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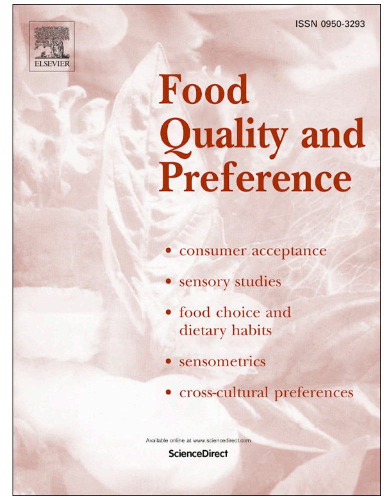

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Overcoming barriers to consumer acceptance of 3D-printed foods in the food service sector

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Abstract

The purpose of this study is to investigate the potential uptake and inhibitors of 3D-printed food applications in the food service market to provide market salient evidence to inform business investments. An online survey was designed and distributed to an adult Irish population and was completed by 1,045 participants. The collected data was analysed using Structural Equation Modelling to test a hypothesised model of willingness to try 3D-printed food applications. Results showed that perceived personal relevance of the technology is a strong positive determinant of willingness to try (Standardised β = 0.614***). Novel Food Technology Neophobia (NFTN) represents a barrier to willingness to try 3D-printed food applications as evident from its significant negative direct effect (Standardised β = -0.167***). NFTN is also found to have a depressing indirect effect when mediated through perceived personal relevance (Standardised β = -0.202***), while the importance consumers attach to naturalness is yet another barrier (Standardised β = 0.053*). Overall, considering its total effect, NFTN (Standardised β = -0.369***) presents the greatest barrier to willingness to try 3D printed foods.

The role of trust in science by directly diminishing the effects of NFTN (Standardised β = -0.445***) and the importance of naturalness also emerges (Standardised –β = 0.137***). Consequently, this work has identified some of the major obstacles facing the technology in the forms of NFTN and the importance of naturalness but has pointed to possible resolutions in building continued support and trust in science, and a focus on designing and delivering both customisable consumer-focused food products and accompanying marketing strategies that communicate and emphasise the personal benefits that this novel food technology affords.

Keywords: 3D printing, Food service sector, Trust in science, Novel Food Technology Neophobia, Perceived personal relevance, Consumer acceptance

1. Introduction

The purpose of this paper is to investigate the potential for 3D printing technology in Ireland and the potential constraints and inhibitors to market acceptance and uptake of the technology. To address this question, the paper seeks to reveal the factors that either promote or inhibit consumers' acceptance of the technology in the foodservice market. Foodservice, or out-of-home dining, may be defined as "all food consumed and prepared out of home" (Bord Bia, 2019). The decision to focus on this market is due to the fact that it is a substantial market and has a high penetration and exposure rates among consumers given its spatial distribution and its attractiveness given today's consumer lifestyles. In 2019, pre-Covid 19, the market was worth in the region of €6.33B in terms of consumer expenditure. The foodservice sector in the Republic of Ireland is highly competitive with over 27,000 outlets distributed across a variety of business types, but faces considerable cost pressures due to a shortage of skilled staff and high labour content (Bord Bia, 2019). Given the conflicting force of the need to differentiate yet facing high operational costs, 3D printing offers enormous potential to operators within the sector. More importantly, given consumers' wide exposure to the foodservice sector, it provides an entrée for this novel technology and an opportunity for consumers to experience it for the first time, building a sense of familiarity with 3D printing and opening up further opportunities in the consumer market, the holy grail for commercialisation.

Benefits of 3D printing in the food environment present exciting possibilities in terms of customization to meet specific dietary requirements, managing food waste (Fuller, 2021) or, more generally, to appeal to consumers' desire for new hedonic and self-expressive benefits through the physical construction and presentation of food itself (Burke *et al*., 2021). However, lack of familiarity with a novel food/ technology is often cited as a barrier to acceptance (Jung *et al*., 2022; Schäufele *et al*., 2019). This has led to the recommendation, in the case of novel foods, to establish them in the context of the familiar (Lombardi *et al*., 2019; Siegrist, *et al*., 2008a). Consequently, our interest is to identify the determinants of consumers' willingness to try 3D printing applications situated within a familiar context, such as the food service market, where the person is aware of the technology being applied to create the food, but is not required to learn how to use it (Bos *et al*., 2018). Placing the technology in a familiar context enables the consumer to visualize the technology in their everyday lives in ways that offer benefits to them, such as, convenience, health and enjoyment. Additionally, understanding the determinants of willingness to try the 3D food printing applications set in this context provides a critical insight into responses to foods derived from this technology in more transparent supply chains (i.e., where the consumer knows that it is a 3D-printed food or contains a 3D-printed food component). Exposure to the technology through food service applications can also support broader uptake of application. This perspective aligns to the position that exposure is the main building block of familiarity, so it is reasonable to argue that food service has a potential role in driving consumer acceptance of the technology.

Consumer acceptance of new food technologies can be challenging due to its newness and unfamiliarity to end users. These concerns are likely to also exist with novel 3D food printing applications. 3D food printing is considered to be a relatively young and developing technology, having been in existence since the early 2000s, with the development of the first open-source 3D food printer called 'Fab@Home' (Malone and Lipson, 2007). Since then, the number of studies exploring the characteristics of 3D printed foods has climbed steadily, where foods such as fruit and vegetables (Dersossi *et al*., 2018; Severini *et al*., 2018), pasta (Van der Linden, 2015), cheese (Le Tohic *et al*., 2018), meat (Dick *et al*., 2019), bread dough (Liu *et al*., 2019; Yang *et al*., 2018), chocolate (Hao *et al*., 2010; Mantihal *et al*., 2018), and more novel products such as insect-based cereals (Severini *et al*., 2018) have been investigated.

3D food printing may be described as the layering of food material using a computerised process (Huang *et al*., 2013). Using this method, a multitude of intricate and complex 3D objects can be printed, limited only by the physical properties of the food material (i.e., sufficient structural integrity for layering) and stability of the design (i.e., one with a stable equilibrium or low centre of gravity is better suited) (Liu *et al*., 2017). 3D food printing is thought to be a beneficial concept in helping to improve an individual's health status in terms of personalised nutrition. Using 3D printing technology, a user can potentially 3D-print a meal or snack tailored to their specific health needs, as opposed to a generalised portion which is mass manufactured to suit the average person (Caulier *et al*., 2020; Pérez *et al*., 2019; Sun *et al*., 2015).

