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Review Article

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Comparison of Food Sensory Perception and Consumer Acceptability Between Traditional Standardized Booths and Immersive Virtual Environments

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Abstract

Immersive technologies, such as virtual reality (VR), are increasingly being explored to enhance the contextual relevance of consumer testing while preserving rigorous laboratory control. This study investigated the impact of immersive contexts on the sensory perception of food products by comparing a standard physical sensory booth (SB) and a VR of restaurant (V-restaurant) using a repeated measures design where a consumer panel evaluated each matrix once per environment. For the chocolate chip biscuit matrix, the immersive context of the V-restaurant significantly altered product optimization profiles; the optimal just-about-right (JAR) score for sweetness decreased from 43% in the SB to 35% in the V-restaurant, while the perception of excessive chocolate intensity ("Too Much") increased sharply from 55% in the SB to 83% in the V-restaurant. Conversely, for the orange juice matrix, evaluation in the V-restaurant slightly increased the optimal JAR score for sweetness from 33% SB to 35% V-restaurant, while the optimal sourness score decreased from 38% to 30%. These matrix-dependent variations underscore that immersive environments can drastically shift consumer attribute ideal-scaling compared to traditional analytical laboratory settings.

Keywords

Virtual reality, Sensory analysis, Contextual influence, Ecological validity, Consumer

Introduction

Sensory analysis constitutes a fundamental tool for assessing the perception and acceptability of food products. Historically, this discipline has developed through an experimental approach aimed at measuring a product's sensory attributes such as taste, aroma, and texture under strictly controlled conditions. Within this framework, evaluations are generally conducted in standardized SB compliant with the International Organization for Standardization (ISO) 8589 standard, participants in this condition did not use a head-mounted display (HMD), as the SB served as a non-technological experimental baseline designed to minimize external influences and ensure the reproducibility of measurements. However, this approach relies on the implicit assumption that sensory responses observed in laboratory setting accurately reflect real-world consumer behavior.

However, contemporary research in sensory analysis and consumer science demonstrates that food perception does not depend solely on intrinsic properties but rather results from a complex interaction between the product and its consumption context [1]. The context encompasses a set of extrinsic factors including the physical characteristics of the environment (lighting, decor, and

ambient sound), social dimensions (the presence of others), as well as the cognitive and emotional factors associated with the eating experience [1, 2].

These elements can significantly influence the hedonic evaluation of a product and modulate the perception of certain sensory attributes, such as bitterness, sweetness, or freshness. Consequently, evaluating a food product in a neutral and artificial environment may lead to discrepancies between the performance observed in the laboratory and that observed in real-life consumption situations [3, 4].

This issue relates to the concept of ecological validity, which denotes the capacity of an experimental method to reproduce the natural conditions in which a behavior occurs. In traditional SB, the absence of contextual stimuli may lead participants to adopt an analytical posture, focusing on the precise identification of sensory attributes rather than a spontaneous and hedonic consumption experience. This phenomenon, often termed laboratory bias, may limit the predictive validity of the results regarding actual consumer behavior [5].

To overcome these limitations, some studies have proposed conducting *in-situ* sensory tests in real-world environments such as restaurants, cafés, or homes. Although these approaches enhance the ecological validity of the data, they nonetheless present several significant constraints, notably high logistical costs, difficulty in controlling environmental variables, and low reproducibility of experimental conditions. In this context, the emergence of immersive technologies, and more specifically VR, offers new perspectives for the study of eating behavior and sensory perception.

VR allows for the simulation of realistic consumption environments while maintaining rigorous experimental control. Through the integration of immersive visual and auditory stimuli, this technology fosters a sense of presence, defined as the subjective impression of being physically situated within the simulated environment [6, 7]. According to the theory of presence, when this feeling is sufficiently strong, individuals' emotional and behavioral responses within the virtual environment can be comparable to those observed in real-life situations. Thus, VR constitutes a promising tool for studying the influence of consumption context on food perception and acceptability.

