The Effect of Virtual Reality and Immersive Environments on Sensory Perception of Chocolate Products

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Sensory evaluation is usually carried out in traditional sensory booths which are highly controlled in order to minimise the influence from potential distractions. However, the controlled environment could affect consumers' sensory perception and their overall engagement and result in limited ecological validity. Virtual reality (VR), as an immerging technology, has attracted much attention in recent years since it is highly interactive and engaging. The acceptability and emotional responses of milk, white and dark chocolate were evaluated under three contextual settings, including the sensory booth (control) and two VR environments (360-degree videos based on VR headsets, a pleasant sightseeing tour and a live music concert). Untrained participants (N = 67) were asked to rate their liking of taste/flavour, sweetness, bitterness, cocoa flavour, dairy flavour, texture, hardness, smoothness, aftertaste and overall liking based on the 9-point hedonic scale. The just-about-right-scale (JAR) was also applied for the intensity of sweetness, bitterness, cocoa flavour, dairy flavour and overall texture. Emotions were evaluated using the check-all-that-apply (CATA) method. The results of this study showed the significant impacts of contextual settings on chocolate acceptability, especially for cocoa flavour. Besides, emotions elicited regarding dark chocolate were highly relevant to environments as well. The combination of dark chocolate and "virtual live concert" positively affected consumers' emotions as well as their hedonic responses with terms such as "adventurous" and "energetic". On the contrary, dark chocolate under the other two environments were associated with negative emotional terms, such as "bored", "worried", "disgusted" and "aggressive". Further research is needed to match each chocolate type to a suitable VR environment for more reliable and ecologically valid sensory responses. Those environments achieved by VR headsets could be useful in testing newly developed chocolate products before launching.

Keywords: Virtual reality, immersive environments, acceptability, emotions, chocolate products

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Chapter 1

Literature Review

1.1 Introduction

Virtual reality (VR) is an emerging technology that provides artificially simulated environments based on computer technology and relevant software (Thurman, 1993). The artificial environment can be either 360-degree recorded videos and pictures or animated scenes, which could be similar or completely different from the real world (Joiner, 2018). VR usually provides fully immersive environments based on VR headsets, which is different from augmented reality (AR) or mixed reality which simulates artificial objects in the real environment. There are two categories of VR, namely immersive VR and non-immersive VR (Martirosov & Kopecek, 2017). Both of them are achieved by mobilising at least two of the five basic senses of the user, which are sight and hearing. VR has become more and more common in our daily life. For example, VR can enrich people's entertainment life on the basis of immersive sensory experience regarding games, movies, travelling and even shopping (Jia & Chen, 2017). It has also been commonly applied in training and education areas, such as supporting the teaching and learning process (Smutny, Babiuch, & Foltynek, 2019). In addition, applying VR technologies in sensory science seems to be an emerging research field due to the limited ecological validity of traditional sensory booths (Stelick & Dando, 2018).

1.2 Development of virtual reality

With regard to the development of VR, it was firstly mentioned in the novel "Pygmalion's Spectacles", which was written by Stanley G.Weinbaum in 1935. It described a google-based VR system in which smell and touch can be holographically recorded (Drummond, Houston, & Irvine, 2014; Martirosov & Kopecek, 2017). In the early 1950s, an evolutionary multisensory simulator, "Sensorama" was developed by Morton Heilig. As one of the earliest VR systems, it was based on an arcade-style theatre cabinet which could simulate not only sight and hearing but also smell and touch through smell generators, fans as well as vibrating chairs (Martirosov & Kopecek, 2017). Based on the previous invention, he developed the first prototype of a head-mounted VR equipment in 1960, which was called "Telesphere Mask". There was a significant breakthrough of VR in the year of 1987 since a range of VR devices, including the Dataglove and the EyePhone head-mounted display, have been developed by Jaron Lanier (Drummond et al., 2014). In addition, NASA also contributed to the evolution of VR technology regarding the application in astronautics (Martirosov & Kopecek, 2017). People were able to access to the first few VR prototypes at the marketplace in the 1990s, such as Sega VR headset (1993) and Nintendo Virtual Boy (1995). The quality and functions of VR headsets have been dramatically developed in the past twenty years. The current VR headset is usually controlled by a controller and is able to connect to other digital devices such as cell phones.

1.3 Key characteristics

VR allows users to enter a virtual world by just using a headset. It is relatively safe since the virtual environment is standardised under controlled conditions. VR is highly engaging based on the immersive environment simulated by the relevant software (Dalgarno & Lee, 2010). The interactivity of VR technologies relies on the high-resolution 360-degree vision and 3D sound experienced by the user (Sherman & Craig, 2018). As interactivity is closely associated with the quality of the VR experience and user satisfaction, it has made up a large proportion of total investments in VR technologies (Jerald, 2015).

On the other hand, the degree of immersion perceived by the user is also important. The feeling of immersion in virtual environments also refers to the sense of presence, which is the other key characteristic of VR technologies. The specific term “presence” in VR refers to the subjective perception of being in a virtual environment, which is a psychological sense (Slater, 1999). Certain attempts have been conducted for achieving a better sense of presence in the virtual environment (Sherman & Craig, 2018). However, it has been reported that the user-perceived sense of presence could be affected by various factors, such as the characteristics of the user, their psychological activity and the types of environments they experienced (Baños et al., 2004; Diemer, Alpers, Peperkorn, Shiban, & Mühlberger, 2015). Therefore, multiple factors and dimensions should be considered in terms of improving users’ immersive VR experience.

1.4 Current application

Based on its characteristics, VR has been extensively applied in various fields, such as entertainment, training and education as well as medical (Martirosov & Kopecek, 2017; Yiannakopoulou, Nikiteas, Perrea, & Tsigris, 2015). Few studied also explored its application in tourism and manufacturing industries (Choi, Jung, & Noh, 2015; Loureiro, Guerreiro, & Ali, 2020). Apart from that, there is an emerging trend regarding its application in the field of sensory science (McCrickerd & Forde, 2016). The following part of the review focussed on the major application of VR technology, with an emphasis on sensory science.

1.4.1 Entertainment

VR has been applied successfully in the entertainment industry due to marketplace needs. It has been reported that the Compound Annual Growth Rate (CAGR) of global VR revenue is projected to be 55% in a 5-year period starting from 2018 (Research and Markets, 2017). An increasing number of companies are paying attention to VR technologies in terms of enjoyment purposes. For example, apart from the manufacturers for VR devices, some other companies who focused on social networking and media also provide VR-based 360-degree videos and 3D audio (Schütze & Irwin-Schütze, 2018). As a result of the market competition, consumers tend to spend less money on purchasing VR products than a few years ago. Besides, they have more choices regarding the available software and applications in VR products, such as video games which play an important role in VR markets (Chung, Lee, Kim, & Koo, 2018).

Plante, Aldridge, Bogden, and Hanelin (2003) investigated the effect of VR on psychological benefits during aerobic exercise. Participants (N = 88) were randomly assigned to one of three different conditions, which were moderate cycling on a stationary bicycle, playing a VR bicycle game and combining both conditions together. Each session lasted for 30 minutes. Based on their results, the combination of VR and exercise enhanced participants' enjoyment, energy, and reduced tiredness. Thus, it might be better to apply VR and exercise together for positive psychological effects. Jang and Park (2019) explored the perspectives of players toward VR games based on an integrated adoption model. They found that there were several factors that could affect players' continual intention, including indirect motivations such as interactivity and direct hindrance like perceived cost. Therefore, it is important to improve the VR experience for users by controlling both direct and indirect factors. In terms of interactivity, Hsu (2011) designed an interactive VR motion simulator for entertainment purposes. This motion simulator consisted of four basic components, which are a bilateral control interface, a motion simulator, networking and a VR device. According to the results, this interactive VR motion simulator improved the performance of virtual environments, which could be validated and improved for further application.

1.4.2 Training and education

VR technologies provide highly interactive immersive environments which can be accessed immediately. Previous research has proved the effectiveness of VR in training and education, such as increasing learning performance, facilitating usability, and enhancing interaction (Martirosov & Kopecek, 2017). Importantly, VR has a high potential for training emergency service personnel such as army, police and firefighters (Moskaliuk, Bertram, & Cress, 2013a, 2013b). As it is dangerous and costly to train them in real environments and situations, VR could be a good alternative choice for their continuous and intensive training. In addition, VR technologies also provide convenience for educational purposes that are relatively difficult to achieve. For example, VR is a helpful tool for medical students to explore delicate internal organs instead of using cadaver dissection (Nicholson, Chalk, Funnell, & Daniel, 2006).

With regard to the recent application of VR in training and education, various disciplines have been involved. Chien, Hwang, and Jong (2019) developed a spherical video-based VR environment for students to whom English is a foreign language. Students were situated in authentic English-speaking contexts and their speaking performance was reflected by a peer assessment strategy. Based on an experiment conducted in a high school English course, this approach was effective to improve learners' English in terms of speaking, critical thinking, and learning motivation. Furthermore, it was also helpful in reducing learners' anxiety. Checa and Bustillo (2019) combined VR and history teaching together. They reported that the semi-guided tour in immersive VR was an effective method which conveyed historical knowledge during the experience. Apart from that, VR has also been reported to be beneficial for subjects requiring spatial skills, such as organic chemistry (Dünser, Steinbügl, Kaufmann, & Glück, 2006; Hauptman, 2010). Edwards, Bielawski, Prada, and Cheok (2019) developed an immersive learning environment called the VR Multisensory Classroom (VRMC), which was based on a head-mounted display as well as special gloves with built-in sensors that were able to capture hand movements and give haptic feedback to the user. According to the evaluation results, the first prototype provided a highly engaging, motivated and interesting learning process for the organic chemistry subject. As a novel immersive learning approach, VR has the potential to be used for multiple educational purposes in the future.

