Edible innovations

Testing the WOW impact of 3D printed chocolate packaging

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Edible innovations: Testing the WOW impact of 3D printed chocolate packaging

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ABSTRACT

3D food printing is an emerging processing technology with a profound impact on both the food industry and consumer experiences. It currently makes it possible to process a wide range of food materials into custom-designed and safe-to-consume 3D printed foods. One notable application lies in the creation of customized, fully edible packaging using ingredients that are safe for human consumption. The study presented in this paper examined consumer attitudes and emotions to 3D printed edible packaging in gastronomic experiences, comparing a milk chocolate snack served in a fully 3D printed edible chocolate packaging to one served in a traditional ceramic packaging. The results show that compared to the ceramic packaging, the edible packaging elicits higher levels of surprise, fascination, and desire, thereby increasing the overall positive consumer experience by more than 10 %. Part of this work aims to familiarize consumers with this innovative type of 3D food, demonstrating its relevance and potential to the food industry. The findings contribute to understanding consumer attitudes towards 3D printed foods and suggest a new potential field of research establishing a path to strengthen its common application in gastronomy.

1. Introduction

The development of new gastronomic concepts and experiences has been enhanced by the possibilities and methods offered through the synergy between design and technology (Çalışkan, 2024). A clear example of this synergy is observed in fine dining restaurants, where chefs often develop of their own technologies to enable novel ideas and concepts (Blutinger, 2023), thereby reinventing approaches to consuming food (Blutinger, et al., 2023; Anukiruthika et al., 2020). This development, known as Food Design, refers to the interdisciplinary creative process of conceptualizing and crafting food experiences that enhance enjoyment and appreciation through sensory, aesthetic, and cultural aspects, involving not only the creation of new foods but also innovative product design, such as packaging, presentation, and preservation methods (Alami, 2024; Schifferstein, 2023).

In recent years, the development of so-called gastronomic experiences has provided consumers with a change in perspective on food intake and its broader implications for the economy, culture and society (Vélez, 2012). Eating, beyond fulfilling a mere physiological need, has evolved into a social activity that transcends mere sustenance (Schifferstein, 2023; Bertran et al., 2020; Gupta, xxxx). The act of consuming food engages each of the human senses, resulting in multi-dimensional sensory experiences (Sotelo Díaz et al., 2020). Consequently, the customization of dishes for specific experiences, the use of new culinary tools, and working with the surprise factor have become some of the most prominent and often-used elements in such gastronomic experiences (Kuhn et al., 2023; Massa et al., 2023).

Food designers are continually faced with new challenges arising from evolving consumer demands, contributing to the continuous evolution of gastronomic experiences, driven by a sophisticated and highly competitive market (Massa et al., 2023). For this reason, the introduction of new technologies into these gastronomic experiences has become increasingly popular, with the incorporation of visual elements such as video mapping and visual projectors to enhance the multisensory dining experience (Furió Vita et al., 2017).

One of the most prominent and widely used technologies for product design across various sectors, such as medicine, architecture, automotive–and even the food sector, is 3D printing (Raiapaksha et al., 2021).

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While this technology entered the domain of food production only a few years ago, specialized 3D printers tailored for food printing are now available (Waseem et al., 2023; Mantihal et al., 2020). The application of this technology is widely used in product design due to its ability to improve the entire creative process thanks to innovative potential and modelling and customization capabilities (Omar Balderrama-Armendáriz, 2015). Therefore, 3D printing offers a degree of flexibility and versatility in food processing that had not been achieved with conventional methods in the food industry (Omar Balderrama-Armendáriz, 2015), thereby saving time, costs, and energy resources (Hasan et al., 2022).

Examples such as the chocolate shell of an Easter egg or the wafer of an ice cream cone are perfect examples of edible packaging that is fully integrated with the dessert. Since it is edible, the consumer consumes it as part of the overall dessert experience, blurring the line between packaging and food (Hasan et al., 2022). Despite being a wrapper, consumers may not perceive it as traditional packaging because it is clearly part of the enjoyment of the food. On the other hand, the 3D printed wrapper not only acts as protection for the dessert, but can also be customised with different ingredients, flavours, textures, and nutritional properties, which enhances the sensory dimension of the dessert (Trajkovska Petkoska et al., 2021). 3D technology allows innovative shapes and textures to be designed, elevating the product perception and creating a more distinct line between packaging and food. Therefore, although the 3D printed wrapper may appear to be part of the dessert, it should be considered a package in every sense.