Although there are many publications discussing the fundamental science behind 3D food printing technologies and printability of potential food materials (Le-Bail *et al*., 2020; Liu *et al*., 2021; Zhu *et al*., 2019), there are few available on consumer attitude and acceptance of the technology. This is an important knowledge gap and increases the risks of investment in this novel technology. Siegrist (2008) reported the vital importance of involving the consumer at the initial stages of product development in order to increase chances of success in the marketplace, as a multitude of factors, beyond stated benefits, can impact on consumer acceptance of novel food technologies and products which cannot be overlooked at the research and developmental phase.

Based on the few studies currently available on consumer acceptance of 3D food printing, the terminology used in association with the technology (e.g., "printer"), the degree of safety and palatability of the food produced by the printer, and the potentially impaired nutritional value of the food were some of the primary consumer concerns that negatively impacted acceptance (Brunner *et al*., 2018; Lupton and Turner, 2016). A common consensus across studies currently available involving consumer perceptions of 3D food printing shows that many participants were previously unaware of the technology and initially did not recognise any true value in using the technology for themselves (Brunner *et al*., 2018; Lupton and Turner, 2016). As argued by Caulier *et al*. (2020), an awareness of the perceived benefits of the technology did not have a significant effect on the consumer's acceptance or perception of 3D-printed foods; however, it was observed that repeated consumption (over a period of four weeks) was found to be much more compelling in positively impacting participant liking of the 3D-printed food product. Similar to other forms of innovations in food and food processing, factors such as neophobia (both of novel foods and novel food technologies) and degree of trust (in food regulatory bodies, scientists, government etc.) can also pose challenges to consumer acceptance and must be overcome in order to encourage consumers to be willing to purchase and/or try a product produced by novel food technologies in the first place (Lim *et al*., 2021; Losada-Lopez *et al*., 2021; Wezemael *et al*., 2010).

In keeping with the knowledge deficit perspective, much discussion has focused on whether or not the provision of risk benefit information to consumers can alleviate their concerns about novel food technologies and combat neophobic tendencies (Bruhn, 2007; Hansen *et al*., 2003; Rollin *et al.*, 2011). This 'knowledge deficit' perspective has received some criticism as it represents a relatively flawed and simplistic approach to explaining the rational for risk aversion in consumers when faced with food produced using novel food technologies (Runge *et al*., 2018). Rollin *et al*. (2011) argued that understanding and addressing consumer evaluations of, and responses to, novel technologies is a much more complex and multifaceted issue, involving an understanding of consumers' risk-benefit analysis, socio-demographic characteristics, established public knowledge and information, including the level in trust in the source of information). As Hansen *et al*. (2003) stated "[…] where trust is lacking, merely 'stating the facts' is not a viable strategy in risk communication, no matter how sound the underlying science is".

The present study aims to address the current paucity of research into the determinants of 3-D printed foods acceptance. It will achieve this by identifying the predominant factors determining the willingness of Irish consumers to try 3D-printed foods in the food service context. The research is based on an online representative sample of 1,045 Irish consumers. It is anticipated that the research findings will help inform global ingredient suppliers, manufacturers, and food service operators when designing, developing and implementing the use of 3D food printing technology in such a way that 3D food printers become an enduring and practical technology rather than a fleeting novelty. As 3D food printing has been shown to be beneficial in valorising food waste streams (Jagadiswaran *et al*., 2021) and providing personalised nutrition to enhance the health of individuals (Caulier *et al*., 2020; Sun *et al*., 2018), it is of current relevance to promote sustainable food technologies to global consumers and those operating in the food industry in order to address these immediate challenges. Whether that is by utilising the full potential of food products to avoid unnecessary food waste, or producing tailor-made snacks and meals to satisfy each consumers' unique nutritional needs instead of a mass manufacture of a generic product which only satisfies a portion of the population.

The structure of the paper is as follows. The next section will develop a series of hypotheses to explain the relationships between constructs implicated in the willingness to try variable based on findings in earlier studies. Considered together, these hypotheses form our overall model of willingness to try (Fig. 1) and will help reveal the mediating relationships that need to be understood in explaining the willingness to try 3D food printing applications. Following the hypotheses, we will progress to the methods applied and particular attention will be paid to our measurement model establishing convergent and discriminant validity use pre-validated items. Then, we test our model, before discussing the findings and implications for practitioners.

2. Hypotheses

Based on the literature available on the factors effecting general consumer acceptance of novel food technologies, the following section identifies the key factors which would be expected to influence consumer acceptance of 3D-printed food applications. A selection of these factors have also been accounted for in the few studies involving consumer acceptance of 3D-printed foods, where novel food technology neophobia (NFTN), perceived relevance/benefit, and attitudes towards naturalness have been shown to be significant factors in determining consumer acceptance (Brunner *et al*., 2018; Hassel, 2018; Lupton and Turner, 2016). The current work will establish a more complete model of the intention to use 3D printed technology through the development of a set of hypotheses that will reveal both the direct and indirect (mediated) effects between our independent and dependent variables.

2.1.1. Consumers' perceived personal relevance of novel food technologies

Perceived relevance is defined as the extent of which a person thinks something will contribute positively to their life (Celsi *et al*., 1992; Davis *et al.,* 1989). According to Greehy *et al*. (2013), individuals evaluate and prioritise products produced by novel food technologies according to their personal orientations and values, and perceived relevance of benefits offered by that product. As each individual has a unique life path and set of circumstances, personal values and benefits associated with technologies relevant to them personally can vary immensely (Henchion *et al*., 2013).

Other studies have shown that, when an individual perceives a product to be of high personal relevance to them, they are more likely to form a positive attitude towards that product and are more likely to purchase (Dean *et al*., 2012; Kang *et al*., 2013). For example, individuals who are eco-conscious might perceive environmentally sustainable textiles as highly relevant to their own life and will therefore, feel a stronger desire to purchase in order to actively reinforce their interpretation of their projected self-image (Kang *et al*., 2013). In essence, individuals might be more willing to purchase items which they perceive as a way of enabling them to live the type of life for which they strive.

Therefore, it is proposed that:

H1: *There is a direct and positive relationship between the perceived personal relevance of the novel technology and consumers' willingness to try 3D-printed foods applications.*

2.1.2. Novel food technology neophobic behaviours affect willingness to try 3D food printing technologies

Novel innovative technologies are often rejected by consumers as the technology enters the marketplace due to negative and suspicious feelings (Chen *et al*., 2013; Wezemael *et al*., 2011). This can be due to a phenomenon known as 'Novel Food Technology Neophobia' (NFTN), which is a multidimensional concept comprised of perceived needs, choices, risks and media, as embedded in the scale developed by Cox and Evans (2008) to measure consumer acceptance of foods produced using novel technologies.