1.4.3 Medical

VR technologies have also been applied in the medical field, especially considering clinical assessment and rehabilitation. Morel, Bideau, Lardy, and Kulpa (2015) summarised the advantages and limitations of VR in balance assessment and rehabilitation. In general, VR is usually used to control stimuli presented to patients during balance assessment. The progression of patients could, therefore, be accurately evaluated and compared with different populations. With regard to VR in balance rehabilitation, new generation tools could be created together with the development of assessing methods for these tools. It has been reported that VR-based therapy might improve walking speed and facilitate independent community ambulation (Darekar, McFadyen, Lamontagne, & Fung, 2015). Therefore, it might be applicable to balance and gait training in terms of stroke rehabilitation. On the other hand, Cikajlo and Potisk (2019) observed the clinical effectiveness of using immersive 3D VR to treat people who have Parkinson's disease. They compared the effects of immersive 3D VR and non-immersive 2D exergaming for a 3-week duration. Based on their results, participants who were treated with 3D VR performed better. However, no significant difference in clinical tests was observed between two groups of people assigned to different environments. They concluded that the immersive 3D VR might contribute to a higher enjoyment score, which is associated with better functional performance than non-immersive 2D exergaming.

1.4.4 Sensory science

Apart from the application fields discussed above, there is an emerging research interest regarding the application of immersive environments or VR in sensory science. The eating environment is considered to have significant impacts on consumers' sensory perception as well as hedonic responses towards most food products (Stelick & Dando, 2018). In sensory science, booths are normally used for the evaluation of food products. However, consumers' sensory responses under booths may not be relevant to their actual experience since the testing environment is highly controlled. This could be one of the reasons why many novel products which are the most liked in consumer trails, fail in a short time period after launching to the marketplace (Köster, 2009). The highly controlled sensory booths do not reflect the real situation, and eventually, the obtained results from such setup would have low ecological validity (Crofton, Botinestean, Fenelon, & Gallagher, 2019). Therefore, the interest in using VR technologies in sensory science has increased dramatically in recent years.

Few studies combining VR technologies and sensory science have been conducted in recent years. Some of them improved the ecological validity of sensory tests by simulating physically immersive environments, such as a bar, a coffeehouse and an aeroplane (Bangcuyo et al., 2015; Holthuysen, Vrijhof, de Wijk, & Kremer, 2017; Sester et al., 2013). Sinesio et al. (2018) explored the overall liking and perceived freshness of tomato and wild rocket salads when they were tasted under two settings, an immersive environment and a traditional booth. They evaluated the utility of an immersive multisensory room which was designed to simulate conditions close to real life. The immersive environment was majorly based on large wall screen projections of a 7-min holiday farm video. They observed higher liking scores of both vegetables when they were consumed in the immersive multisensory room. However, the discrimination efficacy of different freshness of both vegetables was lower in the immersive environment than in the booth. Further research might be needed to determine if the results are product dependent and if they are influenced by the immersive environments. Most recently, Picket and Dando (2019) tested how context influences the sensory perception of two alcoholic drinks, beer and sparkling wine. Two virtual settings including a bar and a winery were formed based on 360-degree videos and overlaying audio. They observed that participants felt more appropriate when they consumed beer and sparkling wine in the virtual bar and winery settings, respectively. In addition, consumers tended to be more willing to pay for the sparkling wine in the winery setting. In general, the perceived appropriateness and enjoyment of the eating process for certain food products could be largely influenced by the context. Therefore, it is better to take context into consideration when we carry out sensory tests.

Although only a few studies have been conducted, their results were positive and promising, which highlighted the importance of context as well as ecological validity. The application of VR technologies in sensory science helps us to better understand ecologically valid consumer experiences for certain food products (Ares, 2019). Thus, it is necessary and important to further investigate this field. VR headsets could be considered as a practical choice to achieve the ecologically valid sensory results since they are highly interactive. As they have been rarely applied in sensory science, it could be a possible gap to be investigated in the next few years.

1.5 Objective

This research aimed to investigate the effect of immersive VR environments on consumers' sensory acceptability and emotional responses of three major chocolate types, which are white chocolate, milk chocolate, and dark chocolate. Three contextual settings were applied in the sensory evaluation process, including two 360-degree recorded videos achieved by VR headsets, and a traditional sensory booth which was the control setting. As the increasing awareness of limited ecological validity in sensory tests, this study also aimed to explore the potential of VR technology as a support in regular sensory tests.

Chapter 2
Materials and Methods

2.1 Participants

A total number of 67 untrained participants (31 males and 36 females, from 20 to 50 years old) were recruited voluntarily through Lincoln University intranet. All participants claimed that they were not allergic to the chocolate ingredients involved in this research. A brief introduction about products and sensory procedures was given first. According to Lincoln University Policies and Procedures (2019-68), they were asked to complete the consent form regarding human ethics before tasting the chocolate products. Sensory sessions were carried out at the sensory laboratory located in RFH building, Lincoln University, Lincoln, New Zealand. There were three sessions conducted on four consecutive days, which were one control session using sensory booths and two sessions using VR settings. The duration of each session was around 15 to 25 minutes per participant, and the order of three sessions was randomised for each participant. Participants were asked to refrain from eating, drinking, and smoking for at least one hour before the sessions.

2.2 Stimuli

Three major chocolate types were used in this research, including Whittaker's 28% Cocoa White Chocolate, Whittaker's 33% Cocoa Creamy Milk Chocolate and Whittaker's 72% Cocoa Dark Ghana Chocolate (J.H. Whittaker & Sons, Ltd, Porirua, New Zealand). These chocolate products were purchased from a local supermarket before conducting sensory sessions. They were purchased in blocks and served in squares, and they were stored in sealed containers at 4 ℃ in a refrigerator (Samsung, Seoul, South Korea) when they were not in use. The preparation and sampling process were conducted within two hours prior to the sensory sessions to prevent chocolate samples from being stale. Three stimuli (white, milk and dark chocolate) were assessed preliminarily by a focus group panel (N = 4) within Lincoln university to make sure they have notable differences in terms of certain attributes, such as sweetness and cocoa flavour. In each sensory session, each chocolate square was served in a transparent plastic cup coded with a 3-digit random number for identification. The presentation order of the three samples was randomised and balanced for each participant to prevent bias.

2.3 Sensory procedure

At the beginning of sensory sessions, a brief explanation of the procedures was given to all participants. They were instructed regarding the proper operation and wearing of the VR headsets as well as how to answer questions in tablets. Three sensory sessions were randomly carried out for each participant. After signing the consent form, participants were instructed to evaluate three randomly ordered chocolate samples from left to right under one of three contextual settings (booth or two VR settings). In the questionnaire, participants were asked to rate the acceptability of ten attributes of each chocolate sample, including taste/flavour, sweetness, bitterness, cocoa flavour, dairy flavour, texture, hardness, smoothness, aftertaste and overall liking. The acceptability test was based on the 9-point hedonic scale, which represented nine hedonic responses using number 1 (dislike extremely) to 9 (like extremely) with a neutral response at 5 (neither like nor dislike) (Peryam & Pilgrim, 1957). Sweetness, bitterness, cocoa flavour, dairy flavour and overall texture were also evaluated by a just-about-right-scale (JAR) in terms of both intensity and acceptability (1 = too little, 2 = just about right, 3 = too much for sweetness, bitterness, cocoa flavour and dairy flavour; 1 = too soft, 2 = just about right, 3 = too hard for overall texture; Li, Hayes, and Ziegler, 2014). The next question was purchase intent of each chocolate sample (Would you purchase this product if it was available at a reasonable price where you normally shop?), and the answer was based on a binomial scale (1 = No, 2 = Yes). The last section of this questionnaire was the evaluation of emotional responses. The check-all-that-apply (CATA) method was used with a list of 33 emotional terms that were pre-selected previously from 48 original terms (Ng, Chaya, & Hort, 2013; Torrico et al., 2018). These terms were adventurous, satisfied, active, affectionate, calm, energetic, enthusiastic, free, friendly, glad, good, happy, interested, joyful, loving, merry, nostalgic, peaceful, pleased, pleasant, secure, warm, bored, disgusted, worried, aggressive, daring, eager, guilty, polite, steady, understanding and wild. Plain crackers and water were used to cleanse participants' palate in between different chocolate samples.

2.4 Contextual settings

Three contextual settings were used in this research, including the traditional sensory booth which was the control setting and two VR settings achieved by VR headsets. The sensory booth was located at the RFH building, Lincoln University, Lincoln, New Zealand. Individual booth units were separated by a solid protection panel, and there was a worktop within each isolated booth unit for placing samples and tablets (Figure 2.1, a and c). The booth temperature was set to 18 ℃, and white-colour fluorescent lights were used during the whole sensory evaluation process.

For sensory sessions associated with the two VR settings, they were carried out in an isolated focus room which differs from the booth (Figure 2.1b). Four Oculus Go All-in-One VR Headsets (32 GB) with independent controllers were used for the generation of immersive VR environments (Oculus VR, LLC., Menlo Park, California, U.S.). Both VR environments were 360-degree videos selected from a video, movie and photo platform called VeeR VR, which was available within the VR headset itself

(VeeR VR, San Francisco, U.S.). VeeR VR is a premium VR entertainment platform with more than ten thousand high-quality videos, photos, and interactive experiences. The VR settings used for this research were selected by a focus group (N = 4) from a list of 14 preliminarily evaluated 360-degree videos (VeeR VR). There were at least two instructors to help participants wear the VR headsets and place samples during the entire sensory session under VR settings. Chocolate samples were served to participants after they were wearing the headsets and earphones. Participants were instructed to take headsets off and start answering questions on tablets when they finished tasting. This process was repeated for each participant until the tasting of all three chocolate samples has been completed under each VR setting.

With regard to the VR environments, they were two 360-degree recorded videos (VeeR VR) that could elicit different feelings and emotions from participants. The first VR environment was titled as "Pure relaxation in the luxurious apartments Vidamar resorts Algarve". As shown in Figure 2.1 (d1-d3), this video was a sightseeing tour in a 5-star hotel located in Guia, Portugal. It had a duration of 41 minutes along with relaxing music, which showed beautiful sceneries such as a nice swimming pool and a peaceful beach. The second VR environment was titled "Elemental Live – Halloween" (Figure 2.1, e1 and e2), which had a duration of 54 minutes. It was a noisy live music concert, which was held on a cloudy day and was crowded with people. The first and second VR environments were represented by the labels positive VR (PVR) and negative VR (NVR) respectively for convenience, and B was used to represent traditional sensory booths as well.

