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VISUAL SENSORY CUES AND CONSUMER PURCHASE INTENTION TOWARDS 3D-PRINTED MEAT ALTERNATIVES IN MALAYSIA: THE MEDIATING ROLE OF MENTAL IMAGERY AND CONSUMER ATTITUDE, AND THE MODERATING ROLE OF FOOD NEOPHOBIA

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Abstract:

This conceptual paper aimed to examine how visual sensory cues influence Malaysian consumers' purchase intention towards 3D-printed meat alternatives, with mental imagery and consumer attitude as the mediating roles and food neophobia as a moderating variable. This study adopted a conceptual approach grounded in the Stimulus-Organism-Response (S-O-R) framework. The paper synthesised

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existing literature on visual sensory cues, mental imagery, consumer attitude, food neophobia, and purchase intention to propose a comprehensive theoretical model for understanding consumer acceptance of 3D-printed meat alternatives in Malaysia. The proposed framework suggested that visual sensory cues served as external stimuli that evoked mental imagery and shaped consumer attitudes, which subsequently influenced purchase intention. Also, the study found that food neophobia was expected to moderate the relationship between consumer attitude and purchase intention, reflecting the psychological barriers associated with novel food technologies. This paper addressed a critical gap in the literature by integrating visual sensory cues and mental imagery within the S-O-R framework to explain consumer responses to 3D-printed meat alternatives in the Malaysian context, where direct product experience is currently unavailable.

Keyword:

3D-Printed Food, Consumer Attitude, Food Neophobia, Malaysia, Mental Imagery, Purchase Intention, S-O-R Framework, Visual Sensory Cue



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Introduction

Three-dimensional (3D) printing is a novel food processing method that builds food layer by layer from edible feedstock, and its use is not limited to the food industry but also extends to the healthcare industry (Brunner et al., 2018). This innovative technology offers customised food with several unique features in terms of food texture, shape, flavour, functional products, and nutritional value according to individuals' food preferences and dietary requirements (Escalante-Aburto, Ramírez-Wong & Torres-Chávez, 2021; Taneja, Sharma, & Singh, 2022). Interestingly, this technology can produce a wide range of food production, including vegetable purées, doughs, batters, and dairy products (Derossi et al., 2023; Kewuyemi, Kesa, & Adebo, 2022). Aligning with global food security pressure, this technology has emerged as a promising platform to support food sustainability by incorporating alternative ingredients such as algae and insects and food waste into nutritious food (Bhat et al., 2021; Pant, Chan & Lee, 2023; Severini et al., 2018).

This innovative food technology holds significant potential in Malaysia, where food insecurity remains a serious concern due to reliance on imported products to meet daily food needs. Statistical data shows that Malaysia remains heavily dependent on imported food, with projected imports of USD10.09 billion for agriculture, a rise in meat imports to USD742.95 million, and USD1.85 billion for fish and agriculture (Statista, 2026). The widening gap

between import demand and local production suggests the need for innovative and sustainable food technologies to support food security in Malaysia. Therefore, 3D food printing acts as an alternative solution towards food insecurity by creating nutritious food by optimising resources from food scraps to produce specific dietary needs.

Despite its technological promise, consumer acceptance and willingness to purchase 3D-printed food are major concerns for the successful commercialisation of novel foods, especially meat alternatives, which remain largely unavailable in Malaysia. Therefore, consumers have limitations to physically experience the products. Rather, consumers rely heavily on media, namely visual sensory cues, photographs, and videos, to experience products. This creates a critical gap in understanding how consumers interpret and evaluate such products prior to consumption.

As product images or videos, visual information has an impact on the quality perception, the taste expectation, and purchase intention (Petit, Basso & Velasco, 2024; Velasco & Spence, 2024). The use of 3D-printed food in food marketing and other sectors, such as fashion, tourism, and e-commerce, has been well researched (Kim, Kim & Lee, 2024) but there were very few studies that specifically focus on 3D-printed food and the context of Malaysia. Although attitudinal measures were used, Cunningham et al. (2026) pointed out that there is a need for other experiential approaches to consumer evaluation other than attitudinal measures in the case of 3D-printed food. On the other hand, the current literature has yet to determine the connection between what is perceived visually and the psychological reaction. In particular, it lacks an explanation of how visual cues translate into psychological responses in novel food contexts. Mental imagery is another crucial element in influencing consumer emotional responses and purchase intention in an online setting (Barrett et al., 2025; Lee, Lee & Kim, 2024). However, the study on mental imagery in 3D food printing remains scarce. Existing studies on 3D-printed food focus mainly on trust, risk, and attitude, without examining how consumers mentally construct product experiences they have never directly encountered.

Previous literature found that food neophobia serves as a moderating variable in the relationship between visual sensory cues, mental imagery, and attitude towards consumer purchase intention. Consumers fear consuming new foods, which they have not experienced or recognised in the past (Lee et al., 2021; Pliner & Hobden, 1992). Empirical evidence further suggests that consumers with high levels of food neophobia tend to have negative attitudes towards innovative food technology, while consumers with lower levels are more engaged and tend to accept such products (Barrena & Sánchez, 2012). Considering that 3D-printed food as a meat alternative remains largely unfamiliar among Malaysian consumers, investigating food neophobia as a moderating effect offers a beneficial investigation.

While previous studies have consistently established attitude as a significant predictor of behavioural intention, insufficient attention has been given to explaining how favourable attitudes are formed in the absence of direct product experience. In the Malaysian context, where 3D food printing implementation remains at an early stage, and consumers have not yet adopted the technology, with awareness levels remaining generally low, the majority of the population has had no direct experiential exposure to meat alternatives produced through 3D food printing. Without direct sensory exposure, consumers rely on external informational cues to form evaluative judgements. Prior research confirms that consumers evaluate unfamiliar products through available visual cues and their relation to previously known products. The visual depictions then trigger mental simulation that positively influences purchase intentions.

