Adoption of 3D food printing technologies in the food industry

by

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Abstract

3D Food Printing (3DFP) technology is emerging as a promising solution for consumer demands on food personalization, nutrition, and sustainability, given its unprecedented levels of customization and versatility in food applications. While the majority of research on 3DFP has focused on technological advancements, there has been a recent interest in understanding consumer acceptance. However, successful application of 3DFP relies on industry stakeholders' acceptance as well as that of consumers. Economic, social, and business implications in the practical adoption in the food industry of 3DFP have been overlooked. Opinions about technology implementation from early adopters are valuable for potential adopters' decision-making, while potential adopters' perspectives can reveal adoption opportunities and barriers. Implementation of the well-known Diffusion of Innovation (DOI) framework has supported the examination of innovation adoption considering the adoption process, adopter characteristics, technology characteristics and social factors.

Therefore, this research investigated the determinants of 3DFP adoption in the food industry through a three-phase approach; 1) a literature review of existing research on 3DFP acceptance, 2) an interview study with nine food businesses around the globe implementing 3DFP technologies to understand adoption process and factors influencing practical adoption, and 3) an online survey among 118 representatives from food sectors in Alberta, Canada, to examine readiness for adoption. The DOI model was implemented to study the current and potential adoption of 3DFP, an approach not researched before.

The literature review confirmed that most of the research on 3DFP acceptance has focused on consumers' viewpoints, with a notable gap in understanding industry perspectives and practical adoption factors among industry food sectors. In phase two, interviews with 3DFP industry adopters revealed early adoption in food service, confectionery, protein alternatives, and healthcare food manufacturing businesses. Businesses entrepreneurial spirit, technology compatibility with business needs and public interest encouraged early adopters to 3DFP adoption. Businesses acknowledged 3DFP benefits over

conventional technologies in operational efficiency, product design, customization, food versatility, convenience, and sustainability with benefits prioritized according to business food sector context. Small scale, high investment cost, negative consumer perception and low involvement of large organizations emerged as challenges for sustainable adoption in food businesses. To overcome barriers to 3DFP adoption, it is paramount to address the technology small scale. This will enhance visibility and accessibility of 3D printed products, raising awareness and interest among consumers and potential users. Moreover, as per businesses opinions, consumers' low awareness and hesitancy about 3DFP require resolution through market education, alternative technology labelling, and use of food and technology familiarity.

In the third phase, among Alberta food service, confectionery, bakery, and healthcare food service sectors, the most relevant 3DFP features for potential implementation were costs per serving, technical support, technology maintenance, ease of cleaning and efficiency. Nearly three-quarter of Alberta food sector participants lack knowledge about 3DFP. Two thirds of the participants showed interest in adopting 3DFP. Full-scale projects, training programs, government initiatives, knowledge-sharing programs and demonstrated effective and economically viable applications are crucial to realize its potential across food sectors and support readiness for 3DFP adoption. Implementation of the DOI model revealed that despite a wide range of benefits of 3DFP, the technology must align with business objectives and processes and demonstrate advantages over conventional methods for increased adoption by subsequent adopters. Determinants of 3DFP adoption in the food industry identified in this research provide valuable insights for academia, policy makers, food industry stakeholders in Alberta and similar food sectors in other unexplored areas.

Preface

This thesis is an original work by Daniela Juliana Guáqueta García under the supervision of Dr. Wendy Wismer and Dr. John Wolodko, with funding from an Alberta Innovates grant to Dr. John Wolodko.

Chapter 2 of this thesis will be submitted to Journal Trends in Food Science and Technology. I conceptualized the study. I conducted the data collection, analysis, visualization, and original draft preparation with the collaboration of a graduate student (Laura Lopez-Aldana). The last version of the study was reviewed and edited by Laura Lopez, Dr. Wendy Wismer, and me. Dr. John Wolodko reviewed and provided editorial comments on the manuscript.

Chapter 3 of this thesis has been submitted for publication to the British Food Journal. Dr. John Wolodko, Dr. Wendy Wismer, and I conceptualized and designed the study. I collected, analyzed, and interpreted the data and drafted the manuscript. Dr. Wendy Wismer contributed to the manuscript edits. Dr. John Wolodko reviewed and provided editorial comments on the manuscript. This study received ethics approval from the University of Alberta Research Ethics Board 2 under the project name "Adoption of 3D food printing in the food industry", Pro001210228, August 11th, 2022.

A version of **Chapter 4** of this thesis will be submitted to MDPI Foods for publication. Dr. John Wolodko, Dr. Wendy Wismer, and I conceptualized and designed the study. I collected, analyzed, and interpreted the data and drafted the manuscript. Dr. Wendy Wismer contributed to the manuscript edits. Dr. John Wolodko reviewed and provided editorial comments on the manuscript. This study received ethics approval from the University of Alberta Health Research Ethics Board - Health Panel under the project name "Perception and readiness for adoption of 3D food printing in Alberta food businesses", Pro00121507, August 29th, 2023.

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I want to acknowledge the support I received from the Alberta Food Processing Center team to distribute the survey conducted in Alberta food sectors. The kind feedback from Mei Tom from Alberta Health Services to the survey is gratefully appreciated. I profoundly thank the teamwork with Laura Lopez to write the literature review presented in Chapter 2 of this thesis. I thank Farrah So for her advice on the participant recruiting process of Alberta's food businesses for the survey.

Finally, I want to thank the unlimited support and love from my life confidant, Harold Bustos, without him I would have not been able to go through this journey, living the process with resilience and going after a fulfilling graduate experience. I thank the always-present encouragement from my parents, Jaime Guáqueta and Diana García, for reminding me to always go after my dreams, be open to learning new things, and give my best and more. Lastly, I want to thank Christy Alsado, a friend who accompanied me during the ups and downs of this journey and reminded me of the beauty of the simple things in a friendship.

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Chapter 1 – Introduction

Innovation in food processing methods is essential for addressing current global challenges in food sustainability, safety and supply chain security (Konfo et al., 2023; Siegrist & Hartmann, 2020). In recent years, 3D food printing (3DFP) has emerged in the food industry as a potential game-changer to disrupt supply chains and business models, while contributing to the resolution of those challenges (Escalante-Aburto et al., 2021; Tran, 2019).

1.1 3D Food Printing (3DFP)

3DFP technologies present a ground-breaking fusion of technology and gastronomy, gaining attention for their potential to transform food production and consumption. Compared to traditional food manufacturing techniques (e.g., extrusion, molding), 3DFP introduces the layering of edible materials to construct 3D edible foods (Wegrzyn et al., 2012), enabling precise control over ingredient placement, portioning, and design (Sun et al., 2018), resulting in previously unattainable levels of culinary customization. The versatility of 3DFP, allowing for customization, ingredient flexibility, and the ability to configure food layer by layer, has broadened the range of applications for this technology (Kewuyemi et al., 2022).

1.2 3DFP applications

3DFP offers a vast array of applications from food service (Ross et al., 2022) to space missions (Enfield et al., 2022). In healthcare, 3DFP offers customization and enhancement of food sensory and nutritional properties (Dankar et al., 2018; Escalante-Aburto et al., 2021). It enables the production of personalized foods with specific nutritional attributes such as high-protein (Chow et al., 2021, p. 20; Riantiningtyas et al., 2021), low-sugar (Khemacheevakul et al., 2021), fiber-enriched (Krishnaraj et al., 2019), or vitamin-fortified (Derossi et al., 2018). This customization is beneficial for catering to specific populations food preferences, health conditions (dysphagia or elderly populations) (Hemsley et al., 2022; Kouzani et al., 2017), or dietary requirements (military soldiers or children) (Caulier et al., 2020; Derossi et al., 2018; Tabriz et al., 2021), making it easier for individuals to consume nourishing and pleasing meals.

Moreover, 3DFP has the potential to address food sustainability and climate change by streamlining food supply chains (Dankar et al., 2018), utilizing sustainable ingredients (e.g., insect-based proteins, algae) (Severini et al., 2018; Uribe-Wandurraga et al., 2020), and promoting food up-cycling practices by repurposing food such as agri-food waste (Chuang et al., 2022; Jagadiswaran et al., 2021; Muthurajan et al., 2021) or meat-industry by-products (Bhat et al., 2021). In addition, 3DFP holds promise in addressing global food security challenges by facilitating the production of alternative protein foods, such as plant-based or lab-grown meat, mimicking typical food structure of animal-based proteins to facilitate consumer acceptance (Bedoya et al., 2022; Handral et al., 2022; Ramachandraiah, 2021).

Culinary creativity is another area where 3DFP excels; it can ease rapid food product prototyping (Derossi et al., 2023), create unique gastronomic experiences (Lupton & Turner, 2018a), and offer intricate and appealing products (Jia et al., 2016), enabling chefs to design visually stunning edible structures that would be impossible to achieve through traditional cooking methods. Particularly, utilization of 3DFP in confectionery businesses is convenient to respond to the pursuit of innovation and the recent consumer demands for personalization (Jia et al., 2016).

1.3 Application of 3DFP in the food industry

The inception of the 3DFP market was initially observed by hardware manufacturing, and, in recent years, there has been growing recognition of the emergence of 3D-printed food items (Nopparat & Motte, 2023). The application of 3DFP in the food industry began in bakery and confectionery sectors, constituting over 67 % of the 3DFP market in 2019 (BCC, 2020). However, 3DFP has started to emerge into consumer experiences across retail, food service, and food processing industries either in small and medium enterprises (SMEs) and a few large multinational companies. Companies like Mondelez and Hershey have introduced 3D chocolate printers. SugarLab and La Miam Factory offer customized sweets in the US and France, respectively. Additionally, Barry Callebaut's Monalisa brand provides large-scale customized chocolates. BeeHex, a NASA spin-off, explores space food development and currently offers automated 3DFP printing systems for bakery and pastry applications.

Expanding beyond chocolates and pastries, innovative applications of 3DFP have evolved in other food sectors such as pasta, alternative proteins, and foods for healthcare. Barilla's BlueRhapsody brand has processed sophisticated 3D printed pasta shapes. Nourish3D offers personalized vitamins, and Gastronology has worked toward 3DFP textured-food outsourced production for dysphagia diets. Alternative protein businesses, such as RevoFoods, Novameat, Plantish, and GoodMeat, have developed meat analogues as potential sustainable alternatives to mimic animal-based proteins, using plant-based or cell-cultured proteins. These products have been sold in retail and restaurants in Europe. In the food service sector, FoodInk was the first 3DFP restaurant in London. Haute cuisine restaurants in Europe and North America have implemented 3DFP to offer unique consumer experiences showcasing the printer and presenting intricate food designs within their plates. Overall, customization, consumer experience, sustainability, and nutrition are the predominant value propositions of 3DFP implementation in the food industry.

1.4 Pro-innovation bias and balance of 3DFP adoption factors

In research, pro-innovation bias might lead individuals to focus on benefits of an innovation while neglecting potential adoption limitations (Rogers, 1995). In the field of 3DFP, the majority of 3DFP research has focused on technical and product development (Hussain et al., 2022; Pulatsu & Lin, 2021), emphasizing its innovative features in food customization, efficient use of ingredients, and culinary creativity. However, the practical implications of adopting the technology, such as the economic, social, and business sustainability aspects, are overlooked (Dabbene et al., 2018). The success of integrating innovations into the food supply chain relies on businesses' receptiveness to embrace it in addition to its technical feasibility (Schiefer & Deiters, 2022).