Several recent studies have already evidenced the impact of virtual environments on consumer sensory responses. For instance, research regarding chocolate has shown that virtual environments congruent with the product, such as a comfortable living room or a café, can significantly increase liking and acceptability scores [4, 8]. Similarly, research conducted on coffee and beer has demonstrated that certain environmental stimuli, notably music or visual ambiance, can modify the perception of specific sensory attributes such as bitterness or freshness. These results suggest that integrating context into sensory evaluation protocols could provide data that is more representative of actual consumer behavior [3-5]. Within this perspective, the present study aimed to explore the potential of VR as a sensory evaluation tool by comparing responses obtained in a traditional SB with those collected across virtual environments. More specifically, evaluations were conducted in a V-restaurant. The objective is to examine the extent to which these environment influence the perception and acceptability of common food products, such as biscuits and orange juice, while assessing the reliability of VR as a complementary method to classical sensory analysis approaches [9, 10].

Materials and Methods

Participants and panel

The study was conducted with a panel of 40 students, consisting of 31 women and 9 men, with a mean age of 25.58 ± 2.15 years (range: 21 - 33). Participants were selected based on their familiarity with the tested products, specifically biscuits and orange juice. The use of an untrained consumer panel was preferred to reflect spontaneous hedonic reactions and to approximate real-market conditions. Prior to the experimentation, participants were informed of the protocol and provided their informed consent to participate in the study [5, 6].

VR equipment and experimental environments

Immersion was achieved using Oculus VR headsets (Meta Quest series). Virtual environments were developed using the unity engine to simulate various consumption contexts while maintaining experimental control over variables. All evaluations were conducted under standardized conditions to minimize external bias; the physical laboratory was maintained at a constant temperature of 22 ± 2 °C, and orange juice samples were served chilled at 7 ± 1 °C.

The protocol compared two experimental conditions:

1. Physical SB, serving as the baseline (or reference) condition. This environment was designed in accordance with ISO 8589:2007, featuring neutral white lighting (6500 K) and an odor-free atmosphere. Panelists in this condition did not wear HMD, ensuring standard non-technological control.
2. V-restaurant: a social environment simulating a restaurant with warm decor and characteristic background noise [4]. The V-restaurant environment was selected to investigate the effect of a socially and sensorially rich context on food perception, as biscuits are also frequently consumed in cafés, restaurants, and hospitality settings in association with beverages and social interactions (Figure 1).

These environments were used to examine the influence of the consumption context on sensory evaluation of the products.

Food samples

Two food matrices were selected for the study:

- Biscuits: Chocolate chip biscuit (a whole-grain cereal-based biscuit containing 16% cocoa-based chocolate chips). The attributes evaluated included hardness, grittiness, sweetness, and chocolate intensity.
- Orange juice: Participants evaluated several sensory

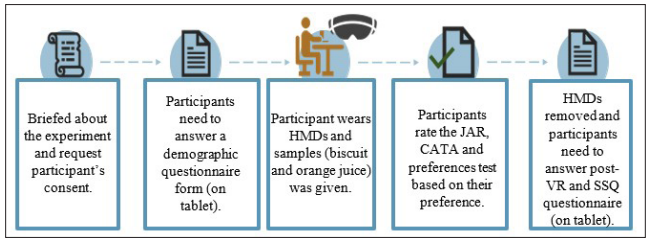


Figure 1: Flowchart of the experimental sensory evaluation protocol.

attributes, notably sweetness, acidity, and freshness. The orange juice selected for evaluation was a standardized commercial product with 100% fruit content (Sio 100% orange). No extrinsic sugar or matrix modifications were introduced by the experimenters prior to serving.

- The samples were presented under standardized conditions to ensure comparability of assessments across the different experimental conditions [11, 12]. To maintain consistency, orange juice samples (50 mL) were served chilled at a controlled temperature of 7 ± 1 °C in 100 mL transparent plastic cups.