Taken together, this reveals a specific and previously unaddressed gap. Prior studies on 3D-printed food acceptance in Malaysia have examined trust, risk, and general attitudinal responses (Ng et al., 2022; Kanwal et al., 2025), but none have jointly modelled visual sensory cues and mental imagery as sequential antecedents of attitude formation under conditions of zero direct product experience. This study addressed that gap by integrating visual sensory cues and mental imagery within a single S-O-R framework and by testing food neophobia as a boundary condition on the resulting attitude–purchase intention relationship, an integration that has not previously been examined for 3D-printed meat alternatives in the Malaysian market. In particular, the current study incorporated visual sensory cues and mental imagery as antecedents of attitude formation within the Stimulus-Organism-Response (S-O-R) framework. It posited that consumer behaviour emerged through sequential stages of external stimulation, internal psychological processing, and behavioural response to positioning consumer attitude as the critical organism-level mediator through which visual stimuli shape the behavioural intentions of Malaysian consumers toward 3D-printed meat alternatives.

Literature Review

This chapter reviews the literature underlying five key constructs examined within the S-O-R framework: visual sensory cues, mental imagery, consumer attitude, food neophobia, and purchase intention. In the current study, visual sensory cues served as the stimulus elements. This study believed that visual sensory cues evoked consumer mental imagery that subsequently shaped consumers' product attitudes and purchase intentions. Also, consumer attitude functioned as the organism construct through which stimuli were internally processed. In this study, purchase intention represented the behavioural response, and food neophobia was treated as a moderating variable. This acknowledged that consumer perceptions of novel technology were critical determinants of attitudes and purchase intentions toward 3D-printed foods. Together, these constructs provided the theoretical basis for understanding how Malaysian consumers formed attitudes and purchase intentions towards 3D-printed meat alternatives in the absence of direct product experience.

Definition of 3D Printed Food as a Meat Alternative in Malaysia

Three-dimensional (3D) food printing is an additive manufacturing technology that fabricates edible products by depositing food materials, such as purées, pastes, gels, and powders, layer-by-layer based on a computer-aided digital design (Ng et al., 2022). Unlike conventional food processing methods, 3D food printing enables the production of customised food products with precise control over shape, texture, nutritional composition, and visual appearance according to individual consumer preferences (Miller, Scarlett, & Akanbi, 2024).

This technology has gained growing traction as a novel approach to solve the many problems associated with food security, environmental sustainability and the ever-increasing demand for alternative protein sources, globally. In the recent years, the world is seeing the emergence of a new class of products to replace the negative environmental impact on the conventional livestock and production: cultured meat, plant-based meat and 3D-printed meat (Lanz et al., 2024). While the use of 3D food printing is gaining popularity, some previous studies have been identified with different conclusions regarding consumers' acceptance of 3D food printing. For instance, most consumers would be more favorable toward the 3D printed meat compared to cultured meat because of the more familiar and perceived certainty of the ingredients, said Lanz et al. (2024). Likewise, Miller, Scarlett, and Akanbi (2024) proposed that one of the biggest benefits of 3D food printing is its ability to create visually appealing,

highly personalized food products, which can lead to an improvement in the perceived value to consumers. Some scientists suggested that a mere technological innovation wouldn't be sufficient to positively influence consumers' willingness to accept new food technologies since consumers' doubts about the new technology could persist, even if the technology is environmentally and nutritiously beneficial (Kanwal et al., 2025). In conclusion, although 3D food printing has a lot of potential in enhancing the functional foods, other psychological and perceptual factors will impact on their acceptance aside from the technological properties of the food print.

There is not much empirical research conducted on 3D printed food in Malaysia and it has become more theoretical over the years. The overall awareness and attitude towards 3D-printed foods among Malaysian consumers is low, but can be improved based on the readiness to eat 3D food and the perception of benefits 3D food printing technology as mentioned by Ng et al. (2022). In the extension of this research, Kanwal et al. (2025) found that the attitude of the consumers towards 3D-printed foods is a positive predictor of their acceptance and that food neophobia and food technology neophobia also affect their acceptance of 3D-printed foods. In recent years, in the Malaysian literature, the psychological factors of curiosity, ethics and perceived risk were introduced by Latip et al., (2025) in their study on consumers' attitudes towards 3D-printed food. Overall, the studies indicate that Malaysian consumers look at 3D-printed food not just technologically, but also psychologically, which affect their behaviour.

Overall, previous studies have substantially advanced the understanding of consumer acceptance of 3D-printed food by focusing on technological innovation, perceived benefits, and individual psychological characteristics. Nevertheless, limited attention has been devoted to understanding how consumers initially evaluate the product through its visual presentation before forming attitudes and purchase intentions. This limitation is particularly important in Malaysia, where consumers have little or no direct experience with 3D-printed meat alternatives. Under such circumstances, consumers are likely to rely on visual information to construct mental representations of the product before making consumption decisions. Therefore, this study extends the existing literature by integrating sensory marketing and consumer psychology perspectives to examine how visual sensory cues stimulate mental imagery, which subsequently influences consumer attitudes and purchase intentions towards 3D-printed meat alternatives in Malaysia.

Visual Sensory Cue

Visual sensory attributes are the visual properties of a product prior to initial contact with it. These are the cues to consider and are the most important sources of information when evaluating the product, namely: colour, shape, texture, size and overall presentation (Krishna, 2012). Likewise, Azman et al. (2024) define visual sensory cues as the characteristics of the products that are perceived by the consumers' eyes which can stimulate their expectations of product quality, freshness and attractiveness prior to their consumption. Thus, the consumer does not have first-hand experience of the product and the importance of visual cues is increased to minimize uncertainty and form the initial impression of the product (Krishna & Schwarz, 2014).