Overcoming the pro-innovation bias in the adoption of 3DFP requires a balanced evaluation, encompassing not just its exciting potential but also the practical challenges of integrating it into food industry practices (Rogers, 1995). A comprehensive assessment of the opportunities and barriers to its adoption is essential to ensure a realistic understanding of the implications of the technology in the industry application and to facilitate informed decision-making. This could support successful acceptance of the technology (Rogers, 1983), particularly if adopters' perceptions are considered during early technology development (Siegrist, 2007).

1.5 Adoption Framework of Innovations

Among the several frameworks that have been utilized in research to explore the factors contributing to the successful adoption of innovation, Rogers (1983) proposed the Diffusion of Innovation (DOI) model which consists of a process-oriented approach to adoption (Taherdoost, 2018). Covering factors influencing the adoption from technology, adopters, and social system angles (Taherdoost, 2018), the DOI model serves as a tool for comprehending the dynamics of innovation diffusion across diverse contexts and, consequently, guiding practitioners in their approaches for successful adoption (Inwood et al., 2009).

The DOI process consists of five steps divided in two main stages: initiation and implementation (Priyadarshini et al., 2019). The first consists of (1) knowing about the innovation, (2) assessing its characteristics, and (3) deciding to adopt or reject it. The second stage is prompted by the decision to adopt the innovation. It entails the (4) implementation to gauge its suitability, and (5) confirmation of the adoption decision to continue or discontinue its usage (Priyadarshini et al., 2019). This model includes five innovation characteristics that influence decision making, such as relative advantage, compatibility, complexity, observability, and trialability. The more positive the characteristics are perceived, the more likely the innovation will be adopted (Rogers, 1983).

The number of individuals adopting an innovation increases over time and eventually stabilizes upon the achievement of successful implementation. According to Rogers (1983), the trajectory of innovation adoption is determined by the different adopter categories. The earliest adopters are the 'innovators' and 'early adopters', followed by the 'early majority', 'late majority', and 'laggards'. They differ in their innovativeness (i.e., attitudes toward adopting innovations) and risk adversity of which the former two (innovators and early adopters) more readily take the risk of adopting an innovation (Rogers, 1983). Innovators and early adopters might be more open to trying avant-garde food innovations, the early majority might require more familiarization, and late majority and laggards adopt when the innovation is widely adopted or becomes a necessity (Rogers, 1983). Early adopters play a significant role in shaping the acceptance or rejection of innovations because they are often sought by prospective adopters for their insights on technology before making adoption decisions (Rogers, 1983).

Rogers' (1983) DOI model, utilized for the last five decades, has facilitated an understanding of innovation acceptance across industries such as agriculture (Lavoie et al., 2021), healthcare (Matthews et al., 2016; Scott et al., 2008), and manufacturing and IT technologies (Handfield et al., 2022; Mamun, 2018; Moore & Benbasat, 1991; Yi et al., 2006). In food innovation, it has been used to elucidate acceptance of new products, technologies, and trends, including nanotechnology (Chang et al., 2017), genetically modified foods (Alalwan et al., 2023), organic foods (Li et al., 2021), sustainable winemaking (Douglas & Donaldson, 2023), and blockchain for food production (Ali et al., 2023). The innovation assessed in the present study is the technology of 3DFP. The aforementioned innovations share with 3DFP the fact of being innovative to the food industry with the aim to solve societal concerns such as food security, nutrition, and sustainability.

1.6 Assessments of 3DFP adoption in the food industry

The existing research on 3DFP acceptance has primarily focused on consumer perspectives. Acceptance of 3DFP by consumers has been found to be influenced by prior knowledge (Lupton & Turner, 2018c; Ng et al., 2022), psychological variables such as new food and food technology neophobia (Feng et al., 2022; Lee et al., 2021; Ross et al., 2022), demographic characteristics (Brunner et al., 2018; Lunden et al., 2020; Tesikova et al., 2022), technology and food familiarity (Manstan & McSweeney, 2020; Mantihal et al., 2019), and perspectives of the technology and the end products (Ng et al., 2022). 3DFP commercial success achievement relies on consumers' opinions (Jayaprakash et al., 2018) as they elucidate the product desirability (Talens et al., 2022). However, perspectives from industry stakeholders are also crucial as they implement the technology to facilitate product availability while considering the techno-economic viability and consumer response. Thus, both roles are essential for obtaining a 3DFP established market.

Few published studies have explored the views of industry players to assess technology applicability in the food industry. Jayaprakash et al. (2020) assessed 3DFP experts' perspectives about 3DFP readiness and potential application through a three-phase study. They first interviewed 25 Finish industry experts (food manufacturers, distributors, and researchers) who identified the maturity of the paste-like extruder system ready for industrial scaling but emphasized the critical role of the hardware-software system in determining market viability. Afterward, from 50 surveyed participants, primarily from academia (72%) and a minority from food-related businesses (10%), the most important attributes of 3DFP were identified as cleanliness, multilateral compatibility, speed, and integration with post-processing. In the final phase, industry experts indicated using 3DFP for customized snacks in public places as the potential application to move forward the technology outside of the small-scale production.

Rogers & Srivastava (2021) evaluated opportunities and challenges for a sustainable 3DFP food supply chain. They interviewed twelve European individuals involved with extrusion-based food printing technology providing products or services, of which five were 3DFP ingredient or product manufacturers in the confectionery, pasta, and nutrition sectors. They identified slow printing speed, high costs, consumer resistance, and lack of regulations for creation rights, food safety and responsibilities as barriers to adoption. Participants identified health centres, nutritionists, and gyms as key stakeholders to contribute to the awareness of 3DFP and acceleration of its diffusion, while health-conscious consumers and individuals with health issues were considered as the potential early adopters of 3DFP.

To understand potential user perspectives towards 3DFP applicability, research has mainly focused on healthcare. Burke-Shyne et al. (2021) explored nutrition and 3D printing experts' perspectives on potential uses, awareness, and social attitudes of 3DFP for improving individuals' health and nutrition. While recognizing benefits in reducing food waste, participants cited slow printing speed and high costs as obstacles for clinical settings. Smith et al. (2022) assessed health professionals' views on 3DFP for dysphagia patients, noting potential improvements in food appearance but raising concerns about the effectiveness of improving patient quality of life through the visual appeal of food. A follow-up study by Smith et al. (2022b) revealed user challenges and expensive equipment costs from the perspectives of dysphagia patients and their caregivers. Other research focused on educational settings, especially for food and nutrition dissemination (Gosine et al., 2021). Participants acknowledged 3DFP's potential to increase food engagement, create appealing food, and reduce waste through by-product utilization. However, lack of noticeable uptake of the technology was one of the limitations to consider using it.

Although the adoption of 3DFP is expanding across the food industry, it is growing slowly compared to non-food 3D printing technology (Nopparat & Motte, 2023), with a limited number of businesses employing it. According to Charlebois & Juhasz (2018), 3DFP sustainability relies on diverse stakeholders' perspectives. However, factors influencing the effective adoption of 3DFP and potential adoption in different areas of the food industry are underexplored. Identifying challenges and opportunities for 3DFP businesses in various food sectors during technology implementation clarifies technology readiness and prospects.

Uncertainty can be a significant obstacle to adopting a new emerging technology, but it can be lessened if the stakeholders are aware of the innovation's benefits and drawbacks (Rogers, 1983). On one hand, insights from food businesses with experience on 3DFP adoption are relevant for potential stakeholders as their opinions bring practical insights into the applicability of 3DFP. On the other hand, the viewpoints of potential users in the food industry could reflect their attitudes toward the new technology, which is crucial for understanding their readiness for adoption. Limited research has focused on the factors influencing diffusion and adoption of 3DFP by food industry players. Particularly, there is a notable gap in considering the business standpoint of 3DFP among actual or potential users in food sectors. Thus, viewpoints from both groups could help understand the factors influencing the adoption of this novel technology in the food industry.

1.7 Outline and Objectives

The aim of this thesis was to analyze the determinants of 3DFP adoption in the food industry. This research consists of three phases to investigate factors that influence adoption of 3DFP among consumers and current and potential adopters in the food industry (Figure 1.1). The first phase consisted of a review of published literature of research on 3DFP acceptance through technology perceptions and product evaluations involving end-consumers, current users and potential users. The second and third phase consisted of a sequential exploratory mixed-method design (Creswell, 2014), composed of an interview study with current adopters of 3DFP, followed by a quantitative survey study of potential adopters in Alberta, Canada (Figure 1.1).

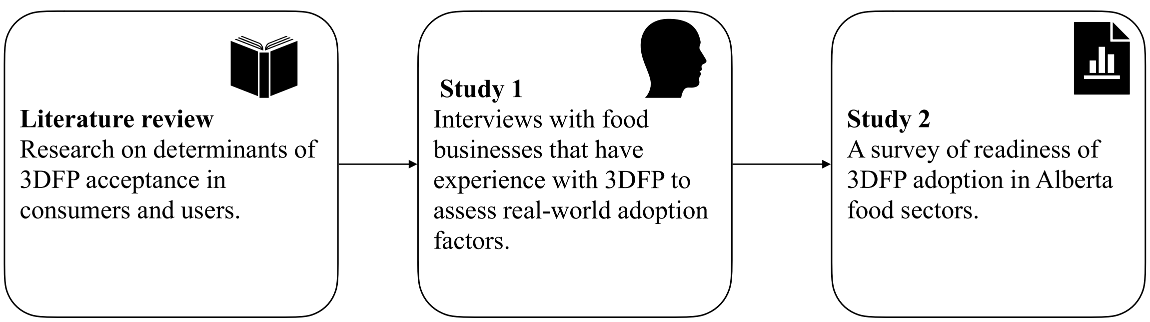


Figure 1.1. *Thesis framework: literature review (Chapter 2), interviews with businesses experienced with 3DFP (Chapter 3; study 1), and survey of readiness for adoption in Alberta food sectors (Chapter 4; study 2).*

To the best of my knowledge, 3DFP adoption by food industry stakeholders has not been explored before under the lens of Rogers' DOI model, thus this thesis contributes to this research gap. The DOI model was utilized as a theorical framework to gather insights from current adopters and potential adopters' perceptions in the food industry about 3DFP implementation in their food sectors (Figure 1.2.). By utilizing this approach, this thesis examined opportunities and barriers for successful adoption, which are intended to inform the food industry for decision-making and academia for further technology developments.

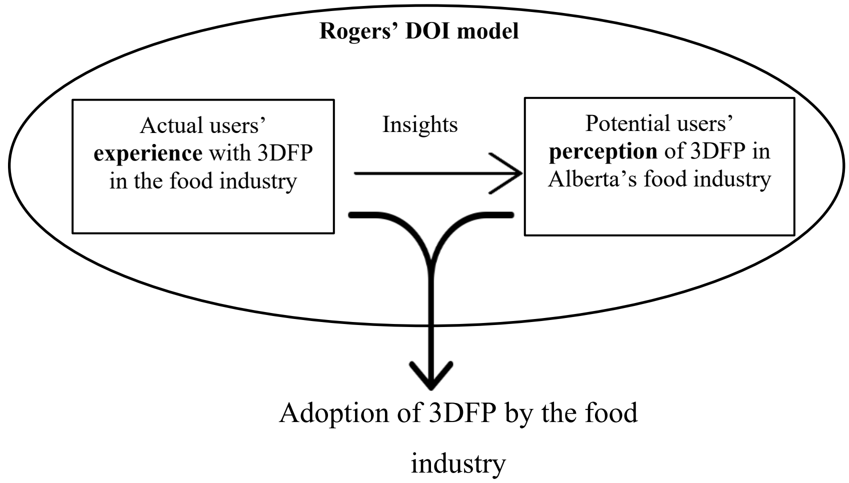


Figure 1.2. *Framework for the study of 3DFP adoption in the food industry*

Given the significant role of early adopters in the diffusion of innovations, it was hypothesized that interviewing current 3DFP users could collect real-world insights into the adoption process, technology, social and adopters' characteristics influencing 3DFP adoption. Therefore, the first study (Chapter 3) aimed to investigate the experiences of food businesses that have adopted 3DFP to understand the factors influencing adoption from a business standpoint based on the DOI model. The secondary objectives of this study were to 1) investigate their experience adopting 3DFP based on Rogers' DOI model, 2) examine DOI's characteristics of innovation for 3DFP to identify aspects that drive and challenge the adoption, and 3) examine the prospects and potential solutions to adoption of 3DFP in food businesses. This study entailed a qualitative research approach of semi-structured interviews with food businesses that adopted 3DFP technologies and represented a variety of food sector 3DFP applications.

