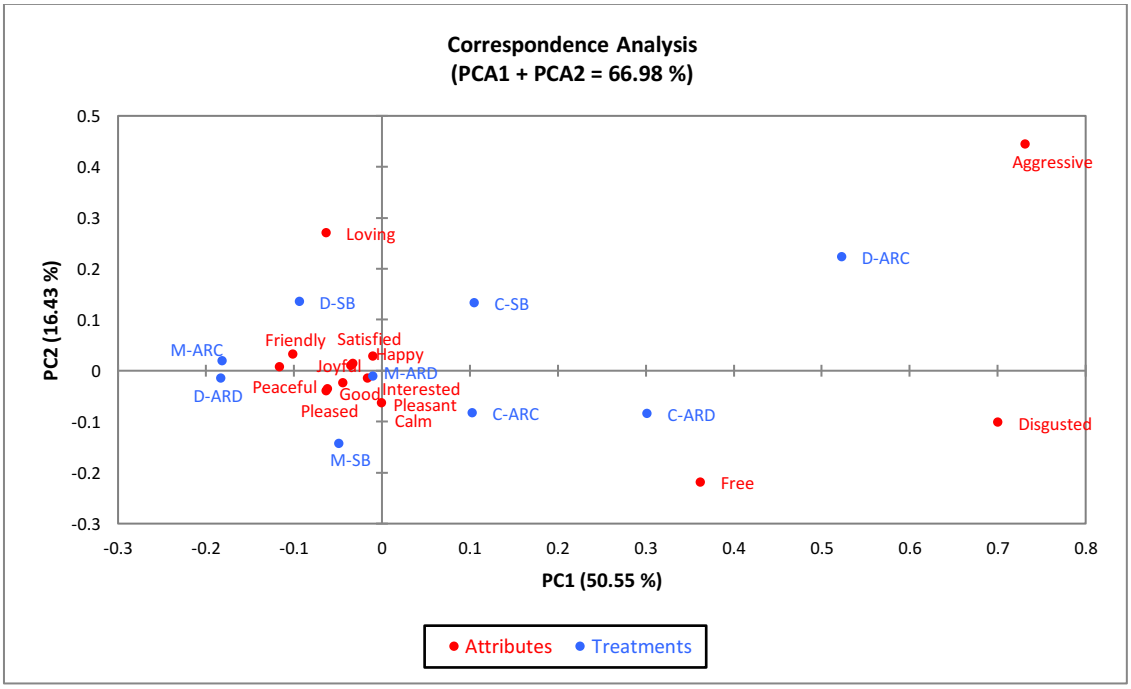
(b)

Figure 3. (a) Correspondence analysis of the CATA attribute terms for the yoghurts in different environments and (b) principal coordinate analysis of the CATA descriptive terms with the overall liking score (OL).

