



ARTICLE



<https://doi.org/10.1057/s41599-025-05916-3>

OPEN

Modeling the intention to accept 3D-printed foods: the role of religious beliefs, food neophobia and food technology neophobia

Sara Kanwal^{1,2}, Sauda Salim Hamdun Al Marhoobi³, Saad Mahmood Bhatti^{1,2}, Asma-Qamaliah Abdul-Hamid¹, Norhidayah Suleiman^{4,5} & Mohd Helmi Ali^{1,6}✉

3D-printed food offers promising solutions for prevailing food industry issues and has attracted growing research interest, particularly regarding consumer acceptance. However, previous studies have failed to determine how consumers' religious beliefs, food neophobia, and food technology neophobia shape their intention to accept 3D-printed food. This study uses the Theory of Planned Behavior (TPB) to explore how religious beliefs affect consumers' intentions to accept 3D-printed food, mediated by TPB constructs and moderated by neophobia levels. Data were collected through cross-sectional questionnaires from 306 residents in Malaysia, a country characterized by diverse religious backgrounds, and analyzed using partial least squares structural equation modeling. The results showed that consumers' attitudes, perceived behavioral control, and subjective norms positively mediated the influence of religious beliefs on intention to accept 3D-printed food. Findings confirm that the intensity of food and food tech neophobia influences whether consumers' intention to accept 3D-printed food is strengthened, weakened, or unaffected. This study adds to the research on consumer behavior and food technology adoption by understanding the role of religious beliefs and core constructs of TPB as drivers of consumers' intentions to accept 3D-printed food.

¹UKM-Graduate School of Business, Universiti Kebangsaan Malaysia, UKM Bangi, Selangor, Malaysia. ²Institute of Business and Management, University of Engineering and Technology, Lahore, Punjab, Pakistan. ³Modern College of Business and Science, Muscat, Oman. ⁴Faculty of Food Science and Technology, Universiti Putra Malaysia, UPM Serdang, Selangor, Malaysia. ⁵Laboratory of Halal Science Research, Halal Products Research Institute, Putra Infoport, Universiti Putra Malaysia, Seri Kembangan, Malaysia. ⁶Global Entrepreneurship Research and Innovation, Universiti Malaysia Kelantan, Kota Bharu, Malaysia. ✉email: mohdhelmiali@ukm.edu.my

Introduction

With the emergence of Industry 4.0—3D printing has significantly penetrated the market across various sectors—seeing a substantial rise in its applications in the manufacturing, aerospace, medicine, and food industries (Lanz et al., 2024). The future of the 3D printing food industry is promising, and Mordor Intelligence (2024) forecasts that its value will increase from \$0.68 billion to \$2.71 billion by 2029. Although initially an expensive technology, advancements and sophisticated applications in engineering and research have made 3D printing affordable and user-friendly (Baiano, 2022). Initially, 3D food printers were designed to produce customized culinary decorations and foods with various 3D shapes. Their current capabilities extend beyond this; 3D printing facilitates the production of food items customized to individuals' dietary habits, lifestyle choices, and taste preferences (Brunner et al., 2018). 3D food printing focuses on digital gastronomy and offers the freedom to fabricate intricate and complex designs that are otherwise impossible using conventional cooking techniques (Lee et al., 2021). Thus, 3D food-printing devices are proliferating in the market, providing an increasingly innovative, efficient, unconventional, and sustainable approach to food production (Nopparat and Motte, 2024).

Researchers and food manufacturers are increasingly exploring 3D printing technologies (Baiano, 2022). However, consumer preferences for 3D-printed foods remain unclear in both advanced economies (Manstan and McSweeney, 2020) and emerging markets (Yang et al., 2024). Studies suggest that individuals' intention to accept 3D-printed foods is necessary for their consumption and is shaped by consumers' attitudes, subjective norms, and perceived behavioral control (PBC; (Yang et al., 2024). Similarly, Lee et al. (2021) found that features such as creativity, fun, health, and natural content drive consumer interest in 3D-printed foods. However, how belief systems influence attitudes, norms, and PBC toward 3D-printed food remains unclear. Religious beliefs significantly influence food choices, especially in faiths with dietary doctrines (Ong et al., 2024). Individuals' motivations to consume a particular food may differ. One significant reason why religious consumers may purchase certain foods is to align themselves with their perceived ethical, morally right, and permissive religious beliefs (Minton et al., 2019). Khan et al. (2022) showed that religiosity shapes people's subjective norms, attitudes, and PBC around food purchasing. Prior research also links religious beliefs to behaviors related to special foods (Minton et al., 2019), food waste (Filimonau et al., 2023), and food hygiene practices (Al Bayari et al., 2023) etc.

Although experts predict that household kitchens will soon be equipped with 3D food printers (Yang et al., 2024), unconventional methods raise concerns, often prompting distrust due to perceived unnaturalness (Lanz et al., 2024). Food neophobia leads some consumers to avoid novel foods, unlike those willing to explore unfamiliar culinary options (Dupont et al., 2022), influencing their consumption behaviors (Hamlin et al., 2022). As food neophobia shapes how individuals perceive the value of 3D-printed foods, it is pertinent to investigate whether it strengthens or weakens their acceptance of the foods. Moreover, skepticism extends to food manufacturing technologies (Lee et al., 2021). Evans et al. (2010) showed that while food neophobia is strongly linked to food technology neophobia (FTN), it is less effective in gauging consumer reactions to foods produced using novel technologies. Although research highlights the need to create hedonic value for high-FTN individuals (Lee et al., 2021), literature on how FTN influences consumer intention to accept 3D-printed food remains scant. Brunner et al. (2018) argued that assessing consumer intentions to accept 3D-printed foods is

essential before developing or producing them. Therefore, this study aimed to ascertain:

- how consumers' religious beliefs affect their intention to accept 3D-printed foods;
- how consumers' religious beliefs influence their subjective norms, attitudes, and PBC towards their intention to accept 3D-printed foods;
- how consumer attitudes, subjective norms, and PBC impact their intentions to accept 3D-printed foods; and
- how food and NTFs moderate the link between consumer attitudes, subjective norms, PBC, and the intention to accept 3D-printed foods.

Theoretical foundation and hypotheses development

Theory of Planned Behavior (TPB). The TPB is widely recognized for its effectiveness in predicting consumers' behavioral intentions across different contexts, including irradiated foods (D'Souza et al., 2021), game meat (D'Souza, 2022), genetically modified (GM) foods (Dupont et al., 2022) and 3D-printed foods, among others (Yang et al., 2024). The TPB is suitable for explaining gain-oriented behaviors through a cognitive evaluation of outcomes—such as the costs, benefits, and risks associated with accepting 3D-printed food (Hoesterey et al., 2023). The TPB's flexible structure allows for the inclusion of additional constructs, making the extended TPB model more resilient (Yang et al., 2024). (Stone et al., 2022) also found that TPB constructs, such as attitude and subjective norms, significantly affect consumers' willingness to try unconventional foods, such as insect-based foods—supporting TPB's relevance to 3D-printed food acceptance.

This study applied the TPB by integrating consumers' religious beliefs to predict their intention to accept 3D-printed food. Religiosity is a key determinant of food consumption behavior, as religious scriptures provide guidelines for accepting or rejecting certain foods (Kirmani et al., 2023). Intrinsic religiosity can also predict planned behavior regarding novel food technologies such as 3D printing (Yang et al., 2024). Conner (2015) suggested that theoretically significant moderating variables can enhance the predictive power of TPB. Food neophobia and FTN refer to individuals' psychological reluctance traits linked to their acceptance of novel foods (Brunner et al., 2018) and significantly influence individual perceived values for 3D-printed foods (Lee et al., 2021). Accordingly, this study uses food neophobia and FTN as moderators that can affect the relationship between TPB constructs and consumers' intentions to accept 3D-printed foods. All hypothesized relationships are summarized in Fig. 1.

Religious beliefs and intention to accept 3D-printed food.

Certain religions fundamentally shape people's evaluations of innovations related to food consumption (Matsuoka et al., 2023). Their beliefs often contain explicit dietary guidelines or implicit norms about what is permissible or morally acceptable, such as halal food in Islam, Kosher in Judaism, and vegetarianism in Hinduism (Minton et al., 2019). Devout followers of such religions may evaluate novel food technologies through a religious lens (Chaloupkova et al., 2025). This evaluation can facilitate the intention to accept novel foods if they are congruent with the beliefs and religious dietary laws. For instance, Roslin et al. (2022) highlighted that clear halal certifications could improve Muslim consumers' intention to accept 3D-printed foods, thereby ensuring ingredient traceability and purity.