The visual characteristics of food have been consistently shown to have a significant influence on consumers' food consumption evaluation in previous studies. Consumers' perceptions of taste, quality and eating experience are heightened by attractive food presentation (Azman et

al., 2024). In the same vein, Miller et al. (2024) reported that the 3D food printing technology will help manufacturers produce food products with appealing designs, and highly customisable; Scarlett et al. (2024) reported that the versatility of 3D food printing will improve the attractiveness and perceived value of meat alternatives. The results of this study were confirmed by Sakri et al. (2026) who discovered that the image of a food evokes the consumers' image of eating and Liu et al. (2022) who found that the consumers' sensory expectations were significantly shaped by the inclusion of pictures in the food stimuli. These works indicate that the visual sensory information is meaningful to the consumers even before consumption as it conveys information about the product.

The need for visual sensory cues is even more critical with 3D printed meat alternatives, where people aren't able to taste the foods they are looking to eat. This is particularly the case in Malaysia where the 3D printing of meat alternatives is not available. Consumers' knowledge of the technology is low and most consumers are relying on visual information to evaluate the product as they have little experience with the technology (Ng et al., 2022; Kanwal et al., 2025). It is hypothesized that the visual sensory cue will be one of the external cues that will be important to consumers' perception of meat alternatives printed in 3D.

To sum up, past studies have demonstrated that visual sensory cues have an important influence on consumer evaluations. But, the literature has focused more on the effect of the visual impact itself on the consumer's behavior and has not focused as much on the psychological mechanisms through which the visual information impacts consumer behavior. Therefore, findings from this study indicate that visual sensory cues can activate consumers' mental imagery that affects their attitudes and meat alternative purchase intentions for 3D-printed meat alternatives.

Mental Imagery

Mental imagery refers to consumers' ability to mentally simulate or imagine a product experience without direct physical interaction with the product (Krishna, 2012). It allows consumers to create sensory representations based on external information, such as product images, videos, or descriptions, before actual consumption. Similarly, Elder and Krishna (2022) described mental imagery as a cognitive process that enables consumers to mentally experience a product through multiple senses, making it particularly important when direct product experience is unavailable. Therefore, mental imagery serves as an important mechanism that helps consumers evaluate unfamiliar products and reduce uncertainty during decision-making.

Previous studies consistently reported that mental imagery positively influences consumers' product evaluation and behavioural responses. Consumers who generate stronger mental imagery are more likely to develop favourable attitudes, stronger emotional engagement, and higher purchase intentions towards a product (Elder & Krishna, 2022). Likewise, Li, Daugherty, and Biocca (2003) suggested that consumers increasingly rely on mental imagery when evaluating products that cannot be physically experienced because external information enables them to mentally simulate product consumption. Supporting these findings, Sakri et al. (2026) found that visual food images stimulate consumers' consumption vision and demonstrated sensory mental imagery influences consumers' food-related responses by strengthening imagined sensory experiences before consumption. Collectively, these studies

suggest that mental imagery bridges external product information with consumers' cognitive and behavioural responses.

Mental imagery is particularly relevant in the context of 3D-printed meat alternatives because consumers generally have no prior experience with the product. Consequently, they are likely to depend on visual information to imagine the product's appearance, texture, and consumption experience before forming evaluations. This situation is especially relevant in Malaysia, where 3D-printed meat alternatives are not yet commercially available. Existing Malaysian studies have primarily focused on consumer awareness, attitude, perceived benefits, and technology acceptance (Ng et al., 2022; Kanwal et al., 2025), while the role of mental imagery remains largely unexplored. Therefore, this study proposes that mental imagery functions as an important cognitive mechanism through which visual sensory cues influence consumers' attitudes and purchase intentions towards 3D-printed meat alternatives.

Consumer Attitude

Consumer attitude is a general positive or negative attitude towards a product or behavior (Ajzen, 1991). Consumer attitude towards novel food technologies can be defined as consumers' evaluation of the positive or negative perception of eating a novel food product, as in the case of 3D printed food. Building on this Brunner et al. (2018) have proposed that the more consumers understand that they are benefiting from new food technologies the more positive attitude they will likely have, while the less they know, the less positive attitude they will likely have, or the attitude may be negative.

Previous studies have consistently highlighted the importance of consumer attitude in determining the acceptance of 3D-printed food. Ng et al. (2022) found that Malaysian consumers generally demonstrated neutral attitudes towards 3D-printed food due to their limited awareness and familiarity with the technology. However, consumers who perceived greater benefits from the technology developed more favourable attitudes. Similarly, Kanwal et al. (2025) reported that consumer attitude significantly influenced consumers' intention to accept 3D-printed food, indicating that favourable attitudes encourage greater acceptance of the technology. More recently, Latip et al. (2025) extended these findings by demonstrating that curiosity positively influences consumer attitude, while perceived risk and ethical concerns affect purchase intention indirectly through attitude. These findings indicate that consumer attitude plays an important role in translating consumers' cognitive evaluations into behavioural intention.

Other than that, recent studies on alternative protein products also reported that consumers with positive evaluations of sustainable food innovations are more willing to purchase and consume these products (Lanz et al., 2024) This suggests that consumer attitude is influenced not only by the technological characteristics of the product but also by consumers' overall perceptions and evaluations towards the product. Therefore, consumer attitude is expected to play a significant role in encouraging consumers' purchase intention towards 3D-printed meat alternatives.