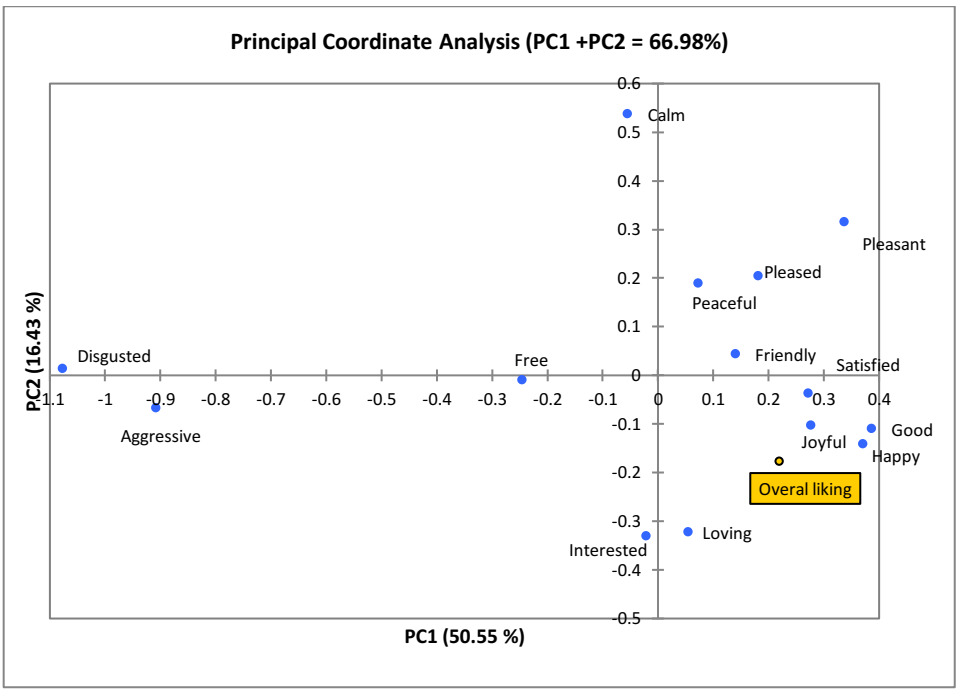
4.4 Emotional responses

The results of the correspondence analysis of emotional terms for the yoghurts in different environments were shown in Figure 4 (a). The total of PC1 (50.33%) and PC2 (16.43%) can explain 66.89% of the variability. According to the Cochran's *Q* test results, 14 emotional terms were significantly different, including "satisfied", "calm", "free", "friendly", "good", "happy", "interested", "joyful", "loving", "peaceful", "pleased", "pleasant", "disgusted" and "aggressive". Specifically, dairy yoghurt under SB and ARD, mixed yoghurt under all contexts and coconut yoghurt under SB and ARC were associated with nine positive emotional terms ("friendly", "satisfied", "happy", "joyful", "pleased", "good", "interested", "loving" and "peaceful") and one neutral emotional term ("calm"). In addition, the emotional term "free" was associated with C-ARD treatment. On the other hand, negative terms like aggressive and disgusted were linked with the diary yoghurt under ARC.

Figure 4 (b) presents the results of the principal analysis of the emotional terms concerning the overall liking score. In general, the positive emotional terms were positively associated with the hedonic score of yoghurt products in terms of "satisfied", "happy", "good", "joyful", "pleasant" and "peaceful". On the contrary, negative emotional terms such as "aggressive" and "disgusted" were negatively correlated with the overall liking scores.



(a)



(b)

Figure 4. (a) Correspondence analysis of the emotional terms for the yoghurts in different environments and (b) principal coordinate analysis of the emotional terms with the overall liking score.

4.5 Principal component and cluster analyses of the yoghurt samples under three contexts

PCA biplot visualized the associations between nine yoghurt-environment combinations and hedonic scores of yoghurt products' ten sensory attributes. According to Figure 5, the principal component one was 91.70% while the principal component two was only 3.80%, which explained 95.49% of data variability in total. Liking vectors of most attributes were aligned with the horizontal axis (PC1) with the squared cosines ranging from 0.80 to 0.96. But the liking vectors of appearance and aftertaste were linked with the vertical axis, which was PC2 with squared cosines from 0.00 to 0.18. Liking vectors of taste/flavour, sweetness, sourness, mouthfeel and overall liking were close to each other. Liking vectors of aroma and colour were closely correlated with viscosity. Otherwise, the liking vector of appearance was not close to the colour as they were almost orthogonal. For different treatments, dairy yoghurt and mixed yoghurt, regardless of the contextual effects, were highly associated with the liking of mouthfeel, sourness and viscosity, and relatively linked with the liking of taste/flavour, sweetness, aroma, colour and overall liking. In contrast, coconut yoghurt was negatively associated with the liking of all evaluated attributes under all environments.