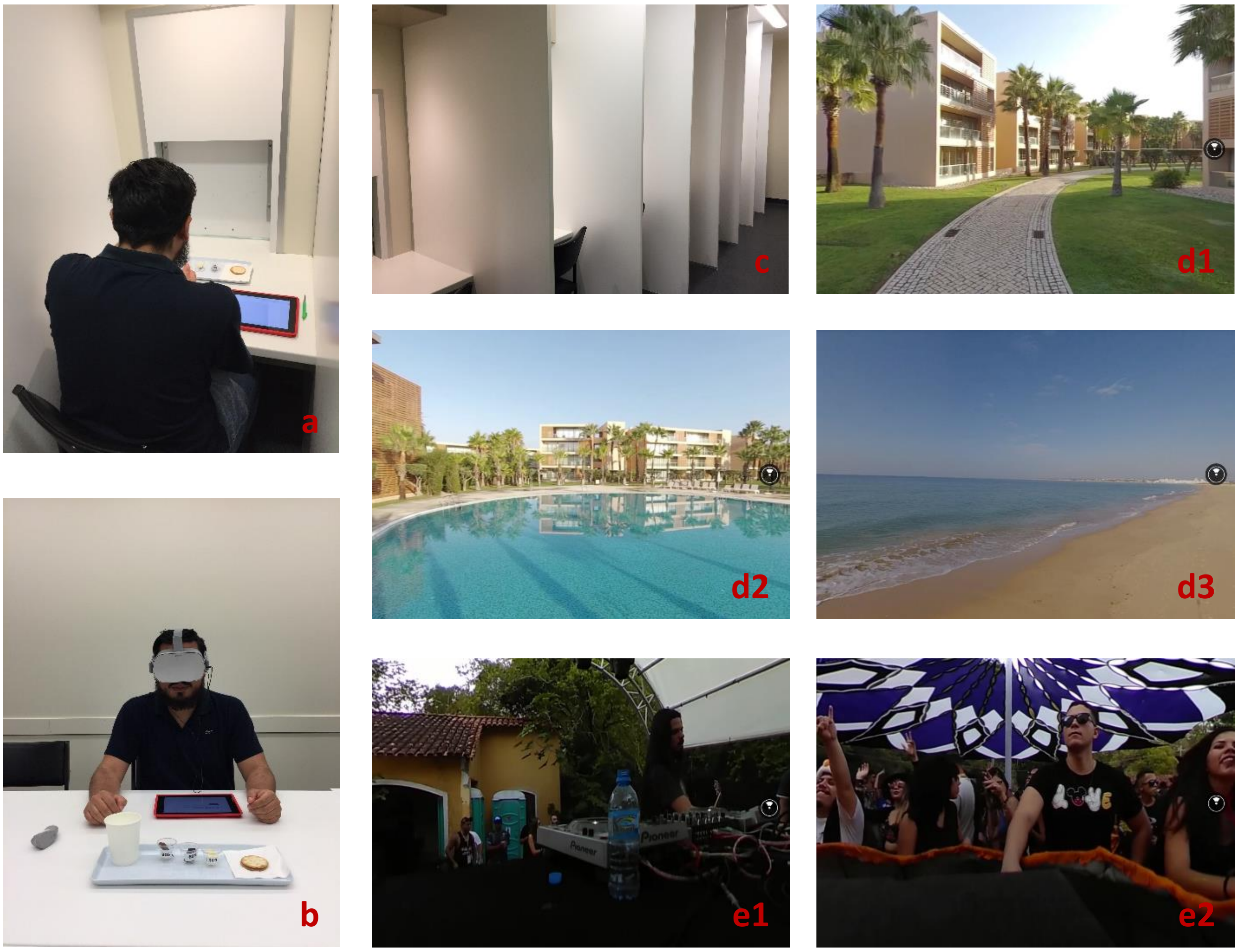

Figure 2.1 Contextual settings* for the sensory evaluation of chocolate products
*a: booth set up, b: VR set up, c: sensory booth setting, d1-3: positive VR setting, e1-2: negative VR setting; VR environments were obtained from the VeeR VR app (VeeR VR, San Francisco, U.S.)

2.5 Statistical analysis

A 3 × 3 factorial design was used in this research, which referred to three chocolate products and three contextual settings. The hedonic scores derived from three chocolate samples under different settings were analysed using analysis of variance (AVOVA) with a generalised linear model (GLM). Mean comparisons were carried out by a post-hoc Tukey's Honestly Significantly Different (HSD) test. Penalty analysis was applied to the JAR data in order to determine how much the overall liking and acceptance of chocolate samples were influenced by their attributes. The effect of contextual settings was also considered in this research. The CATA emotional responses of chocolate samples under different settings were assessed by Cochran's Q test, Correspondence Analysis (CA) and Principal Coordinate Analysis (PCoA) (Gunaratne et al., 2019; Sharma, Swaney-Stueve, Severns, & Talavera, 2019; Torrico et al., 2018). With regard to the purchase intent, it was analysed for multiple comparison based on Cochran's Q test and simultaneous confidence intervals testing as well. Principal Component Analysis (PCA) was used to analyse the relationship between hedonic acceptability of ten attributes and chocolate samples under different environmental settings. The PCA results were presented as a product-attribute biplot. Chocolate samples under different settings were categorised by Agglomerative Hierarchical Cluster (AHC) Analysis. The dissimilarity of them was analysed based on the Euclidean distance and the Ward's method. The responses given through an electronic questionnaire were collected by RedJade Sensory Software (Martinez, California, U.S.). Data were analysed using Minitab 18 (Minitab, LLC, State College, Pennsylvania, U.S.) and XLSTAT Statistical Software 2016 (Addinsoft, New York, U.S.). A confidence level of 95% was applied to the statistical analysis, and data were presented as mean ± SEM.

Chapter 3

Results

3.1 The effect of environments on sensory acceptability of chocolate products

3.1.1 Hedonic ratings

Table 3.1 shows the analysis of variance (ANOVA) results of treatment effects on liking scores of ten evaluated sensory attributes, including taste/flavour, sweetness, bitterness, cocoa flavour, dairy flavour, texture, hardness, smoothness, aftertaste, and overall liking. Chocolate types (milk, white, dark) and environments (PVR, NVR, B) were two major factors in this research. In addition, the interaction between chocolate types and environments was also considered. As can be seen in Table 3.1, liking scores of all attributes were significantly affected by the type of chocolate products ($p < 0.05$). Importantly, the environment also had a significant effect on the liking of cocoa flavour of chocolate products ($p < 0.05$). As compared to the two individual factors, the interaction between chocolate types and environments did not significantly affect liking scores of the evaluated sensory attributes ($p > 0.05$).

Table 3.1 ANOVA* table for liking scores of sensory attributes

Treatment Effects*	Sensory Attributes									
	Taste/Flavour		Sweetness		Bitterness		Cocoa Flavour		Dairy Flavour	
	F**	P**	F	P	F	P	F	P	F	P
Chocolate	70.80	***<0.01***	32.42	***<0.01***	26.37	***<0.01***	21.15	***<0.01***	66.19	***<0.01***
Environment	1.50	0.22	1.38	0.25	1.15	0.32	3.11	***<0.05***	0.57	0.57
Chocolate*Environment***	0.78	0.54	0.40	0.81	0.34	0.85	0.09	0.99	0.04	1.00
Treatment Effects	**Sensory Attributes**									
	Texture		**Hardness**		**Smoothness**		**Aftertaste**		**Overall Liking**	
	F	**P**	**F**	**P**	**F**	**P**	**F**	**P**	**F**	**P**
Chocolate	30.35	***<0.01***	37.70	***<0.01***	84.88	***<0.01***	58.91	***<0.01***	67.93	***<0.01***
Environment	0.12	0.88	0.28	0.76	0.34	0.71	0.43	0.65	1.09	0.34
Chocolate*Environment	1.09	0.36	0.48	0.75	0.18	0.95	0.69	0.60	0.24	0.92

*ANOVA: Analysis of variance [3 types of chocolate products (milk, white and dark) and 3 contextual settings (positive VR, negative VR and sensory booth); Liking scores were based on the 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely; Peryam & Pilgrim, 1957)
F: F-value, mean square/mean square error; P: *p* value, treatment effects are considered as significant if the *p* value was less than 0.05 (significant results were ***italicised and bolded*)
***The effect was associated with both chocolate types and environments

The mean values and standard error of the liking scores of three chocolate products (milk, white, dark) under three different environments (PVR, NVR, B) are shown in Table 3.2. In general, milk chocolate had the highest liking scores of the evaluated sensory attributes, followed by white chocolate. However, the two types of chocolate products (milk and white) were not significantly different regarding the liking scores of most attributes (p > 0.05) except cocoa flavour (p < 0.05). Milk chocolate under PVR and white chocolate under B scored 6.51 ± 0.20 and 5.06 ± 0.24, respectively, for the liking of cocoa flavour, which were significantly different from each other (p < 0.05). Dark chocolate was the least liked chocolate type, and its liking scores of taste/flavour, dairy flavour, smoothness, aftertaste and overall liking were significantly different from other two chocolate types regardless of environments (p < 0.05). Considering the effect of environments, there was no significant differences among PVR, NVR and B within the same type of chocolate product (p > 0.05). The liking scores of the evaluated attributes under PVR were similar and generally high for both milk chocolate and white chocolate, whereas generally high liking scores of evaluated attributes were obtained under NVR for dark chocolate.