Food Neophobia

Food neophobia refers to an individual's reluctance to consume unfamiliar or novel foods (Pliner & Hobden, 1992). The concept is generally regarded as a relatively stable personality

trait that influences consumers' willingness to try new food products. As food innovation has shifted towards technologically produced foods, researchers have extended this concept to food technology neophobia, which specifically reflects consumers' resistance towards foods produced using emerging technologies rather than the food itself (Lee et al., 2021). Therefore, consumers' acceptance of innovative food products depends not only on the product itself but also on their willingness to embrace unfamiliar food technologies.

Recent studies have increasingly recognised food neophobia as one of the major barriers to the acceptance of 3D-printed food. Consumers who perceive 3D-printed food as unfamiliar or unnatural are generally less willing to evaluate or consume the product, despite recognising its potential nutritional or environmental benefits (Lanz et al., 2024). Likewise, Lee et al. (2021) suggested that consumers with higher food technology neophobia tend to perceive greater uncertainty and lower trust towards foods produced using emerging technologies. These findings indicate that consumers' evaluation of 3D-printed food extends beyond its functional benefits, as psychological resistance towards unfamiliar technologies also influences their acceptance.

More recently, researchers have begun to examine food neophobia not only as a direct predictor of consumer acceptance but also as a condition that influences the strength of other behavioural relationships. For example, Kanwal et al. (2025) found that food neophobia and food technology neophobia significantly moderated the relationship between consumer attitude and intention to accept 3D-printed food among Malaysian consumers. This finding suggests that even consumers who hold favourable attitudes towards 3D-printed food may still hesitate to purchase the product when they possess high levels of food neophobia. Therefore, food neophobia is expected to act as an important boundary condition that weakens the positive influence of consumer attitude on purchase intention towards 3D-printed meat alternatives.

Purchase Intention

Purchase intention refers to consumer willingness to purchase a particular product in the future and is widely recognised as one of the strongest predictors of actual purchasing behaviour (Spears & Singh, 2004). According to the theory of planned behaviour, intention represents consumers' readiness to perform a behaviour and is directly influenced by their evaluation of the behaviour (Ajzen, 1991). As a result, purchase intention has been extensively applied in consumer behaviour research to explain consumers' acceptance of innovative products before they become commercially available.

With the rapid development of sustainable food technologies, purchase intention has become an important outcome variable for evaluating consumer acceptance of novel food products, including cultured meat, plant-based meat, and 3D-printed food. Previous studies suggested that consumers are more likely to purchase innovative food products when they perceive greater benefits, trust the technology, and develop favourable product evaluations (Lanz et al., 2024; Reuben et al., 2025; Siegrist & Hartmann, 2024). In addition, recent studies highlighted that consumers' acceptance of alternative proteins is influenced not only by functional product attributes but also by psychological factors, such as familiarity, perceived naturalness and emotional evaluation, before the actual purchase decision is made.

Research on 3D-printed food has reported similar findings. Ng et al. (2022) found that Malaysian consumers' willingness to consume 3D-printed food increased when they perceived greater benefits from the technology. More recently, Kanwal et al. (2025) demonstrated that consumer attitude is the strongest predictor of intention to accept 3D-printed food, whereas food neophobia and food technology neophobia influence the strength of this relationship. Latip et al. (2025) further explained that consumers' purchase intention is indirectly influenced through attitude, suggesting that behavioural intention develops after consumers have cognitively evaluated the product and resolved their concerns regarding its risks and ethical implications.

Unlike conventional food products, consumers cannot evaluate 3D-printed meat alternatives through direct consumption because the products are not yet commercially available in Malaysia. Consequently, purchase intention is expected to be formed based on pre-consumption evaluations generated from available information rather than actual experience. This suggests that consumers' behavioural intention may depend on how they mentally process visual information and develop favourable attitudes towards the product before making a purchase decision. Therefore, purchase intention remains an appropriate behavioural outcome for explaining consumers' acceptance of 3D-printed meat alternatives.

The Stimulus–Organism–Response (S-O-R) Model

The conceptual model used in this research was derived from a model of environmental psychology, which relates the external environmental features to humans' behaviour, the S-O-R framework by Mehrabian and Russell (1974). In this model, an external stimulus (S), defined as any discrete environmental cue perceived by an individual, is processed internally by the organism (O), resulting in a cognitive or affective state. This inner state then manifests itself in a reaction (R), generally an approach/avoidance reaction to the stimulus (Mehrabian & Russell, 1974). The S-O-R framework started in the field of emotional responses to physical stimuli and has expanded to other fields of research, such as marketing and consumer behaviours. Store atmospherics, website design, or product images have often been used as the sensory cue to investigate the relationship between internal consumer states (e.g., emotion, mood, and attitude) and purchase-related outcomes (e.g., purchase intention, product evaluation, and purchase) (Turley & Milliman, 2000).

The S-O-R framework was utilised in this study for two reasons. First, it provided a clear structure for organising the five constructs under investigation into a coherent causal sequence. Visual sensory cues (S) functioned as the external stimulus that initiated the consumer evaluative process. Mental imagery and consumer attitude (O) represented the internal cognitive and affective states through which the stimulus was processed and interpreted. Purchase intention (R) constituted the resulting behavioural response. Accordingly, the study's conceptual mapping was consistent with recent applications of the S-O-R framework, including studies showing that mental imagery serves as the organism-level mechanism linking visual stimuli to consumer purchase-related responses in digital retail and live-streaming commerce contexts.

Second, the S-O-R framework was suitable for examining consumer responses to product categories that have yet to be directly experienced. In the Malaysian context, consumers lacked a stable, pre-formed evaluation of 3D-printed meat alternatives due to limited physical interaction. Behavioural responses are filtered through internally generated organism states,

constructed primarily from imagined rather than actual sensory experiences. The S-O-R framework's explicit distinction between external stimuli and internal processing made it apt for modelling how a visual cue, without any other form of product exposure, can be cognitively and affectively elaborated into a behaviour and, ultimately, an intention to purchase.