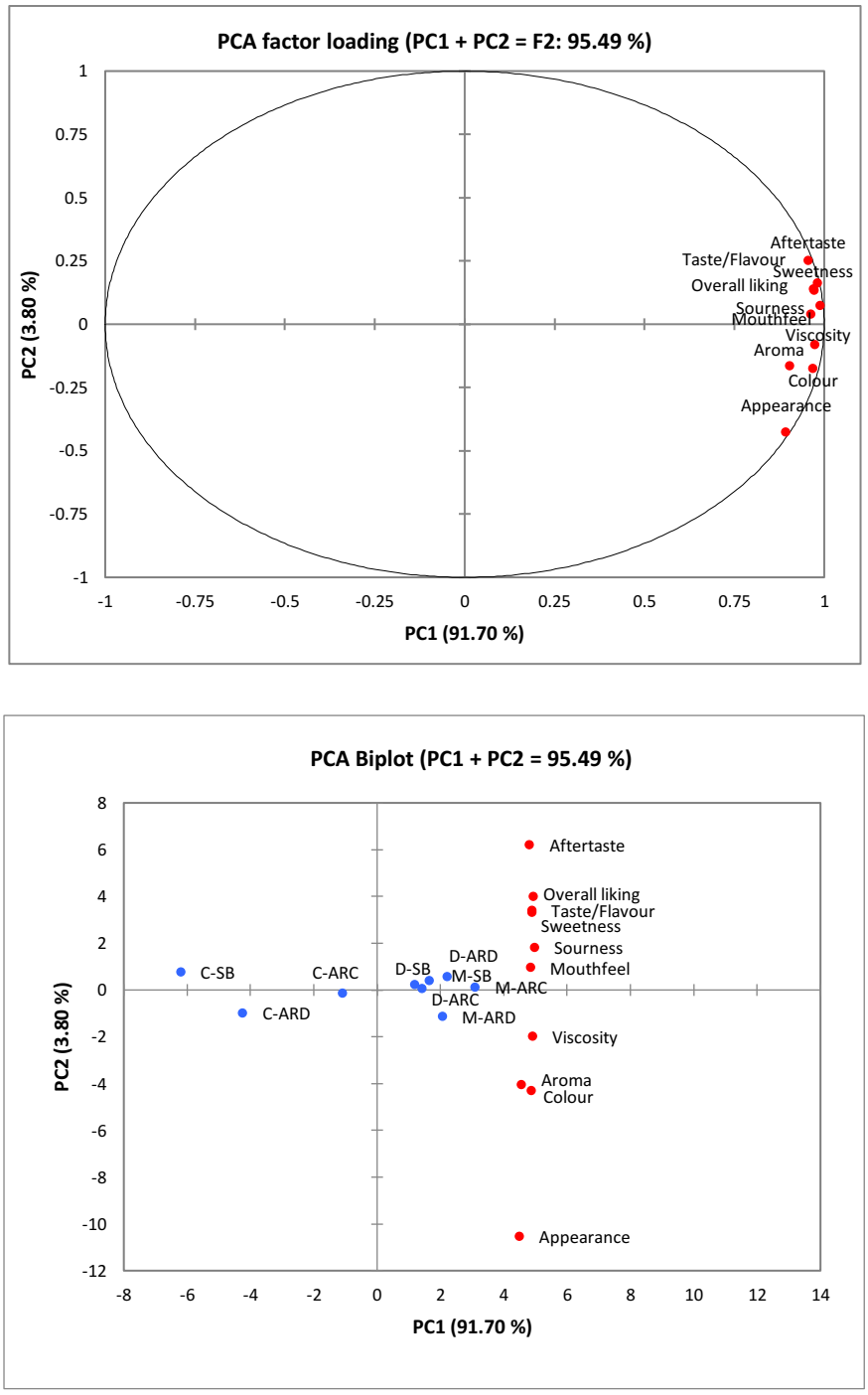


Figure 5. Principal component analysis (PCA) biplot regarding hedonic scores of yoghurt attributes in three contextual settings.

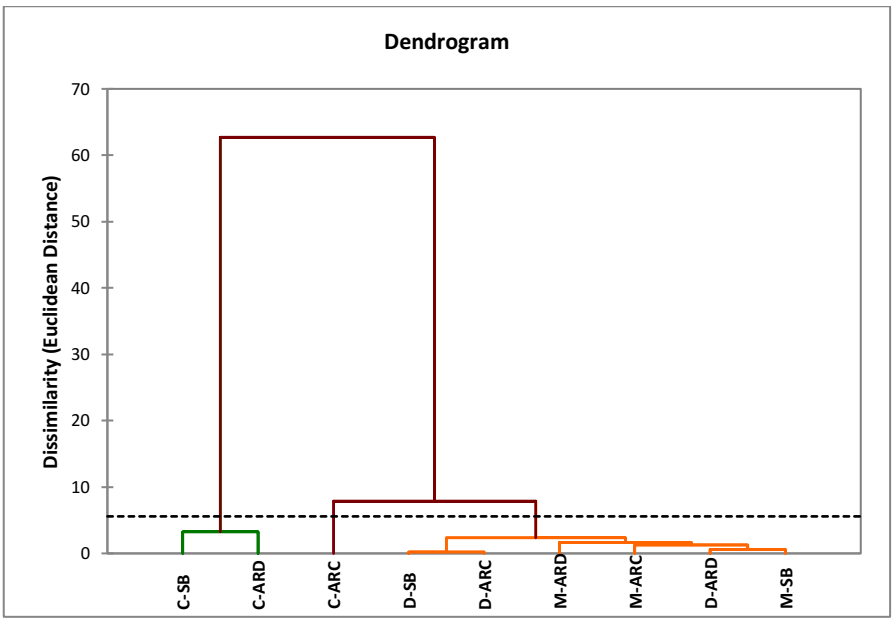


Figure 6. Dendrogram of agglomerative hierarchical clustering (AHC) grouping yoghurt products under different environments.