Conversely, skeptic evaluation involves perceiving production methods as morally questionable or disrespectful to religion,

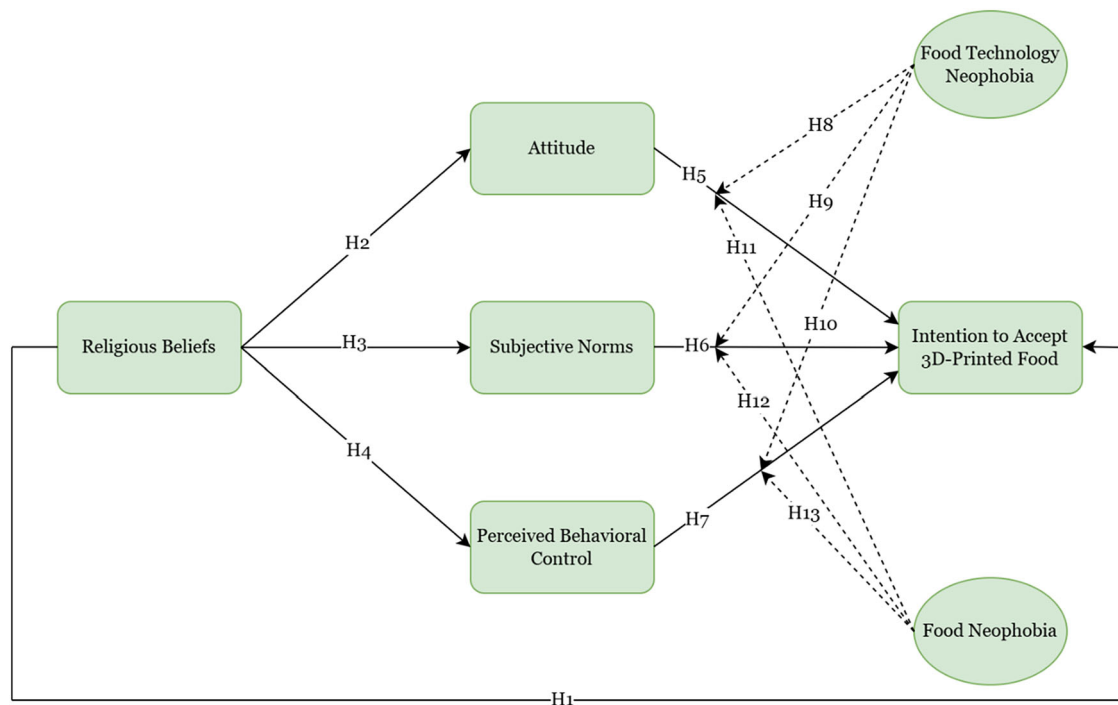


Fig. 1 Research framework.

which can lead to the rejection of novel foods (D'Souza et al., 2024). For example, certain religious communities are skeptical of GM foods due to permissibility-related uncertainties (Omobowale et al., 2009). Some religious conservatives may view these technologies as interfering with nature and thus reject them because of ethical or theological objections. Lanz et al. (2024) indicated that 3D-printed food may be considered unnatural and artificial, significantly reducing its acceptance among populations sensitive to such factors. Alternatively, some religions may value the responsible use of technology (Soleymani et al., 2024), accepting ethically marketed foods that minimize food waste and prioritize animal welfare and responsible consumption. Consequently, 3D food printing may align well with religious and ethical frameworks (Mudau and Adebo, 2024). Because literature provides contrasting findings regarding relationship between religious beliefs and acceptability of novel foods, thus further context-specific investigation and empirical testing is needed. Hence, we propose the following hypothesis:

H1: Religious beliefs significantly influence consumers' intention to accept 3D-printed food.

Religious beliefs and attitudes. Religion is a social determinant of food consumption behavior (Aslan, 2023). While motivations for consuming specific food vary, moral behavior reflects one's religious beliefs (Ong et al., 2024). Religiosity as a commitment can impact one's food preferences, such as the acceptance or avoidance of certain foods (Aslan, 2023). Certain religions provide guidelines for consumers' diets—e.g., kosher laws in Judaism, halal in Islam, vegetarianism in Hinduism, and animal restrictions in Buddhism (Minton et al., 2019). Moreover, religious beliefs can have differential effects on consumer food preferences based on the type of food (Ong et al., 2024). For example, strict rules may apply to meat-based products like sausages but not to plant-based items like chocolate. Nearly half of the global population follows religions that have rules about consuming meat (Soleymani et al., 2024). 3D food printing can help address these diverse needs by incorporating various ingredients and

replicating complex food structures to align with religious dietary requirements (Lanz et al., 2024).

Religiosity may also affect attitudes related to ethical and sustainable behaviors (Singh et al., 2021). For example, the doctrines of certain religions provide a moral obligation for the responsible use of natural resources (Kirmani et al., 2023), which is often reinforced by prominent religious authorities (e.g., Pope Francis in Christianity), shaping followers' actions (Pegan et al., 2023). Moreover, religiosity is important for improving food security by shaping individual attitudes (Aslan, 2023). 3D printing, as an affordable and innovative technology, can lower economic costs, reduce food waste in traditional food supply chains, and promote sustainable food production (Millán, 2024). However, certain religious guidelines dictate daily food safety practices. For instance, Islam encourages adequate hygiene and food safety practices, such as washing hands before eating (Al Bayari et al., 2023). 3D-printed food addresses food security and handling issues by enabling customised, nutritionally balanced meals made from mechanically mixed ingredients (Mudau and Adebo, 2024). Therefore, we propose the following hypothesis:

H2: Religious beliefs significantly influence consumers' attitudes towards 3D-printed food.

Religious beliefs and subjective norms. Individuals who gain approval within their value systems are more inclined to adopt certain behaviors (Filimonau et al., 2023). Social pressures within religious contexts can also influence consumer purchase intentions. Numerous studies have confirmed how religiosity frames subjective norms across various domains, such as apparel products (Zaki and Elseidi, 2024) and food waste intentions (Elhoushy and Jang, 2021). Highly religious individuals often align their behavior with that of influential religious figures—such as devout family members or peers—leading them to prefer religiously compliant products and services (Graafland, 2017).

As religious values influence the attitudes and behaviors of a religious community, they will also impact the subjective norms of individuals close to religious individuals (Zaki and Elseidi,

2024). Strong religious beliefs encourage individual subjective norms toward consuming socially responsible products (Graafland, 2017). While sustainability is a growing concern even in less religious societies, religiosity is a key driver of sustainable consumption in highly religious contexts (Orellano et al., 2020). For example, religions such as Islam, Christianity, Judaism, and Hinduism discourage food waste (Kirmani et al., 2023) and promote environmentally sustainable behaviors among their followers (Singh et al., 2021). Similarly, when one's religious peers recognize food wastage as sinful, it will influence the individual's subjective norms for reducing food waste and promoting environmental consciousness (Filimonau et al., 2023), potentially increasing the acceptance of 3D-printed food. The actions of religious family members are typically governed by subjective norms, which are often contingent on religion and the level of religiosity within the family (Kasber et al., 2023). Thus, it is postulated that

H3: *Religious beliefs significantly influence consumers' subjective norms for 3D-printed food.*

Religious beliefs and perceived behavioral control. When individuals believe that they can manage external and internal factors—such as time and skills—that affect their behavior, they are more inclined toward that behavior (Ajzen, 1991). Those with strong religious inclinations often perceive the world through the prism of their faith, which influences their beliefs and attitudes. Consequently, these religious convictions affect PBC (Jackson and Bergeman, 2011). Greater religiosity is often linked to a stronger sense of self-regulation, authority, and control over one's behavior (Kasber et al., 2023). For example, devout Muslims strictly adhere to halal guidelines (Khan et al., 2022).

3D food printing technology provides complete control over ingredients, enabling consumers to customize, verify, and personally manage the food-printing process (Brunner et al., 2018); this makes it easier for religious people to ensure that 3D-printed food complies with their religious dietary laws, increasing PBC. Similarly, certain religions promote the responsible use of natural resources like food (Aslan, 2023), and followers with high PBC are more likely to minimize food waste (Filimonau et al., 2023). As 3D food printing optimizes the use of ingredients, it aligns with religious individuals' PBC and desires to limit food waste (Millán, 2024). Additionally, certain religious doctrines emphasize the responsibility of managing food insecurity (Mudau and Adebo, 2024). Through 3D-printed food technology, religious individuals may feel empowered to fulfill both ethical and spiritual duties, enhancing their PBC. Hence, we hypothesized the following:

H4: *Religious beliefs significantly influence consumers' PBC for 3D-printed food.*

Attitude and intention to accept 3D-printed food. An individual's attitude reflects their holistic assessment of objects, such as food, capturing their sentiments and opinions (Yang et al., 2024). People with a favorable disposition toward 3D-printed foods view them as cutting-edge, thrilling, and futuristic (Lupton, 2017), which can increase their inclination to consume such products. For instance, those who view 3D-printed food as nutritious and eco-friendly (Brunner et al., 2018) are more inclined to select it over conventional alternatives (Manstan and McSweeney, 2020). Furthermore, those with a favorable view of 3D-printed food tend to endorse it to others, potentially amplifying its acceptance and appeal (Yang et al., 2024).

Brunner et al. (2018) found that individuals familiar with 3D food printing exhibited less attitude enhancement than other participants. Caulier et al. (2020) emphasized that consumers'

attitudes become more favorable as they acquire hands-on experience or knowledge of 3D-printed foods. While the reliance on physical infrastructure and skilled labor has made traditional manufacturing methods costly, particularly in developing nations (Baiano, 2022), 3D printing has emerged as a promising solution for developed countries, fostering entrepreneurship among independent freelancers and small-scale manufacturers (Nopparat and Motte, 2024). Overall, attitude significantly shapes the intention to utilize 3D food-printing technology, ultimately affecting real-world adoption (Yang et al., 2024). Lee et al. (2021) suggested that individuals' values and attitudes are pivotal in determining their consumption intentions for 3D-printed foods. Therefore, we hypothesized the following:

H5: *Consumers' attitude significantly influences their intention to accept 3D-printed food.*

Subjective norms and intention to accept 3D-printed food.

Consumer-centric subjective norms revolve around individuals' perceptions of how their consumption of novel foods is viewed by family members, friends, and peers, as well as expectations shaped by others with similar values (D'Souza et al., 2021). This perception is grounded in the notion that individuals' behaviors are shaped by the viewpoints of influential figures whom they seek to emulate (Khan et al., 2022). Socially desirable opinions significantly impact food consumption decisions (Aslan, 2023). Subjective norms are pivotal catalysts for consumer goods in developed (Graafland, 2017) and developing markets (Zaki and Elseidi, 2024).

Aslan (2023) and Kirmani et al. (2023) similarly found that subjective norms significantly and favorably influence intention and actual behavior. People are more likely to purchase 3D-printed food when there is social consensus among their companions regarding its consumption (Yang et al., 2024), highlighting the role of social validation in consumer adoption of 3D-printed foods. Yang et al. (2024) further confirmed that peer influence significantly shapes individuals' intentions to adopt 3D food-printing technology. Therefore, we hypothesized the following:

H6: *Subjective norms significantly influence consumers' intention to accept 3D-printed food.*

Perceived behavioral control and intention to accept 3D-printed food.

