

UNDERSTANDING CONSUMERS' INTENTION TO ACCEPT 3D-PRINTED FOOD: AN INVESTIGATION OF MUSLIM YOUTH IN MALAYSIA

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Abstract

The research on 3D-food printing is substantial provided the current trend of using novel technologies for sustainable food production—from minimizing the food shortage, wastage to preserving environmental resources. Nevertheless, examining the potential acceptance of 3D-printed food among consumers is imperative before its commercial availability. Through a survey this study investigated whether three factors (product judgment, religious belief, and perceived risk) influence Muslim consumers' intention to accept 3D-printed food. This study further examines if the theory of planned behaviour (TPB) core constructs mediate the above-addressed link. The data was collected from 250 Muslim youth respondents in Malaysia and was analysed via PLS-SEM. Findings suggest that 3DFP could satisfy specific niche Muslim market segments if risks and judgement associated with 3D-printed foods, consumers' religious belief and TPB core constructs are taken into account for marketing 3D-printed food.

Keywords: 3D-printed food, Malaysia, product judgment, religious belief, sustainable food production, theory of planned behaviour

INTRODUCTION

3D food printing (3DFP) technology—via modified shapes, colours, tastes and even nutrition—enables customized and innovative food manufacturing, which can immensely benefit food manufacturing, processing and retailing (Xiao et al. 2025). Positive developments of 3DFP include personalized nutritional diets for consumers having chewing/ swallowing difficulties and custom ingredient choice—plant-based vs meat-based or organic food options (Ramundo et al. 2020). Lee (2021) highlighted users of 3DFP by global market size ranking commercial users (43.5%) at the top, government (25.8%) at second place, then hospitals (20.8%) and lastly household (9.9%). In recent years, 3D-printing technology has expanded beyond its initial industrial and medical applications into the realm of food production. While this innovative technology has captured the attention of many, little is known about how consumers perceive 3D-printed food and their willingness to incorporate it into their diets. Given the novelty of this food technology, concerns about perceived risks associated with such foods, personal preferences due to religious belief and positive/ negative judgements about them may motivate/ prevent consumers from embracing 3D-printed foods (Pant et al. 2021).

In Europe, for instance, companies like byFlow (Netherlands) have pioneered the commercial use of 3D-food printers for creating intricate designs in fine dining (Caulier et al. 2020). Similarly, in Spain, a company called Natural Machines has developed Foodini, a 3D-food printer aimed at making healthy and personalized meals accessible to consumers (Portanguen et al. 2019a). The United States has also been a major player in advancing this technology, with research initiatives exploring its potential in creating nutrient-dense meals for healthcare and space missions. In Asia, countries like China and Japan have integrated 3DFP into their food innovation strategies, focusing on sustainable production methods, including the use of alternate inputs like algae/ insect protein etc. (Shigi & Seo 2024). All this production and application is mostly confined to Non-Muslim countries, yet there is a gap concerning Muslim consumers as there doesn't exist any policy for the regulation and production guidelines to cater to Muslims. 3DFP, however, can modify the foods to suit personal preferences of each religious/ non-religious group about their health concerns, eating habits and taste choice (Caulier et al., 2020).

3D printing has long been used in engineering field, however, 3DFP concept was first addressed in 2007 (Pereira et al., 2021). Since then, the idea of using 3D technology for food manufacturing and food security has gained attention (Brunner et al., 2018; Liu et al., 2017; Manstan and McSweeney, 2020). Nevertheless, acceptance of 3DFP among religious Muslim consumers could be challenging as currently 3D food inputs neither undergo food

safety nor halal certification (Baiano, 2020). Therefore, consumers' acceptance of 3DFP is an imperative concern and examining its critical determinants and underlying mediating mechanisms is necessary, yet current literature fails to address them. Previous literature has discussed how consumers' acceptance of novel foods is influenced by factors like food neophobia or food technology neophobia (Lee et al. 2021; Brunner et al. 2018; Ng et al. 2022; Silva et al. 2024).

Thus, this study within the context of 3DFP focuses on examining the effect of factors such as product judgement, perceived risk and religious belief. This study also examines the theory of planned behaviour (TPB) core constructs as mediators. Literature suggests that consumers' acceptance towards 3DFP is derived by several factors including product judgment and perceived risk which are meaningful in the opinion forming process towards novel foods (Ambali & Bakar 2013a). For Muslim consumers—which are the key focus of this study—religious belief can be a significant driver of 3D-printed food acceptance alongside product judgment and perceived risk, however, scarcely studied before (Siegrist & Hartmann 2020).