The current paper reports a questionnaire study that explored people's experience of a 3D printed chocolate edible packaging for a gastronomic event. We measured participants' general attitude towards 3D food printing, compared the degree to which they had a wow-experience between a conventional ceramic packaging and a 3D printed chocolate packaging, and studied the influence of participants' prior information about the packaging on their wow-experience. The results of the study provided new insights into the reception of this innovation in the gastronomic world, contributing to the ability to predict emotional responses to these products from the use of this methodology.

In particular, this article focuses on analysing the WOW effect in reference to the potential added value of 3D printing for edible packaging. Therefore, the novelty of this technology and the applicable design considerations will be key variables in this study.

1.1. 3D food printing and the packaging sector

Presently, 3D printing receives significant research interest within the food sector because of its manyfold advantages, such as the customization of food designs, nutritional enhancements, supply chain simplification, and processing compatibility with a wide range of edible materials (Liu et al., 2017). One notable example of an edible and printable material is chocolate. Many chocolate production companies are investing in technological equipment to produce high-quality chocolate products, despite the substantial challenge posed by the current high costs of these systems. Conversely, traditional chocolate production devices often fall short of meeting the prerequisites for creating innovative products due to their inherent limitations. Consequently, there is a demand for cost-effective, high-capacity alternatives, driving the adoption of 3D printing in chocolate processing and production (Xie et al., 2016).

The food sector has significantly benefited from 3D printing technologies. The possibilities offered by this technology represent a major advance in terms of personalization to satisfy specific dietary requirements, use of leftover food, and even appealing to the interest of consumers through the construction and design of the food itself (Ross et al., Sep. 2022; Jagadiswaran et al., 2021). However, despite research highlighting the capabilities of 3D printing technologies for various food ingredients and materials (Waseem et al., Sep. 2023; Pulatsu and Lin, Jan. 2021; Le-Bail et al., 2020), consumer acceptance of new food technologies remains challenging due to their novelty and unfamiliarity (Jung et al., 2022). The synergy between novel food products and cutting-edge processing technologies can cause distrust, potentially resulting in consumer rejection. 3D food printing, having been integrated into the food industry in recent years, can be considered a novel food processing technology (Brunner et al., 2018), necessitating efforts to foster consumer acceptance across different contexts.

Recent research has demonstrated that consumer acceptance of 3D food printing is influenced by the terminology used to describe the technology and food processing (Ross et al., 2022). Terms such as "printed food" or "food produced by a printer" evoke feelings of insecurity among consumers, related to perceived nutritional deterioration of the food and potential health risks associated with novel products. This perception is considered one of the main factors negatively affecting acceptance (Brunner et al., 2018). In addition, 3D printing technology applied to digital gastronomy has facilitated the development of new shapes, colours, flavours, and textures, giving rise to phenomena such as "food selectivity" (rejection of certain foods due to sensory attributes, such as smell, texture, flavour, colour, or even temperature.). Such attitudes have a negative influence on the experience and consumption of a variety of foods. Furthermore, phenomena like neophobia (reluctance to try and new foods) have been enhanced by consumers' hesitance to try products produced using new food production technologies (Lee et al., 2021).