As PBC reflects control beliefs—how individuals perceive access to resources needed to act—greater self-control signals a heightened motivation to engage in specific behaviors (Singh et al., 2021). Individuals who lack the resources and opportunities to engage in certain behaviors are less inclined to adopt them, even with positive attitudes and social support (Aslan, 2023). This implies that adequate resources are necessary to execute certain activities or behaviors (Filimonau et al., 2023). Moreover, individuals embrace a behavior only when the challenges associated with its implementation are deemed manageable (Kirmani et al., 2023).

The literature shows that PBC is a strong antecedent of consumption intention for foods such as irradiated foods (D'Souza et al., 2021). This is because individuals perceive that consuming such food types is easy and gives them the freedom to choose. Similarly, 3D food printers provide consumers with both hedonic and utilitarian value, making the technology convenient (Lee et al., 2021). People evaluate obstructions, resources, opportunities, and behavioral control before consuming 3D-printed foods (Yang et al., 2024). Those who perceive the technology as user-friendly will consume 3D-printed food products. Thus, individuals with a high PBC for 3D-printed

foods are more likely to consume them. Hence, we propose the following hypothesis:

H7: *PBC significantly influences consumers' intention to accept 3D-printed food.*

Moderation of FTN. Consumers often resist novel food technologies, viewing novel foods as less beneficial than natural alternatives (Lanz et al., 2024). This avoidance is often driven by FTN especially when unconventional processes alter, remove, or add components, making the food seem less natural (Manstan and McSweeney, 2020). The literature on FTN is gaining prominence regarding consumers' acceptance of novel products, such as GM (Conroy and Errmann, 2023) and 3D-printed foods (Lee et al., 2021). Studies have linked distrust of science, limited understanding of food technology advancements, and unfamiliarity with functional components as precursors of FTN (Dupont et al., 2022). Individual attitudes shaped by FTN are major barriers to novel food acceptance. Moreover, FTN significantly moderates consumers' food attributes and perceived value relationships concerning 3D-printed food (Lee et al., 2021); thus, it could similarly moderate the relationship between consumers' attitudes and intention to accept 3D-printed foods.

People also avoid food technology when they perceive that their society does not recognize or accept novel foods (Dupont et al., 2022). Even those who adapt to technological food innovations are influenced by subjective norms. Technologies altering internal food structures (e.g., gene grafting) are perceived as more intrusive, lowering PBC and purchase intent compared to external-tech changes like robotics (Conroy and Errmann, 2023). Conversely, those with high innovativeness are more likely to accept 3D-printed foods (Yang et al., 2024). Thus, we propose the following hypotheses:

H8: *FTN moderates the relationship between consumers' attitudes and intention to accept 3D-printed food.*

H9: *FTN moderates the relationship between subjective norms and consumers' intention to accept 3D-printed food.*

H10: *FTN moderates the relationship between PBC and consumers' intention to accept 3D-printed food.*

Moderation of food neophobia. Fear of unfamiliar food reflects a tendency to avoid new culinary offerings, especially those created by novel technologies such as cultured meat (Hamlin et al., 2022) or 3D-printed food (Lee et al., 2021). Hence, assessing food neophobia is crucial for understanding and predicting consumers' psychological responses and intentions toward unfamiliar foods. Rozin et al. (2008) highlighted that humans reject food because of sensory aversion, fear of unfavorable consequences, or disgust. As 3D-printed food is manufactured from liquid materials and slurry paste, it can evoke disgust due to its sensory characteristics (Manstan and McSweeney, 2020). However, perceived benefits and nutritional knowledge can improve consumer attitudes towards 3D-printed food (Brunner et al., 2018). Lupton and Turner (2018) found that most consumers expressed concerns about the safety, nutritional value, and the idea of consuming food made using a printer. The term "printer" itself negatively influenced participants' receptiveness despite arguments regarding its potential benefits. However, a minority of adventurous diners were willing to consume 3D-printed food.

Studies report mixed findings on the moderating effects of food neophobia on the relationship between consumer attitudes and their intention to adopt novel foods, showing both positive effects (D'Souza, 2022) and no effect (Huang et al., 2019). D'Souza (2022) also found that food neophobia positively influences subjective norms and novel food consumption intention, but cannot confirm the significance between consumers' PBC and

intention. These inconsistencies highlight the need to further explore food neophobia's moderating role in the context of 3D-printed foods. Thus, consumers with high or low neophobia may differ in attitudes, subjective norms, and PBC, yet still show similar consumption intentions. Therefore, we hypothesized the following:

H11: *Food neophobia moderates the relationship between consumers' attitudes and intention to accept 3D-printed food.*

H12: *Food neophobia moderates the relationship between subjective norms and consumers' intention to accept 3D-printed food.*

H13: *Food neophobia moderates the relationship between PBC and consumers' intention to accept 3D-printed food.*

Research methodology

Sampling and data collection. Prospective consumers of 3D-printed food in Kuala Lumpur, Malaysia, were selected for data collection for several reasons. First, Kuala Lumpur is Malaysia's largest metropolitan area, with a growing 8.8 million population (World Population Review, 2024). Second, Malaysia is religiously diverse, with Islam, Hinduism, Buddhism, and Christianity practiced freely (Al-Ansi et al., 2019), creating a unique cultural and ethnic mix. Third, many of its restaurants and food chains offer local and ethnic cuisines, catering to variety-seeking consumers seeking novel food experiences as well as diverse religious groups (approx. 60% Muslims, 20% Buddhists, 9% Christians, and 6% Hindus; (Al-Ansi et al., 2019). As this study considers religious beliefs as a major variable regarding intention to accept 3D-printed foods and related neophobias, sampling from an area rich in religious and dietary diversity was appropriate.

The G*Power tool was used to calculate the minimum required sample size (Hair et al., 2022). Using parameters of $f^2 = 0.15$ (effect size), $\alpha = 0.05$ (error probability), power = 0.95 (1- β err prob), and six predictors (Faul et al., 2007), the minimum sample was 146 respondents. Ethical approval was obtained, and a pre-test with 50 respondents was conducted before the main survey was conducted. The pre-test helped refine the questionnaire by evaluating its meaningfulness and clarity, overall structure and the scales' reliability and validity. Given the novelty of 3D-printed food concept, a brief introduction and potential benefits such as automation of food manufacturing, nutritional customization and use of alternate food sources etc., were also included in the questionnaire and information sheet during pre-testing. These benefits represent the core concept behind 3D food printing (edible foods) and differentiate it with the traditional foods. The pre-test results indicated satisfactory reliability and validity of scales; thus, the same approach was followed in the main survey. The questionnaire was further improved based on the feedback from four academicians before full-scale data collection.

Convenience sampling was used, with a screening question ("Are you familiar with 3D-printed food products?") to ensure respondents were eligible to answer the survey. The screening question excluded those who did not know or had never heard of 3D-printed food to avoid any assumption—or comprehension-based responses (Lee et al., 2021). After screening, participants were briefed about the concept and potential benefits of 3D-printed food to ensure consistent understanding (an introductory explanation of 3D-printed food was included in the questionnaire; see the Appendix). Participants were given an information sheet that outlined the study's purpose, addressed data confidentiality matters, and informed them that participation was unpaid and voluntary.

An informed consent form was also attached with the information sheet which required an agreement from the participants to take part in this study. Informed consent form

Table 1 Sociodemographic details.					
	N	%		N	%
Gender			Location of living		
Male	167	54.5	Rural Area	67	21.9
Female	139	45.5	Urban City	239	78.1
Total	306	100.0	Total	306	100.0
Age			Job role		
18–25	54	17.6	Government Sector	42	13.7
26–35 Years	87	28.4	Private Sector	129	42.1
36–45 Years	98	32.0	Self-employed	86	28.1
46–55 Years	67	21.8	Not employed	49	16.0
Total	306	100.0	Total	306	100.0
Marital status			Education		
Single	108	35.3	Secondary School	8	2.6
Married	194	63.4	Pre-University	47	15.4
Divorced	4	1.3	Tertiary Education	251	82.0
Total	306	100.0	Total	306	100.0
Monthly household income					
Less than RM 3000	13	4.2			
RM 3001–RM 5000	37	12.0	Household size		
RM 5001–RM 7000	54	17.6	≤3 people	73	23.9
RM 7001–RM 9000	111	36.2	4–6 people	195	63.7
>RM 9000	91	30.0	7–9 people	38	12.4
Total	306	100.0	Total	306	100.0

clearly mentioned several points including that participants have read the information sheet, they were given time to think about the questionnaire and all the questions have been answered to their satisfaction. To tackle the potential social desirability bias, all participants were asked to fill in the questionnaire in a separate and private space with no interference of any research team member. The paper/pencil method was used to collect the data between May and July 2024. A total of 400 participants were screened, 55 of whom were excluded because they answered “no” to the screening question, and 345 responses were received from the participants who answered “Yes, I know about 3D-printed foods/I have heard about 3D-printed foods”. After eliminating 39 incomplete responses, 306 valid responses (88% response rate) were used for data analysis.

Research instrument. The questionnaire was prepared in English after reviewing prior literature and using validated scales from previous studies, which were modified as needed to fit the current study’s context. Four items were adapted from Awan et al. (2015) to measure religious belief and were modified to suit current study’s context. The items included “I will eat food based on my religious guideline”, “I will eat healthy food based on my religious guideline”, “if my religion forbids eating any food, I will avoid it” and “I will eat food that is approved by my religious authority”. High scores represented stronger adherence to food consumption-related religious beliefs. Four items measuring attitude were adopted from Lee et al. (2021). Four items for subjective norms and five items for consumer PBC were adapted from D’Souza et al. (2021). Five questions measuring the intention to accept 3D-printed food were adapted from Hoesterey et al. (2023). Four items adapted from Brunner et al. (2018) originally proposed by Cox and Evans (2008) measured FTN. Ten items measuring food neophobia were adopted from Lee et al. (2021). High scores on FTN and food neophobia scale represent high degree of neophobia. This study used a 7-point Likert scale to measure all items (1; do not agree at all, to 7; completely agree). A

Table 2 Full collinearity test.							
Items	RGB	ATD	SJN	PBC	FTN	FNO	ITA
VIF	1.629	1.883	1.902	1.485	1.243	1.204	1.674
Values							
Source: Author’s data analysis. RGB religious beliefs, ATD attitude, SJN subjective norms, PBC perceived behavioral control, FTN food technology neophobia, FNO food neophobia, ITA consumers’ intention to accept 3D-printed food.							

detailed questionnaire in four sections is provided in the Appendix.