Proposed Hypotheses

Visual Sensory Cue and Mental Imagery

Visual sensory cues provide consumers with the first source of information when evaluating a product before direct experience. In food consumption, product appearance such as colour, shape, texture and presentation helps consumers imagine the product and reduce uncertainty during decision-making (Krishna & Schwarz, 2014). Recent studies reported that visual food images stimulate consumers' consumption vision and strengthen their sensory expectations before consumption (Kim, 2025; Liu et al., 2022). Likewise, Miller, Scarlett, and Akanbi (2024) suggested that the visually appealing and customisable appearance of 3D-printed food enhances consumers' product evaluation. Since 3D-printed meat alternatives are not yet commercially available in Malaysia, consumers are expected to rely heavily on visual information to mentally construct the product experience. Thus, the following hypothesis was proposed.

H1: Visual sensory cues positively influence mental imagery towards 3D-printed meat alternatives.

Mental Imagery and Attitude

Mental imagery enables consumers to mentally experience a product before actual consumption by transforming external information into imagined product experiences (Elder & Krishna, 2022). Through mental imagery, consumers are able to anticipate how a product looks, tastes, and feels, resulting in more favourable product evaluations. Recent studies found that stronger mental imagery positively influences consumers' emotional responses and product evaluation, particularly for unfamiliar food products presented through digital media (Kim, 2025; Peng et al., 2025). Since Malaysian consumers have no prior experience with 3D-printed meat alternatives, mental imagery is expected to facilitate a more favourable attitude towards the product. Thus, the following hypothesis was proposed.

H2: Mental imagery positively influences consumer attitude towards 3D-printed meat alternatives.

Mental Imagery, Visual Sensory Cues and Attitude

According to the S-O-R framework, external stimuli influence behavioural responses through consumers' internal psychological states (Mehrabian & Russell, 1974). In the present study, visual sensory cues represented the external stimulus, whereas mental imagery reflected consumers' internal cognitive processing before forming product evaluations. Previous studies suggested that visual information stimulated consumers to mentally simulate product experiences, which subsequently influences their product evaluation (Elder & Krishna, 2022; Kim, 2025). Therefore, mental imagery was expected to explain how visual sensory cues were translated into favourable consumer attitudes towards 3D-printed meat alternatives. Thus, the following hypothesis was proposed.

H3: Mental imagery mediates the relationship between visual sensory cues and consumer attitude towards 3D-printed meat alternatives.

Attitude and Purchase Intention

Within the S-O-R framework, consumers' behavioural responses are influenced by their internal evaluations after being exposed to external stimuli (Mehrabian & Russell, 1974). Consumer attitude represents an individual's overall evaluation of a product and plays an important role in determining behavioural responses. Recent studies found that favourable attitudes significantly increase consumers' intention to accept 3D-printed food (Kanwal et al., 2025; Latip et al., 2025). Likewise, studies on alternative protein products reported that positive product evaluations encourage consumers' willingness to purchase sustainable food innovations (Lanz et al., 2024). Thus, the following hypothesis was proposed.

H4: Consumer attitude positively influences purchase intention towards 3D-printed meat alternatives.

Food Neophobia as Moderator

Food neophobia refers to consumers' reluctance to consume unfamiliar foods and is recognised as one of the major barriers to the acceptance of innovative food products (Pliner & Hobden, 1992). As 3D-printed meat alternatives represent a new food technology, consumers with higher food neophobia are more likely to perceive uncertainty and hesitate to purchase the product (Lee et al., 2021). More recently, Kanwal et al. (2025) demonstrated that food neophobia weakens the relationship between consumer attitude and intention to accept 3D-printed food, indicating that favourable attitudes may not always translate into behavioural intention when consumers possess high levels of food neophobia. Thus, the following hypothesis was proposed.

H5: Food neophobia negatively moderates the relationship between consumer attitude and purchase intention towards 3D-printed meat alternatives.

Proposed Conceptual Framework

The current study employed the quantitative methodology due to its theoretical foundation and contextual factors. In particular, a cross-sectional research design was utilised to examine the relationships among visual sensory cues, mental imagery, attitudes, food neophobia, consumers' purchase intentions, and 3D-printed meat alternatives. As 3D-printed meat alternatives were not yet available in Malaysia, the survey instrument employed a stimulus-based approach. A conceptual framework was developed based on the arguments and propositions established in this review (see Figure 1). The framework consisted of five constructs derived from the S-O-R framework (Mehrabian & Russell, 1974). These constructs were adapted from Lyu and Huang (2024) to represent visual sensory cues, mental imagery, and the attitude pathway. Also, constructs on attitude and intention pathways, as well as the moderating role of food neophobia, were adapted from Kanwal et al. (2025) and Lee et al. (2021).

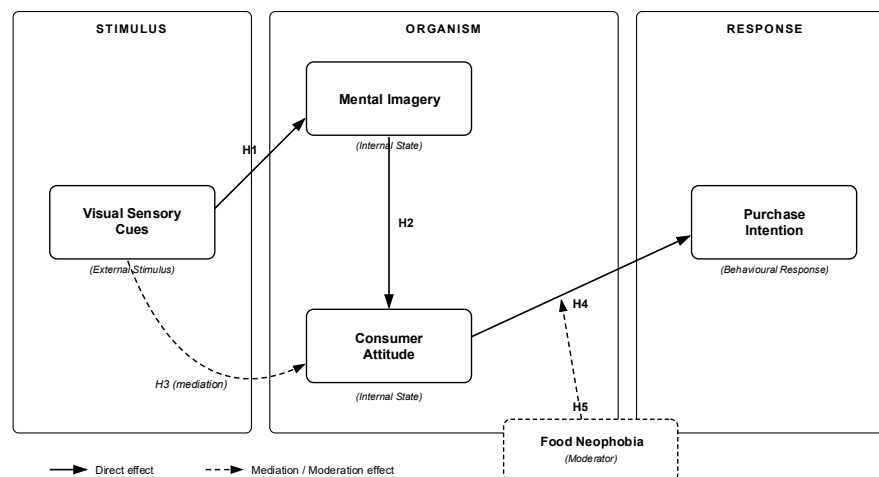


Figure 1: Proposed Conceptual Framework

Source: Adopted and Adapted from Lyu and Huang (2024), Kanwal et al. (2025), and Lee et al. (2021)