Figure 6 shows that the dendrogram of nine yoghurt-context combinations (3×3 treatments). Two main cluster groups were presented, which referred to (1) coconut milk-based yoghurt under the sensory booth and AR dairy view settings, and (2) coconut yoghurt under AR coconut view, dairy yoghurt and mixed yoghurt under all environments.

4.6 The purchase intent of yoghurt samples under different environments

Table 3 presents the frequencies of yoghurt samples' frequencies of purchase intent (dairy yoghurt, coconut yoghurt and mixed yoghurt) under three environments (SB, VRC and VRD). Both dairy yoghurt (61.9-68.3%) and mixed yoghurt (63.5-69.8%) acquired higher purchase intent than coconut yoghurt regardless of environments. Besides, the coconut yoghurt (41.3-55.6%) under all environments had the lowest purchase intent. The frequencies of purchase intent were not significant among dairy yoghurt under all contexts, mixed yoghurt under all contexts and coconut yoghurt under ARD. In contrast, the purchase intent of mixed yoghurt under ARD was significant with coconut yoghurt under the ARC and SB. Therefore, consumers would like to buy dairy yoghurt and mixed yoghurt in the market.

Table 3. The purchase intent frequencies of yoghurt products under three contexts.

Treatments [1]		Purchase Intent (%) [2]
Yoghurt	**Environment**	
Dairy	SB	68.3 [bc]
	ARC	68.3 [bc]

	ARD	61.9 [abc]
Coconut	SB	41.3 [a]
	ARC	42.9 [ab]
	ARD	55.6 [abc]
Mixed	SB	63.5 [abc]
	ARC	66.7 [abc]
	ARD	69.8 [c]

[1] Dairy yoghurt, non-dairy yoghurt (coconut-based yoghurt) and mixed yoghurt (50% dairy yoghurt and 50% non-dairy yoghurt) were tested under environments (SB: sensory booth, ARC: AR coconut view, ARD: AR dairy view). [2] Cochran's *Q* test with Marascuilo procedure was applied for multiple pairwise comparisons (n=63); frequencies with different superscript (a, b, c) in the purchase intent column indicate significant differences ($p < 0.05$).

4.7 The results of consumers consumption behaviour on yoghurt

Table 4 shows the results of yoghurt consumption frequencies, reasons for yoghurt consumption, and factors that participants consider most when purchasing yoghurt. For the results of purchase frequencies, about 60.4% of participants selected "two or three times a week" or "sometimes in a week" while 14.3 % of consumers ate yoghurt every day and the left 25.4% people had relatively low consumption frequencies. Regarding to the reasons for yoghurt consumption, 71% consumers considered "health" and "taste" to be the first reason, following by "nutritional" (60.3%), "probiotics" (49.2%), "as a habit" (28.6%) and "emotional pleasant" (15.9%). Approximately 58.7% of consumers selected "price" as the most important factor that affected the purchase intent. "Brand", "type (dairy yoghurt or non-dairy yoghurt)" and "packaging" of the yoghurt were less selected factors, accounting for 28.6%, 20.5% and 15.9%, respectively. Only 9.5% of consumers concerned with "locally produced", and 6.3% of consumers considered "organic" as the most important information that influenced the purchase decision.

Table 4. Investigation on consumers' consumption frequencies, reasons and major factors.