Table 3.2 Liking scores* of chocolate products under different environments

Treatments**		Sensory Attributes				
Chocolate	**Environment**	**Taste/Flavour**	**Sweetness**	**Bitterness**	**Cocoa Flavour**	**Dairy Flavour**
	PVR	6.73 ± 0.22^{a}	6.48 ± 0.23^{a}	5.96 ± 0.21^{a}	6.51 ± 0.20^{a}	6.69 ± 0.21^{a}
Milk	NVR	6.63 ± 0.23^{a}	6.30 ± 0.25^{a}	5.67 ± 0.21^{ab}	6.27 ± 0.21^{ab}	6.66 ± 0.23^{a}
	B	6.78 ± 0.20^{a}	6.36 ± 0.23^{a}	5.82 ± 0.22^{a}	6.15 ± 0.22^{ab}	6.49 ± 0.22^{a}
	PVR	6.58 ± 0.22^{a}	6.25 ± 0.25^{a}	5.51 ± 0.22^{abc}	5.51 ± 0.22^{bc}	6.25 ± 0.25^{a}
White	NVR	6.57 ± 0.21^{a}	6.02 ± 0.26^{a}	5.51 ± 0.20^{abc}	5.40 ± 0.21^{bc}	6.24 ± 0.22^{a}
	B	6.19 ± 0.25^{a}	5.67 ± 0.29^{ab}	5.22 ± 0.23^{abcd}	5.06 ± 0.24^{c}	6.13 ± 0.27^{a}
	PVR	4.99 ± 0.26^{b}	5.05 ± 0.26^{b}	4.76 ± 0.28^{bcd}	5.55 ± 0.27^{bc}	4.78 ± 0.26^{b}
Dark	NVR	5.06 ± 0.25^{b}	5.03 ± 0.24^{b}	4.64 ± 0.26^{cd}	5.40 ± 0.25^{bc}	4.88 ± 0.21^{b}
	B	4.55 ± 0.29^{b}	4.85 ± 0.26^{b}	4.40 ± 0.31^{d}	5.08 ± 0.30^{c}	4.66 ± 0.23^{b}
Treatments		**Sensory Attributes**				
Chocolate	**Environment**	**Texture**	**Hardness**	**Smoothness**	**Aftertaste**	**Overall Liking**
	PVR	6.79 ± 0.21^{a}	6.73 ± 0.20^{a}	7.10 ± 0.18^{a}	6.49 ± 0.23^{a}	6.87 ± 0.22^{a}
Milk	NVR	6.57 ± 0.23^{ab}	6.60 ± 0.22^{a}	7.08 ± 0.20^{a}	6.31 ± 0.24^{a}	6.93 ± 0.21^{a}
	B	6.75 ± 0.21^{a}	6.61 ± 0.20^{a}	7.13 ± 0.17^{a}	6.70 ± 0.23^{a}	6.79 ± 0.21^{a}
	PVR	6.72 ± 0.20^{a}	6.55 ± 0.19^{a}	6.79 ± 0.21^{a}	6.28 ± 0.26^{a}	6.43 ± 0.24^{a}
White	NVR	6.55 ± 0.18^{ab}	6.34 ± 0.20^{ab}	6.70 ± 0.20^{a}	6.08 ± 0.27^{a}	6.33 ± 0.26^{a}
	B	6.48 ± 0.23^{abc}	6.58 ± 0.20^{a}	6.54 ± 0.22^{a}	5.99 ± 0.26^{a}	6.16 ± 0.26^{a}
	PVR	5.34 ± 0.24^{d}	5.27 ± 0.26^{c}	5.36 ± 0.24^{b}	4.78 ± 0.27^{b}	4.91 ± 0.27^{b}
Dark	NVR	5.67 ± 0.21^{cd}	5.46 ± 0.24^{c}	5.24 ± 0.23^{b}	4.70 ± 0.28^{b}	5.13 ± 0.25^{b}
	B	5.79 ± 0.25^{bcd}	5.55 ± 0.25^{bc}	5.22 ± 0.25^{b}	4.46 ± 0.30^{b}	4.70 ± 0.29^{b}

*Liking scores were based on the 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely; Peryam & Pilgrim, 1957); Results were expressed as mean ± SEM (standard error of the mean, N = 67)
**3 types of chocolate products (milk, white and dark) were tested under 3 contextual settings (PVR: positive VR, NVR: negative VR and B: sensory booth)
$^{a\text{-}d}$ Results with different superscripts in each column within each attribute indicate significant differences (Tukey's HSD test, *p* < 0.05)

3.1.2 Just-about-right (JAR) results

Figure 3.1 to 3.3 show the JAR frequencies (%) and mean drops based on penalty analysis for three chocolate products (milk, white, dark) under three environments (PVR, NVR, B), regarding their sweetness, bitterness, cocoa flavour, dairy flavour and overall texture. As shown in Figure 3.1, milk chocolate had the highest selections of JAR for cocoa flavour (75%) and overall texture (81%) under

B, whereas the highest proportion of participants (75%) selected JAR for dairy flavour under PVR. Milk chocolate under NVR had highest selections of “too little/soft” for both cocoa flavour (31%) and overall texture (27%), and “too much” for dairy flavour (27%). The frequencies of sweetness and bitterness for milk chocolate were similar under three environments. For white chocolate (Figure 3.2), JAR was selected most frequently for sweetness (46%) and overall texture (87%) under B, as well as for bitterness (46%) and cocoa flavour (54%) under PVR. White chocolate under NVR had the highest selection of JAR for dairy flavour (63%). Selections of “too much/hard” for bitterness (0-1%), cocoa flavour (0%) and overall texture (4-9%), as well as “too little” for sweetness (0-1%) and dairy flavour (3-10%) of white chocolate were negligible regardless of environments. With regard to dark chocolate (Figure 3.3), JAR was selected most frequently for sweetness (46%), bitterness (40%), cocoa flavour (54%), and overall texture (63%) under PVR. Dark chocolate under NVR had the highest selection of JAR for dairy flavour (37%). The frequencies of “too much” regarding sweetness, dairy flavour and “too little/soft” regarding bitterness, cocoa flavour, overall texture of dark chocolate under three environments were negligible.

Penalty analysis was conducted based on both JAR frequencies and the overall liking scores of chocolate products considering the environments. As shown in Figure 3.1 to 3.3, the threshold for the population size was set as 20%. The attributes that appeared in the upper right-hand corner of the penalty plot were considered to have negative effects on the liking of products since more than 20% of people thought they were either “too much/hard” or “too little/soft” (Palazzo & Bolini, 2017). Accordingly, both milk chocolate and white chocolate were penalised for being too sweet and not bitter enough, which was opposite to dark chocolate. Milk chocolate under both PVR and NVR were penalised due to not enough cocoa flavour. In addition, “too much” dairy flavour for milk chocolate under both NVR and B also affected their overall liking scores. The penalty analysis results for both white chocolate and dark chocolate were generally consistent under three environments, of which cocoa flavour and dairy flavour were penalised for being “too little” and “too much” for white chocolate respectively, whereas the opposite happened with dark chocolate. Moreover, the liking of dark chocolate seemed to be affected by its hard texture as well.

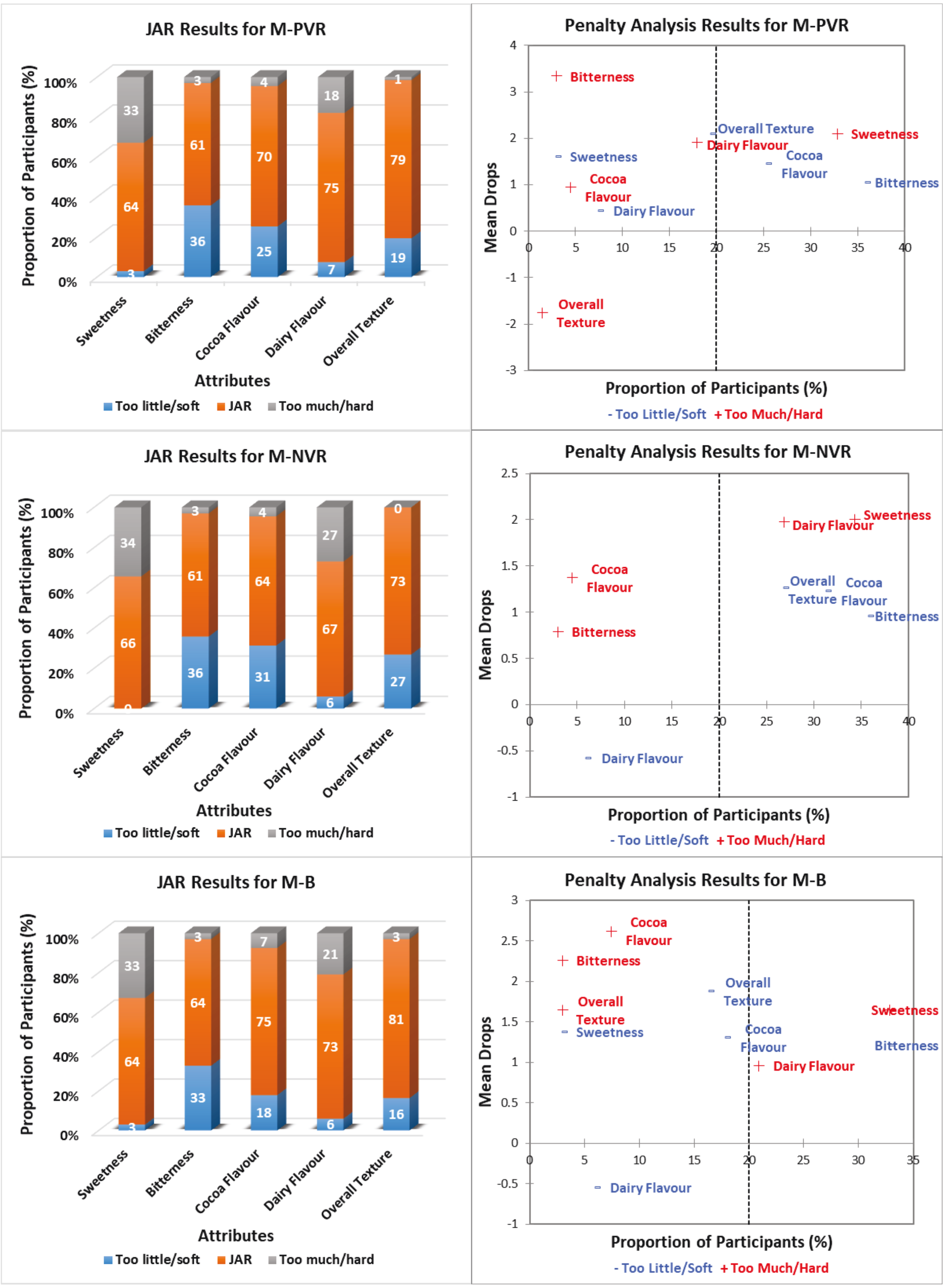

Figure 3.1 Just-About-Right (JAR) frequencies and penalty analysis results* regarding milk chocolate attributes under different environments**