According to Charlebois & Juhasz (2018), 3DFP has the potential to transform the landscape of food production on a global scale, including within Canada. In 2020, early adoption of 3DFP in Canada represented approximately 5.54% of the global market value (BCC, 2020). The province of Alberta is the third-largest contributor to Canada's gross domestic product (Statistics Canada, 2024), which positions the Alberta food industry as an ideal candidate to explore the adoption of 3DFP. The food service and processing and healthcare sectors are important for Alberta's economy and population wellness (Statistics Canada, 2023). These sectors have been identified as key for diffusion of 3DFP adoption (Mantihal et al., 2019; Rogers & Srivastava, 2021).

Analyzing technology applicability through real-world case studies can aid in understanding stakeholders' attitudes towards its features (Rogers 1983). Thus, it was hypothesized that leveraging the global experience of 3DFP adoption in similar sectors (assessed in Chapter 3) can help study perceptions from food industry stakeholders in Alberta. Given the early stage of 3DFP adoption worldwide, it was hypothesized that the state of adoption of 3DFP is still in the early stages or almost null in Alberta. Adopters' characteristics, such as innovativeness and level of knowledge, alongside technology perceptions, affect the adoption of novel food technologies (Rogers, 1983). Thus, it was hypothesized that stakeholder characteristics and technology perceptions can influence willingness of Alberta food sectors toward 3DFP adoption.

Therefore, the second study aim was to assess the readiness of 3DFP potential adoption in the respective sectors in Alberta by utilizing descriptive scenarios from 3DFP business experiences described in the study of chapter 3, and incorporating the adopter categories and technology characteristics described in the DOI model. The secondary study objectives consisted of examining 1) the level of knowledge and extent of adoption of 3D printing technologies, and innovativeness, 2) the perceptions toward 3DFP based on its benefits, features for implementation, and DOI's characteristics of innovation, and 3) the willingness and perceived relevance of strategies to adopting the technology in the targeted Alberta food sectors. This study consisted of an on-line survey conducted in the Alberta food service, confectionery, bakery, and healthcare food service sectors.

Chapter 2 – Determinants of consumers and users' adoption of 3D food printing – A systematic review

2.1 Introduction

3D food printing (3DFP) is a food processing method that enables unprecedented intricate food designs and personalized food automation in the food manufacturing, retail, and hospitality sectors. Moreover, 3DFP holds the potential to respond to market trends and global challenges such as food sustainability (Chuang et al., 2022; Ramachandraiah, 2021) and nutrition (Escalante-Aburto et al., 2021) given its benefits for ingredient versatility (Kewuyemi et al., 2022) and control over ingredient placement (Sun et al., 2018).

The majority of published reviews of 3DFP applications have focused on technical aspects, including food materials (Pulatsu & Lin, 2021), printing platforms (Hussain et al., 2022), and potential applications such as nutrition, health, and sustainability (Bhat et al., 2021; Zhong et al., 2023). However, in addition to technical and product developments, 3DFP's widespread successful adoption depends on the acceptance of both individuals who will implement the technology and those who consume the end products. In the food supply chain, industry users' viewpoints are key as they include techno-economic viability perspectives while considering the market response. At the same time, end-consumers' perspectives are indispensable as they ultimately decide the commercial success of 3DFP (Jayaprakash et al., 2020). Moreover, with the potential evolution of 3DFP into a kitchen appliance, consumers could become "prosumers", producing and consuming their food using the technology (Jayaprakash et al., 2018). Insights from both groups are valuable for understanding factors that influence the widespread adoption of 3DFP.

Factors influencing consumer acceptance, such as food technology neophobia, product appearance and texture, and health and safety concerns have been briefly discussed in some previous reviews (Baiano, 2020; Hassoun et al., 2022; Pereira et al., 2021). To the best of the authors' knowledge, no published study has comprehensively reviewed technical, social, and personal factors influencing 3DFP acceptance by end-consumers and technology users. This literature review aimed to identify determinants affecting 3DFP acceptance by systematically reviewing existing research on technology perceptions and product evaluations. It also investigated the current state and prospects of 3DFP acceptance research, considering the research approaches and the variety of food applications surveyed. This review holds significance for industry and academia seeking a comprehensive understanding of 3DFP acceptance to develop strategies to support widespread adoption.

2.2 Methodology

2.2.1 Selection and screening of relevant studies

This article relies on a systematic review of existing research about 3DFP acceptance. It includes assessments of individuals' perceptions about 3DFP and product evaluations of 3D-printed foods. A Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) diagram (Page et al., 2021) was used to record and report included research studies (Figure 2.1.). Web of Science, Scopus, and ProQuest databases were used to gather relevant peer-reviewed studies that assessed opinions on 3DFP, using keywords of concepts such as: (3d food printing, 3d printed food, or 3d printing of foods) AND (awareness, perception, attitude, adopt, benefit, opportunity, challenge, barrier, motive, reason, accept, or decision) AND (survey, questionnaire, interview, or focus group). 3D-printed food product tasting studies were retrieved from the Web of Science and Scopus, using variations of keywords such as: (3d food printing, 3d printed food, or 3d printing of foods) AND (sensory panel, sensory profile, sensory properties, or sensory evaluation). This search was last updated in August 2023. Out of 213 articles initially retrieved, 136 were screened by the first author excluding duplicates and non-retrievable reports. Seventy-five potentially eligible studies were identified after excluding non-research articles, from which 48 were selected for review for meeting relevant review topic criteria.

2.2.2 Data extraction and analysis

Studies selected were organized into two groups based on study types: one focusing on technology perceptions without product evaluations and the other on product tastings through sensory evaluations. The studies were also categorized based on participants' profiles: industry users and end-consumers. Study methods and factors impacting 3DFP acceptance were identified and compared among the reviewed studies. The analysis drew inspiration from a previous study examining factors influencing free-from food consumption (Savarese et al., 2021). Concepts about factors shaping attitudes toward new food technologies and influencing food choices were derived from pertinent publications (Schiefer & Deiters, 2022; Siegrist, 2007). After identifying group determinants, a conceptual map was developed to illustrate factors influencing users' and end-consumers' acceptance of 3DFP and 3D-printed foods (Figure 2.2). Additionally, the studies were quantitatively analyzed to assess the current research on 3DFP acceptance, categorizing studies based on participants' geographic locations and profiles and the food applications explored in perception and product tasting studies.

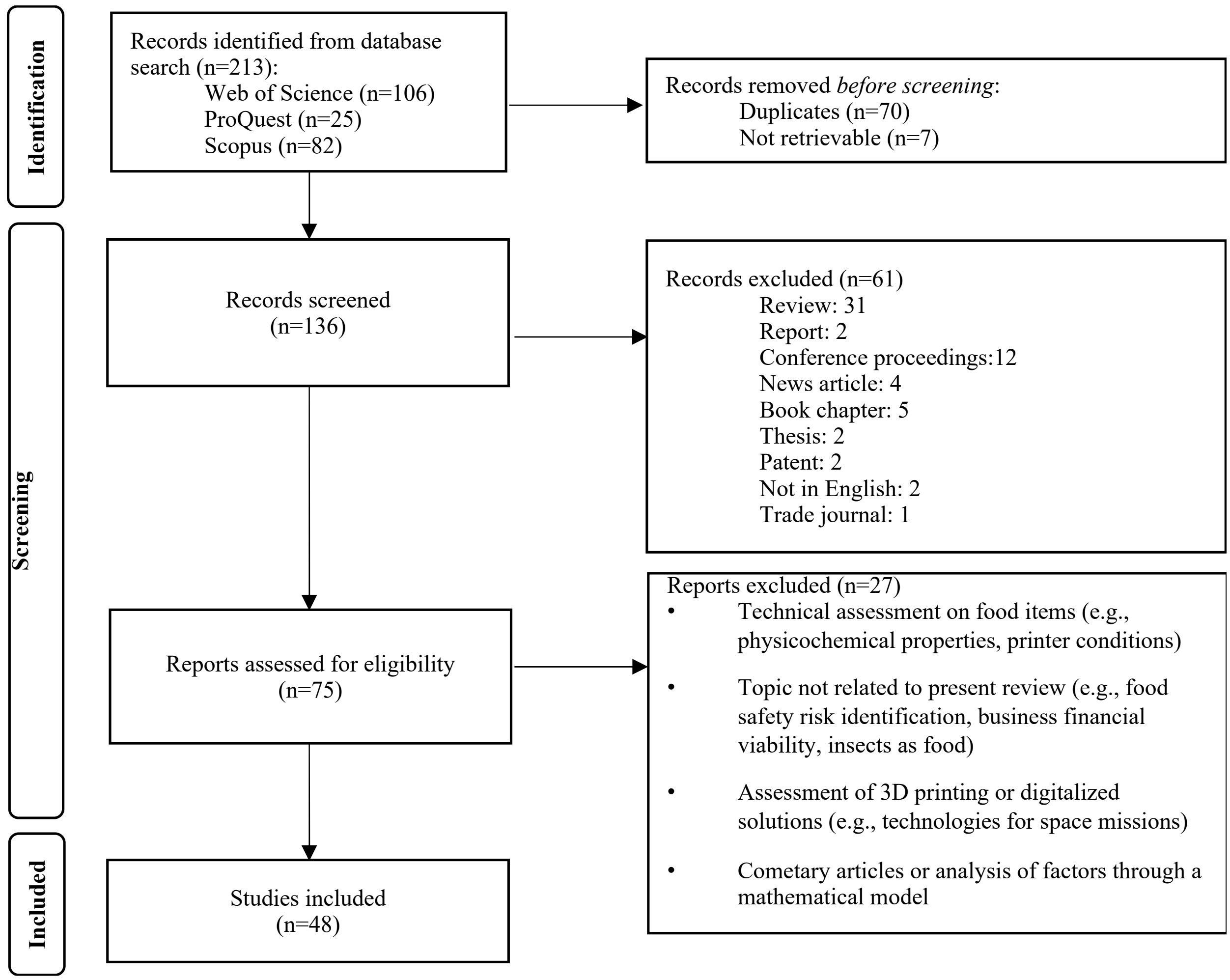


Figure 2.1. *PRISMA flow diagram for identification of studies via databases.*

2.3 Results and discussion

2.3.1 Determinants of 3DFP acceptance

Technology and product characteristics, social variables, and personal traits influence perceptions toward 3DFP technology and 3D printed food products, shaping 3DFP acceptance and receptiveness (Figure 2.2). Factors influencing users and consumers differ according to their role in interacting with 3DFP. On the one hand, users' perceptions of 3DFP are shaped by technology name, novelty, cost, usability and effectiveness, users' prior knowledge about 3DFP, and the observed use of the technology by other users. On the other hand, factors influencing consumers' attitudes include product and technology characteristics, trust in science, information provided and trusted organizations, observed use of 3DFP, demographics, new food and food technology neophobia, food familiarity, and prior knowledge about 3DFP (Figure 2.2.).