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

This study utilizes TPB to argue the hypothesized relationships. TPB extended the premise of theory of reasoned action (TRA) (Ajzen & Fishbein, 1980) to address additional important factors beyond broad attitudes in predicting peoples' intention to behave leading to actual behaviour (Wicker, 1969). TPB provides support for peoples' attitude, social norms and perceived behavioural control (PBC) as core constructs influencing their behavioural intentions. Attitudes refer to the evaluation of one's behaviour. Social norm refers to the shared understanding among members of a society to choose the right behaviour without formal enforcement (Melnik et al. 2022). TPB further suggests that intentions transform into behaviour when PBC is high. PBC referred to as the perception of an individual regarding their ability to perform a behaviour (Shalender and Sharma, 2021). To study the intention to accept 3D-printed foods by Muslim consumers the TPB model was revisited and extended. Literature recommends that extending TPB model to suit the research variables is even more resilient (Abbasi et al., 2021; Meng and Cui, 2020). Thus, as an extension of TPB, consumers' religious belief and product judgement as suggested by (Wilkins et al., 2019) and perceived risk suggested by (D'Souza et al., 2021) are incorporated as precursors intention to accept 3D-printed food. Fig. 1 given below depicts this study's conceptual model.

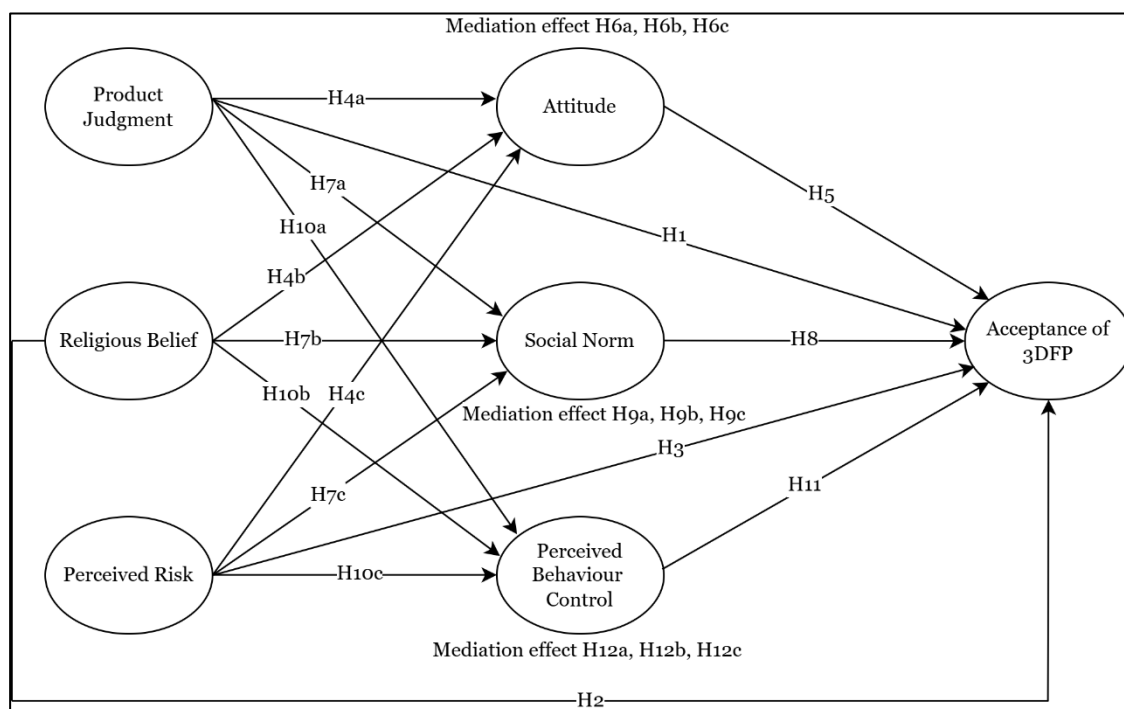


Figure 1. Conceptual framework

2.1 PRODUCT JUDGEMENT AND INTENTION TO ACCEPT 3DFP

Product judgement can affect the religious consumers' decision in accepting foods including the novel foods (Wilkins et al. 2019). Literature reflects that product judgement has a strong relationship with accepting the consumption of food manufactured via new food technology with halal certification. Literature also suggests that halal marketing could facilitate promoting international foods in local markets when local people can identify with these foods. For instance, there are 1.6 billion Muslims worldwide who prefer consuming halal food due to religious reasons (Annabi and Ibidapo-Obe, 2017). For these consumers halal protocol for food is vital in shaping their favourable attitude and intentions towards halal food than non-halal food products (Rahman et al., 2015). Any negative news about the origin/ ingredients of production of 3D-printed foods among Muslims can affect their decision about this food technology. Likewise, positive news could lead to a favourable decision. Building

on this logic, we hypothesize that stronger a Muslim faith, stronger will be their judgement of halal vs non-halal food product.