Empirical evidence suggests that specific attributes, such as enhanced taste, health benefits, and natural content, can significantly increase consumer acceptance of new foods, which leads to a better understanding of positive attitudes and purchase intentions (Lee et al., 2021). In this context, 3D printing technologies enable food and packaging to be enriched with additional attributes, such as vitamins, minerals, and other nutrients, providing added health benefits. 3D printing enables personalized options for both food and packaging, allowing for customization based on individual preferences or dietary needs. For instance, packaging could be fortified with specific nutrients for children, enhancing the product's value. Consumers could also choose packaging made from dark or white chocolate, sugar-free versions, or select specific nutrients to be included. This level of personalization not only enhances the overall experience but also caters to the growing demand for tailored health and nutrition options. Recent research on attitudes and emotional responses towards 3D printed chocolate has indicated that the application of 3D printed chocolate layers with varying sugar content can achieve a considerable reduction in sugar without altering the overall perception of sweetness or general taste (Khemacheevakul et al., 2021). Similarly, the printing quality of dark chocolate enriched with carob in different proportions has also been evaluated. In this way, natural sugar replacement was achieved while enhancing the nutritional and functional properties of dark chocolate. These findings establish new research avenues for 3D-printed chocolates sweetened with natural alternatives (Cikrikci Erunsal et al., 2023). Moreover, another study successfully developed 3D-printed chocolates with low-fat content by replacing cocoa butter with water-in-oil emulsions based on gum Arabic (You et al., 2023). These innovations highlight the potential of 3D printing technology to produce healthier and more functional chocolate products.

Similarly, attributes such as improved edibility, fun, and creativity significantly improve both utilitarian and hedonic (pleasure) value, findings that have been widely supported in a variety of contexts, including in the realm of food and 3D printing (Rodríguez-Parada et al., 2023). Related research investigated different 3D chocolate and cream cheese configurations with two rheologically and texturally very different phases and their effect on mechanical properties and sensory perception. The results demonstrated that mouthfeel was directly correlated with the 3D configuration of the phases. Likewise, it was shown that the 3D configuration of phases with different rheological properties represents considerable potential for adjusting sensory properties. Consumers' satisfaction when trying the samples

significantly depended on the sensation/texture perceived in the mouth and hardness of the product. Therefore, these findings represent a step forward in satisfying consumer needs through 3D product design (Burkard et al., 2023). In similar terms, related research determined the influence of the macroscopic structure of chocolate bars with 3D-printed proteins on instrumental texture properties and sensory perception. The results showed that protein bars with a concentric pattern of chocolate filling were significantly harder than bars with a chocolate coating. In terms of perceived chewiness and flavor, diners found no significant differences between bars that differed in filling pattern. Therefore, changing the macroscopic structure (impression pattern) helped to modify the instrumental and sensory properties without affecting the flavour (Zhu et al., 2021). In the same way, related research documented the development of a child-friendly oral dosage form of hydrophilic and lipophilic active compounds through the use of 3D printing of chewable chocolate. The adoption of 3D printing as a manufacturing process allowed flexibility in dosage adjustment and active participation of the patient in personalizing the design, providing a more attractive option for pediatric patients (Karavasili et al., 2020). Another study presented consumers with different designs that differed in shape complexity and ingredients (marzipan and chocolate). The results showed that participants preferred shapes with greater complexity and that taste preference mainly depended on material selection. In addition, the results demonstrated that participants preferred 3D-printed shapes that achieved high fidelity when recreating the computer-aided design (CAD) (Chirico Scheele et al., 2022).

3D printing has also permeated in the packaging sector, developing intelligent sensory packaging variants, including packaging with personalized shapes and die-cuts (Tracey et al., 2022; Leontiou, et al., 2023). Recent advancements in edible materials as added value to packaged foods have been empirically documented with successful applications in meat products, fruits and vegetables, among others (Trajkovska Petkoska et al., 2021). Related to this, the use of 3D printing has established the challenge of creating printed packaging from agri-food waste (Pant, 2146), which has driven the development of food-based packaging reliant on edible raw materials (Prakash et al., 2019). This factor is considered of research interest, warranting further investigation to gauge user acceptance across diverse contexts.

1.2. Emotional response to 3D printed food

From a social point of view, public opinion mostly approves of the development of new food technologies, especially 3D food printing. For example, in the work of (Lupton, 2017), they analysed online news reports on this topic and concluded that the reception was “overwhelmingly positive”, describing this new food technology as futuristic, creative, healthy, efficient, and sustainable. However, literature also presents cases that contradict these claims when individual diners’ emotional responses to unfamiliar products they have to eat are analysed. These cases of adverse reaction, however, are not so much to be found in the production or handling technology used but in the origin of the raw material of the food. For example, the work of (Hellali & Koraï, 2023) has identified a clear reticence among diners to consume recycled food, indicating that the higher the level of innovation in the food, the lower the intention to consumer the product. Another example is the case of insect-based foods (Liceaga, 2022), which, although they are safe and nutritious foods, people have adverse emotions. In this type of experience, at an emotional level, fear appears, which the researchers called food neophobia. Interestingly, when comparing the service of a human waiter with the use of robots in food preparation and customer interaction, the emotional reactions are completely different, provided that the food remains traditional. For example in the study by (Park, 2023), this comparison was made between robots and waiters in the preparation of coffee. In this case, the coffee prepared by robots induced more dynamic and positive emotions in the users, with no differences in the acceptance of the coffee itself.