NFTN varies across different contexts. For example, Siegrist *et al*. (2008b) reported that consumer acceptance can fluctuate based on the technological application, where consumers were seen to be more accepting of nanotechnology being used in food packaging rather than in the food itself. Vidigal *et al*. (2015) also observed a difference in levels of consumer neophobia of different manufacturing processes of foods where Brazilian consumers were more accepting of processes which were seen as familiar and safe (e.g., traditional processing, pasteurisation); on the other hand, consumers were less accepting of these same products if they were produced using non-traditional and novel processes such as nanotechnology and Genetic Modification (GM), due to an increased level of perceived risk and negative perception of these technologies.

In the few studies of consumer attitudes towards 3D-printed foods studies available to date, it has been found that foods produced by 3D food printers are looked upon with suspicion by consumers, where fears generally derive from the uncertainty of the manufacture and nutritional quality of the printed foods (Brunner *et al*., 2018; Lupton and Turner, 2016). Hartmann and Siegrist (2017) suggested that consumers may regard foods which are 3D-printed as riskier to consume when compared to foods produced using gene technology, as the food as well as the technology can be seen as novel, meaning there is additional uncertainty and unease to comprehend. Similarly, in a quantitative study carried out by Brunner *et al*. (2018), it was observed that, despite the provision of targeted communication to their participants (n = 260) relating to the application of the technology, food technology neophobia persisted and even increased in some cases.

Therefore, it is proposed that:

H2: *There is a direct and negative relationship between novel food technology neophobia and the consumer's willingness to try 3D-printed food applications.*

2.1.3. Consumer relationship with naturalness

In recent years, consumer demand for foods which are perceived as natural has been increasing (Staub *et al.,* 2020). However, the term naturalness is not well-defined and tends to vary depending on context and type of product (Schiano *et al*., 2021). Some have suggested that the degree of processing which food products are subjected to can be considered a measurement of naturalness, where foods which most resemble their native form are more natural than those which have been processed (Rozin, 2006). Whereas, others have proposed that physical changes (i.e., cutting, mashing etc.) are more natural than chemical changes (i.e., GM, additives) (Evans *et al*., 2010). According to Román *et al.* (2017), when food products are labelled as being natural, they are perceived to be better tasting, more nutritious and less harmful to the environment. In response to this, those involved in the manufacture and marketing of food have come to realise the considerable value which consumers place on perceived naturalness and have therefore made an increased effort to accentuate this particular aspect of their product over other characteristics on packaging labels and in marketing campaigns, further fuelling the narrative that natural is superior (Siegrist and Hartmann, 2020a).

Studies involving consumer perception of 3D-printed foods have reported that there is a general sense of apprehension surrounding the levels of processing 3D printing would add to already processed (i.e., cooked, chopped, blended etc.) food purées (Brunner *et al*., 2018; Lupton and Turner, 2016). There is a general consensus that the consumers' perceived level of processing subjected to foods is inversely proportional to that of perceived naturalness (Etale and Siegrist, 2021; Evans *et al*., 2010; Rozin, 2005; Rozin *et al*., 2012). This sentiment was also evident in works by Rozin (2005) and Rozin *et al*. (2012), where consumers were of the belief that where a food product had more steps involved in its manufacturing process, it was less 'natural'. Therefore, despite the possibility of 3D printing ingredients which should be perceived as natural, such as fruits and vegetables (Dersossi *et al.,* 2018), consumers for whom naturalness is important may perceive 3D-printed foods as ultra-processed and unnatural due to the number of processing steps (e.g., blending of mixtures and sometimes addition of additives such as texturisers to create suitable textures for printing).

Therefore, it is proposed that:

H3: *There is a direct and negative relationship between the importance of naturalness and consumers' willingness to try 3D-printed food applications.*

2.1.4. Consumer innovativeness and adoption behaviour

Consumer innovativeness has been described by Steenkamp *et al*. (1999) as a consumer's predisposition towards the purchase of new or different products or brands, in favour of repeat purchasing of common or familiar products purchased previously. There is evidence (Rogers, 2010) that the degree of consumer acceptance of 'newness' can be a predictor of the probability of consumers adopting novel technologies, and the level of consumer innovativeness has been shown to have a direct and positive effect on innovation adoption behaviour (Arts *et al*., 2011; Wang *et al*., 2008). Clearly, 3D food printing can be described as a novel, innovative and disruptive food technology (Berman, 2012; Kietzmann *et al*., 2015), which can be attractive to innovators and early adopters who want to be the first in their social group to explore the newest creative culinary technology. Therefore, it is proposed that:

H4: *There is a direct and positive relationship between consumer innovativeness and consumer willingness to try 3D-printed food applications.*

2.1.5. Consumers' level of trust in science impacts their willingness to try

Consumer trust in the industry, media, scientists and the government has been shown to play a decisive role in opinion and attitude formation towards acceptance of novel food technologies (Cvetkovich and Lofstedt, 1999; Søndergaard *et al*., 2005). It has been recognised by Roosen *et al*. (2015) that consumers with a high degree of trust generally exhibit lesser efforts of self-protection behaviour (i.e., are less risk-adverse) and are more willing to pay for novel foods than those with a lower degree of trust. Moreover, Bord and O'Conner (1990) observed that consumers who show trust in the food industry, government regulatory agencies or science have been more accepting and receptive of foods manufactured by novel food technologies.

Therefore, it is proposed that:

H5: *There is a direct and positive relationship between consumers' level of trust in science and their willingness to try 3D-printed food applications.*

2.1.6. Relationship between trust in science and the importance of naturalness to consumers

According to Siegrist and Hartmann (2020a), consumers often use a combination of cues and heuristics, such as perceived naturalness and or trust, to evaluate and form judgements of novel foods and foods produced using novel methods. Science has brought many advances beyond nature in terms of processes which have enabled the variety and availability of safe foods that characterise contemporary society (Chávez-Dulanto *et al*., 2021). In doing so, trust in science has acted as a substitute for naturalness when making food-related decisions. However, a recent rise in consumers' perception of the importance of naturalness can be seen to coincide with a reduced level of trust in science, which has been amplified by high profile cases of food related dilemmas such as GM foods (Maghari and Ardekani, 2011) and E-numbers (Haen, 2013), and may have led to consumers preferring to form their opinions and judgements based on naturalness, rather than trust.