Sensory evaluation methods

The sensory evaluation was based on two primary approaches. The first method was the JAR scale, used to assess whether the intensity of specific sensory attributes was perceived as optimal. Participants evaluated attributes such as sweetness, acidity, hardness, and grittiness using a five-point scale ranging from "much too low" to "much too high" [9, 12].

The second method was check-all-that-apply (CATA) technique. Participants were asked to select, from a predefined list of sensory and emotional descriptors, all the terms they considered appropriate to describe the tasted products. For the biscuit sample, a list of 24 descriptors (12 sensory and 12 emotional) was provided, while for the orange juice, 20 descriptors (10 sensory and 10 emotional) were used. These terms (e.g., 'crunchy', 'hard', 'happy', and 'calm') were selected based on preliminary consumer focus groups and existing literature to ensure familiarity among untrained panelists. This approach allows for characterizing the global perception of products based on the terms associated by consumers across the different environmental contexts [5, 10]. To minimize bias, the order of the descriptors was randomized for each participant.

The evaluation followed a repeated measures design where each panelist participated in a single tasting session. Within this session, each food sample (biscuits and orange juice) was evaluated once under each contextual condition (SB and V-restaurant).

Comfort and immersion measurement

In order to control potential effects related to the use of VR, the simulator sickness questionnaire (SSQ) was administered to identify any symptoms of cybersickness among the participants [11]. The SSQ monitored 16 physiological symptoms (e.g., general discomfort, fatigue, headache, eye strain, blurred vision, and nausea) rated on a 4-point scale (0 = none to 3 = severe). These symptoms were analyzed across three subscales: nausea, oculomotor strain, and disorientation, to ensure the technology did not bias sensory scores through physical discomfort.

In addition, a 6-item presence scale was used to assess the level of immersion and the psychological sense of "being there" experienced by participants within the virtual environment [6, 7]. Participants rated items such as their sense of involvement and the realism of the visual environment on a 7-point Likert scale. Notably, both the SSQ and the presence scale were applied strictly to evaluate the virtual reality experience; however, the SSQ was initially administered in the standard physical booth (SB) prior to headset exposure to establish a pre-test physiological baseline control (capturing pre-existing fatigue or discomfort), while the presence scale was applied exclusively post-immersion within the V-restaurant framework.

The data collected from the questionnaires were processed using descriptive statistics analysis with XLSTAT software. JAR scale responses were analyzed by examining the response distribution for each sensory attribute. For the CATA method, the selection frequency of the various descriptors was calculated to identify the terms most frequently associated with the products across the different experimental contexts. Scores from the SSQ and the presence scale were analyzed to evaluate participant comfort and their level of immersion during the VR experience.

Results and Discussion

Effect of context on sensory perception (JAR analysis)

The sensory perception of the two food matrices varied significantly in response to the immersive context. Regarding the orange juice (Figure 2), JAR scores demonstrated high stability across all experimental conditions. Attributes such as sweetness and acidity were rated as "JAR" by the majority of the panel in both the physical booth and the virtual environment (V-restaurant), suggesting that the sensory profile of the liquid matrix appeared relatively robust to environmental influences. 33% of panelists rated the sweetness of the orange juice as "JAR" (Level 3/Green). A significant portion of the remaining panelists felt the sweetness was slightly higher than optimal (Level 4). When evaluated in the V-restaurant, the JAR rating for sweetness increased to 35%.

The results regarding chocolate chip biscuits (Figure 3) demonstrate a higher sensitivity of sensory perception to the environmental context. This difference suggests that immersive environments can modulate the sensory evaluation of complex solid products. In the case of the V-restaurant, the visual and auditory stimuli (clinking cutlery, dining room ambiance) appeared to foster a contextual halo effect for specific attributes. For instance, the JAR rating for sweetness was 43% in the physical SB and 35% in the V-restaurant. This slight decrease suggests that the multisensory restaurant ambiance may have altered panelists' hedonic frame of reference, moderating their perception of sweetness intensity [7, 12].