Data analysis technique. An online “Web Power” application tool investigated multivariate skewness and kurtosis. Mardia’s coefficient showing multivariate kurtosis was 71.261 ($t = 6.437$, $p < 0.01$), and skewness was 6.730 ($t = 343.264$, $p < 0.01$). As the p-values were less than 0.05, it suggested that the data was not normal (Cain et al., 2017). PLS-SEM in SMART PLS (V4.0) was used to test the measurement and structural models for data analysis. PLS-SEM is suitable as it is a well-established method in similar studies for calculating path coefficients in complex structural models with multiple mediators and moderators. It also outperforms covariance-based SEM in examining measurement models and analyzing the exploratory nature of non-normal datasets (Hair et al., 2022). The data were first screened for valid cases to be used in analysis. Tests for reliability and validity were conducted to ascertain the scale’s internal consistency. A structural model was tested to investigate the proposed relationships. Partial least squares prediction was conducted to examine the accuracy of the results.

Results
Sociodemographic profile. The sociodemographic data of respondents are presented in Table 1.

Common method bias (CMB). Harman’s single-factor test and Kock et al. (2021) full collinearity assessment were used to test for CMB. The results revealed a 28.83% variation in a single component, below the 50% threshold (Podsakoff et al., 2012). The VIF values were also below 3.3 (see Table 2), indicating no collinearity or single-source bias. Thus, CMB did not affect the dataset used in this study.

Assessment of measurement model. The findings of the measurement model are shown in Fig. 2. All the constructs examined in this study were reflective; thus, their factor loadings were analyzed. The factor loadings of all constructs are presented in bold values in Table 4 (see the Appendix). They ranged from 0.74 to 0.91, indicating a strong association of items within each construct. Table 3 shows composite reliability ($\rho_a = 0.84–0.98$; $\rho_c = 0.89–0.97$) and Cronbach’s alpha (0.84–0.91). All values exceeded 0.70, indicating internal consistency and reliability. The average variance extracted (AVE) was used to evaluate the convergent validity of the constructs. All AVE values ranged between 0.66–0.81, exceeding the 0.5 threshold, confirming robust convergent validity. VIF values were below 3.3 (Table 3), indicating no multicollinearity (Hair et al., 2022).

Table 3 also shows that the sample scored near neutral (towards a slight disagreement) in religiosity ($M = 3.5$), suggesting moderate religious adherence. This aligns with (Chaloupkova et al. (2025) findings on 3D-printed food—that most consumers displayed moderate religious adherence instead of extreme adherence. Thus, the results are trustworthy and have practical

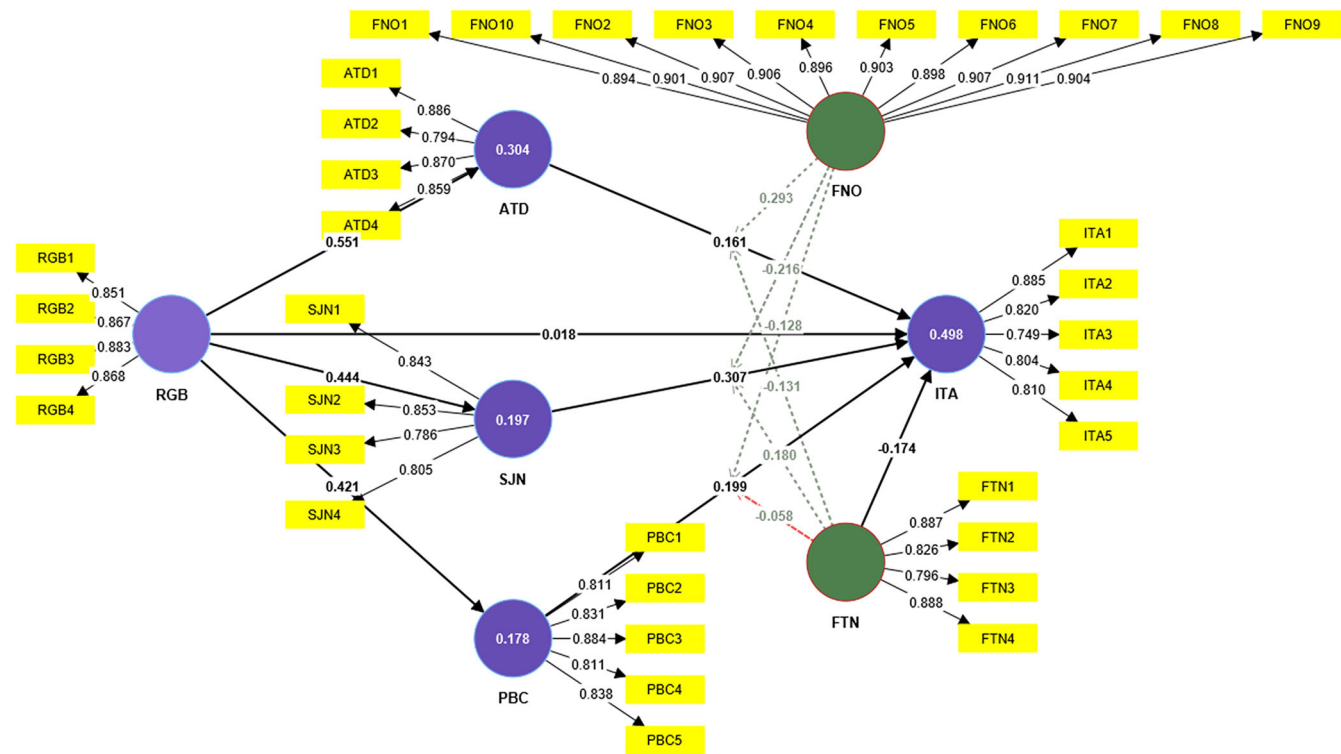


Fig. 2 Measurement model with findings. RGB-religious beliefs, ATD-attitude, SJN-subjective norms, PBC-perceived behavioural control, FTN-food technology neophobia, FNO-food neophobia, ITA-consumers’ intention to accept 3D-printed food.

Table 3 Reliability and validity.										
Variables	Median	Mean	Standard deviation	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted	Variance inflation factors	Skewness	Kurtosis
RGB	3.75	3.534	1.356	0.890	0.891	0.924	0.752	1.674	−0.003	−0.638
ATD	4.50	4.475	1.233	0.875	0.888	0.914	0.727	2.026	−0.241	0.357
SJN	4.25	4.223	1.274	0.841	0.844	0.893	0.676	1.904	−0.346	0.120
PBC	3.70	3.646	1.278	0.892	0.894	0.920	0.698	1.573	−0.133	−0.375
FTN	4.00	3.846	1.518	0.872	0.883	0.912	0.723	1.310	0.183	−0.776
FNO	2.40	2.789	1.443	0.975	0.983	0.978	0.815	1.282	0.900	−0.177
ITA	4.40	4.475	1.349	0.875	0.900	0.908	0.664	−	−0.359	−0.342

Source: Author's data analysis.
RGB religious beliefs, ATD attitude, SJN subjective norms, PBC perceived behavioral control, FTN food technology neophobia, FNO food neophobia, ITA consumers' intention to accept 3D-printed food.

relevance. Moreover, there was relatively low variability in religiosity scores. Although low variation could potentially limit the ability to fully capture different degrees of religiosity across sample, it reflects the social context of current study. This finding demonstrates cultural and religious homogeneity of the sample studied, where religiosity is typically moderate-to-high among individuals. Religious belief's scale further indicated satisfactory reliability and validity (see Table 3) highlighting that it effectively captured differences in religiosity across respondents. This finding aligns with Lemos et al. (2019) and Seo et al. (2022) that religiosity measures often exhibit limited dispersion. Thus, in societies with strong religious/cultural norms people are likely to converge around core beliefs and practices.

Cross-loadings, heterotrait–monotrait (HTMT) ratio, and the Fornell-Larcker criterion were used to test discriminant validity. Table 1a, in the Appendix shows AVE square roots (0.815–0.903, in bold) exceeded inter-construct correlations, meeting the Fornell-Larcker criterion (Hair et al., 2022). HTMT values for all constructs in the upper part of the matrix demonstrated

adequate discriminant validity, with all values below the threshold of 0.90 (Henseler et al., 2015). Additionally, cross-loadings were examined, which supported discriminant validity (Chin et al., 1997).

Structural model assessment. The structural model was assessed by determining path coefficients (β), p -values, coefficients of determination (R^2), effect sizes (f^2), and predictive relevance. Bootstrapping was used to test the proposed hypotheses. The R^2 values (Table 4) indicate that consumers' religious beliefs account for a significant 30.4% variance in consumer attitudes, 19.7% (moderate variance) in subjective norms, and 17.8% (moderate variance) in consumer PBC (Cohen, 1998). Attitudes, subjective norms, and PBC together explained a significant 49.8% variance in consumers' intention to accept 3D-printed food.

The f^2 values (Table 4) represent the individual variance in each variable instead of the shared variation (Hair et al., 2022). The f^2 values indicate that consumers' religious beliefs had a significant impact on their attitudes ($f^2 = 0.436 > 0.35$; (Cohen,

Table 4 Hypotheses testing.