Frequencies of yoghurt consumption	**Percentage (%)**
Everyday	*14.3*
Two or three times a week	*30.2*
Sometimes in a week	*30.2*
Two or three times a month	*12.7*
Sometimes in a month	*11.1*
Occasionally	*1.6*
Reasons for yoghurt consumption	**Percentage (%)**
Health	*71.4*
Taste	*71.4*

Nutritional	*60.3*
Probiotics	*49.2*
As a habit	*28.6*
Emotional pleasant	*15.9*
Factor that consider most when purchasing yoghurt	**Percentage (%)**
Price	*58.7*
Brand	*28.6*
Type (dairy yoghurt or non-dairy yoghurt)	*20.6*
Packaging	*15.9*
Locally produced	*9.5*
Organic	*6.3*

Chapter 5

Discussion

5.1 The effect of contexts on consumer acceptability of yoghurt products

Regardless of environments, consumers significantly liked dairy yoghurt and mixed yoghurt rather than coconut yoghurt. A previous study confirmed that the sensory attributes were the obstacle of the plant-based yoghurts comparing with the traditional dairy yoghurt (Drewnowski & Gomez-Carneros, 2000), and texture and flavour affected the hedonic rating of yoghurts (Janiaski et al., 2016). In the study, coconut yoghurt's ten sensory attributes had the lowest hedonic scores compared with diary yoghurt and mixed yoghurt. However, the hedonic ratings between dairy yoghurt and mixed yoghurt (half dairy yoghurt and half coconut yoghurt) were not significantly different. The aroma and taste of mixed yoghurt had the moderate vanilla flavour companied with a little coconut flavour. The sweetness, sourness, astringent, rheological properties of mixed yoghurt were in the middle between dairy yoghurt and coconut yoghurt, which could be a reason to explain the high liking score of mixed yoghurt. The study of Sanful (2009) compared the yoghurt made from skimmed cow milk with yoghurts made from the cow milk and different proportions of coconut milk, which found no difference among those yoghurts in all sensory attributes. Otherwise, adding coconut milk to the soy milk improved the quality and sensory acceptability of yoghurt products only made from soymilk (Kolapo & Olubamiwa, 2012).

Contexts have a marginal effect on consumer acceptability in this study. The similar results were found in recent studies from cold-brewed coffee (Liu et al., 2019), immersive/real coffee bars (Sinesio et al., 2019), dark/white chocolates (Kong et al., 2020) and no/full sugar chocolate (Torrico et al., 2020), and all of them used immersive technologies to create different contexts to investigate the hedonic ratings or emotional difference during the sensory evaluation of foods. The reasons could be due to no-substantial contrast effect between contexts, eating habit preference, attention bias or individual variations in taste perception (Masi et al., 2015). As mentioned before, consumer acceptability is a multi-dimension process, which could be affected by many aspects. The person in pleasant contexts may give higher liking scores to the same products compared with in disgust contexts (Samant et al., 2017). Physiological factors in tasting can also be the reason to have different taste perceptions. Fungiform papillae density could affect the taste/flavour perception and food preference (Masi et al., 2015). Moreover, the differential taste perception of sweet, umami and bitterness was due to the variation in relevant taste receptor genes and dependent on the individual's age and gender (Feeney et al., 2011). The ambient noise in the serving place significantly influenced the sensory evaluation of sweetness, saltness and overall liking (Woods, 2011). Participants with the natural hating of coconut

smell or flavour reflected that coconut-flavoured food products were unaccepted regardless of different contexts. The position, order and attention bias also affected human judgment (Lawless & Heymann, 2010). Some participants explained that they were aware that the questionnaire was based on yoghurt's sensory evaluation, although they sat in different environments.

However, the ARC and ARD contexts affected the consumers' discrimination of yoghurt products. Under sensory booth, the liking score of the taste, sweetness, mouthfeel and viscosity differed significantly among yoghurt types, whereas the liking scores of those attributes were not significantly different under ARD and ARC. Two AR contexts especially improved the liking scores of coconut yoghurt in all attributes compared with the sensory booths. Some participants reflected that they felt happy and enjoyable under the immersive contexts. When they were in the AR coconut view, the peaceful beach view evoked travelling experience or memories. Similarly, some participants mentioned the terms "cute" or "lovely" to describe the 3D Cow models in the AR dairy view. The positive emotions, familiarities, and imaginations contributed to the higher liking scores of coconut yoghurt or dairy yoghurt under AR contexts. Bangcuyo et al. (2015)' study revealed that participants showed more discrimination in the immersive coffeehouse than the sensory booth. The results from the immersive context presented more accurate for predicting future coffee liking. Overall, although context may not significantly affect the consumer liking of products, it should not be neglect due to its influence on discrimination ability.