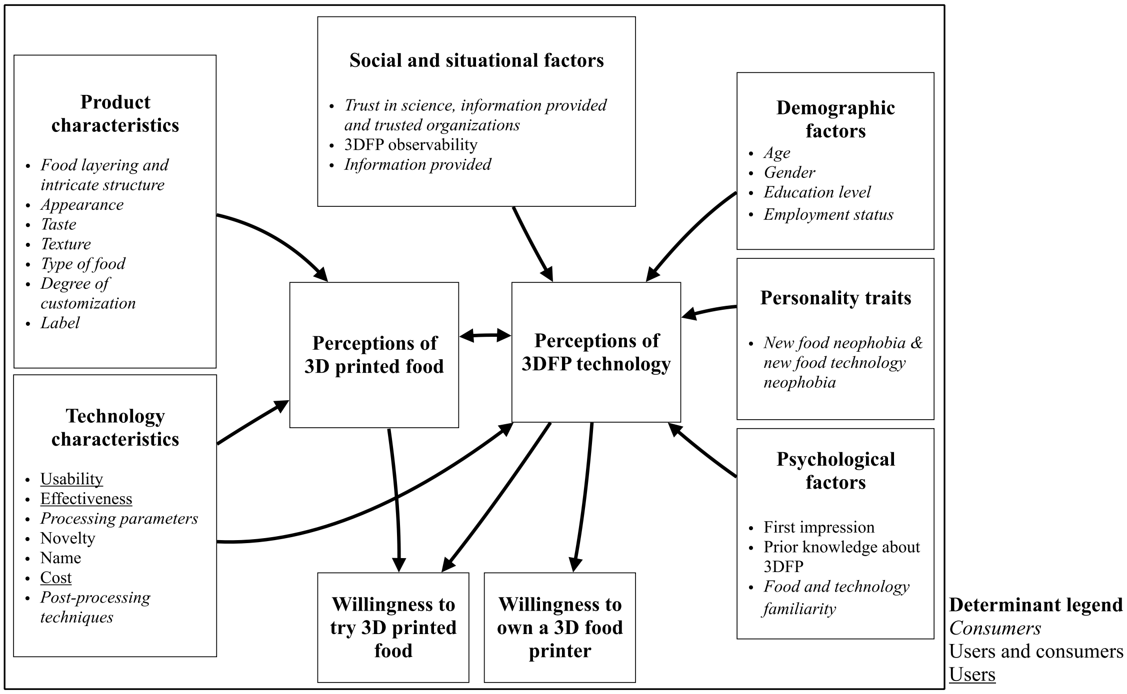


Figure 2.2. *Conceptual model of determinants in adopting 3DFP and its products by consumers and users.*

2.3.2 Demographic factors

Consumers' demographics, such as age, educational level, employment status and gender impact the acceptance of 3DFP (Figure 2.2). Unlike younger people, older individuals exhibit reluctance to accept and eat 3D-printed food (Manstan & McSweeney, 2020; Tesikova et al., 2022). Students are more inclined to explore 3DFP than employed individuals (Ross et al., 2022). Highly educated individuals generally trust printed foods more than those with basic education. Younger people, who are more active on social media, may have increased exposure to 3DFP than other age groups (Tesikova et al., 2022). Thus, highly educated younger individuals are considered early adopters of this technology (Feng et al., 2022).

Some studies found that gender does not affect perceptions towards 3DFP (Lee et al., 2021; Manstan & McSweeney, 2020; Mantihal et al., 2019), while others identified men viewing 3DFP more positively than women (Brunner et al., 2018; Tesikova et al., 2022), consistent with patterns observed in the acceptance of new food technologies (Fell et al., 2009; Rollin et al., 2011). Compared to women, men perceive 3D-printed food as more nutritious, environmentally friendly and natural (Lunden et al., 2020), have a positive perception of 3DFP's environmental benefit, and are more willing to try 3D-printed food (Ross et al., 2022). Safety concerns about the products and trust in the technology challenge women's 3DFP acceptance (Tesikova et al., 2022). Age, gender, and education level could be used to create tailored communication strategies to foster wider acceptance of 3DFP.

2.3.3 Psychological factors and personality traits

2.3.3.1 First impression of 3DFP

Individuals' initial attitudes influence the acceptance of 3DFP (Brunner et al., 2018) (Figure 2.2). Consumers' initial impression is positively influenced by the 3D-printed food's intricate and aesthetic design (Talens et al., 2022; Tesikova et al., 2022) and the perceived utility and hedonic value of the technology (Lee et al., 2021). Making food appealing to support food intake leads consumers to recognize potential health benefits (Lupton & Turner, 2018b; Mantihal et al., 2019). However, alike with other new food technologies, such as gene-modified food, cultured meat, and precision fermentation technologies (Siegrist & Hartmann, 2020), consumers are worried about 3D-printed food safety, naturalness, and healthiness due to the perceived over-processing of food (Lupton & Turner, 2018c; Manstan et al., 2021; Ng et al., 2022; Piwowar et al., 2023), use of food additives (Smith et al., 2022b; Tesikova et al., 2022) and microbial and chemical contamination (Tesikova et al., 2022). Similarly, potential users have concerns about product safety due to the manual handling of food and room-temperature printing process (Gosine et al., 2021; Hemsley et al., 2022; Smith et al., 2022a).

The perception of natural food is connected to how people perceive food safety and the associated risks (Hassoun et al., 2024). Differentiating naturalness from technological influence is vital in adopting new food technologies (Siegrist, 2007) as well as for the extent of food processing influencing product healthiness (Hassoun et al., 2024); otherwise, misperceptions of this relationship will continue affecting perceived 3D-printed food quality. 3DFP can ensure food safety with careful practices, similar to existing food technologies (Burke-Shyne et al., 2021). 3DFP companies could address consumer concerns, including food content, sensory qualities, and processing levels, to enhance 3DFP acceptance (Jayaprakash et al., 2020; Lupton & Turner, 2018c). Moreover, current industry users could show that the technology is secure and produce palatable food to alleviate public doubts about 3DFP (Rogers & Srivastava, 2021). Compliance with existing regulations is essential for ensuring the safety of 3D-printed foods (Burke-Shyne et al., 2021) but first, it is necessary to have clear guidelines of safety rules and parties' responsibilities, and involvement of government entities to develop regulations (Rogers & Srivastava, 2021).

2.3.3.2 Prior knowledge of 3DFP

Prior knowledge of 3DFP dictates the acceptance of 3DFP (Brunner et al., 2018) (Figure 2.2). Informed consumers present positive opinions of its benefits and are more interested in having a 3D food printer as a kitchen appliance (Mantihal et al., 2019) than uninformed individuals (Tesikova et al., 2022). Consumers generally lack knowledge about 3DFP (Brunner et al., 2018; Jayaprakash et al., 2020; Lunden et al., 2020; Lupton & Turner, 2018c; Manstan et al., 2021; Manstan & McSweeney, 2020; Ng et al., 2022), and subsequently struggle to grasp 3DFP's practical application (Lupton & Turner, 2018c) and be hesitant about having 3D-printed food at home due to perceived unfamiliar ingredients, skepticism about information, and concerns about food palatability (Kocaman et al., 2022).

Similar to uninformed consumers, novice industry users are captivated by the technology's novelty, amusement factor, and potential for creating food experiences (Burke-Shyne et al., 2021; Gosine et al., 2021; Hemsley et al., 2022; Smith et al., 2022a), contrasting 3DFP experts focus on 3DFP' practical advantages (Jayaprakash et al., 2020; Rogers & Srivastava, 2021). While potential users in healthcare or educational settings comprehend and react positively to the 3DFP concept, they express reservations about the foreseen experience required (Hemsley et al., 2022) or the effectiveness of the technology supporting users work (Gosine et al., 2021). Educational efforts to introduce 3DFP are necessary to increase 3DFP awareness and positive perceptions (Caulier et al., 2020; Talens et al., 2022).

2.3.3.3 Food and technology familiarity

Food familiarity influences consumers' perceptions and, consequently, the acceptance of 3D-printed foods (Figure 2.2). Consumers tend to be more receptive to 3D-printed confectionery and bakery products than meat or insect-containing snacks (Lupton & Turner, 2018b) as consumers are familiar with intricate designs of confections compared to unconventional foods such as alternative proteins (Manstan et al., 2021) or insects (Lupton & Turner, 2018c). Incorporation of unfamiliar or negative perceived ingredients leads to concerns about product content, sensory attributes, naturalness, and level of processing (Lupton & Turner, 2018c) or generates disgust among consumers (Lunden et al., 2020; Lupton & Turner, 2018b; Manstan et al., 2021). Consumers are more open to 3D-printed foods in food categories already recognized as ultra-processed than those usually considered healthy, such as vegetables or fruits (Lupton & Turner, 2018b).

In addition, consumers find it challenging to imagine the taste and texture of 3D-printed food, drawing on prior experiences with traditional foods to indicate product expectations (Kocaman et al., 2022). For instance, consumers anticipate familiar tastes in 3D printed pizza or pasta but different textures of layered mashed food with vegetables (Lupton & Turner, 2018c). According to healthcare professionals, 3D-printed textured-modified food has to resemble the original product to ease product acceptance (Smith et al., 2022a). Leveraging familiarity with well-accepted food categories can aid in product development strategies to increase acceptance of 3D-printed foods. Moreover, potential users and consumers associate 3DFP as an alternative technique to piping bags and molds (Hemsley et al., 2022; Lupton & Turner, 2018c). Using perceived similarities to familiar methods may help convey the 3DFP value proposition and overcome negative attitudes.

2.3.3.4 New food and new technology neophobia

Consumers' acceptance of 3DFP is influenced by their perceptions of new food technologies and products (Figure 2.2). The novelty of 3DFP has been linked to Food Technology Neophobia (FTN) and

Food Neophobia (FN). Individuals with 3DFP may respond differently about consuming the end-products, depending on their level of FN or FTN (Lee et al., 2021). Both high FTN and FN contribute to negative attitudes towards 3DFP and its products (Brunner et al., 2018; Ng et al., 2022). Fear stemming from unfamiliarity with 3D-printed food and perceived high processing levels contribute to consumers' negative attitudes (Brunner et al., 2018; Tesikova et al., 2022). Additionally, FN influences the perceived value of natural content and creativity of 3D printed products, while FTN affects the relation between natural content and hedonic value (Lee et al., 2021).

In contrast, people with low FTN and a strong willingness to try 3D-printed food express favorable attitudes toward 3DFP (Brunner et al., 2018; Feng et al., 2022; Ng et al., 2022). Technophilia correlates positively with beliefs in 3D-printed food environmental friendliness and healthiness (Manstan & McSweeney, 2020) and, alongside personal relevance, positively impacts the intention to taste 3D-printed foods (Mantihal et al., 2019; Ross et al., 2022). Receptiveness to novel food technologies and foods could elucidate populations likely to embrace 3DFP technology (Kocaman et al., 2022). For instance, societies that practice entomophagy might be more receptive to printed insect-enriched snacks (Lupton & Turner, 2018b) and frequent travelers who exhibit greater openness to food innovation could reflect receptiveness to taste 3D printed food (Piwowar et al., 2023).