H1: Product judgment of religious Muslim consumers significantly affects their intention to accept 3DFP.

2.2 RELIGIOUS BELIEF AND INTENTION TO ACCEPT 3DFP

Religiosity/ religious belief is also recognized as key drivers of consumers' attitudes and behaviours (Rahman et al., 2015). Religiosity of a Muslim represents their belief in God and the degree of how they align with religious teachings (Singhapakdi et al., 2013). Religiosity as a cognitive process is believed to critically influence ethical purchasing behaviour (Alsaad et al., 2021). Ajzen & Fishbein (2005) found that religiosity is an important element in line with TPB for understanding the attitudes and social norms. In Islamic perspective, devout Muslims facilitate other people's needs and rights. They offer support and services to people and society regardless of financial benefits.

Another view from McCullough (2009) and Saroglou (2010) pinpoints that religiosity influences personality and temperament, which leads to pro-social inclinations. Religious people could behave more morally than non-religious ones stemming from the morality guided by their religion. In a Muslim dominant society like Malaysia the guidelines about halal foods are clearly stated from their food licensing authority, JAKIM. JAKIM strongly enforces labelling halal food as halal and obtaining halal certification to market such food with which the Muslims identify and consume (Ambali & Bakar 2013). Thus, religious rules regarding wrong and right/ allowed or not allowed could make the religious consumers confident and entrusted in the product if it satisfies their religion's moral and ethical code. Therefore, we hypothesize that:

H2: Religious belief among Muslims has positive influence on intention to accept 3DFP.

2.3 PERCEIVED RISK AND INTENTION TO ACCEPT 3DFP

Perceived risk could also relate to Muslim consumers' decision to accept novel foods. For example, public debates about the increase in additive food manufacturing noticeably affected people's risk experience regarding such food (Yuan et al., 2018). Hansen et al. (2003) found that when introducing a new and complex food, peoples' judgement of risk is largely influenced by their knowledge about the food product. Thus, a socially responsible consumers' risk perception of 3DFP is likely based on the information received about its societal benefits and contributions (Galati et al., 2019). Because Muslim faith demands its followers to only consume halal food and be more socially responsible/ ethical in their conduct, thus it also psychologically influences Muslim consumers' risk perception compared to the factual risk representation. Study by Legendre & Baker (2022) found that risk perception does not influence the intention of consumers towards new food technology due to negative product information in general, rather it depends upon the valence of information itself. Hence:

H3: Perceived risk among Muslims has positive influence on intention to accept 3DFP.

2.4 MEDIATION OF ATTITUDE

Within the food industry context, attitudes can significantly trigger peoples' intentions and potential behaviours. Consumers' attitude towards innovative food technologies like 3DFP can be uncertain as it depends upon how consumers evaluate these technologies (Brunner et al. 2018). TPB provides conceptual support for the relationship between consumers' attitude and their behavioural intentions to consume 3D-printed food. Extant literature reveals that consumers' positive attitude toward novel foods like 3D-printed food enhances their willingness to accept and consume them (Lee, 2021). A study on 3DFP highlighted that based upon their findings 42% people were found to have acceptance towards 3DFP compared to traditional food (Manstan & McSweeney, 2019). Literature on the acceptance of 3DFP further demonstrates that consumers showed favourable attitude towards 3DFP when sensory and feedback-giving method with open-ended comments was adopted (Manstan et al., 2021). Consumers' reactions also appeared different between two groups, 3D-printed food and conventional food particularly within the context of a secular country, Canada (Manstan et al., 2021).

While several studies proved positive link between attitude and intentions to accept 3DFP due to reasons like complete nutritious food etc (Ng et al. 2022), other studies found negative relationship between them (Caulier et al., 2020). Surprisingly, some studies also point out low association between consumers' attitudes and their intention to accept 3DFP (Pakseresht et al., 2022).

These mixed findings necessitate further examination of attitude-intention to accept link. Specifically, whether attitude as a mediator can facilitate the effect of other variables such as product judgement, perceived risk and religiosity on consumers' intention to accept 3DFP (Cabuk et al., 2014). Studies on new food technology contend that favourable attitude can amplify the effect of product judgement (Etale & Siegrist, 2021), religious belief (Ali & Suleiman, 2018), and perceived risk (Palmieri et al., 2019). Attitude is also proven to strengthen the intention towards consumption of artificial food (Zhang et al., 2020). In similar analogy, attitude towards 3DFP will likely mediate the influence of product judgement, religious belief and perceived risk on consumers' intention to accept 3DFP. Hence:

H4a: Product judgment significantly influences consumer's attitude.