* Penalty analysis was associated with the overall liking scores (9-point hedonic scale)

**M-PVR: milk chocolate-positive VR; M-NVR: milk chocolate-negative VR; M-B: milk chocolate-sensory booth

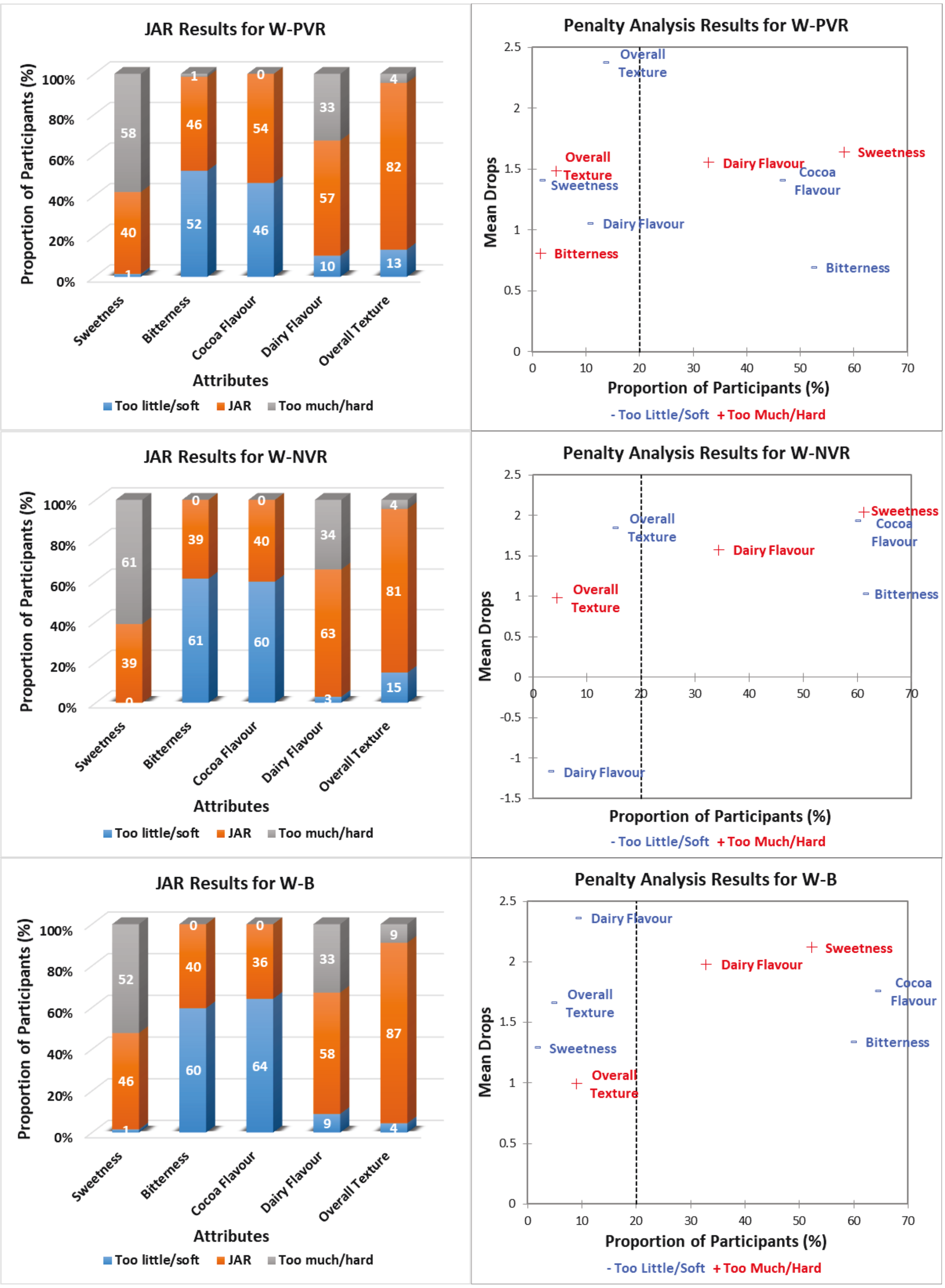

Figure 3.2 Just-About-Right (JAR) frequencies and penalty analysis results* regarding white chocolate attributes under different environments**

* Penalty analysis was associated with the overall liking scores (9-point hedonic scale)

**W-PVR: white chocolate-positive VR; W-NVR: white chocolate-negative VR; W-B: white chocolate-sensory booth

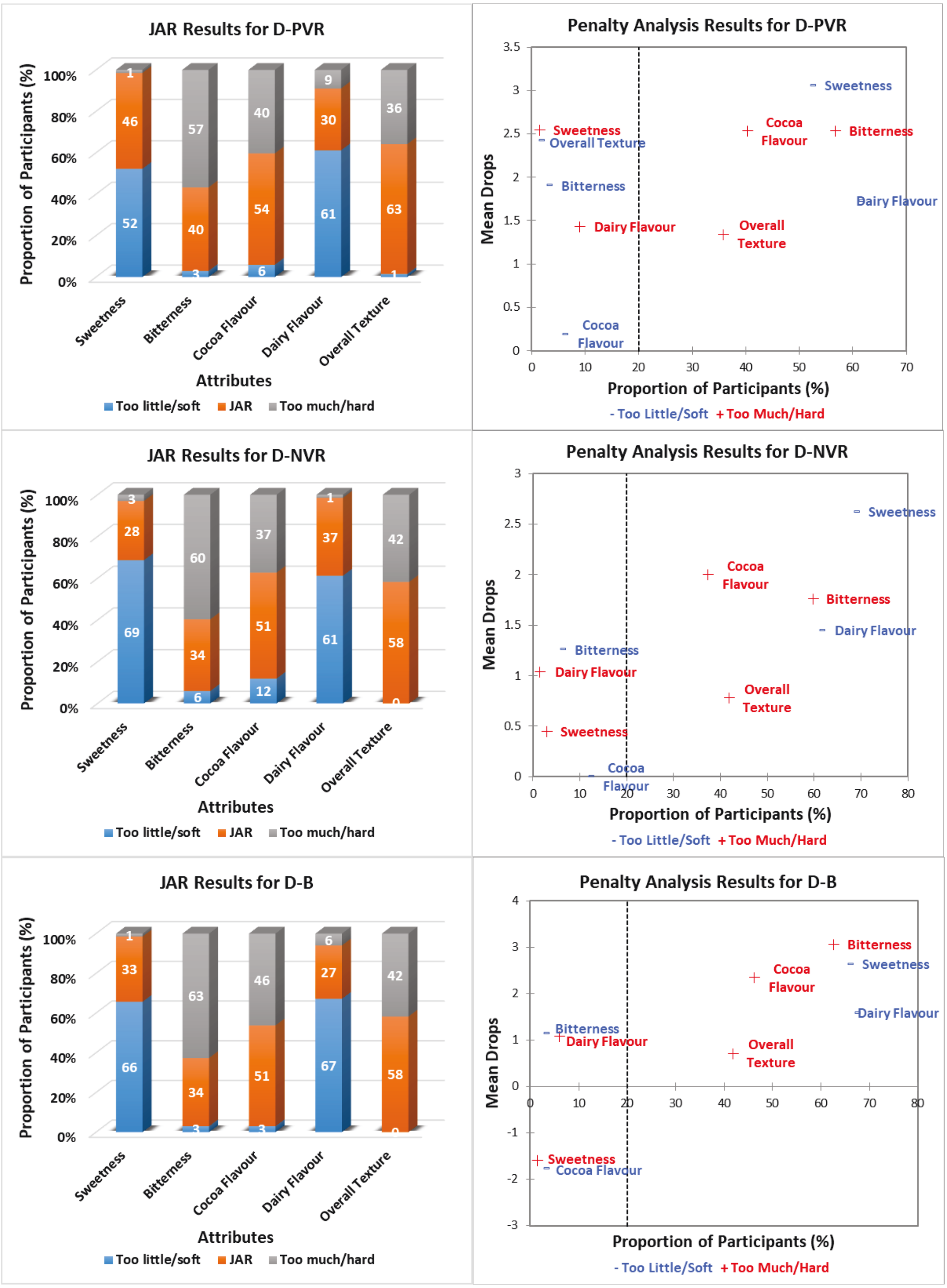

Figure 3.3 Just-About-Right (JAR) frequencies and penalty analysis results* regarding dark chocolate attributes under different environments**

* Penalty analysis was associated with the overall liking scores (9-point hedonic scale)

**D-PVR: dark chocolate-positive VR; D-NVR: dark chocolate-negative VR; D-B: dark chocolate-sensory booth

3.2 Multivariate analysis of chocolate products under different environments

3.2.1 Emotional responses

According to Cochran's Q test results, a total number of 23 emotional terms were significant, including adventurous, satisfied, active, calm, affectionate, energetic, enthusiastic, friendly, glad, good, happy, interested, joyful, loving, peaceful, pleased, pleasant, bored, disgusted, worried, aggressive, polite as well as wild (Table A). Figure 3.4 shows the Correspondence Analysis (CA) and Principal Coordinate Analysis (PCoA) results. The CA displays relationships between emotional terms obtained based on CATA method and three chocolate products considering the contextual effect. As shown in Figure 3.4a, the principal component one (PC1) and principal component two (PC2) were 63.43% and 22.86% respectively, which explained 86.29% of data variability in total. According to CA results, milk chocolate and white chocolate under PVR and B were found to share similar profiles, which were associated with both neutral and positive emotional descriptors such as "peaceful", "pleasant", "good", "satisfied", "glad", "pleased" and "polite". Milk and white chocolate under NVR were also associated with positive terms, such as "affectionate", "interested", "happy", "loving", "joyful" and "friendly". Dark chocolate had highly distinctive groups of emotional terms under either NVR or PVR/B. With regard to D chocolate under NVR, it was related to ardent descriptors including "adventurous", "energetic", "wild", "active" and "enthusiastic". In contrast, Dark chocolate under PVR and B were related to negative terms, such as "bored", "worried", "disgusted" and "aggressive".