2.3.4 Technology characteristics

2.3.4.1 Technology name

How a technology is described influences peoples' perceptions of it (Rogers, 1983; Tversky & Kahneman, 1981). The term "printing" has provoked unfavorable associations with non-food items such as plastic or paper, categorizing food as artificial, unhealthy, unnatural, or ultra-processed (Gosine et al., 2021; Mantihal et al., 2019; Tesikova et al., 2022). Moreover, it has created a frightening perception in users (Gosine et al., 2021) and has impeded the recognition of 3DFP benefits by consumers, resulting in cautious adoption (Brunner et al., 2018). Naming 3DFP differently is essential to tackle negative attitudes in both users and consumers. Otherwise, explanations of the technology's mechanism or references to familiar technologies are necessary to prevent undesired associations or misinterpretations.

2.3.4.2 Technology usability, effectiveness, and accessibility

3DFP must demonstrate superiority over existing methods to justify its utilization by potential users (Gosine et al., 2021). 3DFP has been considered more innovative and versatile than bread makers and sous vide devices (Talens et al., 2022), and when compared to industrial food processing techniques, 3DFP offers unprecedented food customization (Rogers & Srivastava, 2021). However, the current nascent stage of 3DFP impedes the realization of its relative advantages by householders and industry users. The current limited accessibility of the technology in the market, in terms of cost and availability, challenges its adoption. The cost of the technology may decrease as it becomes more widely implemented and available (Smith et al., 2022b). In addition, 3DFP experts and potential users in organizational settings consider that slow printing process and expensive printers challenge its application for large production volumes (Gosine et al., 2021; Hemsley et al., 2022; Rogers & Srivastava, 2021; Smith et al., 2022a) and hinder the cost benefits compared to current processes (Burke-Shyne et al., 2021). Even though potential users recognize the novelty-related cost of 3DFP, they consider that the cost does not justify the benefits of the technology (Smith et al., 2022b).

In addition, for 3DFP to become a viable alternative to piping bags or molds in healthcare settings, issues related to user-printer interaction, printer usability, food consistency, and waste generation during food ink setup need to be addressed (Hemsley et al., 2022). The greater the advantage a new technology offers over conventional methods, the more likely the technology will be adopted (Rogers, 1983). Industry 4.0 technologies, including 3DFP, strive to enable comprehensive digital transformation and sustainable development in the food value chain, cutting costs and time (Hassoun et al., 2023). 3DFP requires usability and scalability improvements to successfully demonstrate its capacities over conventional processing technologies. 3DFP developments should focus on improving processing efficiency and providing high-quality and accessible food products to guarantee food business profitability and consumer acceprtance (Hassoun et al., 2023).

2.3.4.3 Printing parameters and post-processing techniques

Single or multiple 3DFP parameters, such as infill (i.e., the percentage of material that makes up the internal structure), printing speed, and extrusion rate, can alter a product's sensory properties (Burkard et al., 2023), such as texture, taste and appearance. Product infill has been found to affect the texture of food products, ultimately influencing the overall liking (Mantihal et al., 2019). Print stability is a result of printing parameters; it is crucial to optimize printing parameters since products with lower fidelity (i.e., resemblance to the intended shape) have been shown to decrease liking of 3D printed foods (Chirico Scheele et al., 2021; Lille et al., 2020; Liu et al., 2020).

Postprocessing techniques can also impact the sensory characteristics of 3D-printed foods. Explored techniques, such as deep frying, baking, air-frying, steaming, microwaving, and refrigeration, can affect the stability of 3D-printed foods. This impact can be positive or negative, which depends on the product matrix before the post-processing treatment (Feng et al., 2021; Krishnaraj et al., 2019; Theagarajan et al., 2021). Post-processing treatments have an effect on sensory properties such as color and texture, adding a new dimension to 3D printing named as "4D printing"(Pereira et al., 2021). Treating 3D printed products with pH solutions (acidic, neutral, or alkaline) after printing has an impact on their color, flavor, and aroma; addition of a neutral or alkaline solution has shown an increase in liking compared to samples not treated post-printing (Phuhongsung et al., 2020).

2.3.5 Product characteristics

3D-printed food characteristics such as product customization, complex shapes, and food layering have been found to affect the products perceived sensory characteristics, which in turn influence the overall acceptance of the product. The degree of customization of food shapes (Chirico Scheele et al., 2021) and type of ingredients (Caulier et al., 2020; Chirico Scheele et al., 2021, 2023; Keerthana et al., 2020; Lille et al., 2020) have been found to increase product liking; more intricate shapes (Chirico Scheele et al., 2021) and ingredients fitting individuals' taste (Caulier et al., 2020) show greater liking. Layering allows 3D printing to create intricate food structures, which has been shown to increase product liking. When layering is not seamless, it can create a rougher texture, often less preferred (Bracken et al., 2022; Mantihal et al., 2019). Layering can also alter the food formulation without compromising liking by interchanging layers with different concentrations of the ingredient desired to be adjusted. This facilitates the decrease of sugar (Khemacheevakul et al., 2021) or salt content (Fahmy et al., 2021a) without altering the perceived sweetness or saltiness, respectively.

2.3.6 Societal factors: trust and perceived societal impact of 3DFP

Credibility issues regarding 3DFP's purpose, health, cost-effectiveness benefits, and food safety contribute to consumer skepticism (Lunden et al., 2020; Tesikova et al., 2022), which in turn might hinder consumer acceptance. Consumers are reluctant to 3DFP be widely accepted by society (Tesikova et al., 2022). Food processing automation is envisioned by integrating 3DFP as a cooperation system with kitchen personnel (Jayaprakash et al., 2020). Though it is positively considered for reducing food production costs (Manstan & McSweeney, 2020), the use of 3DFP for automating food processing is potentially related to decreased human labor (Charlebois & Juhasz, 2018). Integrating 3DFP into mainstream food production creates concerns about its societal impact on job displacement (Tesikova et al., 2022). Moreover, there is worry about the potential loss of social engagement experienced in traditional cooking practices among householders (Jayaprakash et al., 2020; Kocaman et al., 2022). This could result in using the technology as a supplementary tool rather than a widely adopted technology due to the potential impact of 3DFP on human life.

Conversely, some consumers anticipate positive impacts of 3DFP on meal experiences, improving the relationship with food and undergoing risk-free cooking (Kocaman et al., 2022). Similarly, users believe 3DFP offers social benefits, especially in healthcare, for enhancing the quality of life by providing appealing and safe food for individuals with specific dietary needs (Burke-Shyne et al., 2021; Hemsley et al., 2022). When 3DFP is considered purposeful and relevant to consumers, its utilization resonates (Jayaprakash et al., 2020). Understanding and addressing social dynamics within the 3DFP network (industry users and end-consumers) is important for widespread adoption (Jayaprakash et al., 2020), including incorporating 3DFP into industry processes and everyday people's lives. Trust in the information provided and in science (Kocaman et al., 2022; Ross et al., 2022) and information provided by trusted organizations (Lupton & Turner, 2018b) can help foster acceptance of 3D-printed foods. Trust propelled by experienced researchers or industry professionals could become a key factor in enhancing the technology's credibility.

Cultural differences may influence consumer acceptance, especially for novel food technologies (Giacalone & Jaeger, 2023). Consumers indicated that culture and religion affect their food choices (Lupton & Turner, 2018b). However, the correlation between cultural impact and 3DFP acceptance is understudied. Multicultural research that elucidates different social norms could further investigate the significance and distinction of attitudes toward 3DFP associated with cultures and expand the representation of interested users (Kocaman et al., 2022).

2.3.7 Situational factors

2.3.7.1 Information provided about 3DFP

Targeted information delivery is considered to develop positive attitudes towards 3DFP (Brunner et al., 2018; Ng et al., 2022) (Figure 2.2). While information about 3DFP may not change attitudes among individuals familiar with 3DFP (Brunner et al., 2018), it can turn novice individuals' cautious views into positive ones. Balanced information that addresses concerns transparently is crucial for mitigating skepticism toward 3DFP. Though the emphasis on 3DFP use of natural ingredients or 3D-printed food health is insufficient to overcome negative perceptions (Lupton & Turner, 2018c), providing information that clarifies the use of 3DFP, its minimal effect on food composition and showing its varied applications helps mitigate food neophobia and persuade individuals of 3DFP usefulness (Brunner et al., 2018).

Identifying the effect of information variations and forms could inform communication strategies to support positive attitudes. It has been found that, unlike the provided information about 3DFP, the label of 3D printing in a product increases the perceived product quality and can support a preference for 3D-printed foods over non-printed counterparts (Feng et al., 2022). Some studies have provided information about 3DFP using written descriptions or images, in vivo presentations, or focus groups to assess consumer perceptions (Appendix A). However, the influence of information format to promote 3DFP acceptance is understudied.

2.3.7.2 Observability of 3DFP

3DFP technology has to become commonly used for potential users to observe its successful application, consider implementation and realize technology benefits (Gosine et al., 2021). Showcasing the 3DFP technology and facilitating product tasting increase consumers' awareness (Ng et al., 2022). However, promoting public acceptance of 3DFP involves understanding people's daily food choices and preferences (Lupton & Turner, 2018b). Leveraging favorable situations where 3DFP can fit into everyday routines may support the acceptance and repeated consumption of 3D-printed food (Kocaman et al., 2022;

Motoki et al., 2022). Eating with friends or at festivals are avenues to increase acceptance of 3D-printed foods; advertisements illustrating these scenarios might provoke positive emotions (Motoki et al., 2022). Alternatively, food service businesses are convenient to introduce 3D printed food to consumers due to their widespread reach and exposure (Tesikova et al., 2022). Tasting 3D-printed foods at these establishments carries less risk to individuals than buying the technology for home use. However, FTN could be a significant barrier in the food service sector; therefore, market strategies, trust in science, and highlighting personal benefits could help overcome negative attitudes (Ross et al., 2022).

2.3.8 Research on 3DFP acceptance

2.3.8.1 Participants' location and profile

Participants' location in 3DFP acceptance research spans various developed countries, with a focus on Europe (n=26) and to a lesser extent, Asia (n=14). Some studies involved participants from different continents, such as Europe and Oceania (Burke-Shyne et al., 2021; Jayaprakash et al., 2020). Australia leads individual country studies (n=8), followed by Canada (n=5) and India (n=5). While most studies (n=42) focused on consumers' views on 3DFP, a limited number (n=6) explored experts' and potential users' perspectives at an organizational level. Engaged 3DFP experts include those with academic project experience, food industry professionals, and individuals within the 3DFP supply chain (Jayaprakash et al., 2020; Rogers & Srivastava, 2021). Potential users' perspectives in the industry include individuals with 3D printing or nutrition experience (Burke-Shyne et al., 2021), healthcare professionals assisting dysphagia patients (Hemsley et al., 2022; Smith et al., 2022a), and educators and students of food and nutrition (Gosine et al., 2021).

2.3.8.2 Food applications researched

Of reviewed studies, the inception of research on 3DFP acceptance, with or without product tasting, started in 2018 and 2019, with three published studies each year. The number of studies notably increased from 2020 onwards, with ten studies in that year, twelve in 2021, and sixteen in 2022. Half the studies focused on product tastings, mainly assessing consumer acceptance (Figure 2.3). Two-fifths (40%) of studies explored consumers' or users' perceptions of the 3DFP concept, including technology and product, through interviews or surveys, with one study considering both (Jayaprakash et al., 2020). The remaining 10% of studies investigated concept perceptions and sensory product tasting. Product sensory evaluations have focused on snacks, functional foods, and confectionery, emphasizing nutritional content alteration such as increased protein, fiber reduction, and reduced salt and sugar (Figure 2.3). Sensory tasting studies on sustainable foods have investigated alternative protein applications and the valorization of food by-products.