H4b: Religious belief significantly influences consumer's attitude.

H4c: Perceived risk significantly influences consumer's attitude.

H5: Attitude positively influences consumer's intention to accept 3DFP.

- H6a: Attitude mediates product judgment and consumer's intention to accept 3DFP relationship.
H6b: Attitude mediates religious belief and consumer's intention to accept 3DFP relationship.
H6c: Attitude mediates perceived risk and consumer's intention to accept 3DFP relationship.

2.5 MEDIATION OF SOCIAL NORMS

Social norms can substantially influence the intention to act/ not to act (Ajzen, 2002). Social norms are based on the normative belief regarding peer pressure and a person's motive to conform to those social pressures (Ajzen, 2002). People abide by what they believe is considered acceptable and appropriate by the society and influential people around them (Arvola et al., 2008). Social norms define how a person must respond to the views/ opinions about others (e.g., religious peers around them, their close friends, or family members) (Ajzen, 2002). Social norms and culture are also key drivers of the intention to accept a novel food and actual consumption of both traditional and novel foods. Thus, the acceptance of innovative technologies is also influenced by them (Siegrist, 2008).

Literature suggests that besides conventional food, consumers' intention towards new food technology acceptance like 3DFP is an imperative outcome of social influence (Motoki et al., 2022). Consumers expressing a favourable view of for instance nutritional value of a food believe that one reason they hold the view is due to normative support (Baiano, 2020; Krishnaraj et al., 2019). Past studies demonstrate that social influence can directly affect and can also mediate the influence of individual-level factors such as self-efficacy on organic foods acceptance (Ashraf et al., 2021). However, the role of social norms within 3DFP perspective remains limited in the literature, thus we propose that:

- H7a: Product judgment significantly influences social norms.
H7b: Religious belief significantly influences social norms.
H7c: Perceived risk significantly influences social norms.
H8: Social norms positively influence consumer's intention to accept 3DFP.
H9a: Social norms mediate product judgment and consumer's intention to accept 3DFP relationship.
H9b: Social norms mediate religious belief and consumer's intention to accept 3DFP relationship.
H9c: Social norms mediate perceived risk and consumer's intention to accept 3DFP relationship.

2.6 MEDIATION OF PERCEIVED BEHAVIOURAL CONTROL (PBC)

PBC represents the control and confidence on one's intention to act and actual actions (Ajzen, 2002). Thereby, PBC can directly impact the behavioural intentions/ actual behaviour. Literature suggests that any behaviour can be performed depending upon the capacity of the consumer which is defined by the factors assisting/ dismissing that behaviour. Consumer behaviour is a result of the confidence in one's personal abilities to execute certain behaviour (Bandura, 1982). PBC concept has been widely utilised in the consumer behaviour literature to examine behavioural intentions regarding foods prepared by new technologies (Pakseresht et al., 2021)—halal product consumption (Asnawi et al., 2018), organic foods (Mohammed, 2020) and additive food products (Portanguen et al., 2019b).

Other studies also highlight that PBC have led to favourable/ positive outcome such as food-related behaviours/ intentions. For example, Yang et al. (2024) pointed out that PBC strongly derived the intention to purchase remanufactured items specifically in the circular economy and a closed-loop supply chain (Abbasi et al., 2022). Moreover, PBC directly influenced and acted as a mediator to enhance self-efficacy and organic foods acceptance link (Ashraf et al., 2021). Applying this food analogy to 3DFP product, the following hypotheses are proposed:

- H10a: Product judgment significantly influences PBC.
H10b: Religious belief significantly influences PBC.
H10c: Perceived risk significantly influences PBC.
H11: PBC positively influences consumer's intention to accept 3DFP.
H12a: PBC mediates product judgment and consumer's intention to accept 3DFP relationship.
H12bc: PBC mediates religious belief and consumer's intention to accept 3DFP relationship.
H12c: PBC mediates perceived risk and consumer's intention to accept 3DFP relationship.