5.2 JAR results

JAR and penalty analysis aim to figure out what attributes increase/decrease the liking of the food products, and the effects of those attributes on liking scores are significant or not. In the present study, mixed yoghurt (half coconut yoghurt and half dairy yoghurt) gained the highest "JAR" scores (varied from 51% to 79%) of all attributes (sweetness, sourness, dairy flavour, coconut flavour and mouthfeel) under three contexts. Dairy yoghurt and coconut yoghurt, except the attribute of coconut flavour, had the comparative higher frequencies of "JAR" of the other four attributes than "too little/weak" or "too much/strong". About 38-46% of consumers tasted coconut yoghurt as a "too strong" coconut flavour and 16-17% thought "too weak" coconut flavour under SB and ARD. However, only 6% of participants tasted coconut yoghurt with "too strong" coconut flavour and 57% thought "too weak" of coconut flavour under ARC. The result hints that the ARC could affect the consumer perception of coconut yoghurt, which is consistent with the non-parametric Freidman analysis. The reason could be linked to expectations. When people were in the AR coconut view, the environment acted as a reminder to attract consumers' attention to the coconut flavour. Visual cues, like the colour of the food, light of the serving place, and the environments' vies, affect consumer judgment/liking of food products (Piqueras-Fiszman & Spence, 2015). The positive/negative emotion occurs when the food taste is

beyond/disconfirmed expectation (Spence, 2015). Moreover, 56-59% of consumers tasted the dairy yoghurt "too weak" coconut flavour regardless of environments, which was understandable due to no coconut ingredient in the recipe.

For the penalty analysis, “too much/strong” sourness and coconut flavour and “too little/weak” sweetness, dairy flavour and mouthfeel significantly decreased liking scores of coconut yoghurt under SB and ARD. In contrast, “too much” sweetness and “too little/weak” sourness and coconut flavour were the main factors to affect the liking scores of coconut yoghurt under ARC. Regarding dairy yoghurt, "too much" sweetness and "too little" sourness contributed greatly to the decrease in overall liking scores under all environments. Besides, mixed yoghurt's overall liking was significantly declined by "too little/weak" sourness, mouthfeel, coconut flavour and dairy flavour regardless of the effect of context.

5.3 Attribute terms and emotional responses of yoghurt

The results of PCA analysis of CATA attribute terms of yoghurt samples under different contexts show the same type yoghurts were close with each other, such as C-SB, C-ARC and C-ARD; D-SB, D-ARC and D-ARD; M-SB, M-ARC and ARD; The positions of nine combinations in the map mainly depended on the yoghurt type rather than the environment. As shown in the figure, the dairy yoghurt and mixed yoghurt were linked to positive words in terms of "homogeneous", "smooth", "sweet" and "creamy". Those words are also used to describe the desired food texture (Schouteten et al., 2017). In addition, the PCoA analysis proved the positive association between those items and overall liking. On the contrary, the coconut yoghurt was associated with "firm", "sour" and "astringent" that had a negative correlation with the overall liking. This could be used as a reason to explain the lower hedonic scores of coconut yoghurt.

Emotion responses of yoghurt samples did not show too much different under different contexts. In other words, no effect of contexts and yoghurt samples on emotion responses were found in the study. The most frequencies of emotional terms were ten positive terms, two negative terms and two neutral terms. As shown in the figure, almost all positive emotional terms and seven treatments (C-SB, C-ARC, C-ARD, D-SB, D-ARD, M-SB, M-ARC and M-ARD) were clustered in the middle of the map of PCA analysis, whereas the D-ARC were closer to the negative terms such as "aggressive" and "disgusted". The finding is controversial to the recent sensory studies using virtual reality technologies (Kong et al., 2020; Torrico et al., 2020). These studies showed that, regardless of chocolate types, positive emotional terms (e.g. “loving”, “happy”, “friendly”) were associated with the positive VR environment, neutral emotional terms (e.g. “calm”, “secure”) were linked to the sensory booth, and passive emotional terms (e.g. “worried”, “guilty”) were correlated to the negative VR environment. Three points could explain the reasons for the controversial findings. The first point is due to the immersive