In studies investigating technology and product perceptions, healthcare, food sustainability and confectionery applications are predominant. Assessments of perceptions about 3DFP for healthcare applications have focused on texture-modified food, while sustainability applications have explored alternative proteins and sustainable ingredients (e.g., insects and algae). Applications that have received relatively less attention in the current research landscape are categorized as "others", including fast food, education, retail products, food service, innovation, and household use.

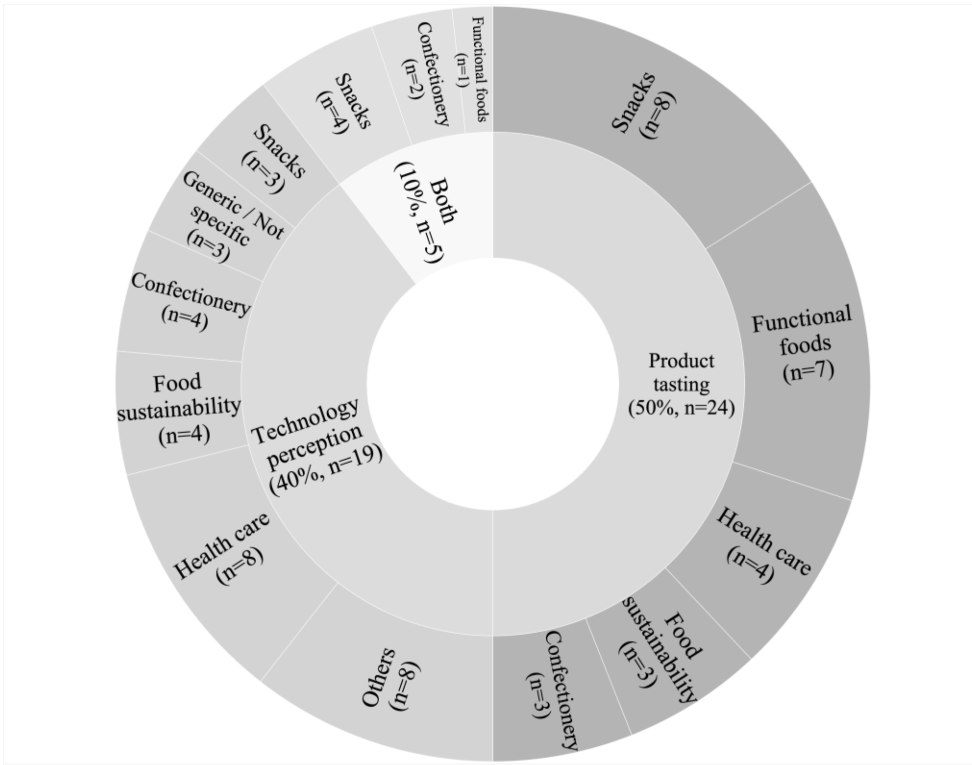


Figure 2.3. *Food applications in studies that assessed 3DFP perceptions, product tasting, and the combination of perceptions and product evaluations (Both)[1] . *Fast food, education, retail products, food service, innovation, and household use.*

2.3.8.3 Further research opportunities to assess users' perceptions of 3DFP

3DFP is recognized for potential contribution to environmental sustainability (Burke-Shyne et al., 2021; Gosine et al., 2021; Jayaprakash et al., 2020; Rogers & Srivastava, 2021), but some opinions suggest that 3DFP sustainability could be compromised due to food miles required for distribution if used for mass production (Burke-Shyne et al., 2021). People are more likely to embrace new food technology when they directly experience its benefits (Siegrist, 2007). In the case of 3DFP, individuals can experience 3DFP benefits by noting the product's physical and sensory aspects, as opposed to promissory environmental or nutritional benefits. Effective communication of 3DFP benefits is crucial when advantages are not directly observed (Lunden et al., 2020; Siegrist, 2007; Talens et al., 2022). However,

[1] The total number of applications may exceed the sum of grouped studies as the estimate considers multiple food applications assessed in single studies.

concrete case studies could demonstrate 3DFP's sustainability and health capabilities, providing valuable information for potential users in the industry or for consumers.

In addition, research on industry opinions examining their interest and the practical application of 3DFP is limited. Food products of reviewed studies highlight opportunities for further research in food sectors where 3DFP use is emerging, such as confectionery, alternative protein, and food service. Involving potential industry stakeholders in studies assessing these applications could provide relevant insights into businesses' receptiveness to 3DFP.

2.3.8.4 Further research opportunities to assess consumers' perceptions of 3DFP

Few studies have explored consumers' perceptions using actual 3D-printed food products, instead images of commercial 3D printed products or products that resemble 3D printed food characteristics have been used (Appendix A). Examining individuals' attitudes using actual 3D-printed food helps assess perceptions based on real experiences. However, the limited scale of desktop 3D food printers limits the samples required for a representative group of consumers. This poses challenges for sensory analysis preparation, as printing must be done well in advance, potentially risking the product's characteristics. Perceptions of 3DFP applications have focused on healthcare, especially for dysphagia diets. However, sensory assessments involving the actual target population are lacking. Using products resembling 3D-printed food products has helped evaluate sensory attributes and consumers' attitudes toward hypothetical 3D-printed foods (Feng et al., 2022; Manstan et al., 2021). This strategy could be used to assess acceptance among target audiences in healthcare facilities.

Contrasting 3D printed products' sensory profiles with conventional counterparts is crucial, especially for protein alternatives, where mimicry is essential for successful consumer adoption (Ramachandraiah, 2021; Tsai & Lin, 2022). Sensory analyses have helped to identify 3DFP's capability to arrange ingredients layer-by-layer, influencing the perception of food sensory attributes (Fahmy et al., 2021a; Khemacheevakul et al., 2021). Future research could explore how ingredient distribution affects the acceptance of protein alternatives, emphasizing 3DFP's significance over conventional processing methods used for available alternative proteins in the market.

2.4 Conclusions

This literature review identified that most studies assessing 3DFP acceptance and perceptions have focused on consumer insights with or without undergoing a product tasting. A minority of studies have explored users' perceptions, mostly from experts in the field of 3DFP in academia and the food industry and potential users in healthcare. Additionally, this article presents a framework highlighting the determinants influencing 3DFP acceptance among industry users and consumers, including technology features, product attributes, social variables and individual characteristics.

Factors influencing users and consumers differ, given their interaction with the technology. Factors affecting 3DFP users' acceptance include challenging technology usability, economic viability, process efficiency and lack of knowledge and observed use of 3DFP. Determinants of end-consumer acceptance encompass demographics, previous 3DFP knowledge, new food neophobia, new food technology neophobia, food familiarity, trust in science and information provided, exposure to 3DFP, and product attributes. In addition to food layering, printing parameters, and post-processing techniques, perceived food safety, healthiness, and naturalness affect consumer acceptance of 3D-printed foods.

Factors supporting further technology acceptance include convenient environments, renaming 3DFP, regulatory compliance, informing rational benefits over conventional methods, and leverage of food familiarity. While 3DFP offers many unique benefits, communication of these benefits must be tailored according to the different needs of both food industry users and consumers. Subsequent research is advised to refine the acceptance model by incorporating additional determinants or exploring connections among the factors.

Chapter 3 – A diffusion of innovation (DOI) analysis of 3D food printing adoption among food sector early adopters

3.1 Introduction

3D food printing (3DFP) is a novel technology consisting of a layer-by-layer food setting where the 3D shape is determined by a digital design made with a computational tool (Wegrzyn et al., 2012). 3DFP offers several unique features that appeal to the food industry, including the ability to customize food sensory attributes and nutritional content (Dankar et al., 2018), integrate digital gastronomy (Sun et al., 2015), design functional products for targeted populations (Portanguen et al., 2019), process a wide variety of foods (Kewuyemi et al., 2022), contribute to food sustainability integrating sustainable ingredients (Bhat et al., 2021; Handral et al., 2022; M. Wang et al., 2022) and adding value to food waste (Pant et al., 2023), and accelerate the product development process (Derossi et al., 2023). Due to the diverse benefits offered by 3DFP, its potential application spans multiple food-related sectors, such as food processing (Rogers & Srivastava, 2021), hospitality (Ross et al., 2022), and healthcare (Burke-Shyne et al., 2021).

The adoption of 3DFP technologies is nascent compared to the more mature application of 3D printing in other manufacturing sectors (e.g., medical equipment, tools, construction, automotive, and aerospace). 3DFP accounts for approximately 3% of the overall market of 3D printing (BCC, 2020; McWilliams, 2021). However, the 3DFP market is projected to undergo significant growth with a high Compound Annual Growth Rate (CAGR) of 16.1% from 2020 to 2025 (BCC, 2020). In 2019, bakery and confectionery products accounted for approximately 67% of the 3DFP market (BCC, 2020), although 3DFP prevalence in the food industry has expanded to other sectors, such as protein alternatives, pasta, food service, and healthcare food.

Given the early relevance of 3DFP in the food industry, some studies have discussed technology attributes that influence its applicability (Lee, 2021; Taneja et al., 2022). However, the market success of innovative food technologies such as 3DFP relies on the acceptance of both consumers and technology users (Jayaprakash et al., 2020; Siegrist & Hartmann, 2020). Most 3DFP research has chiefly concentrated on consumers' perspectives, neglecting the practical implications of adopting this technology from economic, social, and sustainability standpoints (Dabbene et al., 2018) by technology users.

Industry players are relevant as they consider techno-economic factors and consumer response to assess 3DFP adoption, but their perspectives have received little attention. Previous studies have examined business potential, maturity level, and business sustainability from individuals within the technology supply chain, including researchers, food processors, consultants, businesses using 3DFP, and equipment providers (Jayaprakash et al., 2020; Rogers and Srivastava, 2021). Potential adoption has concentrated in healthcare (Burke-Shyne et al., 2021; Smith et al., 2022a). Despite the vast array of benefits technology offers, it is suggested that successful business adoption is closely related to the technology's ability to meet specific market demands (Handfield et al., 2022). Moreover, Charlebois & Juhasz (2018) emphasized the relevance of diverse perspectives for 3DFP sustainability. However, factors influencing the effective adoption of 3DFP and its practical application in different areas of the food industry are underexplored.

The Diffusion of Innovation (DOI) framework has been frequently used to explore factors contributing to the successful adoption of innovation in diverse fields such as 3D printing (Handfield et al., 2022), blockchain for food supply chain (Yi et al., 2022), consumer segmentation (Brunner & Nuttavuthisit, 2019), digital technologies in farm management (Giua et al., 2021), and food service (Inwood et al., 2009). This model consists of a five-stage process-oriented approach: (1) learning about the innovation, (2) assessing its characteristics, (3) deciding on adoption or rejection, (4) implementing, and (5) confirming continuation or discontinuance of adoption (Khan & Woosley, 2011; Taherdoost, 2018). Moreover, it includes five aspects of successful innovation: the relative advantage over previous technologies, the compatibility with adopters' values, previous experience and infrastructure, the complexity of using and learning the technology, the feasibility of conducting trials, and the observability of the technology used in the social system. A positive perception of the innovation attributes is closely associated with a favorable adoption outcome (Rogers, 1983).