METHODS

3.1 SAMPLING AND DATA COLLECTION

Prospective consumers of 3D-printed food in Selangor, Malaysia, were selected for data collection for several reasons. First, Selangor is Malaysia's largest metropolitan state, with a growing 7.4 million population (Department of statistics Malaysia, 2025). 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 belief as a major variable regarding intention to accept 3D-printed foods, sampling from an area rich in religious and dietary diversity was appropriate. Recruitment criteria and quotas have been established for youth over the age of 18 to

35 years old who were currently working in Selangor. Convenience sampling technique is used for data collection. The locations chosen are coffee shops that sell coffee and pastries where the place youth spend their time. 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. The final sample of participants is composed of 24.4% men, and 75.6% women with a total sample size of 250 respondents.

3.2 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 to measure perceived risk, six items for attitude, four items for social norms, six items for perceived behavioural control and four items for acceptance towards 3D products were adapted from D'Souza et al. (2021). Four questions measuring the religious belief were adapted from Awan (2015). Four items measuring product judgment were adopted from Wilkins et al. (2019). This study used a 7-point Likert scale to measure all items (1; do not agree at all, to 7; completely agree).

3.3 DATA ANALYSIS TECHNIQUE

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

The sociodemographic data of respondents is presented in Table 1.

Table 1. Sociodemographic details.

	N	%		N	%
Gender			Location of living		
Male	61	24.4	Rural Area	62	24.8
Female	189	75.6	Urban City	188	75.2
Total	250	100.0	Total	250	100.0
			Job role		
Age			Government Sector	27	10.8
18 - 20 years	85	34.0	Private Sector	56	22.4
21 - 30 years	143	57.2	Self-employed	21	8.4
31 - 35 years	15	6.0	Housewife	5	2.0
35 years and above	7	2.8	Others	141	56.4
Total	250	100.0	Total	250	100.0
			Education		
Marital status			Secondary School	4	1.6
Single	215	86.0	Pre-University	69	27.6
Married	35	14.0	Tertiary Education	177	70.8
Total	250	100.0	Total	250	100.0
Monthly household income					
Less than RM3,000	198	79.2	Household size		
RM3,001 – RM5,000	30	12.0	≤ 3 people	66	26.4
RM5,001 – RM7,000	4	1.6	4-6 people	139	55.6
RM7,001 – RM9,000	4	1.6	7-9 people	40	16.0
> RM9,000	14	5.6	≥ 10 people	5	2.0
Total	250	100.0	Total	250	100.0

Table 2. Descriptive statistics (n=250).

Variables	Mean	Std. Deviation	Skewness	Std. Error	Kurtosis	Std. Error
Product Judgement	4.24	1.32	-.329	.154	.026	.307
Perceived risk	4.25	1.43	-.163	.154	-.342	.307
Religious belief	5.55	1.36	-.936	.154	.621	.307
Social norms	3.61	1.41	-.176	.154	-.263	.307
Attitudes	4.45	1.19	-.236	.154	.499	.307
Perceived behavioral control	3.36	1.42	.075	.154	-.520	.307

Acceptance toward 3D food	4.02	1.16	.137	.154	.558	.307
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All the constructs examined in this study were reflective; thus, their factor loadings were analyzed. The factor loadings of all constructs ranged from 0.55 to 0.90, indicating a strong association of items within each construct. **Table 3** shows composite reliability ($\rho_a = 0.70$ -0.91; $\rho_c = 0.81$ -0.93). 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 0.52-0.79, 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. Results of measurement model analysis.

	Items	FL	ρ_a	ρ_c	AVE	VIF
Product Judgment	PJ1	0.866	.861	.906	.707	2.117
	PJ2	0.883				
	PJ3	0.804				
	PJ4	0.808				
Perceived Risk	PR1	0.840	0.875	.914	.726	1.615
	PR2	0.873				
	PR3	0.855				
	PR4	0.839				
Religious Belief	RB1	0.813	0.832	.888	.664	1.408
	RB2	0.742				
	RB3	0.878				
	RB4	0.807				
Social Norms	SI2	0.877	0.913	.939	.793	1.585
	SI3	0.884				
	SI4	0.895				
	SI5	0.906				
Perceived Behavioral Control	PBC1	0.699	0.904	.927	.679	1.500
	PBC2	0.868				
	PBC3	0.847				
	PBC4	0.752				
	PBC5	0.902				
	PBC6	0.859				
Attitudes	AT1	0.674	0.900	.924	.670	1.878
	AT2	0.867				
	AT3	0.793				
	AT4	0.858				
	AT5	0.867				
	AT6	0.836				
Acceptance of 3D printed foods	ACC1	0.887	0.708	0.811	.527	-
	ACC2	0.808				
	ACC4	0.600				
	ACC5	0.556				

Heterotrait–monotrait (HTMT) ratio, and the Fornell-Larcker criterion were used to test discriminant validity. **Table 4** shows AVE square roots (0.726–0.890, 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).