The emergence of more recent science-led modern food technologies, such as *in-vitro* meat production, can be seen as "extending human control" over what is considered natural and resonate in a negative light for consumers (Rozin, 2005). Despite many of the companies involved in *in-vitro* meat or GM foods production stating these technologies to be more environmentally friendly and to support sustainable food supplies (Aleph Farms, 2021; Phillips, 2008), consumers who have a 'natural preference' may view these technologies as destructive to what is natural and, therefore, dismiss those involved in the food chain, such as scientists, who may be associated with unnatural or ultra-processed food manufacture (Rozin *et al*., 2004). In addition to this, such as in the case of food irradiation or GM foods, consumers may perceive new food technologies to have unknown consequences which cannot be understood or prevented without long-term testing and observation (Frewer *et al*., 2011). To counteract this fear of human intervention, consumers have developed more of an affinity towards natural food products which are perceived to be lower risk (Frewer *et al*., 2011; Rozin *et al*., 2004). For example, Siegrist and Sütterlin (2017) reported that, despite being informed of a greater risk of developing colon cancer with the consumption of traditional meat, consumers will often choose traditional meat products over cultured meat (i.e., *in-vitro* meat) products due to issues of trust in the information given.

Conversely, Bearth *et al*. (2014) suggested that, when trust in food regulators and risk communicators are high, consumers don't equate natural with being unequivocally safe. In the same study, it was observed that consumers who perceived more benefits in the use of artificial additives in foods were reported as being more trusting in regulators and had less preference for natural additives. Due to a higher level of trust in food regulators, consumers are able to remove or lessen the doubt that there are sufficient processes in place to ensure the safety of their food, thereby reducing the reliance on the natural heuristic (Bearth *et al*., 2014).

Therefore, with these factors in mind, it is proposed:

H6: *There is a direct and negative relationship between the level of trust in science and the perceived importance of naturalness.*

Given H3, this leads to the proposition;

H7: *There is an indirect and negative relationship between trust in science and consumer willingness to try 3D-printed food applications, mediated through the importance of naturalness.*

2.1.7. Trust versus mistrust: Impact of technology neophobia on willingness to try

Cox and Evans (2008), conceptualise NFTN as comprised of risk, lack of benefit and quality or health concerns. Trust is often a substitute for knowledge in the process and safety of food manufacturing (Siegrist and Cvetkovich, 2000) and, therefore, the degree of trust in scientists and other actors within the food chain to do their job to the highest standard is an important factor influencing the level of perceived risk and quality concerns (Siegrist, 2000) and, as a consequence, their level of NFTN. Studies have established that scepticism in formal institutions involving the food industry are linked to higher incidences of novel food technology neophobia (Dolgopolova *et al*., 2015, Huang *et al*., 2019, Siegrist *et al*., 2008a). This is also supported by findings that people who exhibited higher trust in institutions also tended to associate new technologies with increased benefits and less risks (Siegrist *et al.,* 2008b). Furthermore, without the combination of perceived benefit and trust in the actors behind the manufacture of that food product, consumers are less likely to be willing to purchase (Frewer *et al*., 2003).

Based on the argument above, the following hypotheses are proposed:

H8: *There is a direct and negative relationship between the level of trust in science and consumers' level of novel food technology neophobia.*

Drawing upon H2 it is proposed:

H9: *There is an indirect and positive relationship between trust in science and consumer willingness to try 3D-printed food applications, mediated through novel food technology neophobia.*

2.1.8. Barriers to willingness to try: Novel Food Technology Neophobia and perceived personal relevance

Certain studies have shown that the purchase of novel food products by consumers can be perceived as a way of building social status (Barrena and Sánchez, 2013; Perrea *et al*., 2017; Rogers, 2010), which is a key element of the consumer value model (Papista and Krystallis, 2012) and perceived benefit that enhances perceived personal relevance. Thus, while novelty has been linked directly to personal relevance, it is to be expected that higher levels of NFTN based on perceptions of risks or the view that the technology is unnecessary or perhaps raises quality concerns (Cox and Evans, 2008) would be anticipated to have a negative relationship on perceived personal relevance. NFTN can lead to dissonance or incongruence in terms of association with the consumer's lifestyle and what they perceive as useful or relevant (Giordano *et al*., 2018).

Others involved in similar areas of study have also suggested that, where consumers believe there to be a lack of necessity for new food technologies, they also perceive novel food technologies as high risk with low/no clear benefit and are less likely to be willing to try the product in the first place (Napier *et al*., 2004). Therefore, we argue that, without personal relevance, consumers will not be willing to try 3D-printed food applications.

With these points in mind, the authors would propose the following hypotheses:

H10: *There is a direct and negative relationship between novel food technology neophobia and the consumer's level of perceived personal relevance of 3D food printing applications.*

H11: *There is an indirect and negative relationship between novel food technology neophobia and consumers' willingness to try 3D-printed food applications mediated through perceived personal relevance.*

3. Methods

3.1. Data collection and sample

In total, 1045 individuals who identify as Irish and are long-term residents in the Republic of Ireland were recruited to participate in completing the online survey during November/December 2020. The survey was delivered online via the Qualtrics platform (QualtricsXM, Dublin, Ireland) to their consumer panel. Quality control protocols were in place to ensure the integrity of the data (e.g., avoidance of over-surveying participants and professional survey takers). Participants who are currently working/studying or have had previous experience in the fields of food production, home appliances, production or consumer or market research were omitted from the recruitment process in order to exclusively gather data from the average lay citizen. The age bracket of the sample cohort recruited ranged from 24 to 65 years of age; 49.8 % of the total sample were male (n = 520) and 50.25 % were female (n = 525). The overall sample was representative of adults in Ireland with respect to age and gender distribution when compared to Census 2016 (Central Statistics Office, Ireland, 2016). Details of the recruited sample characteristics can be found in Table 1. Ethical approval was sought and granted in October 2020 by the Social Research Ethics Committee at University College Cork.

3.2. Measurement Model

To test the series of hypotheses established above, measures for the focal constructs were identified and selected by drawing on pre-existing and validated scales and items. Novel Food Technology Neophobia (NFTN) drew upon the work of Cox and Evans (2008), the importance of naturalness drew on multiple sources (Hansen *et al*., 2018; Squires *et al*., 2001, Tobler *et al*., 2001). Trust in science drew on the work of Bak *et al*. (2001), indicators for perceived personal relevance were sourced from Kang *et al*. (2013), while measures of consumer innovativeness were drawn from Goldsmith and Flynn (1992).