Conversely, the neutral and isolated environment of the traditional SB maintained a relatively balanced perception of complex attributes. This was most evident in the chocolate intensity attribute: while 55% of participants judged it as "too much" in the physical SB, this percentage surged to 83% in

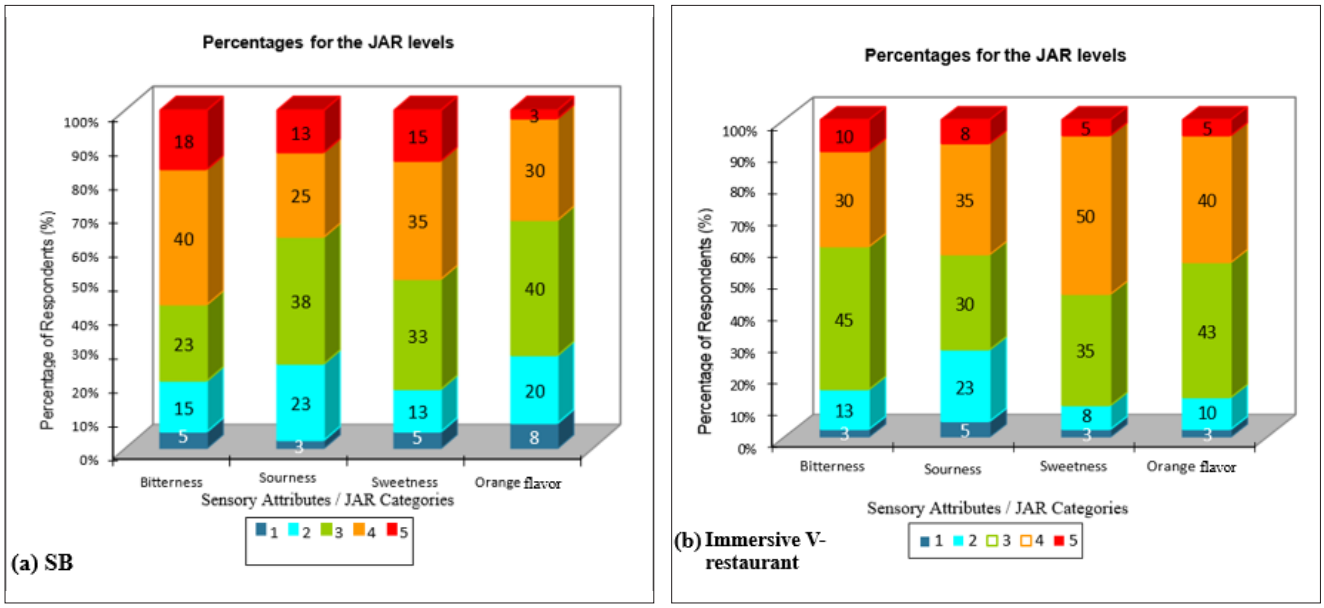


Figure 2: JAR percentage distributions for orange juice attributes across: **(a)** SB and **(b)** Immersive V-restaurant.
Note: Data is plotted using the full 5-point evaluation scale (from 1 to 5) to show detailed panelist distribution.