These studies show that the acceptance of a food is not determined solely by technology, such as 3D printing. For example, (Isaías et al., 2023) indicates that food acceptance is determined by taste, palatability and the perceived quality of the food as a whole. Furthermore, these researchers found that it is not only the characteristics of the food that influence taste, but also the environment, i.e. the physical context and the people with whom the food is eaten, as well as cognitive factors, such as the expectations that the person had before the experience. In addition, according to (Doty & Bromley, 2014), tasting a dish provokes physiological reactions that aid ingestion and digestion through the generation of saliva, hormones related to digestion and the movement of the digestive system. For these reasons, positive emotions evoked by a food improves the eating experience, as well as its digestion.

More examples of emotional responses but with a particular focus on 3D printing of food can be found in the work of (Chen et al., 2022), which highlights the challenge of printing meat analogues. Despite being safe, sustainable and inexpensive, these meat analogues often lack flavour, texture, and colour, sensory properties that directly affect diners’ perceptions. However, there are contexts where the acceptance of 3D printed food is secondary to its functional and nutritional advantages, such as in food created for long duration space missions (Santhoshkumar et al., 2024), where a less pleasurable taste is accepted in favour of creating a la carte, adaptable and customisable food.

Emotional responses to food are crucial for certain segments of society, such as seniors accustomed to traditionally prepared foods. A study (Shigi & Seo, 2024) was conducted on elderly people in Japan analysed their acceptance of 3D-printed food. The researchers indicated that the most important characteristics for elderly individuals to consume these foods were determined by their environmental awareness, viewing them as useful rather than desirable options. Another review (Liu et al., 2022) looked more deeply into how older people experience these new foods, concluding that foods that are soft, smooth and have some humidity produce positive emotions. They also point out that, for this demographic, it is important to make food visually appealing. Interestingly, another study (Yu et al., 2023) also highlights the importance of positive visual perception in children, and the shapes and tastes of food, making a difference to adult food.

If the emotions perceived by children, older adults, and the general public are positive, 3D food technology has significant potential for development, with substantial environmental, economic, and social impacts.

The production of edible packaging via 3D printing can significantly reduce reliance on non-biodegradable plastics, thereby mitigating waste accumulation and promoting a circular economy. By integrating packaging that can be consumed along with its contents, this method addresses one of the major environmental challenges associated with traditional plastic waste (Ncube et al., 2020). Additionally, 3D printing facilitates the local production of packaging, such as within restaurants or small-scale facilities. This localized production model can reduce the carbon footprint associated with transportation and long-term storage, which are typically significant sources of CO_2 emissions in conventional supply chains (Leontiou, 2023). Furthermore, the technology allows for precise customization of packaging, optimizing material use and reducing waste. This efficient use of resources supports environmental sustainability by minimizing excess materials and promoting better resource management (Trajkovska Petkoska et al., 2021).

2. Material and methods

This article presents a study on the application of edible 3D printing in a hypothetical gastronomic event. For this purpose, a customised packaging was designed. With the aim of creating a design for a specific gastronomic event, this work focused on a hypothetical university event in which students and attendees are offered a chocolate dessert to be consumed while standing up. The dessert was presented in an edible container that was designed for the study to be 3D printed using milk

chocolate. A questionnaire measured acceptance of this chocolate packaging, compared to a traditional ceramic container, as well as the degree to which the stimuli evoke pleasant surprise, fascination, and desire, which together represent a "wow-experience".