While the original NFTN scale (Cox and Evans, 2008) was originally constructed with four dimensions, one item was employed for information and media. As a single item cannot be tested for reliability or validity this dimension of NFTN was dropped from our conceptualisation. Tables 2 and S1 (in the appendix), presents the specific indicators (items) used to measure each latent construct.

All latent variables in the model were conceptualised and measured as reflective variables. All independent variables were measured using a 1-7 point (strongly disagree- strongly agree) Likert scale. The dependent variable, willingness to try 3D-printed food applications (adapted from Bäcktröm *et al.* (2004)), was measured using a 1-7 point (extremely unlikely to use – extremely likely to use) Likert scale.

A maximum likelihood confirmatory factor analysis was carried out to test the measurement model using AMOS 25. As proposed by Podsakoff *et al*. (2003), a common methods latent factor was introduced to ensure that our measures were free of common methods bias.

Consumer innovativeness drew on items used by Goldsmith and Flynn (1992). Initially, it contained six items; however, all but two items were deleted due to low factor loadings. Regarding Novel Food Technology Neophobia (NFTN), the model draws upon the conceptualisation of Cox and Evans (2008). The original NFTN scale identified 13 items which loaded into four factors, one as single item factor which we dropped as outlined earlier. During the initial stage of data analysis, NFTN was identified as a second order construct with three underlying sub-dimensions, risk, lack of benefits and quality concerns (Cox and Evans, 2008) (see Appendix 1). This configuration was integrated into our measurement model.

The CFA for our measurement model yielded the following results; Chi-square (χ^2) = 678.5, df =256, p = .000, (χ^2)/df = 2.651, goodness of fit index (GFI) = 0.949, adjusted goodness of fit index (AGFI) = 0.936 comparative fit index (CFI) = 0.967, the Tucker-Lewis index (TLI) = 0.961, and the root mean square error of approximation (RMSEA) = 0.040, demonstrating good fit (Byrne, 2001). Individual items, standardised loadings, P-values and reliability values are provided in Table 2. Reliability is demonstrated through the use of both Cronbach's alpha scores and composite reliability (Table 2) with all constructs meeting the desired 0.70 threshold (Nunally, 1981).

All standardised factor loadings demonstrate statistical significance ($P < .01$) on their corresponding construct. With the exception of Trust in Science (AVE=0.47), the average variance extracted (AVE) for each construct (Table 3) meets the 0.50 threshold (Hair *et al*., 1995). To justify the retention our measure of trust in science we draw on the works of Acquila-Natale and Iglesias-Pradas (2020) and Huang *et al*. (2013) who argue that AVE values higher than 0.4 are acceptable if composite reliability (Trust in Science CR= 0.72) is higher than 0.6 (Fornell and Larcker, 1981). Furthermore, Cheung and Wang (2017) suggested that the case for convergent validity is stronger when the standardized factor loadings of all items are not significantly less than 0.5. Thus convergent validity is supported for all our latent constructs.

Discriminant validity is supported by the fact that the average variance extracted exceeds the squared correlation coefficient for each pair of latent factors (Table 3; Fornell & Larcker, 1981). Consequently, the measures of the constructs used in the model achieve satisfactory reliability, convergent and discriminant validity while accounting for common methods bias.

4. The Structural Model and Results

4.1. The structural Model

The structural model, including three covariates, age, gender and education, was tested and yielded the following fit results; Chi-square ($\chi 2$) = 1061.658, df =320, p = 0.000, ($\chi 2$)/df = 3.318, goodness of fit index (GFI) = 0.933, adjusted goodness of fit index (AGFI) = 0.915, the comparative fit index (CFI) = 0.943, the Tucker-Lewis index (TLI) = 0.933, and finally the Root Mean Square Error of approximation (RMSEA) = 0.047. All met accepted thresholds (Byrne, 2001), enabling us to proceed to test our hypotheses and interpret our results.

A descriptive account of the data is presented in Table 4. Consistent with the findings of others (Eurobarometer, 2005; Fell *et al*., 2009), it was observed that males were more likely to use novel food technologies (e.g., 3D food printing applications) than females, though it must be noted the overall scores for both genders were relatively low. In the age category, a negative relationship was seen where willingness to try declined as the age of consumers increased. In the employment category, students were more likely to be interested in trying 3D food printing applications than those who were retired or fully/partially employed. A Eurobarometer report (2005) also found that students and other young people were generally more likely to have positive perceptions of novel technologies, such as biotechnologies.

4.2. Results

The model explains 57.0% of the variation in our dependent variable, willingness to try 3D-printed food products in out-of-home situations. Tables 5 and 6 present substantial support for our hypotheses, with the exception of H4 and H5. The standardized estimates for our direct effects are provided in Table 5. The first feature to note is that perceived personal relevance is the dominant factor that influences the willingness to try 3D-printed food applications in a foodservice context. Its standardized coefficient is substantial and significant (H1 $\beta = 0.614$***) and considerably larger than the direct effect of NFTN ($\beta = -0.167$***) (Table 5). However, NFTN also has a significant negative effect on perceived personal relevance (H10 $\beta = -0.329$***). Thus, NFTN had both direct and indirect effects on willingness to try. To estimate this indirect effect, we followed the approach of Preacher and Hayes (2004) and Zhao *et al*. (2010) and applied bootstrapped tests (5000 samples). This approach revealed that the indirect effect of NFTN, mediated through perceived personal relevance, is negative and significant ($\beta = -0.202$***) (Table 7) while the total effect of NFTN on willingness to try is also found to be substantial ($\beta = -0.369$***).

On analysing the relationship between trust in science and willingness to try 3D-printed food applications, we find the direct effect to be insignificant (H5 $\beta = -0.054$ ns). AMOS 25 provides unstandardized (standardized unavailable) estimates for specified indirect paths where there is more than one mediator. Consequently, we were able to test the proposed indirect effect between trust in science and willingness to try, mediated through NFTN. Table 6 presents the unstandardized estimates of this indirect path and reveals an indirect and mediated effect between trust in science, *via* NFTN, to willingness to try that was positive and significant (H9 $\beta = 0.137$***). Consequently, trust in science, by reducing NFTN, increased willingness to try 3D-printed food applications.

Trust in science also has a direct and negative effect on the importance of naturalness (H6 $\beta = -0.137$***), while the importance of naturalness reduced willingness to try 3D-printed foods (H3 $\beta = -0.053$*) (Table 5). Returning to Table 6, the unstandardized estimates reveal the mediating effect of naturalness, where we find that the path was positive, but only significant at the 90% confidence level (H7 $\beta = 0.014$*).