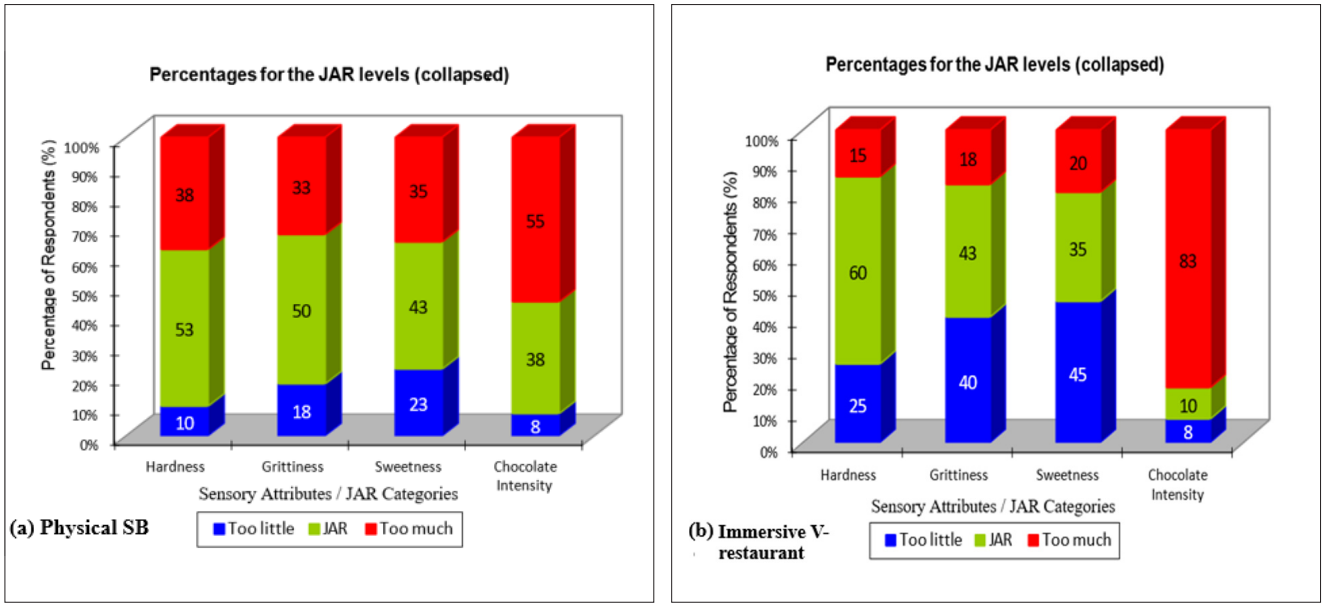


Figure 3: JAR percentage distributions for chocolate chip biscuit attributes across: **(a)** Physical SB and **(b)** Immersive V-restaurant.
Note: For enhanced scannability, the original 5-point evaluation scale was collapsed into three main functional categories: 'too little' (combined level 1 and 2), 'JAR' (level 3), and 'too much' (combined level 4 and 5).

the V-restaurant, dropping the JAR score to just 10%. This suggests a multisensory enhancement effect, where the rich, immersive atmospheric cues of the restaurant environment cross-modally accentuated the perceived dominance of the chocolate flavor, pushing it significantly past the optimal JAR zone compared to standard laboratory conditions.

Regarding texture, descriptors such as hardness and grittiness remained relatively stable, though a slight shift was noted in the V-restaurant. This observation may be linked to a phenomenon of multisensory congruence; the auditory cues of a dining setting can reinforce perceptual expectations related to the freshness and "crunch" of the food [4]. This ability of VR to recreate ecologically valid contexts confirms that it can complement traditional SB by providing data that reflects real-world consumption behavior without compromising precision [13, 14]. The enrichment of the sensory experience through virtual stimuli is consistent with previous findings regarding immersive technologies that stimulate consumer satisfaction by compensating for the sensory limitations of the digital world through increased visual immersion [15, 16].

These findings align with previous studies comparing SB and virtual environments. Bangcuyo et al. [5] demonstrated that immersive contexts enhanced ecological validity in coffee sensory evaluation relative to standard laboratory conditions. Similarly, Bin Zulkarnain et al. [9] validated a virtual sensory laboratory as a reliable alternative to physical booths for

consumer evaluations. More recently, Bin Zulkarnain and Gere [10] showed that different environmental contexts—laboratory, real beach, and VR beach significantly modulated the sensory perception of coconut water, consistent with our findings for orange juice and biscuits.