Methodology

This conceptual paper employed a quantitative research design to empirically investigate the proposed framework. Specifically, a cross-sectional research design was utilised to examine the relationships among visual sensory cues, mental imagery, consumer attitude, food neophobia, and purchase intention towards 3D-printed meat alternatives. The approach could capture consumer perceptions and behavioural intentions at a single point in time, consistent with previous studies on the acceptance of novel food technologies. This design enabled the efficient and cost-effective collection of data from a large sample of participants, making it suitable for investigating consumer responses to 3D-printed food products in the Malaysian context.

Population and Sampling

The target population for this study comprised Malaysian consumers aged 18 years and above. This was because they represented the primary potential market for 3D-printed meat alternatives. Also, only those with knowledge of 3D food printing and online platforms were included in this study. Considering that 3D-printed food products were not yet commercially available or widely recognised in Malaysia, a non-probability convenience sampling technique was highly appropriate. This strategy is commonly used in research on novel food technology acceptance when specific population characteristics cannot be fully defined. In particular, the convenience sampling method allows data to be collected from participants who are easy to reach via the internet and social media. The minimum number of participants recommended for the Partial Least Squares Structural Equation Modelling (PLS-SEM) analysis was 200, whereas participants in previous studies on 3D-printed food acceptance in Malaysia ranged from 306 to 917. The sample size should be based on the PLS-SEM guidelines and with consideration of the complexity of the structural model, the number of indicators within each construct, and the expected effect size. A sample size of 300 participants was recommended for moderate effect size detection and to estimate the measurement and structural models with high power. The survey was distributed online and via social media to efficiently reach the study's target participants.

Data Collection Procedure

The survey was constructed in Google Forms and disseminated via social media, email, and messaging apps to reach a wide audience across Malaysia. In particular, the survey link was shared across a range of platforms such as Facebook, WhatsApp, and email lists to ensure maximum reach and representation of all age groups, regions, and socioeconomic and demographic groups. The data collection period spanned four to six weeks. The link was shared weekly to increase participation and boost responses. For the study survey, it adopted the stimulus-based approach. It was to address the limitation that Malaysian consumers lacked direct experience with 3D-printed meat alternatives and to ensure that responses were based on a standardised product representation. Accordingly, high-quality images and videos of 3D-printed plant-based meat products were included in the study. The images and videos were expected to enable mental imagery and form attitudes based on consistent product presentation.

Questionnaire Design

The questionnaire assessed five constructs: visual sensory cues, mental imagery, consumer attitude, food neophobia, and purchase intention. All measurement items were adapted from previously validated scales and evaluated using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Table 1 summarises the number, scale type, and sources of each construct in the survey.

Table 1. Summary Of Measurement Scales and Theoretical Sources

Construct / Instrument Section	Number of Items	Scale Type / Nature	Core Literature Sources
Visual Sensory Cues	5	5-point Likert	Azman et al. (2024); Krishna (2012)
Mental Imagery	5	5-point Likert	Babin & Burns (1998); Schlosser (2003); Yoo & Kim (2014)
Consumer Attitude	5	5-point Likert	Brunner et al. (2018); Ng et al. (2022)
Food Neophobia	10	5-point Likert (4 reverse-coded)	Pliner & Hobden (1992); Lee et al. (2021)
Purchase Intention	5	5-point Likert	Spears & Singh (2004); Kanwal et al. (2025)

Source: Azman et al. (2024); Babin & Burns (1998); Brunner et al. (2018); Kanwal et al. (2025); Krishna (2012); Lee et al. (2021); Ng et al. (2022); Pliner & Hobden (1992); Schlosser (2003); Spears & Singh (2004); Yoo & Kim (2014).

Data Analysis

Data analysis was carried out in two distinct phases using Partial Least Squares Structural Equation Modelling (PLS-SEM). The first phase involved evaluating the measurement model (outer model) to establish reliability and validity, while the second phase evaluated the structural model (inner model) to test the hypothesised relationships. PLS-SEM was utilised because it is appropriate for complex framework designs containing multiple constructs,

mediators, and moderators. The statistical analysis was executed using SmartPLS software, an instrument widely employed for testing structural equation models within consumer behaviour research.

Stage 1: Assessment of Measurement Model

Prior to hypothesis testing, the validity and reliability of the measurement model was assessed. In order to assess the internal consistency, Cronbach's alpha and composite reliability (CR) were determined and a value of 0.70 or higher is considered acceptable. Average variance extracted (AVE) was used to assess convergent validity and an AVE of 0.50 or higher was considered satisfactory convergent. To assess the discriminant validity, Fornell-Larcker criterion was used, and the square root of the AVE for each latent construct was found to be higher than its correlations with other constructs. Furthermore, Maximum ratio of correlation among the heterotrait-monotrait (HTMT) was calculated with a maximum of 0.90 for all the correlations which further supports the strict discriminant validity.