Considering the direct and both mediated effects of trust in science and willingness to try 3D-printed food applications, we can see (Table 7) the standardized total effect ($\beta = 0.226$***) is positive and significant. Trust in science matters when it comes to the future demand for 3D-printed foods. However, there is no evidence to support a direct effect; instead, the effect of trust in science was operant through its effects on NFTN and the importance of naturalness.

The analysis proceeded to examine the relationship between our co-variates, age, gender and education, on willingness to try using the standardized total effect to factor in both direct and indirect effects operant through our other variables. The results shown in Table 8 indicate that both age and gender impact willingness to try. Older consumers are less willing try 3D food printing applications than younger consumers. Gender was also found to be related with males displaying a greater willingness to try 3D food printing applications than females.

5. Discussion and Conclusion

While many technologies involved the preparation and provision of food in the foodservice market have been silent and unobserved by the consumer, the use of 3D-printed food applications will reveal significant changes in the ways in which our foods are processed. Thus, the need to address our key findings on the impact of NFTN need to be considered. The evidence shows the direct negative effect of NFTN on willingness to use. In many respects this is what can be expected. However, by separating out indirect effects, the current analysis clearly shows the way NFTN undermines an individual's perception of relevance of the 3D food printing technology to them personally.

Marketing strategists need to be aware of this indirect effect in their endeavours to reach their target audiences by highlighting the personalisation factor of 3D food printing in order to promote the relevance of the technology. Introducing 3D food printing applications into the ubiquitous food service sector allows consumers the freedom and autonomy to try 3D-printed foods with relatively low risk (versus purchasing the technology for home use) which may help to negate initial neophobic inclinations towards 3D-printed foods. Others have also shown that contexts where consumers are perceived to be in control of their exposure to hazards are more accepted than those where exposure is not voluntary (Siegrist *et al*., 2018).

Although 3D food printing technologies are still relatively unknown among consumers (Brunner *et al*., 2018), it is very important to gain a deeper understanding of the thought processes and behaviours contributing to potential barriers to acceptance before attempting to extend the use of the technology into the mainstream marketplace. Findings from this study point to multiple, and sometimes interconnected, influences on consumer intention to use. In line with existing literature (e.g. Greehy *et al*., 2013, Kang *et al*., 2013) perceived relevance was identified as a significant determinant of willingness to try 3D-printed food applications. Thus, a clearer understanding of the consumer through the application of a needs-based segmentation approach in the design of food service products and implementation of marketing and communication strategies will be critical. This reaffirms the importance of holding a consumer-oriented mind-set in the design and development of new products/technologies. Enhancing consumer experience through designing and communicating salient benefits is essential to offset any potential risks that may be perceived. Indeed, Henchion *et al*., (2019) suggests that off-setting risk is dependent on technology application, benefits offered and consumer segment needs. Applications of 3D food printing will be required to communicate the many benefits that the technology offers from the delivery of personalised nutrition snacks and meals where the technology can be used to help individuals reach their own unique nutrition goals in a convenient way (Burke-Shyne *et al*., 2020; Caulier *et al*., 2020) to its ability to support consumers' sustainability concerns through waste reduction.

Extending beyond immediate personal relevance, to be successful the technology will need to be compatible with existing and evolving values and social norms (Rogers, 2010). In socialising these technologies, marketers may tap into consumer-innovators' drive for stimulation, novelty-seeking and/or a need to express identity (Roehrich, 2004). With this in mind, it would be beneficial for potential 3D food printing applications within the food service sector to emphasize the customisability and personalisation features of the technology to appeal to the consumers' individuality so that they feel as though they can enjoy a unique user experience. For example, the technology facilitates the physical construction of foods in novel ways to appeal to the consumer. This presents operators in the food service market, for example restaurants, to construct unique food items themed around special occasions without incurring prohibitive costs. There are emerging examples where these initiatives are being implemented by chefs in high-end European restaurants who have 3D-printed meals of a theatrical nature with novel flavours and textural combinations to showcase the full capabilities of the technology (Ahmed, 2017; byFlow, 2018a; byFlow, 2018b; La Boscana restaurant, 2016).

It interesting to note that the hypothesised role of consumer innovativeness in determining willingness to try was not supported. This is contrary to much of the existing literature which suggests that consumer innovativeness has a positive and direct effect on willingness to try/adopt. In this study we used a domain level innovativeness measure that focused on food. However, given the nature of the application, participants may not have perceived the resultant foods as innovative (e.g., snacks), and thus, rather than food innovativeness being important, it is their perspective of the technology that was key. The analysis highlights the significant direct and indirect influence of NFTN on willingness to try the technology. Equally while the hypothesised direct effect of trust in science on willingness to try was not supported the significance of trust in science lies in its diminishing effects on NFTN and naturalness. These indirect effects have interesting consequences at a higher level and point to the potential role for various stakeholders in improving the prospects and consumer openness to innovative applications of technology in food production.

At a more general level, the paper highlights how the negative effect of NFTN might be mitigated. The findings clearly show that trust in science has a substantial and significant depressing effect. While our complete model addresses the specific application of 3D printing, this particular finding may be generalised to other novel food technologies. Increasing confidence in scientists and science will have a positive impact in the consumer environment and the willingness to embrace new technologies. Thus our findings have broader implications for the nature and content of marketing communications by industry and even policy makers. This will require a more long-term approach and a renewed focus on how food science is portrayed in consumer markets.

[illegible]

In conclusion, the evidence suggests that to successfully introduce 3D food printing applications into the food service sector a multifaceted approach will be required. This work has identified some of the major obstacles facing the technology in the forms of NFTN and the importance of naturalness and has pointed to possible resolution in building continued support and trust for science and a focus on designing and delivering both products and accompanying marketing strategies that communicate and emphasise the personal benefits that this novel food technology affords.

6. Limitations and future work

3D food printers are considered a novel and disruptive technology (Lupton and Turner, 2016). With that said, we are in the midst of experiencing a massive growth of technological advancements at an unprecedented rate and, consequently, the evolution of 3D food printer technologies can be predicted to continually change and adapt according to future trends and demands. Therefore, the results of this study are contingent on the fact that 3D food printers are not currently at the time of writing considered a mainstream technology or commonly used by consumers. However, we must be mindful that, in the near future, the factors affecting Irish consumer acceptance of 3D food printers may change if the technology becomes more readily available and commonplace in consumers' lives, and this must be considered when approaching future studies.

As exclusively Irish consumers were included in this study, this could be considered a limitation as cultural and societal norms tend to differ in other European countries and elsewhere in the world, therefore, attitudes towards the use of 3D food printing technologies might differ depending on the consumer's country of residence. It would an interesting investigation to compare the attitudes of other consumers worldwide and determine differences, if any, in the level of acceptance of 3D food printing applications.