2.1. Stimuli/design method

For this study, we developed a custom-designed 3D printed edible cup shaped product packaging to be used in the context of gastronomic experiences. The method used to design the stimuli was based on the Food Design Thinking method (Zampollo & Peacock, 2016), which involved different stages towards a final product design. The resulting design was approved by several design experts and subsequently validated by making a fully edible 3D printed chocolate product sample (see Fig. 1). The sample was created with the 3D printer Choco Mycusini 1.0 from the company Mycusini in Germany. The material used in this study was the company's own milk chocolate. Likewise, the physical prototype was also used as a pattern for the rendering of the packaging, in this case controlling the amount of information provided by the texture. Specifically, the two stimuli under study, a milk chocolate container and a ceramic container, were rendered. Both were shown in the online questionnaire as images, see Fig. 2. Using renders for both stimuli was ensured equal quality, detail, and realism, which enabled a proper comparison.

2.2. Participants

The case study focused on creating an experience for a hypothetical university event at the university of Cádiz. Therefore, professors and students from the University of Cadiz were recruited with the intention that the information obtained from the study would be applicable in the future to the gastronomic and convivial events that this institution usually organises. A total of 218 participants were involved in the study, with 52.3 % being women, and an average age of 26.74 years (SD = 11.92). All participants volunteered to participate in the study.

2.3. Measures and procedure

The study employed a within-subjects study design: All participants responded to both the ceramic and the chocolate render (in randomized order). Additionally, the study included a between-subjects variable: Half of the participants were informed about the packaging material, the edible nature of the chocolate, and the fact that it was created using 3D printing technology before responding to the stimuli. The other half did not receive this information.

This setup was key for analysing how prior knowledge influenced participants' perceptions, allowing for a more precise assessment of the impact of 3D food printing technology on sensory experiences and emotional responses. By highlighting the innovative capabilities of this technology, the study explored how the 3D printed chocolate manufacturing method could impact participants' emotional responses by generating a "WOW effect". This highlights the transformative potential of 3D printing in shaping the perception and acceptance of edible innovations.

Fig. 1. Photo of the 3D printed milk chocolate desert packaging design.

Emotional experiences and attitudes were measured with an online survey. First, participants reported their emotional responses to the stimuli, followed by statements that measured their attitudes towards 3D food printing. Emotions were measured with PrEmo (Desmet, 2018), an image-based self-report scale that measures 14 distinct emotions (seven pleasant and seven unpleasant emotions, see Fig. 3), using 5-point Likert scales.

An analysis of variance (ANOVA) was performed to assess the impact of providing participants with prior information about the packaging.

Additionally, attitudes were measured through six questions (Table 1), for which respondents answered with "yes", "maybe", or "no". Then, the measured data was analysed.

3. Results and discussion

In our analysis, we focused on the "wow-experience", as conceptualized by (Desmet et al., 2005). This approach operationalizes the wow-experience as comprising three emotions: pleasant surprise, fascination, and desire, with a composite wow-rating calculated by aggravating the ratings of these three emotions. We compared wow-ratings between the two packaging types.

3.1. Effect of the snacks packaging on the WOW index

Table 2 reports the mean ratings (M) and the standard deviation (SD) on the three WOW emotions, for participants who were provided with information about the packaging material and those who were not. The results showed a significant effect (<0,05) of the type of packaging on the overall WOW experience (F = 0 3.92, p = 0.04): Participants experienced 7.49 % higher levels of WOW to the dessert served in the 3D printed chocolate container than to the dessert served in the ceramic container (M = 3.13).

3.2. Influence of prior information about packaging material and processing on emotional responses

The effect of providing prior information that one of the packages is completely edible 3D printed milk chocolate was examined with an ANOVA. The analyses found a significant effect on the WOW index (ceramic F = 4.23, p = 0.04; 3D milk chocolate F = 16.91, p = 0.00), indicating that the WOW experience is higher when prior information about the packaging is provided. In the case of the 3D printed milk chocolate, participants experienced a greater WOW effect and the surprise effect of the milk chocolate snack turned out to be greater as well.

Table 3 shows the results for the ceramic packaging. The results indicate that participants who obtained prior information experienced 10.38 % higher WOW responses. Note, however, that for the emotion fascination, no significant difference was found. This could be explained by the lack of novelty in the information that leads to the lack of changes in the participants' perception of the snack and packaging analysed.