Hypotheses	Beta	CI Min	CI Max	t values	p values	f ²	r ²	Supported?
H1 RGB → ITA	0.018	−0.075	0.104	0.335	0.369	0.000		No
H2 RGB → ATD	0.551	0.481	0.623	12.750	0.000	0.436	0.304	Yes
H3 RGB → SJN	0.444	0.360	0.530	8.660	0.000	0.246	0.197	Yes
H4 RGB → PBC	0.421	0.329	0.524	7.197	0.000	0.216	0.178	Yes
H5 ATD → ITA	0.161	0.053	0.260	2.542	0.006	0.025	0.498	Yes
H6 SJN → ITA	0.307	0.214	0.401	5.460	0.000	0.099		Yes
H7 PBC → ITA	0.199	0.122	0.283	3.964	0.000	0.050		Yes

Moderating Effect	Beta	CI Min	CI Max	t values	p values	Moderated?
H8 FTN × ATD → ITA	−0.131	−0.229	−0.035	2.260	0.012	Yes
H9 FTN × SJN → ITA	0.180	0.099	0.253	3.810	0.000	Yes
H10 FTN × PBC → ITA	−0.058	−0.127	0.026	1.234	0.109	No
H11 FNO × ATD → ITA	0.293	0.212	0.395	5.014	0.000	Yes
H12 FNO × SJN → ITA	−0.216	−0.321	−0.115	3.438	0.000	Yes
H13 FNO × PBC → ITA	−0.128	−0.215	−0.046	2.432	0.008	Yes

RGB religious beliefs, ATD attitude, SJN subjective norms, PBC perceived behavioral control, FTN food technology neophobia, FNO food neophobia, ITA consumers' intention to accept 3D-printed food.

Table 5 Predictive assessment.

	Q ² predict	PLS-SEM_RMSE	LM_RMSE	Difference
ATD1	0.264	1.297	1.293	0.004
ATD2	0.171	1.423	1.431	−0.008
ATD3	0.191	1.254	1.290	−0.036
ATD4	0.223	1.176	1.216	−0.040
ITA1	0.200	1.363	1.402	−0.039
ITA2	0.134	1.422	1.469	−0.047
ITA3	0.041	1.671	1.712	−0.041
ITA4	0.078	1.683	1.736	−0.053
ITA5	0.087	1.695	1.759	−0.064
PBC1	0.142	1.492	1.531	−0.039
PBC2	0.116	1.398	1.436	−0.038
PBC3	0.109	1.424	1.463	−0.039
PBC4	0.112	1.442	1.485	−0.043
PBC5	0.090	1.469	1.464	0.005
SJN1	0.112	1.452	1.455	−0.003
SJN2	0.119	1.472	1.485	−0.013
SJN3	0.085	1.536	1.543	−0.007
SJN4	0.178	1.360	1.357	0.003

Cross-Validated Predictive Ability Test (CVPAT)				
		Average loss difference	t value	p-value
PLS-SEM vs. Indicator average (IA)	ATD	−0.447	4.524	0.000
	ITA	−0.282	3.053	0.002
	PBC	−0.270	2.971	0.003
	SJN	−0.295	3.314	0.001
	Overall	−0.318	4.650	0.000
PLS-SEM vs. Linear model (LM)	ATD	−0.051	1.194	0.233
	ITA	−0.157	3.448	0.001
	PBC	−0.091	1.620	0.106
	SJN	−0.015	0.239	0.812
	Overall	−0.083	3.031	0.003

ATD Attitude, SJN subjective norms, PBC perceived behavioral control, ITA consumers' intention to accept 3D-printed food.

1998) and a moderate impact on their subjective norms ($f^2 = 0.246 > 0.15$) and PBC ($f^2 = 0.216 > 0.15$). Attitudes, subjective norms, and PBC had small effects on their intention to accept 3D-printed food ($f^2 = 0.025$, 0.099 , and $0.050 > 0.02$, respectively).

An importance-performance matrix analysis (IPMA) was conducted (Fig. 1a in the Appendix). In the IPMA, importance

denotes the total effect of predictors on the outcome, whereas performance refers to the actual average score of the predictors. The IPMA shows that consumer attitudes are the most critical predictor of consumers' intention to accept 3D-printed food (highest performance value), followed by subjective norms. Moreover, consumers' subjective norms and PBC were the most significant predictors of their effects (high importance).

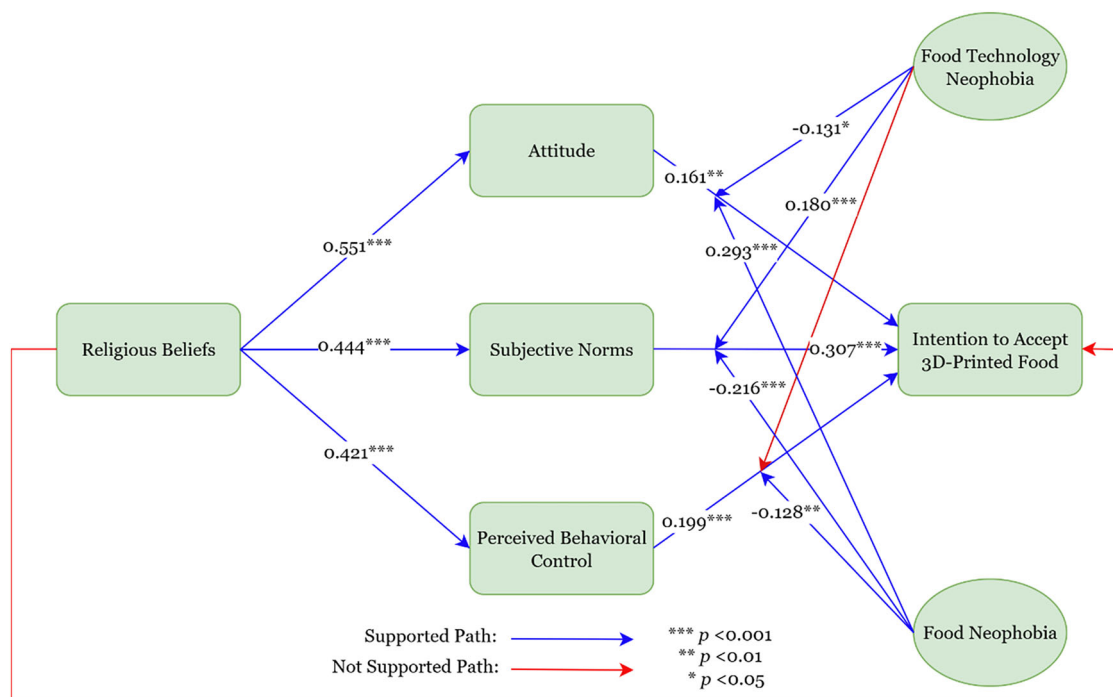


Fig. 3 Final model with findings.

Hypotheses testing. Table 5 presents the hypothesis testing results, showing that consumers' religious beliefs did not directly impact their intention to accept 3D-printed food ($p > 0.05$), rejecting H1. However, religious beliefs significantly shaped consumers' attitudes toward their intention to accept 3D-printed food ($\beta = 0.551$, $p < 0.001$), strongly supporting H2. Religious beliefs significantly influenced subjective norms toward intention to accept 3D-printed food ($\beta = 0.444$, $p < 0.001$), supporting H3; they also strongly influenced consumers' PBC towards 3D-printed food ($\beta = 0.421$, $p < 0.001$), supporting H4. Consumer attitude significantly influenced their intention to accept 3D-printed food ($\beta = 0.161$, $p < 0.01$), supporting H5. Subjective norms significantly affected consumers' intention to accept 3D-printed food ($\beta = 0.307$, $p < 0.001$), supporting H6. PBC also significantly impacted consumers' intention to accept 3D-printed food ($\beta = 0.199$, $p < 0.001$), supporting H7.

The value zero did not fall within the confidence intervals (CI-Min and CI-Max), confirming the findings' credibility and robustness (Hair et al., 2022). FTN significantly moderated the effect of consumers' attitudes and subjective norms on their intention to accept 3D-printed food ($\beta = -0.131$ and 0.180 , $p < 0.05$), supporting H8 and H9. However, FTN did not moderate the PBC and intention to accept 3D-printed food relationship ($\beta = -0.058$, $p > 0.05$), rejecting H10. The red line in the final model highlights the insignificant moderating effect of FTN (Fig. 3). Food neophobia significantly moderated the influence of consumers' attitude, subjective norms, and PBC on their intention to accept 3D-printed food (β values = 0.293 , -0.216 and -0.128 , $p < 0.01$), supporting H11, H12, and H13. The confidence intervals for significant mediation and moderation did not include zero, reinforcing the credibility and robustness of the results.

For a more fine-grained insight regarding the moderating effects, simple slope analysis is provided in Fig. 2a through Fig. 2f in the Appendix. The plots show that consumers' attitudes strongly affected their intention to accept 3D-printed foods when FTN was low than when FTN was high. Contrastingly, subjective norms strengthened consumers' intention when FTN was high.

Moderation plots further demonstrate that at a high level of food neophobia, positive attitudes amplify consumers' intentions to accept 3D-printed foods. Contrarily, subjective norms and PBC strongly guide low food neophobic consumers' intentions towards 3D-printed foods compared to highly food neophobic consumers.

Predictive assessment. To validate the sample's explanatory power, the out-of-sample predictive relevance of each endogenous construct was evaluated using *PLSpredict* analysis (Hair et al., 2022). Table 5 shows that all $Q^2_{predict}$ values exceeded zero, confirming the model's acceptable predictive relevance. A comparison of the root mean squared error values between the PLS-SEM and linear regression models further demonstrated the strong predictive power of endogenous constructs, such as consumers' intention to accept 3D-printed food and PBC. Conversely, attitudes and subjective norms had moderate predictive power. An advanced cross-validated predictive ability test was employed to minimize generalization errors and improve the applicability of the results to other datasets from the same population (Hair et al., 2022). A comparison of the indicator average and linear model forecasts showed a negative average loss value for the PLS-SEM compared to the benchmark values, confirming the enhanced predictive capability of the research model.