Another aspect that could be explored further is to determine the relative importance of the mix of potential benefits that might be more or less salient among consumer segments. The technology offers so many opportunities through customisation in terms of functional, emotional and self-expressive benefits that determine those that are most likely to resonate in different consumer environments (out of home vs in-home) merits consideration. For example, it has been suggested by Sun *et al*. (2015) that 3D food printers could be utilised as a way of reducing food waste and increasing the use of sustainable food sources by disguising less appetising, but sustainable food ingredients such as algae and fungi, in appealing 3D-printed shapes in order to increase consumption of foods that would normally go to waste or alternatively to transform less attractive but healthier foods into forms that are more likely to be consumed by resistant consumer segments such as children.

In addition to this, there are reports of the potential use of 3D food printers as a means of portion control for individuals, where snacks and meals are 3D-printed in portion sizes unique to that individual based on biometric data supplied to the printer software (Lupton and Turner, 2016; Sun *et al*., 2018). Therefore, it would be of value to include items relating to sustainability and the environment in a future study, especially in more recent times when actions against climate change have become increasingly more urgent and compelling (Bouman *et al*., 2020; Mariam *et al*., 2020).

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Tables and Figures

Table 1. Demographic profile of respondents

	Number	Percentage (%)
Total Sample	1045	-
Gender		
Female	520	49.8
Male	525	50.2
Subtotal	1045	100
Age (Years)		
24-34	263	25
35-44	263	25
45-54	256	24
55-65	263	25
Subtotal	1045	100
Education		
Primary	3	0.3
Secondary	344	34
Bachelors	453	45
Masters	189	19
Doctoral	19	2
Subtotal	1008	100
Employment		
Full time	531	52
Part-Time	172	17
Unemployed	111	11
Student	23	23
Retired	65	65
Self-employed	63	63
Unable to work	48	48
Subtotal	1013	100
Marital status		
Single	236	23
Married or living with partner	738	71
Widowed	11	1
Separated/divorced	60	6
Subtotal	1045	100

Table 2: CFA, factor loadings and reliability for dependent and independent variables

Constructs	*p*-Value	Standard Loading
Willingness to try various 3D food printing applications (α = 0.84; CR = 0.81; source: adapted from Bäckström *et al*., 2004)		
Snacks freshly 3D printed on demand from a vending machine in public spaces (e.g., cinema, shopping centres, airports, train stations etc.)	[a]	0.811
3D food printer in the gym/fitness centre	0.001	0.793
3D-printed meal at a restaurant	0.001	0.701
Consumer Innovativeness (α = 0.75; CR = 0.70; source: adapted from Goldsmith and Flynn, 1992)		
In general, I am the last in my circle of friends to know the latest food brand names and new food products	[a]	0.661
In general, I am among the last in my circle of friends to buy a new food product when it appears in the shops	0.001	0.802
Trust in Science (α = 0.80; CR = 0.72; source: adapted from Bak, 2001)		
Most scientists want to work on things that will make life better for the average person	[a]	0.601
Science and technology are making our lives easier and more comfortable	0.001	0.667
Science and technology are helping to improve our health	0.001	0.759
Importance of Naturalness (α = 0.82; CR = 0.76; source: adapted from Hansen *et al*., 2018; Squires *et al*., 2001; and Tobler *et al*., 2001)		
When I purchase foods, I make sure that these are natural	[a]	0.775
I seek to choose food products which are minimally processed	0.001	0.642
I avoid foods that contain artificial preservatives	0.001	0.732
Perceived Relevance (α = 0.94; CR = 0.91; source: adapted from Kang *et al*., 2013)		

The purchase and/or use of 3D-printed food products would let others see me as I ideally would like them to see me	[a]	0.820
The purchase and use of 3D-printed food products could help me attain the type of life I strive for	0.001	0.843
I believe that I could make connections or associations between the purchase and use of 3D-printed products and other experiences and/or behaviours in my life	0.001	0.762
I think that the purchase and use of 3D-printed food products would be of personal importance to me	0.001	0.842
The purchase and use of 3D-printed food products would help me to express who I am	0.001	0.847
Novel Food Technology Neophobia (α = 0.87; CR = 0.95; source: Cox and Evans, 2008)		
Risk	[a]	0.952
Lack of benefits	0.001	0.925
Quality concerns	0.001	0.913

[a] set to 1 for estimation purposes

Table 3: Convergent and Discriminant Validity

	Correlations in the Upper Diagonal, Variance Extracted in the Diagonal, and R^2 in the Lower Diagonal					
	Willingness to try	**Trust in Science**	**Perceived relevance**	**Naturalness**	**Consumer Innovativeness**	**Neophobia**
Willingness to try	**0.59**	0.24	0.71	-0.22	-0.02	-0.54
Trust in Science	0.06	**0.46**	0.18	-0.15	-0.03	-0.60
Perceived relevance	0.51	0.03	**0.68**	-0.15	-0.07	-0.47
Naturalness	0.05	0.02	0.02	**0.51**	-0.18	0.25
Consumer Innovativeness	0.00	0.00	0.00	0.03	**0.54**	-0.73
Neophobia	0.30	0.36	0.22	0.06	0.53	**0.87**

Table 4. Mean scale values (mean of items) for age, gender, education and occupation categories (Scale: 1, low; 7, high)

	Naturalness	Trust in Science	Novel Food Technology Neophobia	Perceived Relevance	Consumer Innovativeness	Willingness to try 3D food printing applications
Mean	5.2	5.4	4.7	3.2	4.1	3.6
Gender						
Female	5.3	5.3	4.8	3.0	4.2	3.4
Male	5.1	5.5	4.6	3.4	4.0	3.8
Age (Years)						
24-34	5.1	5.5	4.7	3.7	4.1	4.0
35-44	5.3	5.6	4.5	3.6	4.3	3.9
45-54	5.1	5.2	4.7	3.0	4.2	3.5
55-65	5.3	5.3	4.7	2.7	3.9	3.0
Education						
Primary	4.8	5.1	4.4	4.0	4.3	3.7
Secondary	4.9	5.2	4.7	3.0	4.0	3.4
Bachelors	5.3	5.5	4.6	3.3	4.2	3.7
Masters	5.5	5.7	4.6	3.4	4.1	3.7
Doctoral	5.4	5.8	4.8	4.0	3.7	4.2
Employment						
Full time	5.2	5.5	4.7	3.5	4.2	3.8
Part-Time	5.4	5.3	4.7	3.0	4.1	3.5
Unemployed	5.0	5.3	4.6	3.2	4.2	3.6
Student	5.1	5.3	4.5	3.7	4.1	4.3
Retired	5.3	5.5	4.8	2.5	3.7	2.7
Self-employed	5.2	5.2	4.8	2.9	4.1	3.1
Unable to work	4.7	5.4	4.6	2.6	3.6	3.2