Table 4. Discriminant Validity.

	ACC	ATD	PBC	PER	RGB	SCN	PDJ
Fornell Fornell-Larcker criterion & Heterotrait-monotrait ratio (HTMT) – Matrix							
ACC	0.726	0.697	0.534	0.217	0.315	0.614	0.557
ATD	0.628	0.819	0.416	0.336	0.417	0.522	0.675
PBC	0.432	0.384	0.824	0.162	0.158	0.564	0.499
PER	-0.189	-0.300	-0.136	0.852	0.132	0.156	0.353
RGB	0.267	0.375	0.084	0.075	0.815	0.192	0.445
SCN	0.505	0.477	0.517	-0.138	0.139	0.890	0.467
PDJ	0.481	0.601	0.447	-0.304	0.392	0.419	0.841

The structural model was assessed by determining path coefficients (β), p-values, coefficients of determination (R^2). Bootstrapping was used to test the proposed hypotheses. The R^2 values (**Fig. 1**) indicate that consumers' religious belief, product judgment and perceived risk account for a significant 41.6% variance in consumer attitudes, 20.8% (moderate variance) in perceived behavioural control, and 17.5% (moderate variance) in social norms (Cohen, 1998). Attitudes, social norms, and perceived behavioural control together explained a significant 46.6% variance in consumers' intention to accept 3D-printed food.

Table 5. Hypotheses Testing.

Hypotheses	Beta	CI Min	CI Max	t values	p values	Supported?
H1 PDJ $\rightarrow$ ACC	0.072	-0.061	0.203	1.086	0.278	No
H2 RGB $\rightarrow$ ACC	0.023	-0.098	0.142	0.374	0.708	No
H3 PER $\rightarrow$ ACC	0.016	-0.099	0.132	0.266	0.790	No
H4a PDJ $\rightarrow$ ATD	0.464	0.335	0.578	7.917	0.000	Yes
H4b RGB $\rightarrow$ ATD	0.209	0.085	0.337	3.390	0.001	Yes
H4c PER $\rightarrow$ ATD	-0.177	-0.292	-0.077	3.144	0.002	Yes
H5 ATD $\rightarrow$ ACC	0.434	0.313	0.549	7.306	0.000	Yes
H7a PDJ $\rightarrow$ SCN	0.420	0.256	0.573	5.186	0.000	Yes
H7b RGB $\rightarrow$ SCN	-0.016	-0.142	0.123	0.227	0.821	No
H7c PER $\rightarrow$ SCN	-0.013	-0.171	0.129	0.165	0.869	No
H8 SCN $\rightarrow$ ACC	0.200	0.082	0.318	3.280	0.001	Yes
H10a PDJ $\rightarrow$ PBC	0.491	0.310	0.642	6.174	0.000	Yes
H10b RGB $\rightarrow$ PBC	-0.095	-0.217	0.046	1.387	0.166	No
H10c PER $\rightarrow$ PBC	0.011	-0.132	0.155	0.147	0.883	No
H11 PBC $\rightarrow$ ACC	0.129	0.013	0.257	2.001	0.046	Yes
H6a PDJ $\rightarrow$ ATD $\rightarrow$ ACC	0.201	0.129	0.277	5.394	0.001	Yes
H6b RGB $\rightarrow$ ATD $\rightarrow$ ACC	0.091	0.036	0.153	3.058	0.002	Yes
H6c PER $\rightarrow$ ATD $\rightarrow$ ACC	-0.077	-0.138	-0.031	2.674	0.008	Yes
H9a PDJ $\rightarrow$ SCN $\rightarrow$ ACC	0.084	0.030	0.15	2.693	0.007	Yes
H9b RGB $\rightarrow$ SCN $\rightarrow$ ACC	-0.003	-0.036	0.025	0.211	0.833	No
H9c PER $\rightarrow$ SCN $\rightarrow$ ACC	-0.003	-0.035	0.028	0.160	0.873	No
H12a PDJ $\rightarrow$ PBC $\rightarrow$ ACC	0.064	0.006	0.146	1.767	0.078	No
H12b RGB $\rightarrow$ PBC $\rightarrow$ ACC	-0.012	-0.041	0.005	1.032	0.302	No
H12c PER $\rightarrow$ PBC $\rightarrow$ ACC	0.001	-0.022	0.022	0.133	0.894	No

Note: RGB – religious belief; ATD, attitude; SCN – social norms; PBC, perceived behavioral control; PER, perceived risk; PDJ, product judgment; ACC, consumers' intention to accept 3D-printed food.