Discussion and concluding remarks

To address issues like food scarcity, security, waste, and general sustainability concerns, numerous studies have explored the predictors of consumers' intention to accept novel foods such as irradiated food (D'Souza et al., 2021) and cultured meat (Hamlin, et al. 2022). However, there is a need for research on 3D-printed foods (Lanz et al., 2024), given their potential to address global food crises. Thus, it is necessary to understand how consumers perceive these benefits and intend to accept 3D-printed food. Existing studies have largely overlooked the link between consumers' religious beliefs and their intention to accept 3D-printed food. They also overlook potential pathways like mediating mechanisms through which religious beliefs foster consumers'

intentions to accept 3D-printed foods. Research on moderating factors from this perspective is also limited. Using TPB, this study explored how consumers' attitudes, subjective norms, and PBC are instrumental in the relationship between consumers' religious beliefs and their intention to accept 3D-printed foods. It also investigated the moderating roles of food neophobia and FTN, particularly in Malaysia's multi-religious context.

Unlike previous studies on religious beliefs, halal foods (Aslan, 2023), and leftover foods (Kirmani et al., 2023), the present study identified an indirect relationship between consumers' religious beliefs and their intention to accept 3D-printed food, mediated by consumer attitudes, subjective norms, and PBC, with subjective norms as the strongest mediator. This is a novel outcome because the core constructs of TPB examined in this study have never been considered as potential pathways in this context. This outcome is also surprising and contrasting to most literature which often anticipates that strong religious beliefs could reduce the acceptance of new technologies due to skepticism or conservatism (D'Souza et al., 2024). The religious and socio-cultural context of this study, i.e., Malaysian setting and other studies conducted in the same/similar contexts provide several possible explanations of why this positive relationship may have emerged.

First, from a religious viewpoint, 3D food printing caters to religious food preferences and assure adherence to religious standards by offering complete ingredient control—for example, halal food compliance for Muslim consumers, and contamination prevention for vegan/vegetarian Buddhist and Hindu consumers. Baharuddin et al. (2023) also corroborate that innovative technologies like 3D food printing are considered reliable in authenticating religious-based food integrity, thus promoting their acceptance. Secondly, Ng et al. (2022) confirmed that diverse communities in Malaysia embraced 3D food printing technology due to its potential benefits such as health, ingredient personalization etc. Moreover, studies on religious beliefs in non-food contexts, Usman et al. (2022) have documented that religious consumers residing in religious economies have accepted innovative technologies which do not interfere with their religious guidelines. Likewise, the notion that 3D-printed food technology aligns with one's religious beliefs could have possibly and unexpectedly increased consumers' intention towards its acceptance.

Consistent with Kirmani et al. (2023) and Singh et al. (2021), this study shows that consumers' religious beliefs can impact their attitudes towards 3D-printed food. Given that some religions promote sustainable consumption and food security through specific dietary guidelines and ethics, highly religious individuals were found to be more likely to accept foods that align with these guidelines and doctrines (Aslan, 2023). Furthermore, it was found that once consumers' positive attitudes develop, their intention to accept 3D-printed food is enhanced. This outcome aligns with similar studies such as Manstan and McSweeney (2020). Thus, consumers' positive attitudes can mediate the impact of their religious beliefs on their intention to accept 3D-printed food.

Consumers' religious beliefs can significantly shape their subjective norms in favor of 3D-printed food. Religious individuals' willingness to accept or purchase food produced using novel technologies depends on how much they value the opinions of their religious peers. As certain religious doctrines promote socially responsible behaviors (Singh et al., 2021), people with high religiosity prefer the sustainable viewpoints of their religious communities and products aligning with their belief systems, including those manufactured using 3D printing technology. This aligns with previous literature in similar contexts, such as apparel (Zaki and Elseidi, 2024) and socially responsible products (Graafland, 2017). Consistent with Yang et al. (2024) and Aslan (2023), subjective norms can influence consumers' intentions to accept 3D-printed foods, as they are more inclined towards

options with positive social consensus and peer acceptance. Hence, consumers' subjective norms mediate the relationship between their religious beliefs and intention to accept 3D-printed food.

Consumers' religious beliefs strongly influence their PBC. People with strong religious inclinations and beliefs possess a higher degree of authority and control over their behaviors, enabling them to choose or avoid foods based on their religious guidelines. 3D-printed food offers a sustainable solution to food scarcity and waste issues. Certain religions promote sustainable consumption; thus, consumers with strong religious beliefs are likely to have a PBC that favors 3D-printed food. This result aligns with Filimonau et al. (2023) and Kasber et al. (2023) in similar contexts. These results further highlight that people with strong PBC have a greater tendency to accept 3D-printed food. Once consumers are free to choose sustainable and customized meal preparation options within acceptable religious standards, they are drawn to the idea. This aligns with studies on Halal foods (Aslan, 2023) and irradiated foods (D'Souza et al., 2021). Thus, consumers' PBC mediates the relationship between their religious beliefs and intention to accept 3D-printed food.

Notably, FTN negatively moderates the relationship between consumer attitudes and the intention to accept 3D-printed foods. Supporting this, studies on 3D-printed foods (Lee et al., 2021) suggest that novel foods often face resistance due to consumer doubts, perceived risk, and unnaturalness. Therefore, even when consumers develop a positive view of 3D-printed food due to its benefits and religious compatibility, FTN lessens their inclination towards such foods. Conversely, consumers with a better understanding of new technologies, familiarity with their functional components, and sufficient education are likely to have lower FTN (Dupont et al., 2022). This justifies the positive moderating effect of FTN on the relationship between consumers' subjective norms and their intention to accept 3D-printed food. When consumers are knowledgeable and familiar with 3D printing technology (low FTN), they are more likely to accept 3D-printed foods despite social reservations.

Studies on novel foods, such as Stone et al. (2022) suggest that curiosity can also strengthen the positive effect of consumers' attitudes and subjective norms on their willingness to try negatively perceived novel foods. In other words, regardless of other motivating factors, individuals with high curiosity may be willing to try new food. Surprisingly, FTN did not moderate the impact of consumer PBC on their intention to accept 3D-printed food. This aligns with the idea that when consumers develop a sense of PBC, they have authority and control over their choices. Thus, their intention to accept 3D-printed food is likely to be affected by the degree of PBC rather than by FTN. These findings are unconventional and thus offer a novel understanding of FTN.

Food neophobia positively moderated the effect of consumers' attitudes on their intention to accept 3D-printed foods. In line with D'Souza (2022) even consumers with a favorable attitude toward 3D-printed food have high food neophobia. Conversely, food neophobia negatively moderates the impact of consumers' subjective norms and PBC on their intention to accept 3D-printed food. This indicates that consumers with high food neophobia are afraid to consume unfamiliar foods despite having favorable subjective norms and PBC aligned with their religious doctrines. As a result, they remain reluctant to try new culinary experiences. These findings are novel and in line with previous studies on 3D-printed food (Lee et al., 2021) and cultured meat (Hamlin et al., 2022). Moreover, existing literature has shown a negative interaction between food neophobia and curiosity—a vital factor influencing the willingness to try novel foods (Stone et al., 2022). This suggests that, regardless of other factors, such as social approval, curious customers—particularly adventurous and variety-seeking diners—may show an increased

intention to try novel foods. Nevertheless, high food neophobia among curious customers interferes with their willingness to consume novel foods and is likely to reduce it. Surprisingly, the moderation of FTN and food neophobia have opposite directions on the same constructs. It could be because FTN is technology-specific, when making food-related decisions it may enhance sensitivity to social pressures. Contrastingly, food neophobia, as a general aversion to unfamiliar foods, may prompt reliance on attitudes but diminishes social pressure and PBC-related pathways. This remarkable finding remains an open question and warrants investigation in the future.

Theoretical implications. First, using a sample of Malaysian consumers, this study provides valuable insights into the role of religiosity and TPB constructs in influencing the intention to accept 3D-printed food in developing countries. Unlike previous studies in related contexts, this study shows that consumers' religious beliefs indirectly influence their intention to accept 3D-printed food via three mediators: positive attitudes, subjective norms, and PBC. Second, this study is the first to extend the TPB framework to empirically examine how religious beliefs affect intention to accept 3D-printed food by shaping its core constructs. Prior research has explored religiosity and consumer behavior in other contexts, such as halal (Aslan, 2023) and special foods (Minton et al., 2019). Third, while most studies assess the independent effect of religiosity or TPB constructs on intention, this study integrates both into a single framework. Finally, this study showed that food neophobia and FTN may weaken or strengthen the impact of consumers' attitudes, subjective norms, and PBC on their intention to accept 3D-printed food. Highly neophobic consumers are less inclined toward novel foods compared to less neophobic consumers. Supporting this, existing literature suggests that technological knowledge and functional familiarity can reduce neophobia, increasing intention to accept novel foods (Dupont et al., 2022).

Practical implications. The findings offer practical implications for organizations introducing 3D-printed food, as well as food practitioners, retailers, marketers, and decision-makers developing food-related strategies and policies. These findings might guide stakeholders in enhancing Malaysian consumers' intentions to accept 3D-printed foods. While meeting religious requirements is essential, practitioners must also consider the mediating factors—consumer attitudes, subjective norms, and PBC—through which religious beliefs influence intention. As 3D-printed food was unavailable in Malaysia during data collection, knowledge of the upcoming technology formed the basis for consumers' responses. Therefore, this study provides practical information for the introduction of the technology to the market. Practitioners must ensure that Muslim and non-Muslim consumers are transparently informed about the inputs used in 3D-printed food, reassuring all religious communities that production protocols respect their beliefs. Displaying halal and non-halal certifications on ingredients and final products can further ease concerns and help foster favorable consumer attitudes toward the technology.