The PCoA results show the relationship between emotional terms and the overall liking scores of three chocolate products under three different contextual settings (Figure 3.4b). Only the terms "aggressive", "disgusted", "worried" and "bored" were selected in relation to the lowest mean values (< 5.0) for the overall liking of chocolate products under different environments. It was also shown in Figure 3.4b, where these four descriptors were the farthest from the overall liking label. However, terms such as "pleased", "glad", "good", "loving", "friendly", "peaceful", "pleasant", "affectionate", "satisfied" and "joyful" contributed to higher overall liking scores of chocolate products considering the contextual effect (> 5.0).

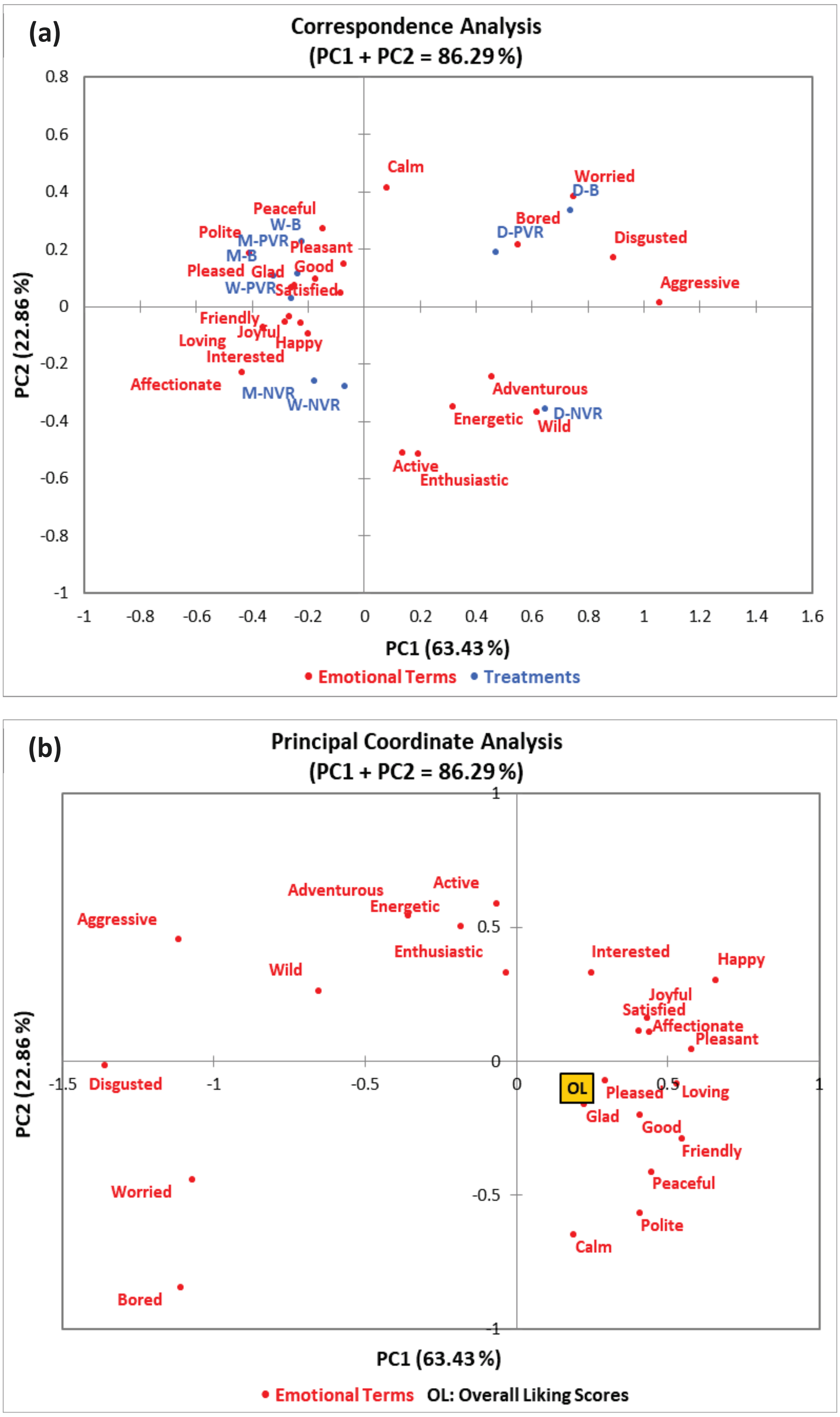

Figure 3.4 **(a) Correspondence Analysis (CA) of emotional terms for chocolate products tasted under different contextual settings*; (b) Principal Coordinate Analysis (PCoA) of emotional terms regarding the overall liking scores**

*M-PVR: milk chocolate-positive VR; M-NVR: milk chocolate-negative VR; M-B: milk chocolate-sensory booth; W-PVR: white chocolate-positive VR; W-NVR: white chocolate-negative VR; W-B: white chocolate-sensory booth; D-PVR: dark chocolate-positive VR; D-NVR: dark chocolate-negative VR; D-B: dark chocolate-sensory booth

3.2.2 Principal component and cluster analyses of the chocolate products under different environments

The Principal Component Analysis (PCA) and Agglomerative Hierarchical Clustering (HCA) results are shown in Figure 3.5. PCA biplot visualised the associations between liking scores of ten attributes and three chocolate products (milk, white, dark) considering the contextual effect (Figure 3.5a). The principal component one (PC1) and principal component two (PC2) were 91.72% and 6.64% respectively, explaining totally 98.36% of data variability. Liking vectors of most attributes were well linked with the horizontal axis, which was PC1 (squared cosines varied from 0.91 to 0.99, data not shown). The liking vector of cocoa flavour was aligned with the vertical axis, which was PC2 (squared cosine was 0.53, data not shown). Liking vectors of most attributes except cocoa flavour were close to each other in Figure 3.5a, indicating their positive association. In addition, the liking vector of cocoa flavour was not well correlated with liking vectors of hardness and texture since they were almost orthogonal. In terms of chocolate products, milk chocolate was highly correlated with the liking of cocoa flavour under PVR and NVR, and milk chocolate under B was more correlated with the overall liking as well as the liking of bitterness, sweetness, smoothness, dairy flavour, aftertaste and taste/flavour. In addition, white chocolate was relatively associated with the liking of hardness and texture under PVR and NVR. However, dark chocolate was negatively correlated with the liking of all evaluated attributes regardless of the contextual effects.

Figure 3.5b shows the dendrogram based on AHC for 9 chocolate-environment combinations (3 × 3 factorial design). Three main cluster groups were formed, which were (1) dark chocolate under all environments, (2) milk chocolate under all environments, (3) white chocolate under all environments.

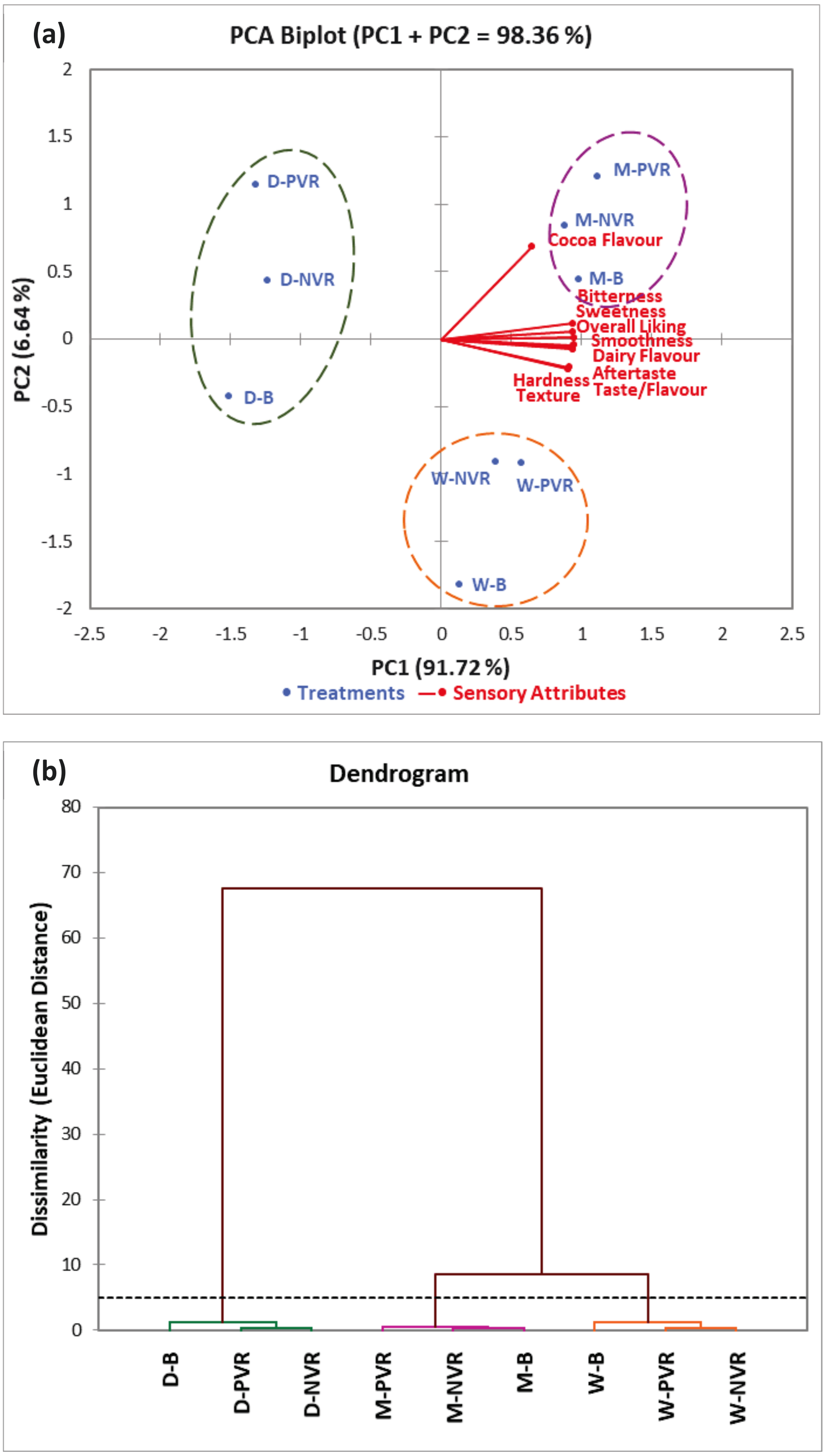

Figure 3.5 **(a) Principal Component Analysis (PCA) biplot regarding liking scores* of chocolate attributes in different environments**; (b) Dendrogram of Agglomerative Hierarchical Clustering (AHC) grouping chocolate products under different environments****