In addition, early adopters are the initial risk-takers drawn to innovation (technology), facing challenges and opportunities in its early stages; therefore, they are considered credible sources for guidance on implementing new technology (Rogers, 1983). Food businesses that have embraced 3DFP technologies in recent years are identified as early adopters (Nopparat and Motte, 2023). Examining the factors influencing early adopters' adoption experience with 3DFP in various food sectors could clarify technology readiness and prospects as they have practical and realistic insights into technology performance in real-world settings. Therefore, through the lens of the DOI framework, this study aimed to examine the factors that facilitate or hinder 3DFP adoption and the prospects of this technology by interviewing 3DFP food businesses' early adopters representing different food sectors. This approach to studying 3DFP adoption has not been previously explored.

3.2 Methodology

3.2.1 Participants

Employing purposive sampling (Creswell, 2014), thirty-seven businesses using 3DFP for commercial purposes were identified through online sources such as websites, LinkedIn, news articles, Instagram, and Facebook. Since the study focused on representativeness rather than exhaustiveness, recruiting businesses in different food sectors was relevant to highlight the different applications of 3DFP in the food industry. Potential participants were contacted through company email, telephone, or professional profiles (e.g., LinkedIn). Ten businesses expressed interest in participating in the study after receiving an information letter via email. One participant met exclusion criteria during the analysis phase, resulting in a final sample size of nine. Businesses were actively implementing 3DFP, and interviewees possessed knowledge about the adoption process of the technology in their business. The study protocol was approved by a Research Ethics Board at the University of Alberta (ID: 00120228), all participants completed informed consent, and participation was anonymous.

3.2.2 Data collection

Businesses from around the globe were interviewed through online, recorded, semi-structured, one-on-one sessions conducted on the Zoom® platform. The interviews, conducted in English, lasted from 45 to 60 minutes. Data collection took place from October to November 2022. An interview guide based on the stages of the DOI model adoption process was used to explore the businesses' experiences with technology adoption. This approach allowed for a well-organized narrative, tracking the evolution of adoption from inception to the present and future plans, while capturing knowledge sources, prior experiences, reasons for adoption, and insights on 3DFP characteristics based on DOI's five aspects of innovation. Afterward, participants were queried about 3DFP prospects, focusing on the most significant barriers and proposed solutions to its adoption (Appendix B) (Jayaprakash et al., 2020; Rogers and Srivastava, 2021). Due to the dynamic nature of the open-ended questions in semi-structured interviews (Creswell, 2014; Magaldi & Berler, 2018), follow-up questions were used to ensure effective coverage of planned topics. Data saturation (i.e., no new information gained from additional interviews) was reached after the ninth interview, which is appropriate for business research (Cassell et al., 2018).

3.2.3 Data analysis

Interview recordings were transcribed into text using the Zoom® application and cross-referenced with the original recordings to ensure accuracy. Semi-structured interviews allowed flexible participants' responses; therefore, an inductive and deductive analysis approach was utilized. Thematic content analysis, based on Rogers's DOI framework, was used for coding and analysis (Erlingsson & Brysiewicz, 2017; Matthews et al., 2016). Themes related to experience adopting 3DFP were grouped based on DOI process stages, while factors influencing 3DFP adoption were categorized into the participating food sectors and Rogers' five aspects of innovation (Handfield et al., 2022). Barriers and proposed solutions to 3DFP adoption were categorized into recurring themes identified across interviews (Burke-Shyne et al., 2021). NVIVO 1.7.1 (Lumivero, Denver, United States), a qualitative analysis software, was used for data organization. The research team ensured reliability and validity by discussing data coding and organization. Lastly, frequencies characterized participants' demographics.

3.3 Results and discussion

The first part of this section describes participating businesses' characteristics. Subsequent sections focus on presenting and discussing the adoption process of 3DFP among food sectors (3.4.2), exploring insights into 3DFP based on DOI's five aspects of innovation (3.4.3), and technology's prospects in terms of main obstacles and proposed solutions to 3DFP adoption (3.4.4).

3.3.1 Businesses characteristics

Nine businesses represented food sectors where 3DFP has been adopted; four from confectionery (C1, C2, C3, C4), two food service providers: a restaurant and a caterer (FS1, FS2), two protein alternatives businesses (PA1, PA2), and one food processor of healthcare food (H). Six businesses were located in Europe, two in North America, and one in the Middle East. Participants were categorized as micro and small enterprises, with five businesses having 1 to 10 employees, three with 11 to 21 employees, and one with 11 to 30 employees. Businesses had between one to five years of experience with 3DFP, with the earliest adoption in 2017.

3.3.2 Adoption process of 3DFP among food businesses

The adoption process 3DFP businesses experienced is illustrated in Figure 3.1. In the initial stages, businesses learned and became acquainted with 3DFP capabilities through communication channels and social interactions within the 3DFP network. Upon discovering that 3DFP could have a positive social impact, captivate public curiosity, and address specific consumer needs, businesses were encouraged to explore it. The resonance between 3DFP's novelty and innovative capabilities with their entrepreneurial spirit guided them to consider a business opportunity in applying 3DFP. Participants adopted the technology, either constructing the printers from scratch or adapting 3D plastic printers for food application (n=5), acquired ready-built 3D food printers (n=3), or received a printer from another 3DFP business for on-site testing (n=1).

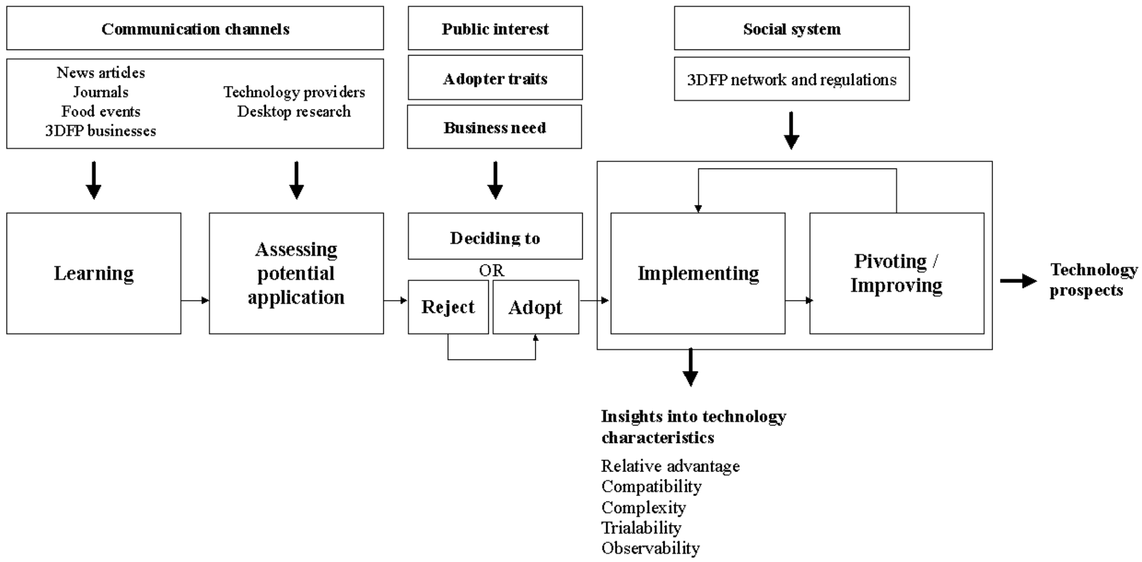


Figure 3.1. *Model of 3DFP technology adoption process based on businesses' experiences and DOI's framework.*

Achieving desirable food appearance and texture through 3DFP proved valuable for protein alternatives, food service, and healthcare food businesses. The alternative protein sector found 3DFP suitable for meeting consumer demands for appealing, meat-like fillets. In healthcare, although initially hesitant about using food-filled cartridges, they considered 3DFP for its capability to use fresh ingredients in texture-modified foods for individuals with dysphagia, improving their joy of eating. Food service businesses were intrigued by the opportunity to offer unique customer experiences through innovative dishes using 3DFP. Meanwhile, confectioneries were similarly motivated by the opportunity to innovate, connect technology with gastronomy, and the observed potential rising market during showcases and client interactions. Resistance to innovation can result from challenges in using or obtaining technology (Kleijnen et al., 2009), as experienced by FS1 and C1, who postponed adoption due to cost and difficult accessibility but embraced the technology because of 3DFP's novelty and ability to create purposeful products. These considerations demonstrate the relevance of technological, social, and adopters' variables in businesses adopting 3DFP technologies.

Based on the DOI model, potential adopters develop perceptions of an innovation before adopting it (Rogers, 1983). Businesses adopted 3DFP over a year before interviews, providing insights into 3DFP characteristics (3.4.3) from actual implementation rather than anticipated perceptions. Businesses encountered challenges while implementing the technology (3.4.4). However, instead of discontinuing its use, they identified solutions to sustain its viability (3.4.4) and sought support from the 3DFP network

(3.4.5), reflecting a pragmatic approach to achieving sustainable adoption. This journey exposes businesses as early adopters for actively exploring and embracing the technology to enhance its practical application and continuous improvement (Rogers, 1983).

3.3.3 Insights into 3DFP characteristics based on the DOI's five aspects of innovation

Considering DOI's five aspects of successful innovation, determinants of 3DFP implementation identified from businesses' experience are shown in Figure 3.2. All five aspects influenced businesses' 3DFP implementation with some sector-specific variations (explored in the following sections; Appendix C). 3DFP relative advantage, compatibility, and complexity pertained to technical attributes often found in adopting food innovations (Chang et al., 2017; Douglas & Donaldson, 2023). Trialability and observability of 3DFP, on the other hand, were influenced by adopters' traits (active collaboration and interest in entrepreneurship and novel technologies), communication channels, and the growing 3DFP network.

Relative advantage	**Compatibility**	**Complexity**	**Observability**	**Trialability**
Product attributes ✓ Complex & detailed design ✓ Product quality • Nutrient retention • Fresh ingredients **Convenience** ✓ Time-saving ✓ Storage-saving **Customization** ✓ Shape ✓ Food formulation **Sustainability** ✓ Food up-cycling ✓ Less plastic use **Process cleanliness** **Technology functionality** ✓ 3D structure and food internal structure ✓ Multiple ingredients at once Autonomous production **Versatility** ✓ Use for different food applications	**Business need** ✓ Complexity in design ✓ Fast prototyping ✓ Versatility ✓ Customization ✓ High-mix, low-volume capacity or vice versa ✓ Technology integration **Business values** ✓ Technology novelty ✓ Social impact ✓ Environmental impact **Business previous experience** ✓ With 3D printing ✓ With other 3DFP applications	✓ Challenging product development (Product formulation vs. product stability) ✓ Software learning curve ✓ Hardware learning curve ✓ Post-processing effect	**Showcasing 3DFP** ✓ Performing demonstrations ✓ Including 3DFP in menus ✓ Getting media attention ✓ 360 photography to showcase products **Observed 3DFP** ✓ 3DFP observed in confectionary, pasta, and alternative protein manufacturing. ✓ 3DFP used in care homes. ✓ 3D printed products in restaurants.	✓ Entre firm collaboration ✓ Self-developed equipment ✓ Owned 3D food printer

Figure 3.2. *Determinants of 3DFP adoption based on DOI's five aspects of successful innovation.*

3.3.3.1 Relative advantage of 3DFP over conventional methods

Potential adopters believe 3DFP should offer relative advantages surpassing traditional methods to validate its adoption (Gosine et al., 2021). Interviewed businesses indicated that 3DFP's distinct advantages lie in enhancing product design and quality through operational efficacy, intricate design creation, versatility, convenience, and customization. However, the relevance of such advantages and the method competing with 3DFP vary based on the food application. 3DFP superiority was compared to molding, extrusion, blending, traditional cooking, and depositing methods. Molding was the most extensively discussed in confectionery, restaurant, and healthcare food businesses, while traditional cooking and single extrusion were compared in the catering and alternative protein sectors, respectively.