Second, as theoretically demonstrated, subjective norms are crucial for establishing consumer intentions to accept novel foods. Hence, marketers must focus on creating a positive social image of 3D-printed food throughout Malaysia through social media campaigns and endorsements by influencers, environmentalists, and celebrities. This can enhance the persuasiveness of messages regarding the nutritional and functional benefits of 3D-printed foods (e.g., meal customization). Since people are influenced by behaviors endorsed by significant figures, social circles can boost the acceptance of 3D-printed food. It also creates curiosity and interest among adventurous diners seeking novel foods as a unique culinary experience.

Fortunately, favorable representation and increased knowledge can help minimize food- and technology-related neophobias.

Third, because PBC influences consumers' intentions toward acceptance, stakeholders and marketers should emphasize the environmental and moral aspects of 3D-printed foods. Promotional campaigns can highlight contributions to sustainable living, food shortage mitigation, and waste reduction to appeal to environmentally conscious consumers and encourage religious leaders and followers to adopt ethical responsibility as part of their beliefs. The efficient use of resources in 3D food printing not only aids in reducing hunger but also supports sustainable consumption, aligning with sustainable development goals (SDG 2, 3, and 12). Overall, these findings offer marketers guidance for promoting 3D-printed foods in the Malaysian market. Moreover, the results have broader relevance and can be applied in other religiously diverse countries, aiding in the development of inclusive, culturally sensitive marketing strategies and policies.

Limitations and further study. First, this was a cross-sectional study; future research should adopt a longitudinal approach. Second, as this study focused on Malaysia's religious diversity, future studies could extend the framework through cross-country comparisons—for example, between developed and developing countries or between religiously dominated and secular societies. Future studies could also compare religion-wise consumption intention of 3D-printed foods. Third, only self-reported measures were used. Future researchers should observe the real-time behavior of consumers by using a prototype or an actual 3D-printed product when launched. Fourth, this study used TPB as an underpinning theory, which deals with the rational side of decision-making. However, factors beyond TPB may also influence intention or be shaped by religiosity. Future studies should consider alternative theories to investigate other factors within this framework.

Fifth, it was clearly explained in the questionnaire that this study is related to edible 3D printed food. However, the screening question broadly covered both interpretations; "having knowledge of/ having heard of 3D-printed food products". Consequently, this study sampled participants with different levels of familiarity together, thus, a sampling bias may exist. The results of this study should be interpreted accordingly. Future studies should perform a detailed analysis and comparison by classifying respondents based upon their levels of familiarity and including people who are unfamiliar with 3D printing food products/technology. Sixth, this study provided potential benefits of 3D-printed foods in the questionnaire solely to ensure a clear understanding of the novel technology. While statistical tests of CMB were also satisfactory, this study acknowledges that such information might influence attitudes and intentions. Future studies should rule out this bias with control groups in an experimental design to validate the results. Moreover, future studies could further opt for a qualitative research design to verify the variation in religiosity across religiously diverse societies.

Data availability

No datasets were generated or analysed during the current study.

Received: 12 December 2024; Accepted: 2 September 2025;

Published online: 29 October 2025

References

- Ajzen I (1991) The theory of planned behavior. *Organ Behav Hum Decis Process* 50(2):179–211. [https://doi.org/10.1016/0749-5978\(91\)90020-T](https://doi.org/10.1016/0749-5978(91)90020-T)

- Al-Ansi A, Olya HGT, Han H (2019) Effect of general risk on trust, satisfaction, and recommendation intention for halal food. *Int J Hosp Manag* 83,:210–219. <https://doi.org/10.1016/j.ijhm.2018.10.017>
- Al Bayari J, Taha S, Suliman A, Osaili TM (2023) The role of food handlers' religious and organizational commitment in food hygiene practices: a structural modeling approach. *Food Control* 150,:109732. <https://doi.org/10.1016/j.foodcont.2023.109732>
- Aslan H (2023) The influence of halal awareness, halal certificate, subjective norms, perceived behavioral control, attitude and trust on purchase intention of culinary products among Muslim costumers in Turkey. *Int J Gastron Food Sci* 32,:100726. <https://doi.org/10.1016/j.ijgfs.2023.100726>
- Awan HM, Siddiquei AN, Haider Z (2015) Factors affecting Halal purchase intention—evidence from Pakistan's Halal food sector. *Manag Res Rev* 38(6):640–660
- Baharuddin A, Ismail W, Lukman A, Ghazali M, Alauddin M, Shaarani S, Wan Harun M, Tuan Ibrahim T (2023) Halal standards as elements in the legal framework of 3D/4D-printed food using source-composition-manufacturing and halal forensic concepts. *Food Res* 6(Supplementary 3):10–22
- Baiano A (2022) 3D printed foods: a comprehensive review on technologies, nutritional value, safety, consumer attitude, regulatory framework, and economic and sustainability issues. *Food Rev Int* 38(5):986–1016. <https://doi.org/10.1080/87559129.2020.1762091>
- Brunner TA, Delley M, Denkel C (2018) Consumers' attitudes and change of attitude toward 3D-printed food. *Food Qual Prefer* 68,:389–396. <https://doi.org/10.1016/j.foodqual.2017.12.010>
- Cain MK, Zhang Z, Yuan K-H (2017) Univariate and multivariate skewness and kurtosis for measuring nonnormality: prevalence, influence and estimation. *Behav Res Methods* 49(5):1716–1735. <https://doi.org/10.3758/s13428-016-0814-1>
- Caulier S, Doets E, Noort M (2020) An exploratory consumer study of 3D printed food perception in a real-life military setting. *Food Qual Prefer* 86,:104001. <https://doi.org/10.1016/j.foodqual.2020.104001>
- Chaloupkova P, Kokoskova T, Ceacero F, Durand C, Onakuse S, Kokoska L (2025) How do you want your steak? Attitudes of European consumers towards 3D printed meat. *Food Qual Prefer* 128,:105487. <https://doi.org/10.1016/j.foodqual.2025.105487>
- Chin WW, Gopal A, Salisbury WD (1997) Advancing the theory of adaptive structuration: the development of a scale to measure faithfulness of appropriation. *Inf Syst Res*, 8(4):342–367. <https://doi.org/10.1287/isre.8.4.342>
- Cohen J (1998) *Statistical power analysis for the behavioral sciences* (2nd ed) Academic Press. <https://doi.org/10.1016/B978-0-12-179060-8.50006-2>
- Conner M (2015) Extending not retiring the theory of planned behaviour: a commentary on Sniehotta, Presseau and Araújo-Soares. *Health Psychol Rev* 9(2):141–145. <https://doi.org/10.1080/17437199.2014.899060>
- Conroy DM, Errmann A (2023) My voice, my choice': impact of food technology conditions and message framing on sense of agency and purchase intent. *Appetite* 181,:106415. <https://doi.org/10.1016/j.appet.2022.106415>
- Cox DN, Evans G (2008) Construction and validation of a psychometric scale to measure consumers' fears of novel food technologies: the food technology neophobia scale. *Food Qual Prefer* 19(8):704–710
- D'Souza C (2022) Game meats: consumption values, theory of planned behaviour, and the moderating role of food neophobia/neophilic behaviour. *J Retail Consum Serv* 66:102953. <https://doi.org/10.1016/j.jretconser.2022.102953>
- D'Souza C, Apaolaza V, Hartmann P, Brouwer AR, Nguyen N (2021) Consumer acceptance of irradiated food and information disclosure—a retail imperative. *J Retail Consum Serv* 63,:102699. <https://doi.org/10.1016/j.jretconser.2021.102699>
- D'Souza C, Adkari A, Alahakoon D (2024) Coupling AI with empirical research—a case of 3D printed food technology. *Food Qual Prefer* 120,:105229. <https://doi.org/10.1016/j.foodqual.2024.105229>
- Dupont J, Harms T, Fiebelkorn F (2022) Acceptance of cultured meat in Germany—application of an extended theory of planned behaviour. *Foods* 11(3):424. www.mdpi.com/2304-8158/11/3/424
- Elhoushy S, Jang S (2021) Religiosity and food waste reduction intentions: a conceptual model. *Int J Consum Stud* 45(2):287–302. <https://doi.org/10.1111/ijcs.12624>
- Evans G, Kermarrec C, Sable T, Cox DN (2010) Reliability and predictive validity of the Food Technology Neophobia Scale. *Appetite* 54(2):390–393. <https://doi.org/10.1016/j.appet.2009.11.014>
- Faul F, Erdfelder E, Lang A-G, Buchner A (2007) G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 39(2):175–191. <https://doi.org/10.3758/BF03193146>
- Filimonau V, Matute J, Kubal-Czerwińska M, Mika M (2023) Religious values and social distance as activators of norms to reduce food waste when dining out. *Sci Total Environ* 868,:161645. <https://doi.org/10.1016/j.scitotenv.2023.161645>
- Graafland J (2017) Religiosity, attitude, and the demand for socially responsible products. *J Bus Ethics* 144(1):121–138. <https://doi.org/10.1007/s10551-015-2796-9>
- Hair, JF, Hult, GTM, Ringle, CM, & Sarstedt, M (2022). *A primer on partial least squares structural equation modeling (PLS-SEM)*. Sage publications
- Hamlin RP, McNeill LS, Sim J (2022) Food neophobia, food choice and the details of cultured meat acceptance. *Meat Sci* 194,:108964. <https://doi.org/10.1016/j.meatsci.2022.108964>
- Henseler J, Ringle CM, Sarstedt M (2015) A new criterion for assessing discriminant validity in variance-based structural equation modeling. *J Acad Mark Sci* 43(1):115–135. <https://doi.org/10.1007/s11747-014-0403-8>
- Hoesterey S, Hemprich C-J, Onnasch L (2023) What drives the acceptability of a sustainable food production technology? Modeling psychological factors. *Sustain Prod Consum* 42:158–169. <https://doi.org/10.1016/j.spc.2023.09.020>
- Huang L, Bai L, Zhang X, Gong S (2019) Re-understanding the antecedents of functional foods purchase: mediating effect of purchase attitude and moderating effect of food neophobia. *Food Qual Prefer* 73,:266–275. <https://doi.org/10.1016/j.foodqual.2018.11.001>
- Jackson BR, Bergeman CS (2011) How does religiosity enhance well-being? The role of perceived control. *Psychol Relig Spirit* 3(2):149–161. <https://doi.org/10.1037/a0021597>
- Kasber A, El-Bassiouny N, Hamed S (2023) Can religiosity alter luxury and counterfeit consumption? An empirical study in an emerging market. *J Islam Mark* 14(7):1768–1792. <https://doi.org/10.1108/JIMA-02-2022-0058>
- Khan A, Arafat MY, Azam MK (2022) Role of halal literacy and religiosity in buying intention of halal branded food products in India. *J Islam Mark* 13(2):287–308. <https://doi.org/10.1108/JIMA-08-2019-0175>
- Kirman MD, Fatah Uddin SM, Sadiq MA, Ahmad A, Haque MA (2023) Food-lever sharing intentions of consumers: an extension of the theory of planned behavior. *J Retail Consum Serv* 73,:103328. <https://doi.org/10.1016/j.jretconser.2023.103328>
- Kock F, Berbekova A, Assaf AG (2021) Understanding and managing the threat of common method bias: detection, prevention and control. *Tour Manag* 86,:104330. <https://doi.org/10.1016/j.tourman.2021.104330>
- Lanz M, Hartmann C, Egan P, Siegrist M (2024) Consumer acceptance of cultured, plant-based, 3D-printed meat and fish alternatives. *Future Foods* 9:100297. <https://doi.org/10.1016/j.fufo.2024.100297>
- Lee KH, Hwang KH, Kim M, Cho M (2021) 3D printed food attributes and their roles within the value-attitude-behavior model: moderating effects of food neophobia and food technology neophobia. *J Hosp Tour Manag* 48:46–54. <https://doi.org/10.1016/j.jhtm.2021.05.013>
- Lemos CM, Gore R, Ivan PE, Shults FL (2019) Dimensionality and factorial invariance of religiosity among Christians and the religiously unaffiliated. *PLoS one* 14.5:e0216352 <https://doi.org/10.1371/journal.pone.0216352>
- Lupton D (2017) Download to delicious': promissory themes and sociotechnical imaginaries in coverage of 3D printed food in online news sources. *Futures* 93,:44–53. <https://doi.org/10.1016/j.futures.2017.08.001>
- Lupton D, Turner B (2018) 'Both fascinating and disturbing': consumer responses to 3D food printing and implications for food activism. In *Digital food activism* (pp. 151–167). Routledge
- Manstam T, McSweeney MB (2020) Consumers' attitudes towards and acceptance of 3D printed foods in comparison with conventional food products. *Int J Food Sci Technol* 55(1):323–331. <https://doi.org/10.1111/ijfs.14292>
- Matsuoka H, Uchiyama Y, Woraitthinan K, Kohsaka R (2023) Does novel food differ in cultural contexts? A comparative analysis of Japanese and Singaporean cultural acceptance through text analysis of mass media. *Curr Res Food Sci* 6,:100436. <https://doi.org/10.1016/j.crf.2023.100436>
- Millán MGD (2024) 3D food printing: technological advances, personalization and future challenges in the food industry. In *J Gastron Food Sci* 37, 100963
- Minton EA, Johnson KA, Liu RL (2019) Religiosity and special food consumption: the explanatory effects of moral priorities. *J Bus Res* 95,:442–454. <https://doi.org/10.1016/j.jbusres.2018.07.041>
- Mordor Intelligence (2024) Food 3D printing market size & share analysis—growth trends & forecasts (2024–2029) Retrieved 19 May 2024 from <https://www.mordorintelligence.com/industry-reports/global-food-3d-printing-market>
- Mudau M, Adebo OA (2024) Three dimensional (3D)-printed foods: a review of recent advances in their ingredients, printing techniques, food printers, post-processing methods, consumer acceptance and safety. *J Food Process Eng*, 47(5):e14621. <https://doi.org/10.1111/jfpe.14621>
- Ng W, Pindi W, Rovina K, Mantihal S (2022) Awareness and attitude towards 3D food printing technology: the case of consumer responses from Klang Valley, Malaysia. *Food Res* 6(4):364–372
- Nopparat N, Motte D (2024) Business model patterns in the 3D food printing industry. *Int J Innov Sci* 16(1):77–94. <https://doi.org/10.1108/IJIS-09-2022-0176>
- Omobowale EB, Singer PA, Daar AS (2009) The three main monotheistic religions and GM food technology: an overview of perspectives. *BMC Int Health Hum Rights* 9(1):18. <https://doi.org/10.1186/1472-698X-9-18>
- Ong AKS, Arriola RSL, Eneria ZMR, Lopez LG, Matias EAL, Diaz JFT, German JD, Gumasing MJJ (2024) 3D bioprinted meat: the values-beliefs-norms