*Liking scores were based on the 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely)

**M-PVR: milk chocolate-positive VR; M-NVR: milk chocolate-negative VR; M-B: milk chocolate-sensory booth; W-PVR: white chocolate-positive VR; W-NVR: white chocolate-negative VR; W-B: white chocolate-sensory booth; D-PVR: dark chocolate-positive VR; D-NVR: dark chocolate-negative VR; D-B: dark chocolate-sensory booth

3.3 The effect of environments on the purchase intent of chocolate products

The frequencies of purchase intent for three chocolate products (milk, white, dark) under three environments (PVR, NVR, B) are shown in Table 3.3. In general, milk chocolate had the highest purchase intent (64.2-73.1%), followed by white chocolate (56.7-62.7%), and dark chocolate had the lowest purchase intent (31.3-43.3%). Milk chocolate and white chocolate were not significantly different in their purchase intent under all environments ($p > 0.05$). However, milk chocolate had significantly higher purchase intent than dark chocolate under PVR, NVR, and B respectively ($p < 0.05$). Although PVR had the highest purchase intent for all three chocolate products, there were no significant differences among the three environments within each chocolate type ($p > 0.05$).

Table 3.3 Purchase intent frequencies of chocolate products under different environments

Treatments*		Willingness to Purchase (%)**
Chocolate	Environment	
Milk	PVR	73.1^{a}
	NVR	64.2^{ab}
	B	70.1^{a}
White	PVR	62.7^{ab}
	NVR	61.2^{ab}
	B	56.7^{abc}
Dark	PVR	43.3^{bc}
	NVR	31.3^{c}
	B	34.3^{c}

*3 types of chocolate products (milk, white and dark) were tested under 3 contextual settings (PVR: positive VR, NVR: negative VR and B: sensory booth)
**Cochran's Q test was used together with Marascuilo procedure for multiple pairwise comparisons (N = 67)
$^{a-c}$ Frequencies with different superscripts within the same column indicate significant differences (Cochran's Q test and Marascuilo procedure, $p < 0.05$)

Chapter 4

Discussion

4.1 The effect of environments on sensory acceptability of chocolate products

4.1.1 Hedonic ratings

In the present study, the type of chocolate was found to have significant effects on the hedonic ratings towards certain sensory attributes (Table 3.1). Milk chocolate seemed to be the most liked product, followed by white chocolate, and dark chocolate seemed to be the least liked one (Table 3.2). The three types of chocolate products used in this research varied in cocoa content, which were 28% (white), 33% (milk), and 72% (dark). Therefore, their sensory attributes could be largely affected by their ingredients, such as sweetness, bitterness and cocoa flavour. Glicerina, Balestra, Dalla Rosa, and Romani (2016) reported that these three chocolate types also have different textual properties. White chocolate has less aggregate structure and the lowest viscosity, whereas dark chocolate has the highest aggregate structure and fewer void spaces between particles. The microstructure and rheological properties of milk chocolate are in-between, which could be the reason for the highest liking scores. It has been reported that consumers prefer less hard and light chocolate products, which could be a support for the findings of the present research as well (Kulozik, Tolkach, Bulca, & Hinrichs, 2003).

As reported by Stelick and Dando (2018), the environment where food products are consumed could affect sensory perception. Some research has already investigated the effect of immersive environments on consumers' responses, such as the enjoyment and purchase intent of alcoholic drinks (Picket & Dando, 2019). The hedonic ratings tend to be higher under immersive environments rather than under the booth (Sinesio et al., 2018). In the present study, the acceptability of chocolate cocoa flavour was found to be significantly affected by the contextual settings (Table 3.1). Chocolate products generally had higher liking scores (but not significant, $p > 0.05$) under PVR and NVR compared to the traditional sensory booth (Table 3.2). Both milk chocolate and white chocolate scored similar and higher liking scores under PVR, whereas Dark chocolate under NVR seemed to be the right combination for better hedonic responses (Table 3.2).

4.1.2 JAR results

JAR results can describe both acceptability and intensity towards sensory attributes of products. The data obtained by JAR scale are usually analysed by penalty analysis, which identifies potential direction where products could be improved (Plaehn, 2013). Three types of chocolate products had various JAR frequencies (%) in this study. In general, milk chocolate seemed to be the most acceptable one among the three chocolate types since its JAR selections for all attributes were comparatively high and similar (64-66% for sweetness, 61-64% for bitterness, 64-75% for cocoa flavour, 67-75% for dairy flavour and 73-81% for overall texture, Figure 3.1). However, the overall liking of milk chocolate was found to be affected by the contextual settings based on the penalty analysis results. The effect of an attribute on overall liking of the product is considered as significant when the proportion of participants' responses to "not JAR" is greater than the commonly used threshold, 20% (Cusielo, da Silva, Tavares-Filho, & Bolini, 2019; Laguna, Varela, Salvador, & Fiszman, 2013). In the present study, both PVR and NVR led to less perception of cocoa flavour for milk chocolate (25% and 31% participants selected "too little" respectively) as compared to the control setting which was B (18% for "too little", Figure 3.1). This might because that both PVR and NVR provided better engagement than sensory booth did, in which participants might focus more on the virtual experience than the chocolate itself. Bangcuyo et al. (2015) also reported that consumers were more engaged in a coffee evaluation session that took place in an immersive virtual coffeehouse rather than in the traditional sensory booth. Therefore, the finding of this research proved that sensory evaluation conducted under immersive VR environments could have better engagement and ecological validity than traditional sensory booths.

On the other hand, white chocolate and dark chocolate had lower JAR selections regarding all attributes compared with milk chocolate (Figure 3.2 and 3.3). About 81-87% of participants found that the overall texture of white chocolate under three environments was just about right (Figure 3.2). Similar to penalty analysis results, the other four attributes of white chocolate, including sweetness, bitterness, cocoa flavour and dairy flavour, were penalised for being either "too much" or "too little" regardless of the environments. For dark chocolate under three environments, all five attributes tended to have great negative effects on its overall liking (Figure 3.3). The sweetness and dairy flavour of white chocolate could be reduced, its cocoa flavour and bitterness could be increased for better catering consumers' preference, while on the contrary for dark chocolate. Overall, contextual settings did not affect the penalty analysis results much for white chocolate and dark chocolate. As it has been mentioned above, white chocolate has 28% cocoa content and less aggregate structure, whereas dark chocolate has 72% cocoa content and the highest aggregate structure (Glicerina et al., 2016). In other words, both chocolate types have extreme cocoa content and textual properties, which could have greater effects than contextual settings (Table 3.1). Milk chocolate has relatively moderate cocoa content (33%) and textual properties, which could minimise the effect of chocolate itself and enlarge the effect of contextual settings (Glicerina et al., 2016). This is probably why the penalty analysis results for milk chocolate were different under three environments.

4.2 Multivariate analysis of chocolate products under different environments

4.2.1 Emotional responses

In the present study, the most frequently selected emotional terms changed depending on both chocolate types as well as contextual settings (Figure 3.4). The descriptors selected for both milk chocolate and white chocolate were generally similar under different environments, which were both neutral and positive, such as “polite” and “affectionate”. However, dark chocolate was associated with distinct emotions in different environments. Dark chocolate under NVR tended to have ardent emotional terms such as “adventurous” and “energetic”. On the contrary, Dark chocolate under both PVR and B were associated with negative terms, including “bored”, “worried”, “disgusted” and “aggressive” which contributed to low overall liking scores of chocolate products (< 5.0). Overall, each chocolate product tasted under PVR elicited generally similar emotions as the control setting, namely sensory booth. However, NVR tended to evoke more passionate emotions from participants, especially towards dark chocolate.

Both VR environments used in this study showed their impacts on consumers’ emotional responses towards chocolate products, especially the NVR. Xu, Hamid, Shepherd, Kantono, and Spence (2019) reported that the environments where food products are consumed could heavily affect consumers’ emotions. They found significant changes in emotions evoked form subjects when ice cream was consumed under laboratory, café, university study area, and bus stop settings. Apart from the visual effect, the auditory effect involved in this study should also be considered since the VR environments were based on videos (Kantono et al., 2018). The liking of the two VR environments was highly subjective as dark chocolate was associated with negative emotions and low overall liking scores under B which was the control setting, the “virtual live concert” setting positively affected participants’ emotional responses and overall acceptance of dark chocolate. According to the results, it seems that dark chocolate would be more suitable to be consumed in a live concert.

4.2.2 Principal component and cluster analyses of the chocolate products under different environments

Three clusters were formed majorly based on the type of chocolate products, whereas contextual settings were found not significant enough to affect the clustering in the present study (Figure 3.5). In general, milk chocolate was the most liked chocolate and dark chocolate was the least liked chocolate based on the PCA results, which is similar to the finding in Table 3.2. Both PVR and NVR were found to have positive effects on either the cocoa flavour liking of milk chocolate or the textual liking of white chocolate. Some previous studies reported that both enjoyment and hedonic responses of food products tended to be higher under immersive VR environments (Picket & Dando, 2019; Sinesio et al., 2018). However, those environments were pleasant and suitable for the consumption of relevant food products, such as tasting sparkling wine in a winery as well as vegetables in a holiday farm. Although the two VR environments used in this research belong to different categories, their positive effects towards certain chocolate attributes were similar. Hathaway and Simons (2017) reported that the hedonic ratings of cookies obtained under relevant immersive VR environments were more reliable and discriminating. Therefore, it would be necessary to select a matched tasting environment for each chocolate product in order to obtain reliable hedonic data. These sensory results could be further used in new product development.