Sensory and emotional responses (CATA analysis)

The sensory space of the orange juice was characterized using principal coordinate analysis (PCoA) based on CATA frequencies. In this analysis, F1 and F2 (Dimensions 1 and 2) represent the principal axes explaining the maximum variance in sensory descriptors across the experimental contexts. Overall liking (OAL) was projected onto these maps as a supplementary variable to identify the drivers of consumer preference (Figure 4).

A clear divergence was observed between the SB and V-restaurant. In the neutral and isolated environment of the physical SB, participants relied more heavily on functional or technical descriptive terms to characterize the products, with OAL for orange juice sample being most closely associated with 'natural taste' and 'refreshing' attributes. Conversely, in the immersive V-restaurant, the drivers of liking shifted toward a more holistic and hedonic profile; OAL moved into closer proximity to 'sweetness' and 'orange flavor.'

These results suggest that immersive environments encourage a more hedonic approach to the tasting experience, where responses include more emotional or contextual descriptors associated with pleasure [4,10]. In the V-restaurant, participants evaluated the product not only based on its intrinsic sensory attributes but also in relation to the overall experience provided by the context. The shift toward flavor-dominant descriptors in the immersive setting better reflects real-world consumption habits, where the environment acts as a sensory lever. Such a holistic approach is necessary to evaluate how the daily introduction of a specific food item impacts consumer perception and diet quality in ecological settings [17].

The multivariate sensory space for the biscuits was similarly mapped using PCoA based on CATA frequencies (Figure 5). The dimensions F1 and F2 explain the principal textural and flavor variance across the samples. For the target chocolate chip biscuit, a notable contextual shift was observed in the drivers of liking (OAL).

In the physical booth (SB), the product profile was characterized by an analytical focus on technical attributes such as 'dry' and 'hard,' and the OAL was lower in this restrictive setting. Conversely, in the virtual environment, the perception shifted toward a more complex and hedonic profile. The OAL for the chocolate chip biscuit moved into closer proximity with 'crunchy' and 'chocolate flavor' descriptors. This suggests that the immersive restaurant ambiance—enriched with social and environmental cues—enhances the salience of positive textural and aromatic traits compared to the isolated laboratory setting. These results further support the hypothesis that immersive environments encourage a holistic evaluation, where positive environmental characteristics influence the overall satisfaction of complex food matrices.

Validation of VR as a sensory tool

An important finding of this study concerns the comparison between physical SB and its V-restaurant. The responses obtained in these two conditions were found to be