Data analysis results given in table 4 show several significant relationships. Consumers' attitude, social norms and PBC strongly and positively influence their intention to accept 3DFP ($\beta=0.434$; $\beta=0.000$; $\beta=0.129$, $p<0.05$). However, none of the variables—product judgement, religious belief and perceived risk—directly affected consumers' intention to accept 3DFP ($p>0.05$). Although product judgment itself did not directly affect intention to accept 3DFP, it significantly influenced attitude ($\beta=0.464$, $p<0.01$), PBC ($\beta=0.491<0.01$), and social norms ($\beta=0.420<0.01$), which in turn influenced intention to accept 3DFP. Likewise, religious belief positively and perceived risk negatively affected attitudes ($\beta=0.209<0.01$; $\beta=-0.177$, $p<0.01$) but did not influence social norms, PBC and consumers' intention to accept 3DFP ($p>0.05$). The result of mediation analysis further demonstrate that attitude mediates all the hypothesized relationships between product judgment, perceived risk, religious belief and intention to accept 3DFP. Nevertheless, social norms only mediate between product judgement and intention to accept 3DFP. Other relationships remain insignificant.

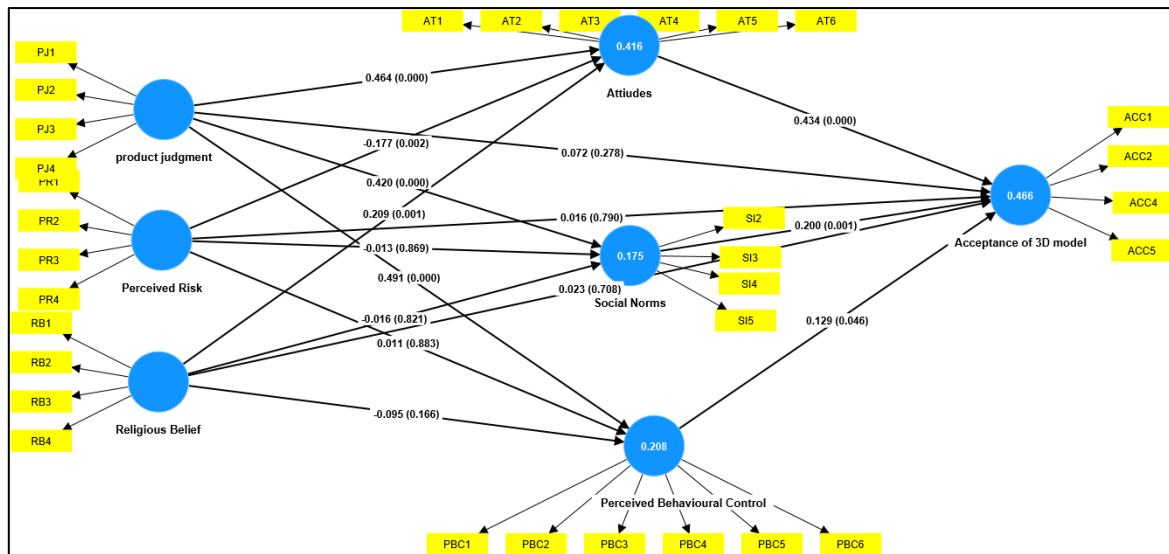


Figure 2. Structural model diagram (direct and mediating effects)

DISCUSSION

This study investigated the factors influencing consumers' acceptance of 3DFP, specifically the direct role of product judgement, perceived risk and religious belief. It also investigated the indirect role of social norms, PBC and attitudes. This study used PLS-SEM technique to analyze and validate the hypothesized research model. The results reveal how product judgement, perceived risk, religious belief alongside TPB core constructs influence Muslim consumers' intention to accept 3DFP. Several relationships were significant. First, some of the TPB core constructs substantially mediate the effect of product judgement, perceived risk and religious belief on the intention to accept 3DFP. In line with the past studies product judgement strongly predicted consumer attitude, social norms, and PBC (Egolf et al., 2019). This explains that when people view the product favorably, they tend to feel more positive about it, believe they can adopt it, and sense supportive social expectations. Finally, all TPB constructs directly influenced intention to accept 3DFP. This outcome in line with (Yang et al., 2024) pinpoints crucial role of TPB constructs in shaping novel food technology acceptance.