Stage 2: Assessment of Structural Model

The hypothesized direct, mediation and moderation relationships were tested on the structural model to confirm the hypothesized relationships. The explanatory power of the model was evaluated by the coefficient of determination (R^2); which values of 0.25, 0.50, and 0.75 were considered as weak, moderate and substantial respectively. To estimate the path coefficients (β) and t-value and p-value for the statistical significance of the variables, the resampling technique known as the bootstrap method was employed, with a re-sample value of 5,000. Meanwhile the mediation was examined using the bootstrapping approach, in order to assess the significance of the indirect effects. Specifically the indirect effect of visual sensory cues on the mental imagery, and then the mental imagery on the consumer attitude, and then the indirect effect of consumer attitude on purchase intention was explored. Proportion of total effect mediated was quantified using variance accounted for (VAF). If the value of VAF was > 80 per cent then it was seen as full mediation, 20 per cent–80 per cent partial mediation, and < 20 per cent no mediation. An interaction between consumer attitude and food neophobia was included in the structural model to test the moderation effects. The interaction effect was also estimated via the bootstrapping technique. Two (high and low levels) of the moderators were depicted graphically to examine the nature of the moderation. The approach allowed us to find out if there was an increase or decrease in the relationship between consumer attitude and purchase intention.

Pilot Study

A pilot study was conducted before the data collection to determine the reliability and validity of the measurement tool and possible issues with the wording, clarity and understandability of the items. In the pilot study, the number of samples collected was 40 while the number of populations was 40. This size was selected due to the recommendation of the methodologist to have at least 30-50 respondents for pilot test to be able to measure instrument performance at baseline. The answers given by the participants were recorded and qualitative feedback was gathered in case of unclear, ambiguous and structuring difficult questions. The preliminary (statistical and qualitative) findings of the pilot study were used to make amendments. The internal consistency of the latent variables was tested with Cronbach alpha coefficients, which resulted in the construction of reliability. Unless the alpha was negative, they were

recommended for revision or deletion of the structure if they were < 0.70 . Cronbach alphas < 0.70 were considered poor internal consistency, were flagged for revising or deleting the item from the structure, except for negative alphas. Finally, all basic constructs had satisfactory levels of internal consistency, and these empirical results were directly used to complete the questionnaire for initial deployment of the primary data collection.

Conclusion

This study aimed to explore the relationships among the visual sensory cues, mental imagery, consumer attitudes, food neophobia, and purchase intention of 3D-printed meat alternatives in the Malaysian context. These constructs were then added to the S-O-R model to create a full theoretical model that included all aspects of measuring consumer evaluations and intentions regarding novel foods that do not have personal experience. Given this research, a conceptual model was designed that intends to act on the external sensory stimuli, which will trigger mental images, thereby impacting the attitude of the consumer towards 3D-printed meat alternatives. The last behavioural response was then purchasing intention, which was expected to be directly affected by the attitudes. Food neophobia, in turn, was added as a moderating variable which, in this case, was expected to decrease the positive link between the consumer attitude and the purchase intention, accounting for the psychological barriers of high food neophobic consumers in the consumption of novel food products.

Theoretical Contributions

The study also added on to the previous studies conducted on food acceptance experiments on 3D-printed food with the introduction of the application of S-O-R framework within the context of Malaysia. It filled in a gap in the way that products were presented visually and perceived by consumers to purchase products that were not physically present. The study was valuable in that the technology of 3D food printing can be applied towards solving food security problems and sustainable food production in Malaysia.

By using visual sensory and mental imagery cues in the same model, a more detailed understanding of the cognitive and affective processes that impact consumer acceptance of novel food technologies was achieved. Specifically, the framework contributed to the theory of food technology acceptance research by introducing the visual aspect of stimuli and mental images as mental processing mechanisms. This design was not following the traditional approach in the technology acceptance models, which were mostly utilitarian in nature (e.g., perceived usefulness and ease of use). The proposed framework highlighted the importance of sensory and imagery processes and allowed for a consideration of the experiential nature of food consumption and the importance of pre-consumption imagery on consumer evaluations.

Furthermore, the inclusion of food neophobia as a moderating variable contributed to a clearer understanding of the boundary conditions governing the attitude–intention relationship in the context of novel food technologies. This intervention was necessary because previous literature had shown mixed findings regarding the moderating effect of food neophobia. Therefore, the evaluated moderation effect successfully accounted for critical individual consumer differences in the acceptance of 3D-printed food products

Practical Contributions

From a practical point of view, the conceptual framework can be of benefit to food manufacturers, marketers and policymakers developing and commercialising 3D-printed meat alternatives. As a product's success depends on using a mental image in the consumer's mind as well as visual sensory cues that impact the attitude and purchase intention of the consumer, they can be utilised in designing a presentation strategy for the product, marketing communication, and consumer education campaign. Food manufacturers should invest in the quality of their product presentation because they will be likely to create strong and detailed mental images that will have a positive effect on their consumer's attitudes and purchase intentions. Accordingly, 3D-printed meat alternatives should be presented as visual properties of the product in the marketing communication because they enable consumers' mental simulation of the food they wish to eat. This can include the use of high-resolution photographs, videos of the product in use in realistic settings, and detailed text that appeals to the senses. These methods may contribute to this, as the consumers are able to imagine the sensory characteristics of a 3D meat alternative without experiencing the product. Also, they address the need for transparent communication when addressing food neophobia and opportunities to familiarise oneself with products, as well as show the benefits, which should help overcome the psychological barriers and assist with the technology acceptance. Policymakers and stakeholders might consider consumer education programmes with accurate information about 3D-printed technology, its importance for food security and sustainability and the safe and quality 3D-printed food products. These efforts can potentially diminish the neophobic reactions and boost consumer willingness to try and accept 3D printed meat alternatives.

Limitations

The scope of this conceptual paper needs to be recognized. The proposed framework and hypotheses are a conceptual study, and need to be validated through empirical research in the future. The proposed cross-sectional approach for examination of empirical data is a 'snapshot' of consumers' attitude and will not reflect attitude change over time and consumers' subsequent purchase intentions. The study would be beneficial if followed up later with a study to monitor the consumer attitude and purchasing intent throughout the years as the 3D food printing products become more prevalent in the Malaysian Market.