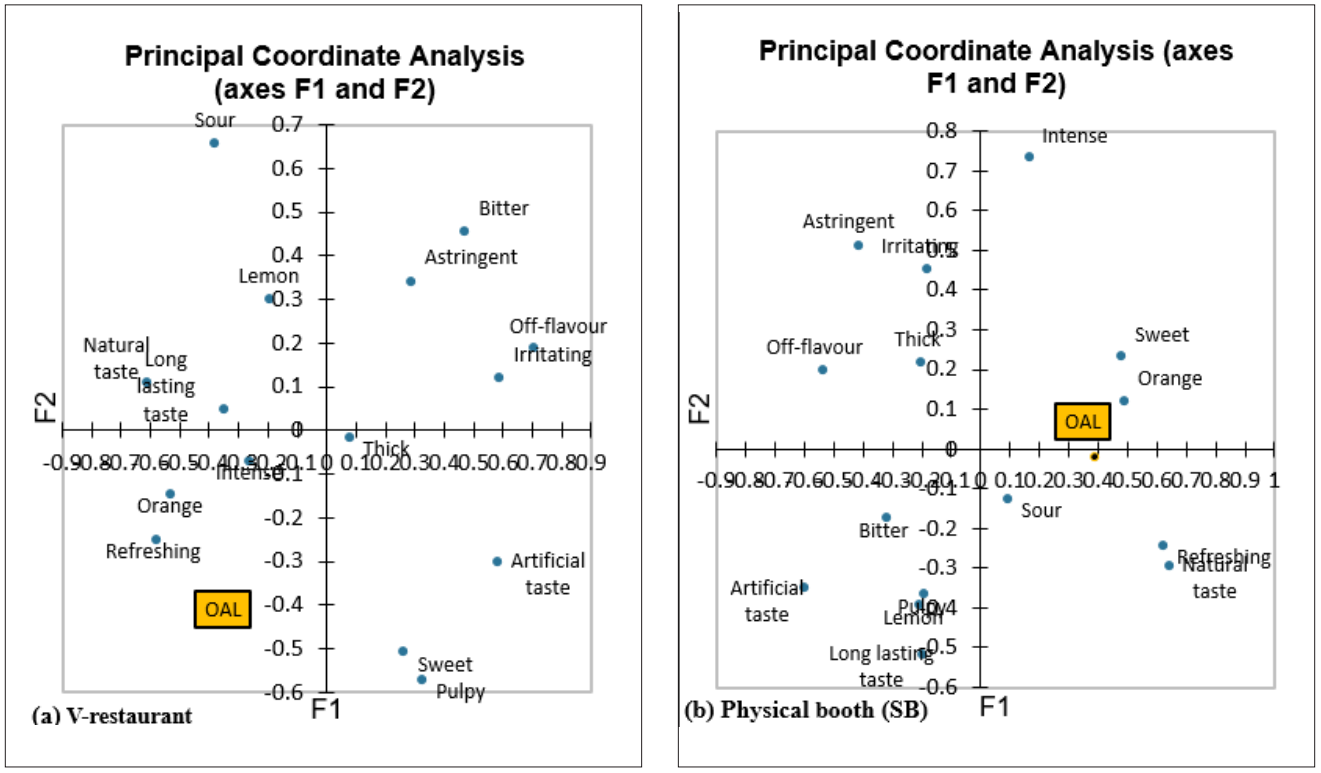


Figure 4: CATA analysis shows differences in sensory and emotional descriptors for orange juice across experimental environments.

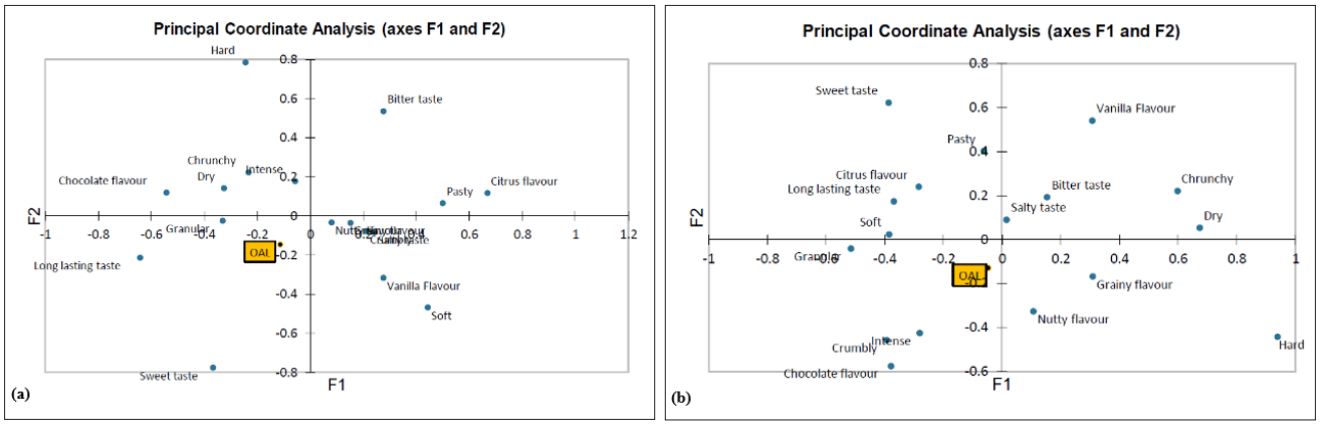


Figure 5: Correspondence analysis factor map of CATA descriptors for chocolate chip biscuits in **(a)** V-restaurant and **(b)** physical booth (SB).
Note: Dimension F1 and F2 explain the variance in sensory attributes, while the yellow box represents OAL as a supplementary variable.

globally similar, indicating that merely wearing the VR headset does not significantly alter the taste perception of the products [12]. This result suggests that VR technology can be used as a reliable experimental tool for sensory analysis. The differences observed between the experimental environments therefore seem to be primarily related to the simulated context, and not to the use of the technological device itself [9].