- evaluation of perceived future food source among younger generations. *Br Food J* 126(9):3505–3528
- Orellano A, Valor C, Chuvienco E (2020) The influence of religion on sustainable consumption: a systematic review and future research agenda. *Sustainability* 12(19):7901
- Pegan G, Del Missier F, De Luca P (2023) Antecedents of green purchase choices: towards a value-oriented model. *J Clean Prod* 399:136633. <https://doi.org/10.1016/j.jclepro.2023.136633>
- Podsakoff PM, MacKenzie SB, Podsakoff NP (2012) Sources of method bias in social science research and recommendations on how to control it. *Annu Rev Psychol* 63(1):539–569. <https://doi.org/10.1146/annurev-psych-120710-100452>
- Roslin UH, Razali MFA, Ghazali MIM, Baharuddin AS(2022) Three-dimensional (3D) printed food products from halal forensic perspective: a preliminary review. *Malay J Syariah Law* 10:54–62
- Rozin P, Haidt J, & McCauley CR (2008) Disgust. In *Handbook of emotions*, 3rd ed (pp 757–776). The Guilford Press
- Seo J-K, Mahudin MB, Sohn YW(2022) The relationship between religiosity and meaningful work among Malaysian Muslim employees: the mediating role of existential labor. *PLoS One* 17:e0279251
- Singh G, Sharma S, Sharma R, Dwivedi YK (2021) Investigating environmental sustainability in small family-owned businesses: integration of religiosity, ethical judgment, and theory of planned behavior. *Technol Forecast Soc Change* 173:121094. <https://doi.org/10.1016/j.techfore.2021.121094>
- Soleymani S, Naghib SM, Mozafari MR (2024) An overview of cultured meat and stem cell bioprinting: how to make it, challenges and prospects, environmental effects, society's culture and the influence of religions. *J Agric Food Res*, 18:101307. <https://doi.org/10.1016/j.jafr.2024.101307>
- Stone H, FitzGibbon L, Millan E, Murayama K (2022) Curious to eat insects? Curiosity as a key predictor of willingness to try novel food. *Appetite* 168:105790
- Usman H, Mulia D, Chairy C, Widowati N (2022) Integrating trust, religiosity and image into technology acceptance model: the case of the Islamic philanthropy in Indonesia. *J Islam Mark* 13(2):381–409
- World Population Review (2024) Retrieved 7 May from <https://worldpopulationreview.com/world-cities/kuala-lumpur-population>
- Yang M, Gao J, Yang Q, Al Mamun A, Masukujaman M, Hoque ME(2024) Modeling the intention to consume and willingness to pay premium price for 3D-printed food in an emerging economy. *Humanit Soc Sci Commun*. 11:274. <https://doi.org/10.1057/s41599-024-02776-1>
- Zaki RM, Elseidi RI(2024) Religiosity and purchase intention: an Islamic apparel brand personality perspective. *J Islam Mark* 15:361–396. <https://doi.org/10.1108/JIMA-09-2022-0257>

Acknowledgements

This research was funded by Geran Universiti Penyelidikan (GUP) from Universiti Kebangsaan Malaysia (grant number GUP-2021-077).

Author contributions

Sara Kanwal: Conceptualization, Investigation, Methodology, Writing—original draft. Sauda Salim Hamdun Al Marhoobi: Validation, Funding acquisition, Writing—original draft. Saad Mahmood Bhatti: Methodology, Investigation, Formal analysis, Writing—review & editing. Asma-Qamaliah Abdul-Hamid: Conceptualization, Supervision, Writing—review & editing. Norhidayah Suleiman: Investigation, Validation, Visualization. Mohd Helmi Ali: Conceptualization, Validation, Supervision, Funding acquisition.

Competing interests

The authors declare no competing interests.

Ethical approval

The questionnaire and methodology for this study were approved by the ethics review committee of the Universiti Malaysia Kelantan, Malaysia and the Institute of Business and Management, UET, Lahore, Pakistan. Ethical approval letter was obtained on 28 February 2024 (Ethics approval number: UKM.B01.01.18.04.800-2/2/12(12)) and May 8th, 2024 (Ethics approval number: Uni/IB&M/Dir/2024/8) respectively. All research procedures were carried out in accordance with the ethical standards of the institutional ethics review committee and were consistent with the 1964 Helsinki Declaration and its subsequent amendments.

Informed consent

Each participant was required to sign a written informed consent form given to them by the research investigator before their participation in the study (conducted between May and July 2024). All participants were given a detailed information sheet that outlined the study's purpose, addressed data confidentiality matters (anonymity, use of data for academic purposes and research publication), potential risks and benefits of the study and informed them that participation was unpaid and voluntary. The informed consent form clearly mentioned that participants have read the information sheet, they can withdraw from the study at any time without penalty, they were given time to think about the questionnaire and all the questions have been answered to their satisfaction. The anonymized responses were used solely for academic purposes, ensuring full adherence to ethical guidelines. The study did not involve vulnerable groups, such as minors, people with disabilities, or other populations requiring special ethical considerations.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1057/s41599-025-05916-3>.

Correspondence and requests for materials should be addressed to Mohd Helmi Ali.

Reprints and permission information is available at <http://www.nature.com/reprints>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2025