Table 4 shows the results specifically for the chocolate packaging. Results show that the WOW experience was 25.04 % higher for the group who received the prior information about the packaging than for the group who did not. In this case, differences for all three WOW emotions reached significance. This indicates an influence of the novelty of the packaging in terms of being edible and 3D printed.

Finally, a comparison between the results of the two participant groups indicated that the Wow effect increased when being informed about the edible and manufacturing properties of the milk chocolate container. Specifically, it is 2.41 higher than the ceramic container. From this data it is deduced that, for the group of respondents, making a 3D printed chocolate packaging and the fact of being able to eat it provokes surprise, fascination and desire and therefore provokes appropriate emotions for the event proposed in this study.

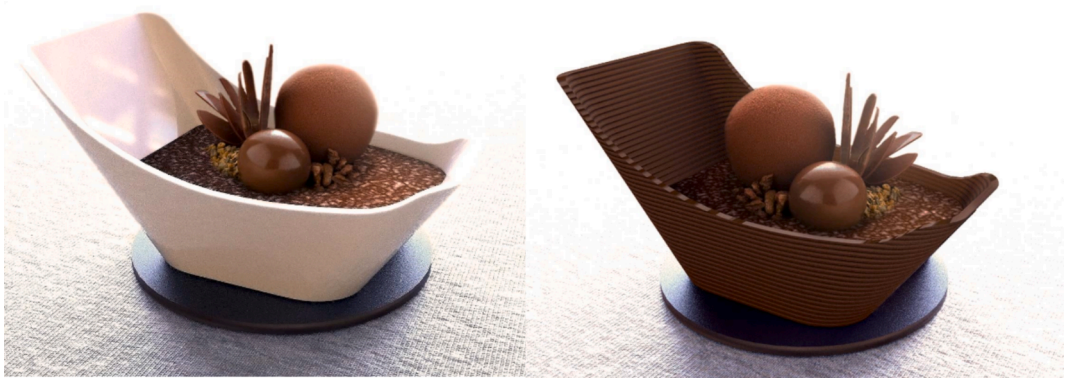

Fig. 2. Realistic renderings of the study stimuli. Left: Conventional ceramic desert packaging; Right: 3D printed milk chocolate desert packaging.

Fig. 3. Visual emotion representations, as measured in the questionnaire. Image from (Laurans & Desmet, 2016).

Table 1
Questions to measure attitude towards 3D food printing.

Q1	Do you know about 3D printing?
Q2	Do you know about 3D food printing?
Q3	Would you like to try this type of food?
Q4	Do you find any kind of advantage in the application of 3D printed food?
Q5	Do you think restaurants could implement this type of technology, such as gastronomic experiences or fine dining restaurants?
Q6	Would you be willing to have a dining experience that included this type of technology?

Table 2
Wow responses (N = 218).

	Ceramic		Milk Chocolate 3D			
	M	DS	M	DS	F-value	P-value
Surprise	2.67	1.30	2.96	1.43	4.73	0.030
Fascination	3.23	1.30	3.34	1.35	0.82	0.366
Desire	2.84	1.50	3.11	1.55	3.35	0.068
WOW Index	2.91	1.05	3.13	1.29	3.92	0.04

Table 3
Impact of information condition on the emotions evoked by the Ceramic packaging.

	No prior info		With prior info			
	M	DS	M	DS	F-value	P-value
Surprise	2.32	1.22	3.02	1.30	16.41	0.000
Fascination	3.29	1.38	3.17	1.22	0.46	0.498
Desire	2.69	1.49	2.98	1.50	2.00	0.161
WOW index	2.77	0.92	3.06	1.14	4.13	0.043

Table 4
Impact of information condition on the emotions evoked by the 3D printed chocolate packaging.