Moreover, perceived risk only showed negative influence on attitude (and no effect on PBC, social norms and acceptance of 3DFP). The hypothesis test result depicts that attitudes leading to consumer's intention to accept 3DFP are dampened with high perceived risk. This outcome is supported by previous research findings (D'Souza et al. 2021). This finding demonstrates that when consumers sense the novel food as risky, it limits their behavioural intentions towards that food due to low attitude level even when previously they held favourable attitude towards it or got peer support for its acceptance. The finding suggests that perceived risk has the tendency to reduce consumers' intention to accept mainly via less favorable attitude. Thus, to counter this negative impact, consumer concerns about 3DFP must be addressed in order to build a positive perception.

Religious belief, surprisingly, did not affect consumers' intention to accept 3DFP. However, as proposed, religious belief was positively related to attitudes, suggesting that some religious viewpoints can prompt more favorably towards accepting 3DFP. However, this predisposition is via attitude rather than through PBC or peer pressure. Aligned with the past work this finding suggests that halal certification is imperative and compulsory for Muslim consumers when deciding to opt for new food technologies (Muflih & Juliana, 2020; Puspita et al., 2020). Thus, broad normative cues about 3DFP may be of lesser importance than halal compliance.

In this study social norms were proven as a significant predictor of Muslim consumers' intention to accept 3DFP. This highlights that the pull of peer and societal influence in technology adoption. Product judgement also influenced consumer acceptance indirectly through social norms. Consistent with the study of (e.g., Ross, 2022) in Irish context, this suggests that marketing cues and messages should be in line with community values/standards. Also, they should assist in creating a desirable image and acceptance of 3DFP. Moreover, social norms were a weaker pathway to achieve consumer acceptance than attitude. At the time of this study, 3DFP had not yet reached the Malaysian consumer market. However, positive link between product judgement and PBC suggests that the concept of 3DFP should be marketed in a way so that it feels familiar to and fits with Muslim eating practices (Wilkins et al., 2019).

Attitude, meanwhile, strongly influenced consumers' acceptance, evidencing that positive evaluations of 3DFP could significantly drive intentions towards it (Ajzen, 1991). Mediation of attitude between product judgement and acceptance further shows how good perceptions of product quality facilitate its willingness to accept. Hence, clearly communicating the attributes and benefits of 3DFP could build positive attitudes ultimately encouraging its acceptance.

5.1 THEORITICAL CONTRIBUTIONS

From a theoretical perspective, this study extends the TPB framework. First, it points out whether product

judgement, perceived risk, and religious belief can predict TPB constructs and resultant Muslim consumers' intention to accept 3DFP. Next, this study reaffirms the direct role and indirect role of attitude to predict consumers' intention towards 3DFP. Findings emphasize that attitude can be a central mediator linking product- and religion-related factors to behavioural intention. This suggests that both cognitive and affective evaluations drive consumer decisions. Secondly, this study proves that perceived risk is important to mitigate because it lowers attitude, which further hinders and creates barriers for technology-acceptance.

Third, including religious belief as an antecedent of TPB constructs is a substantial contribution to the framework bringing new ethical and cultural dimension to the TPB. The findings of this variable indicate that consumers' values and cultural norms can affect how they perceive novel and emerging technologies. This can help reinforce the need to adapt novel food acceptance frameworks to different socio-cultural contexts and markets.

5.2 RETAIL IMPLICATIONS

The findings offer practical guidance for retailers and marketers who wish to introduce 3DFP. First, retailers can strategize shaping positive attitudes by emphasizing benefits of 3DFP—customization, novelty, and convenience. Further retailers should market 3DFP concept in a way to assure that the ingredient choice of 3D-printed foods is under the consumer's control. This will ensure consumer confidence in the production process. Moreover, high-quality products with positive first impressions could bring more benefit.

Retailers can leverage social proof through testimonials, influencer endorsements, and community engagement to foster a sense of approval and acceptance among potential customers. Furthermore, mitigating perceived risks through clear communication about product safety and quality can enhance consumer confidence. Retailers targeting niche markets may need to address ethical or cultural considerations in their messaging. Overall, retailers aiming to introduce 3D-printed food should adopt a holistic strategy that addresses consumer attitudes, social influences, and PBC to drive acceptance.

5.3 LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

This study gives valuable insights about the factors shaping up consumer acceptance of 3DFP. However, other factors—environmental concerns, ethical and cultural values, environmental awareness, sensory expectations—could be further explored for deeper understanding. This study specifically focuses on Muslim community in Malaysia, future comparative studies with secular societies could further address how consumer acceptance of 3DFP differs worldwide.

This study employed young, educated, and urban respondents for data collection, future research can explore diverse sociodemographic groups. This study utilizes a cross-sectional survey design; future research could employ longitudinal or diary designs. Moreover, exploring qualitative data collection methods could also provide useful insights into this topic.

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