technologies used in the sensory study. Virtual reality could work as an isolated space, which means that the VR-environment could be completely changed. In contrast, augmented reality is a mixed-immersive technology that enriches contextual information in the real environment. One of the advantages of AR refers to combine immersive technology with the real world seamlessly. In this regard, most parts of contextual cues, such as the light, colour and location, don't change completely. However, the external contexts in terms of light, colour and location influence consumer perception, expectation, emotion and hedonic ratings of food products (Jaeger & Porcherot, 2017; Quartier et al., 2014). For example, the augmented reality environment does not isolate the real world's visual cues compared with virtual reality technology. The visual cues, as mentioned before, could affect emotions (Spence, 2015). The second point is the design of environmental settings. The previous studies used more comparable environments, such as "VR-dark coffee shop" and "VR-bright coffee shop, " but two AR environments were relatively-weak comparable in this study. Adding yoghurt-related contextual cues in the AR environments enriches the background information of the products and helps consumers understand the products besides. The third point is conscious bias. Participants clearly understand that their judgments are based on the samples rather than the environments where they stay. Therefore, the study's emotional responses appear to reflect feelings based on the products and added contextual information rather than the whole environment.

5.4 Investigation on purchase intent and purchase reasons

Health, taste and nutrition were the most optioned reasons for purchasing yoghurt. Not surprisingly, the above findings reflect consumers' perception of different yoghurts. Dairy and mixed yoghurt are sweet, homogenous, creamy, smooth and fruity flavour while coconut yoghurt is astringent, sour and thick. Although non-dairy coconut yoghurt has its own merits based on healthy properties, coconut yoghurt has no advantages than dairy and mixed yoghurts concerning the sensory aspect. For the most important factor when purchasing, interestingly, the majority of participants put the "price" in the first place. In general, coconut milk-based yoghurts are nearly five times higher than the same portion dairy yoghurt in the local supermarket at Lincoln, New Zealand. If the consumers are not a special population in terms of vegan/vegetarian, they probably like to purchase dairy yoghurt with desirable sensory attributes. Therefore, the above reasons could explain why coconut yoghurt's purchase intent is lower than dairy yoghurt and mixed yoghurt regardless of the effects of context.

Chapter 6

Conclusions

The study investigated the consumer acceptability, JAR attributes, emotional response, purchase intent and consumer purchase behaviour on coconut-milk based yoghurt, dairy yoghurt and mixed yoghurt (half coconut yoghurt and dairy yoghurt) under three environments (sensory booth, AR coconut view and AR dairy view). Although dairy-free yoghurt with promising healthy advantages has been one of the top trends in the food industry, general populations prefer to refuse these plant-based foods due to the high price and unpleasant taste. In the study, participants were asked to evaluate yoghurt samples without telling any background information. Unsurprisingly, consumers prefer the dairy and mixed yoghurt than the coconut yoghurt. Dairy yoghurt and mixed yoghurt were significantly linked to attributes associated with liking scores, such as “sweet”, “smooth” and “creamy” while coconut yoghurt was described as attributes against overall liking in terms of “astringent”, “thin” and “sour”. For JAR results, the sweetness, sourness, dairy flavour and mouthfeel of mixed yoghurt and dairy yoghurt were thought to be Just-about-right, but consumer penalty that coconut yoghurt was “too much” sourness and “too little” sweetness and “too thin” mouthfeel. In general, from the sensory aspect, consumers considered that dairy yoghurt and mixed yoghurt were more delicious than coconut yoghurt, which was confirmed by the investigation of the consumer behaviour and purchase intent in the study. Taste/flavour and health were the most important reasons to determine the purchase intent of yoghurt. Moreover, dairy yoghurt and mixed yoghurt's purchase intent was higher than of non-dairy yoghurt regardless of environments. Overall, plant-based coconut yoghurt had little advantages compared with the dairy/mixed-dairy yoghurt regarding sensory properties.

Yoghurt types significantly differed liking scores of sensory attributes, whereas the environment had a marginal effect on the liking scores. However, AR environments affected sensory discrimination of yoghurt samples. Hedonic taste/flavour ratings on mixed yoghurts were significantly higher than coconut yoghurt under the sensory booths. But the liking scores between mixed yoghurt and coconut yoghurt were not significantly different under ARC. Similarly, the difference of overall liking between dairy yoghurt and coconut yoghurt was significant under ARD and not significant under the sensory booths. The human judgements of yoghurt were affected by the AR environmental settings, mainly for the hedonic responses. In general, the liking scores of coconut /dairy yoghurts were improved by the AR coconut view/dairy view. The background-related AR environmental settings may improve the liking scores of the evaluated product.