The decision-making process of a consumer regarding 3D-printed food products may not be adequately captured by using visual stimuli instead of real product experience. Actual product may also be responded to by consumers differently than visual representations of the product, particularly in regard to sensory-based attributes, which cannot be fully represented (taste, texture, etc.). In the future, when 3D-printed alternatives to meat are in the Malaysian market, further research may be necessary on the addition of further senses and/or taste testing of 3D-printed alternatives to meat may be required.

Study results, however, may only be applicable to general population in Malaysia as it employed a convenience sampling technique. Convenience samples can be biased in that they might over or under-represent certain groups of the population sampled. Probability sampling methods could be used in future research to increase the representativeness of the results.

The study only includes meat alternatives printed in 3D and may not be applicable to other types of 3D-printed food products, including vegetarian or dairy-based. Reactions to foods can vary in terms of familiarity, cultural links and the normality of the food category. More research is needed in the area of consumer response to various food product 3D-printed foods.

Recommendations for Future Research

Future studies can be carried out using a quantitative method and representative number of the Malaysian consumers with the proposed hypotheses to be tested with empirical data. The instrument as proposed in the methodology section should be used to measure the constructs and data should be analyzed by PLS-SEM to examine the hypothesized relationships. The findings from the empirical part would serve as evidence to either reject or accept the conceptual framework proposed and gain insights into the consumer acceptance of 3D printed meat alternatives in Malaysia. Furthermore, qualitative research could be used to supplement quantitative research to gain insights into the consumer's beliefs and motives behind their decisions to purchase the products. The deep probing interviews and focus groups could offer valuable information on the cognition, affective and concerns of the consumers in the evaluation process of 3D printed meat alternatives and what images and imagery cues are likely to affect consumer evaluations. Qualitative research will provide a deeper understanding of the consumer experience and provide input to build more in-depth theory driven models.

Furthermore, experimental studies can be further conducted to study the impact of various forms of visual presentation on mental imagery and intentions to purchase. The researchers were able to manipulate the quality of an image, its styling, the context in which customers used it and the format in which it was presented to find out what the best images were for developing positive mental images and purchase intentions. This experimental study's results will be useful to create marketing communications and product presentation. Meanwhile, longitudinal studies can be carried out to investigate attitude and purchase intention of the 3D-printed food products once they are more popular in the Malaysian market. The perception of the technology could be studied over time, as exposure to the technology grew and the product was released to the market and whether their perception of the technology changed or did not change. This would provide a hint as to consumer acceptance and how the marketing and education program is working.

The differences in cross-cultural consumers' responses to 3D-printed food may suggest different reactions of the consumers to 3D-printed food, which might be attributed to cultural and religious reasons or other factors. The Malaysian population is multiethnic (Malay, Chinese, Indian, and other ethnic groups), providing an opportunity to explore cultural differences in food neophobia, acceptance of novel food technologies, and responses to visual presentations. The outcome of this research may be used as a reference in marketing and product adaptation for cultural sensitivity. Future research should also examine other potential moderators of the attitude-intention relationship, such as food technology neophobia, environmental concern, health consciousness, and trust in technology. These individual difference variables might also be correlated with food neophobia and visual sensory cues and influence consumers' reactions to 3D-printed meat alternatives. The knowledge gap around consumer response can be addressed by further research on these factors, as well as providing insights into how to market and communicate more effectively.

Additional boundary conditions on the attitude-purchase intention relationship can also be examined by prioritising theoretical proximity and practical relevance. Food technology neophobia (FTN) is the most immediate priority: unlike food neophobia, which reflects a general wariness of unfamiliar foods regardless of how they are produced, FTN captures a specific aversion to the production process itself (Lee et al., 2021; Kanwal et al., 2025), which is directly implicated in a 3D-printing production context and may moderate the attitude-intention link even among consumers who are not neophobic toward novel foods in general. Trust in technology is a secondary priority, as it plausibly operates upstream of FTN by shaping whether the production process is perceived as safe and reliable in the first place, rather than acting as an independent moderator of the attitude-intention link. Health consciousness and environmental concern are lower priorities for immediate follow-up, since prior technology-acceptance research (Ng et al., 2022) suggests these operate primarily as antecedents of attitude rather than as moderators of the attitude-purchase intention relationship; their moderating potential is best tested only once the higher-priority factors above have been examined.

Concluding Remarks

This conceptual paper proposed a comprehensive framework for understanding how Malaysian consumers form attitudes and purchase intentions towards 3D-printed meat alternatives through the mediating roles of mental imagery and consumer attitude and the moderating role of food neophobia. The framework outlined the concepts of sensory marketing, consumer psychology, and technology acceptance research and addressed one of the knowledge gaps for consumers' responses to new food products in which they have not had direct sensory or experiential contact.

The proposed framework is of importance to theory, practice, and policy. It extends the S-O-R framework to the world of 3D food printing and includes visual sensory cues and mental images as important variables in consumer responses. It provides actual data to food manufacturers, marketers, and food policymakers to develop strategies to make food products, marketing communications, and consumer education effective. The paper adds to existing literature on food technology acceptance and the development of sustainable and innovative food production systems in Malaysia.

Given the growing trend of 3D food printing technology and the number of applications for sustainable meat alternatives, understanding consumer acceptance is crucial. Therefore, the conceptual framework proposed in this paper provides a foundation for empirical investigation and practical action to facilitate the successful introduction of 3D-printed meat alternatives to the Malaysian market. By addressing consumer concerns, enhancing visual presentations, and promoting favourable attitudes, stakeholders can work towards realising the potential of this innovative technology to contribute to food security, sustainability, and nutritional wellbeing.

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