	No prior info		With prior info			
	M	DS	M	DS	F-value	P-value
Surprise	2.57	1.28	3.34	1.49	16.6	0.000
Fascination	3.11	1.31	3.57	1.36	6.47	0.012
Desire	2.68	1.43	3.54	1.54	18.06	0.000
WOW index	2.79	1.17	3.49	1.32	16.91	0.000

3.3. Attitudes about 3D food printing

Results for the attitude questions are summarized in Table 5. Almost all participants (99 %) were aware of 3D printing (Q1), and about half (47 %) knew about 3D food printing (Q2). Slightly more than half of the participants (65 %) saw an advantage of using 3D printed food (Q4), and 90 % considered 3D food printing beneficial for application in gastronomic experiences and the restaurant sector (Q5). While 76 % of participants expressed interest in trying this type of food (Q3), fewer participants (42 %) reported being willing to have a dining experience that includes this type of technology. At the same time, a similar percentage (41 %) reported that they might be interested in having such a dining experience, indicating a potential interest, and only 17 % reported that they would not be interested at all.

Table 5
Measured attitudes (N = 218).

Attitude question	No (in percentage)	Maybe (in percentage)	Yes (in percentage
Q1	0.9 %	0 %	99.1 %
Q2	53.2 %	0 %	46.8 %
Q3	2.8 %	21.1 %	76.1 %
Q4	3.7 %	31.2 %	65.1 %
Q5	0.9 %	91 %	89.9 %
Q6	16.5 %	41.3 %	42.2 %

4. General discussion

4.1. 3D food printing for gastronomic experiences

This study focused on analysing the potential of 3D food printing for the creation of edible packaging for gastronomic experiences. Specifically, a comparison has been made of a snack presented in a 3D printed milk chocolate packaging and a conventional ceramic one. A questionnaire study measured consumer experience of surprise, fascination, and desire, combining these into a "wow" experience. In general, the results indicate that participants experienced higher levels of wow in response to the edible packaging than to the ceramic packaging. In addition, 3D printed edible packaging appeared to be well-accepted, regardless of whether participants have received information about the packaging material and processing technology.

The results align to findings reported in recent literature, indicating that 3D printing can be a fundamental pillar for the reuse of waste, the circular economy and sustainability (Yoha & Moses, 2023). This reinforces the interest in the application of this technology and continuing the study from this perspective.

Regarding consumer acceptance, the results on the potential of 3D food printing showed that 65 % of participants consider this technology beneficial, and 90 % would implement it in some way in restaurants. This aligns with the positive results on the wow effect and highlights the clear interest in this technology for its application in the gastronomic sector. However, a little less than half of the participants consider it beneficial. This result corresponds to the research of (Brunner et al., 2018) who documented that increased knowledge about this technology increases the acceptance of 3D printed food but maintains the neophobia it raises. On the other hand, the results are reaffirmed by research from Cauler et al (Caulier et al., 2020) where the acceptance of this type of edible product increases as consumers consume and are informed about the origin of the product. So, according to (Mantihal et al., 2019), the hypothesis of this work is reinforced, being of great interest to increase the creation of experiences using this technology to create a solid implementation in the society.

In summary, the results show that participants are attracted to the novelty of edible packaging made by 3D printing. These findings are consistent with recent research related to applications of 3D food printing (Alami, 2024; Nachal, xxxx).

4.2. WOW effect in edible packaging design

Findings have been described according to the principles of innovation and surprise that are relevant in certain contexts related to food since 1996, Furst et al. (Furst et al., 1996) and in 1997 Cohen (Cohen, 1997) have noted that consumers prefer memorable experiences and ecological products, combining the preference for novel gastronomic experiences along with the reduction of environmental impact. This ongoing concern in the food industry is addressed by proposing 3D printing as a possible solution, allowing for emotional impact while reducing environmental impact, as evidenced by the positive reception of 3D printed chocolate in this study.

Rent works, such as those by Kulshreshtha et al (Kulshreshtha & Sharma, 2022), highlight the importance of surprise in gastronomic experiences, especially during the Covid-19 pandemic among Generation Z. This finding also corroborates the interest of the group for the search for surprise in the tasting experience. Similarly, other researchers such as Leung et al (Leung & Loo, 2022) show the importance of surprising consumers, though they do so through complementary service using robots and AI to serve the dishes. Researchers like Panchapakesan et al (Panchapakesan et al., 2022) indicate the importance of the emotional relationship with clients. In both cases it should be noted that it is not an innovation in culinary processes, focusing exclusively on the interaction of diners with their physical and social environment. Therefore, like in this work, an emotional relationship of pleasant surprise is sought in the culinary experience, evidencing the interest in the community to develop experiences that generate surprise, fascination and desire from different points of view.