No effects of environments on emotional responses of yoghurt samples were found in the study. Two created augmented reality environments in the study played as the bridge to enhance the interaction

between consumers and the evaluated products. Although consumers were limited in the study to play with the product-related 3D holograms when sitting in the AR environments, the visual cues evoked consumer's memories or expectation of the product. One advantage of AR technology is combined the real environment with virtual environment seamlessly. The use of AR could reduce the physically uncomfortable caused by virtual reality technology in the sensory evaluation and have the big potential to develop practical advanced mixed-immersive applications in the food industry.

Limitations

The current applications of HoloLens limited the AR environments created in the study. The majority of applications in the Microsoft platform are related to games or basic video/music players. Not many applications could be used in the food study. The AR environments could be better performed by the special-designed Unity program (Unity Software Inc, San Francisco, USA), which needs AR specialists' support. For example, participants use the special application to access the evaluated samples and then, the pre-coded contextual information of the product could show up based on eye-tracking parameters. For future augmented reality sensory studies, technology can improve consumers' experiences and enhance interactions between consumers and products. For example, consumers could operate the AR headset by themselves to access the contextual information of food products.

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Appendix A

Questionnaire

A.1 General questions

1 Gender

(1) Male

(2) Female

(3) Prefer not to say

(4) Other

2 Age

(1) under 20 years

(2) 21-30 years

(3) 31-40 years

(4) 41-50 years

(5) 51-60 years

(6) more than 61 year

3 Ethnicity

(1) Everyday

(2) Two or three times a week

(3) Sometimes in a week

(4) Two or three times a month

(5) Sometimes in a month

(6) Occasionally

4 Select the reason(s) for your yoghurt consumption (you can select more than one)? Multi-select:

(1) Nutritional

(2) Taste

(3) Probiotics

(4) Health

(5) As a habit

(6) Emotional pleasant

(7) Other, explanation

5 What factor that you consider most when purchasing yoghurt? Multi-select:

(1) Flavour/taste

(2) Price

(3) Brand

(4) Type (plant-based/dairy-based yoghurts)

(5) Organic

(6) Locally produced

(7) Packaging

(8) Other, explanation

6 Do you consider yourself.....?

(1) Vegetarian

(2) Vegan

(3) Flexitarian

(4) Pescatarian

(5) None of these options (6) Other, explanation

A.2 Yoghurt evaluation questions

1 Please rate the following attributes based on your liking of the sample:

Appearance

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
1	2	3	4	5	6	7	8	9

Colour

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
1	2	3	4	5	6	7	8	9

Aroma

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
1	2	3	4	5	6	7	8	9

Taste/Flavour

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
1	2	3	4	5	6	7	8	9

Sweetness

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
1	2	3	4	5	6	7	8	9

Sourness

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
1	2	3	4	5	6	7	8	9

Mouthfeel

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
1	2	3	4	5	6	7	8	9

Viscosity

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
1	2	3	4	5	6	7	8	9

Aftertaste

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
1	2	3	4	5	6	7	8	9

Overall liking

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
1	2	3	4	5	6	7	8	9

2 Please taste this yoghurt sample and select all the sensory attributes that you think apply for the sample:

Fruity flavour	Smooth	Light
Diary flavour	Creamy	Firm
Coconut flavour	Astringent	Compact
Vanilla flavour	Homogeneous	Heavy
Sweet	Cohesive	
Sour	Thick	
Plain	Thin	

3 Please rate the following attributes based on the intensity and your liking of the taste:

Sweetness

Not at All Sweet Enough	Just About Right	Much Too Sweet
1	2	3

Sourness

Not at All Sour Enough	Just About Right	Much Too Sour
1	2	3

Dairy Flavour

Much Too Weak	Just About Right	Much Too Strong
1	2	3

Coconut Flavour

Much Too Weak	Just About Right	Much Too Strong
1	2	3

Mouthfeel

Much Too Thin	Just About Right	Much Too Thick
1	2	3

4 Would you purchase this product if it was available at a reasonable price where you normally shop?

1 No

2 Yes

5 Select all the emotions that you think apply regarding this yoghurt sample:

Adventurous	Happy	Bored
Satisfied	Interested	Disgusted
Active	Joyful	Worried
Affectionate	Loving	Aggressive
Calm	Merry	Daring
Energetic	Nostalgic	Eager
Enthusiastic	Peaceful	Guilty
Free	Pleased	Polite
Friendly	Pleasant	Steady
Glad	Secure	Understanding
Good	Warm	Wild