4.3 The effect of environments on the purchase intent of chocolate products

In the present study, participants' purchase intent significantly changed in relation to the type of chocolate products (Table 3.3). Although participants were most willing to pay for three chocolate products under PVR, there was no significant differences among PVR, NVR, and B within each chocolate type. The purchase intent was highly associated with their hedonic responses as well as the PCA results, in which milk chocolate seemed to be the most liked chocolate type (Table 3.2 and Figure 3.5). Many factors could affect consumers' willingness to purchase, such as the nutritional value and health claims of products (Kaur, Scarborough, & Rayner, 2017). Gunaratne et al. (2019) also reported that the packaging could have effects on consumers' acceptance, purchase intent and emotions regarding chocolate products. Participants were more willing to buy milk chocolate majorly due to its moderate cocoa content and textual properties as discussed above (Glicerina et al., 2016). On the other hand, the purchase intent for three chocolate products under PVR were slightly higher (but not significant) than the other two environments. PVR is the abbreviation for "positive VR", which is a pleasant sightseeing tour in a 5-star luxurious hotel (Figure 2.1, d1-d3). As reported by O'Brien and Toms (2010), aesthetically pleasant environments could positively influence consumers' engagement. Thus, the greater purchase intent was possibly correlated with improved engagement perceived by participants under PVR.

Chapter 5

Conclusion

The present study, alongside relevant research on both VR and sensory science, demonstrates that the sensory perception of food products can be largely affected by contextual settings. This study firstly explored the effect of 360-degree immersive videos (based on VR headsets) on sensory perception of chocolate products. The results of this study highlighted the significant impacts of environments on both chocolate acceptability and emotions elicited. As compared to the traditional sensory booth, participants tended to have better engagement when they tasted chocolate products under both VR environments. Therefore, the data could be more ecologically valid as well as relevant to actual consumers' experience. In addition, the combination of dark chocolate and "virtual live concert" significantly affected consumers' hedonic responses and emotions into a positive and passionate direction. However, it might be necessary to further match each chocolate type to a suitable VR environment for more reliable and ecologically valid sensory responses. Those environments achieved by VR headsets could be useful in testing newly developed chocolate products before launching.

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Appendix A

Significant emotional terms based on Cochran's Q test

Table A Frequencies and significance of emotional terms* based on Cochran's Q test**

Emotional Terms	Treatments								
	M-PVR	**M-NVR**	**M-B**	**W-PVR**	**W-NVR**	**W-B**	**D-PVR**	**D-NVR**	**D-B**
Adventurous***	0.06^{a}	0.08^{a}	0.08^{a}	0.06^{a}	0.13^{a}	0.03^{a}	0.15^{a}	0.16^{a}	0.06^{a}
Satisfied	0.24^{a}	0.25^{a}	0.25^{a}	0.22^{a}	0.22^{a}	0.19^{a}	0.08^{a}	0.10^{a}	0.19^{a}
Active	0.12^{ab}	0.24^{a}	0.09^{ab}	0.15^{ab}	0.22^{ab}	0.05^{b}	0.06^{ab}	0.24^{a}	0.06^{ab}
Affectionate	0.12^{abc}	0.13^{ab}	0.12^{abc}	0.15^{a}	0.15^{a}	0.06^{abc}	0.02^{bc}	0.03^{abc}	0^{c}
Calm	0.21^{a}	0.08^{a}	0.25^{a}	0.13^{a}	0.09^{a}	0.18^{a}	0.18^{a}	0.06^{a}	0.19^{a}
Energetic	0.09^{b}	0.19^{ab}	0.10^{b}	0.13^{ab}	0.30^{a}	0.09^{b}	0.13^{ab}	0.27^{ab}	0.13^{ab}
Enthusiastic	0.06^{ab}	0.19^{a}	0.06^{ab}	0.12^{ab}	0.18^{a}	0.02^{b}	0.09^{ab}	0.16^{ab}	0.05^{ab}
Free	0.18^{a}	0.18^{a}	0.13^{a}	0.19^{a}	0.15^{a}	0.09^{a}	0.10^{a}	0.12^{a}	0.06^{a}
Friendly	0.25^{ab}	0.27^{a}	0.27^{a}	0.19^{ab}	0.25^{ab}	0.22^{ab}	0.10^{ab}	0.08^{ab}	0.06^{b}
Glad	0.19^{abc}	0.21^{abc}	0.28^{a}	0.27^{ab}	0.16^{abc}	0.24^{abc}	0.06^{c}	0.09^{bc}	0.09^{bc}
Good	0.43^{a}	0.34^{abc}	0.37^{ab}	0.36^{abc}	0.27^{abc}	0.37^{ab}	0.16^{bc}	0.15^{c}	0.18^{bc}
Happy	0.34^{ab}	0.39^{a}	0.39^{a}	0.42^{a}	0.37^{ab}	0.39^{a}	0.15^{bc}	0.19^{abc}	0.09^{c}
Interested	0.10^{a}	0.18^{a}	0.16^{a}	0.13^{a}	0.16^{a}	0.16^{a}	0.10^{a}	0.08^{a}	0.02^{a}
Joyful	0.42^{a}	0.27^{abcd}	0.34^{abc}	0.36^{ab}	0.39^{a}	0.27^{abcd}	0.12^{cd}	0.13^{bcd}	0.06^{d}
Loving	0.28^{a}	0.24^{ab}	0.22^{abc}	0.24^{ab}	0.22^{abc}	0.19^{abc}	0.05^{bc}	0.08^{bc}	0.03^{c}
Merry	0.09^{a}	0.10^{a}	0.09^{a}	0.15^{a}	0.13^{a}	0.12^{a}	0.08^{a}	0.09^{a}	0.05^{a}
Nostalgic	0.06^{a}	0.06^{a}	0.08^{a}	0.08^{a}	0.06^{a}	0.03^{a}	0.09^{a}	0.06^{a}	0.12^{a}
Peaceful	0.25^{ab}	0.10^{b}	0.21^{ab}	0.31^{a}	0.10^{b}	0.19^{ab}	0.16^{ab}	0.06^{b}	0.10^{b}
Pleased	0.19^{ab}	0.22^{ab}	0.33^{a}	0.24^{ab}	0.21^{ab}	0.25^{ab}	0.10^{b}	0.08^{b}	0.09^{b}
Pleasant	0.36^{a}	0.25^{ab}	0.30^{ab}	0.24^{ab}	0.21^{ab}	0.24^{ab}	0.25^{ab}	0.10^{b}	0.15^{ab}
Secure	0.02^{a}	0.06^{a}	0.06^{a}	0.08^{a}	0.05^{a}	0.09^{a}	0.05^{a}	0.03^{a}	0.08^{a}
Warm	0.15^{a}	0.19^{a}	0.22^{a}	0.16^{a}	0.12^{a}	0.13^{a}	0.09^{a}	0.10^{a}	0.12^{a}
Bored	0.09^{b}	0.09^{b}	0.10^{b}	0.10^{b}	0.10^{b}	0.21^{ab}	0.15^{ab}	0.22^{ab}	0.30^{a}
Disgusted	0.06^{bc}	0.06^{bc}	0.02^{c}	0.06^{bc}	0.09^{abc}	0.08^{abc}	0.22^{ab}	0.19^{ab}	0.24^{a}
Worried	0.10^{ab}	0.03^{b}	0.03^{b}	0.09^{ab}	0.06^{b}	0.09^{ab}	0.18^{ab}	0.13^{ab}	0.25^{a}
Aggressive	0.05^{bc}	0.03^{c}	0.03^{c}	0.03^{c}	0.08^{abc}	0.02^{c}	0.15^{abc}	0.21^{a}	0.19^{ab}
Daring	0.03^{a}	0.05^{a}	0.08^{a}	0.06^{a}	0.03^{a}	0.02^{a}	0.05^{a}	0.08^{a}	0.06^{a}
Eager	0.05^{a}	0.05^{a}	0.03^{a}	0.12^{a}	0.03^{a}	0.03^{a}	0.06^{a}	0.09^{a}	0.09^{a}
Guilty	0.06^{a}	0.05^{a}	0.10^{a}	0.10^{a}	0.05^{a}	0.10^{a}	0.10^{a}	0.06^{a}	0.13^{a}
Polite	0.10^{ab}	0.08^{ab}	0.18^{a}	0.18^{a}	0.10^{ab}	0.12^{ab}	0.03^{b}	0^{b}	0.05^{ab}
Steady	0.08^{a}	0.05^{a}	0.12^{a}	0.09^{a}	0.05^{a}	0.12^{a}	0.09^{a}	0.10^{a}	0.12^{a}
Understanding	0.02^{a}	0.02^{a}	0.06^{a}	0.08^{a}	0.05^{a}	0.05^{a}	0.02^{a}	0.02^{a}	0.05^{a}
Wild	0.06^{b}	0.12^{ab}	0.06^{b}	0.05^{b}	0.12^{ab}	0.03^{b}	0.06^{b}	0.24^{a}	0.13^{ab}

*33 emotional terms were associated with 3 types of chocolate products and 3 contextual settings; M-PVR: milk chocolate-positive VR; M-NVR: milk chocolate-negative VR; M-B: milk chocolate-sensory booth; W-PVR: white chocolate-positive VR; W-NVR: white chocolate-negative VR; W-B: white chocolate-sensory booth; D-PVR: dark chocolate-positive VR; D-NVR: dark chocolate-negative VR; D-B: dark chocolate-sensory booth

**Cochran's Q test was used together with Marascuilo procedure for multiple pairwise comparisons (N = 67)

Significant emotional terms were ***italicised and bolded ($p < 0.05$)

$^{a-d}$ Results with different superscripts regarding each emotional term in each row indicate significant differences ($p < 0.05$); The value of each treatment ranges from 0 to 1, higher values indicate higher frequencies.