Other authors such as Gutjar et al (Gutjar, 2015) used the PrEmo tool to analyse food products to study the relationship between taste and emotion, showing that diners' flavour ratings are influenced by the emotions evoked by the food, confirming the role of emotions as an enhancer of perceived taste.

Desmet et al (Desmet & Schifferstein, 2008) identified five distinct sources of emotions in the gastronomic experience: sensory attributes, experienced consequences, anticipated consequences, personal or cultural meanings and actions of associated agents. This indicates that although the wow effect is relevant for the interpretation of the experience, it can be qualified by the properties of the food itself, by personal and cultural components and other external agents.

4.3. Limitations and further research

This study has several limitations. Firstly, it only focused on 3D printed chocolate edible containers. Comparing edible packaging with different foods and conventional artisanal production (Caulier et al., 2020), requires further studies on the wow effect in a specific gastronomic experience. Additionally, regarding 3D printing of chocolate, textures can be explored with respect to the wow effect and consumer perception (Mantihal et al., 2019). Secondly, the study used only visual stimuli (renders of deserts) (Simmonds & Spence, 2017). Haptic perception should be explored in a future study to fully evaluate sensory perception (Fahmy, 2021). Thirdly, the study analysed prior information about the dessert packaging material using different groups of subjects (Sousa et al., 2020). It was found that obtaining information about a novel process increases the wow effect. Therefore, consumer acceptance of 3D printed foods could be explored with respect to the previous information received. All participants shared cultural traits, minimizing bias, but future studies should consider personal variables and environmental elements. Finally, some control variables such as familiarity and specific tastes in the type of food evaluated should be measured as they could affect WOW effect.

5. Conclusions

This research demonstrates that the degree to which consumers have a WOW experience towards designed snacks is directly influenced by the material of the packaging. Using a fully 3D printed edible chocolate packaging enhances the novelty effect of the consumer's experience, which, in turn, had a positive correlation with the level of acceptance during the trial.

The effectiveness of the WOW effect technique applied to gastronomic experiences has been confirmed, since the results obtained are consistent with those obtained in other studies despite using different techniques. However, this study used images of edible products, which may introduce bias as the gastronomic experience is inherently multimodal. Because the WOW effect is a versatile technique that can be adapted to a multimodal experience, future work should consider environmental variables, such as the setting (indoor or outdoor), temperature, and the diner's posture (seated or standing). Additionally, the

social context and intrinsic user factors, such as cultural background and knowledge of new technologies in gastronomy, should be considered.

In conclusion, 3D food printing is a promising technology that offers numerous opportunities for customization, nutrition, and creativity in the food industry. The ongoing development of this technology has the potential to enable a wide range of future applications, from producing personalized chocolate and other food products to creating of unique gastronomic experiences. It can also serve as a valuable tool for restaurants, enabling them to enhance creativity in both their dishes and desserts. Nonetheless, it is important to carefully address concerns related to safety and consumer acceptance to ensure the successful application of 3D food printing in gastronomy.

Ethical statement

Hereby, I Lucía Rodríguez Parada consciously assure that for the manuscript "Edible Innovations: testing the WOW impact of 3D printed chocolate packaging" the following is fulfilled:

1) This material is the authors' own original work, which has not been previously published elsewhere.
2) The paper is not currently being considered for publication elsewhere.
3) The paper reflects the authors' own research and analysis in a truthful and complete manner.
4) The paper properly credits the meaningful contributions of co-authors and co-researchers.
5) The results are appropriately placed in the context of prior and existing research.
6) All sources used are properly disclosed (correct citation). Literally copying of text must be indicated as such by using quotation marks and giving proper reference.
7) All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

CRediT authorship contribution statement

Lucía Rodríguez-Parada: Writing – original draft, Methodology, Investigation, Data curation. **Sergio de la Rosa:** Writing – original draft, Visualization, Software. **Jesús Sánchez Salado:** Methodology, Investigation, Conceptualization. **Pieter Desmet:** Writing – review & editing, Formal analysis. **Miguel Ángel Pardo Vicente:** Writing – review & editing, Validation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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