Table 5. Bootstrapped standardised direct effects

Direct Effects	**Standardised β**	**SE (Bootstrapped)**	**P**
(H1) Perceived Relevance to Willingness to try	0.614	0.037	***
(H2) Novel Food Technology Neophobia to Willingness to try	-0.167	0.056	***
(H3) Naturalness to Willingness to try	-0.053	0.036	*
(H4) Consumer Innovativeness to Willingness to try	-0.022	0.042	NS
(H5) Trust in Science to Willingness to try	-0.055	0.046	NS
(H6) Trust in Science to Naturalness	-0.137	0.065	**
(H8) Trust in Science to Novel Food Technology Neophobia	-0.445	0.072	***
(H10) Novel Food Technology Neophobia to Perceived Relevance	-0.329	0.040	***

****** 99%, ** 95%, * 90%***

Table 6. Unstandardized indirect effects

Indirect Effects (Bootstrapped sample = 5,000)	**Unstandardised β**	**SE (Bootstrapped)**	**P**
(H7) Trust in Science through Naturalness to Willingness to try	0.013	0.013	*
(H9) Trust in Science through Novel Food Technology Neophobia to Willingness to try	0.137	0.059	***
(H11) Novel Food Technology Neophobia through Perceived Relevance to Willingness to try	-0.337	0.047	***

****** 99%, ** 95%, * 90%***

Table 7. Breakdown of the Total Effects (Bootstrapped 5,000 samples)

	Direct Effect			Indirect Effects			Total Effect		
	Standardised β	**Bootstrapped SE**	**P**	**Standardised β**	**Bootstrapped SE**	**P**	**Standardised β**	**Bootstrapped SE**	**P**
Trust in Science to Willingness to try	0.054	0.046	NS	0.172	0.045	***	0.226	0.040	***
Novel Food Technology Neophobia to Willingness to try	-0.167	0.056	***	-0.202	0.025	***	-0.369	0.057	***

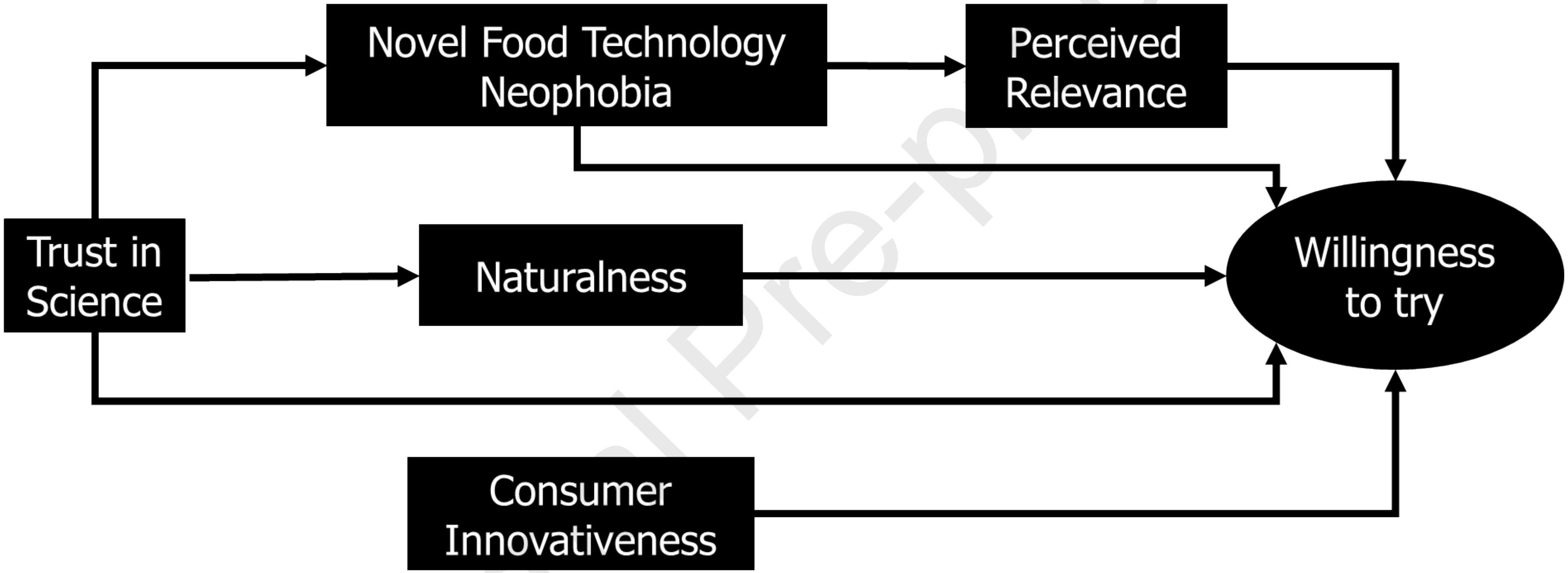
****** 99%, ** 95%, * 90%***

Table 8. Total effects of gender, age and education on willingness to try

Co-variates	Standardised Total Effect	Standardised SE	Two-tailed Sig.
Gender	0.182	0.033	***
Age	-0.307	0.033	***
Education	-0.037	0.035	NS

****** 99%, ** 95%, * 90%***

Figure 1. A basic model of Irish consumers' willingness to try 3D food printing applications



Appendix

Table S1: Items for the dimensions of Novel Food Technology Neophobia

	Measures for the dimensions of Novel Food Technology Neophobia
Risk	New food technologies are something I am uncertain about
	New food technologies may have long term negative environmental effects
	It can be risky to switch to new food technologies too quickly
Lack of Benefits	There are plenty of new tasty foods around so we do not need to use food technologies to produce more
	Society should not depend heavily on technologies to solve its food problems
	There is no sense trying out high-tech food products because the ones I eat are already good enough
Quality Concerns	New food products using new technologies are not healthier than foods created using traditional methods
	The benefits of new food technologies are often grossly overstated
	New food technologies decrease the natural quality of food

Highlights

- Personal relevance is strong positive determinant of consumers' willingness to try
- The role of trust in science diminishes effect of novel food technology neophobia
- Consumer attitude towards naturalness also affected by levels of trust in science