Virtual reality provides a reliable and controlled environment for sensory evaluation [18].

Measures of the sense of presence indicate that participants generally felt highly immersed in the virtual environments. The immersive V-restaurant context achieved substantial presence scores, indicating that contexts rich in visual and auditory stimuli foster a more pronounced sense of immersion [6, 7].

Furthermore, participants reported a higher level of engagement during the VR sessions than during those in the traditional SB. Sensory tests conducted in a laboratory setting can sometimes be perceived as monotonous, which may lead to a decrease in attention during the evaluation. The immersion offered by VR appears to reduce this phenomenon and maintain participant interest throughout the experience [5].

A high level of engagement may contribute to the reliability of responses, in the same way that the fidelity of 3-dimension models is crucial for predicting the bio-functions of new medical materials derived from natural resources [19].

The results obtained from the SSQ indicate higher levels of discomfort in the virtual environment (27.77%) than in the pre-exposure baseline (14.59%).

Within the virtual environment, the specific weighted scores were:

- Nausea: 18.36%
- Oculomotor: 23.88%
- Disorientation: 32.71%

These results show that the disorientation symptoms nearly doubled in the virtual setting compared to the pre-exposure baseline (16.00%), likely due to the high level of immersion and temporary disconnection from the physical space. While these scores indicate noticeable levels of discomfort, particularly regarding disorientation—they provide critical insight into the trade-offs of using immersive VR technology for sensory analysis. Despite this discomfort, participants were able to provide consistent CATA and JAR evaluations, revealing clear contextual shifts in the perception of the orange juice and chocolate chip biscuit samples [11].

To attenuate cybersickness symptoms in future immersive sensory studies, we recommend: (1) incorporating a 3 - 5 min VR familiarization period before evaluation; (2) limiting headset exposure to a maximum of 15 min per condition; (3) using a fully seated evaluation protocol to minimize vestibular-visual conflict; and (4) employing high frame-rate VR displays (≥90 fps) to reduce motion-to-photon latency.

Implications for food innovation and sensory science

The results of this study highlight the value of VR as a tool for improving the ecological validity of sensory tests while maintaining rigorous experimental control. Unlike tests conducted in real-world conditions, which are often difficult to standardize, VR allows for the simulation of various consumption contexts while maintaining reproducible experimental conditions.

From a food innovation perspective, this approach could facilitate the evaluation of new products in realistic consumption contexts. As suggested by recent studies, VR could notably be used to test the acceptability of innovative or sustainable products, such as plant-based alternatives or other emerging food products, in environments that enhance the overall consumption experience [9]. The standardization of immersive testing protocols is essential for ensuring the reliability and reproducibility of sensory evaluations [20].

Conclusion

This study demonstrates that evaluating food products in an ecologically valid immersive environment, such as a V-restaurant, significantly influences consumer JAR attribute scaling in a matrix-dependent manner. For the biscuit sample, the immersive environment amplified the perceived intensity

of formulation flaws, resulting in an increase in the "Too Much" response category for chocolate intensity from 55% to 83%, and reducing the ideal sweetness profile to 35%. For the orange juice sample, the V-restaurant context led to more subtle shifts, increasing the ideal sweetness target to 35% while lowering the ideal sourness perception to 30%. These results indicate that immersive environments do not universally alter all products in the same direction, but rather interact specifically with the food matrix type, providing a more realistic and stringent framework for industrial product optimization than traditional sensory booths.

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None.

Conflict of Interest

None.

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