3DFP excels in creating complex, unique, and appealing food designs not easily achieved by conventional molding, blending, and single extrusion methods. In confectionery and healthcare, 3DFP produces delicate figures through precise, thin layers, enhancing visual appeal. This concurs with nutrition and 3D printing experts' opinions of 3DFP outperforming manual labor and blended meals, delivering consistent texture and appealing shapes (Burke-Shyne et al., 2021). In alternative proteins, unlike single extrusion, a commonly used technology in protein alternatives (Wang et al., 2022), 3DFP replicates sensory profiles through complex food structures, achieving textures and appearance akin to animal-based products while retaining food nutrition content: "*The only way that we realize we could do something like that at scale where we can actually give people what they want is through 3D printing*" (PA2).

3DFP, unlike other methods, suits high-mix, low-volume, or vice versa food production. Compared to single extrusion, it alters ingredients to create uneven alternative protein product appearances with the potential of large-scale production. Meanwhile, confectionery benefits from its precision in low-volume production and intricate detailing, outperforming depositing technologies. Moreover, enabling detachment from a single application with diverse designs and ingredient use, 3DFP competes in addressing supply chain sustainability. It facilitates food up-cycling of visually unappealing produce or by-products, and plastic utilization reduction through 3D-printed edible utensils, as acknowledged by PAs and FSs, respectively. Furthermore, as per confectionery businesses, 3DFP is advantageous for its cleanliness over molds or water-cutting techniques and reduction of storage requirements and plastic waste by using digital files instead of molds, leading to potential cost savings, maximization of resources and diversification of product offerings.

3DFP's relevance on food customization varies by sector. In food service and confectionery, 3DFP is seen as supplementary tool for food customization despite cost and time benefits. In contrast, customization in alternative protein and healthcare food is vital for meeting specific customer needs in design, nutrition, and sensory properties. While businesses find numerous options appealing, some have faced (FS1 and C3) consumer confusion, hindering product adoption. Prioritizing consumer preferences in 3DFP product development encourages the adaptation of technology capabilities.

3.3.3.2 Compatibility with business needs, values, and previous experience

3DFP adoption was influenced by its affinity with adopters' previous experiences, values, and needs. Previous experience with similar technologies, knowledge, and technical skills on innovation are predictors in early adopters' behavior (Dedehayir et al., 2017), evidenced in some confectionery and alternative protein businesses. Having knowledge of 3D printing for non-food applications enabled the adoption of 3DFP technologies by easing the learning curve, particularly for those who adapted or developed a 3D printer for foods. This made their 3DFP implementation and adjustments easier than food service businesses, who were challenged with the use of the printer. In addition, an outward focus on addressing social, health, and environmental concerns, the adopter's self-described entrepreneurship trait, and technology neophilia and interest supported 3DFP adoption, characteristics often seen in early adopters (Dedehayir et al., 2017).

3DFP compatibility with specific business needs was favored due to technology capabilities in food customization, versatility, fast prototyping, high detailing with low production volume, and vice versa, along with technology integration. 3DFP aligned respectively with businesses' goals among the five participating sectors to provide consumers with desired food qualities and enhanced sensory experiences, indirectly supporting the 3DFP implementation in businesses. In the food service and confectionery sector, 3DFP complements the need for visually appealing designs, crucial for offering a captivating consumer experience. In healthcare, 3DFP aids in stimulating appetites by creating attractive food, but the variety of designs is limited due to soft food's lack of post-printing product stability, as observed by H. Alternative protein businesses noted that environmental and health concerns drive consumers' product adoption but demand substitutes that resemble animal protein appearance and texture, conveniently accomplished with 3DFP by producing whole cuts and layered structures. Balancing options with consumer preferences is crucial for adoption, especially recognizing preferences for familiar food shapes in healthcare (Smith et al., 2022b) and protein alternatives (Ramachandraiah, 2021).

Moreover, the versatility of 3DFP makes it potentially adaptable for diverse, new applications. For healthcare food, it could encourage vegetable consumption among children by making attractive, funny shapes and accommodating individual taste alterations experienced by oncology patients by customizing food formulations. 3DFP's fast prototyping ability has enabled the exploration of new business opportunities, such as utilizing and adding value to low-cost waste streams like meat scraps to produce appealing meat products. With the potential to use diverse foods, businesses have expressed their interest in other food materials to expand 3DFP applications beyond confectionery; however, available food inks in the market are limited, hindering the extent of 3DFP applications. Most importantly, 3DFP can support the pursuit of innovation in the food industry due to its versatility, but its application should be purposeful: *"It should eagerly solve a problem, and that's where the adoption takes place"* (H).

3.3.3.3 Complexity factors of using and learning 3DFP technology

The ease of using and learning a new technology impacts its adoption (Rogers, 1983), as noted for 3DFP implementation. Businesses found difficulties with software use, product development, and printer operation. The technology's complexity was mainly due to its steep learning curve, demanding hands-on experience to understand printer's functionality. For instance, businesses (Cs and H) learned that temperature control is a crucial printing parameter impacting product quality. Strict temperature control is vital for texture-modified foods to avoid hard edges, which can be a risk for individuals with swallowing difficulties, and for timely solidification and smooth chocolate tempering to prevent blooming. Yet businesses were eager to explore 3DFP because of its benefits, seeking help from experts to overcome challenges. Their readiness to adopt the technology while surmounting hurdles is typical of early adopters (Rogers, 1983). Once they mastered the printer, using it and training others became easy, according to FS2.

To balance profitability, product stability, taste, and creativity, businesses required extensive testing to understand interactions among food formulation, ingredient behavior, and printer conditions. They learned that controlling food formulations and process conditions is paramount for food stability and desired attributes. For instance, choosing between compound and non-compound chocolate depends on printability, influenced by printing temperature and chocolate's properties. Meanwhile, the stability of alternative protein products relies on formulation and post-processing, emphasizing the importance of food layering and ingredient cohesion to achieve meat-like cuts. Software interaction presented challenges for businesses, especially those unfamiliar (FS1 and FS2) with 3D printing. C1 stated that simplifying the software interface could ease accessibility but limit experimentation with printer parameters. This suggests that software usability and flexibility improvements should consider the user's specific needs and skills.

3.3.3.4 Observability of 3DFP in the food industry

Observability, the degree of visibility, is crucial for adopting new technologies like 3DFP (Rogers, 1983). Businesses stressed the importance of enhancing visibility and promoting 3DFP to encourage wider acceptance. They undertook initiatives of showcasing the technology at events and in digital menus using 360 photos, and attracting media attention through news articles and international TV coverage. On the other hand, their observations about the 3DFP market indicate that 3DFP is still in its early stages in the food service and confectionery sectors while expanding into protein substitutes, pasta processing, and food up-cycling domains. The alternative protein sector was seen as particularly promising for 3DFP application due to the growing number of companies in this field and the increasing availability of 3D-printed meat in European restaurants.

3.3.3.5 Trialability of 3DFP

The technology's trialability (ease of trying) was challenged in the food business, seeking accessible means to test the technology regardless of the limited available or affordable printers. Businesses embraced 3DFP through collaboration, modifying existing technologies, creating or acquiring pre-built printers. Some (C1 and FS2) opted to partner with start-ups or technology providers, establishing a 3DFP community to develop or test printers. Trying different printers allowed understanding diverse platforms, but developing printers based on specific needs required technical skills, as indicated by H and PAs. The alternative venues to grasp 3DFP capabilities demonstrate 3DFP's early development stage and early adopters' risk-taking behavior when embracing the new technology (Rogers, 1983).

3.3.4 Technology prospects: significant barriers and proposed solutions to 3DFP adoption

Businesses described the key factors necessitating resolution to advance the adoption of 3DFP in the food industry as economic viability, technological feasibility, consumer awareness and perception, and overall adoption rate (Figure 3.3). These interconnected factors hinder the complete integration of 3DFP in food businesses, impeding the widespread adoption across the supply chain. A significant hurdle is the small capacity and high cost of 3DFP, resulting in premium pricing for products that discourages consumer acceptance and, consequently, affects 3DFP economic viability. Moreover, large enterprises' slow uptake of 3DFP creates limited market demand and scarcity of products, reducing 3DFP visibility for end-consumers and potential technology users. In addition, consumers have negative or minimal impressions due to a lack of knowledge, challenging end-product acceptance. Overall, the current stage of 3DFP adoption indicates that technological maturity, improved market dynamics and public perception, and education endeavors are required to become successful.

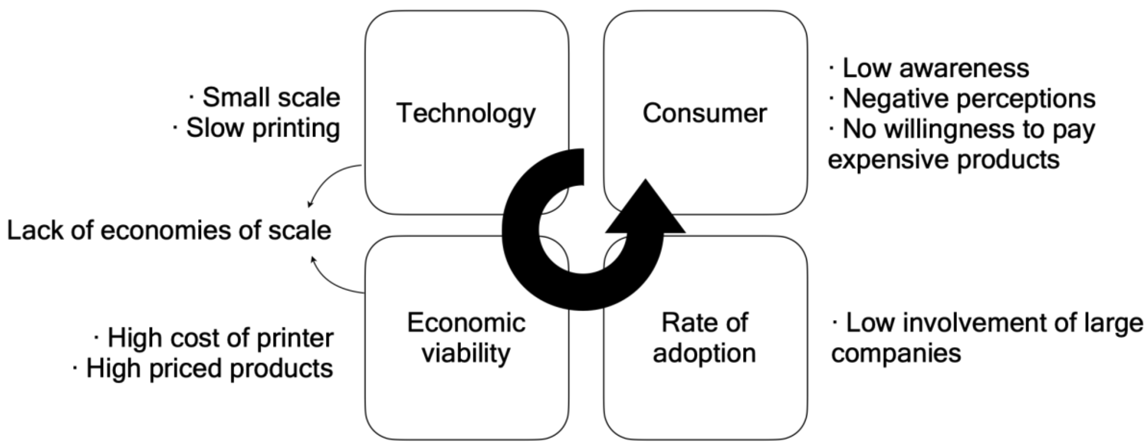


Figure 3.3. *Barriers to 3DFP adoption across the food industry identified by businesses.*

3.3.4.1 Technology feasibility of 3DFP

3DFP's small capacity and slow printing pose significant barriers to successful adoption by food businesses, confirming opinions from potential users in healthcare (Burke-Shyne et al., 2021; Smith et al., 2022a) and industry experts (Rogers and Srivastava, 2021). For 3DFP to succeed on a large scale in sectors such as alternative protein, healthcare food, and catering, limited production capacity must be addressed. Food service businesses have explored printing beforehand and using multiple printers to tackle capacity barriers, which have effectively met production volume, but faster production is desired to achieve profitability. In sectors with higher production volumes, such as alternative proteins, using multiple printers is impractical due to the high cost of printers and space limitations imposed by hardware design. 3DFP readiness for mainstream production is in the development stage. In these sectors, scaling up has presented challenges in maintaining temperature control and managing cleaning processes; however, businesses' main goal is to concentrate efforts on making 3DFP a feasible venture by increasing its scale so they can expand beyond a narrow niche-market scope. It is important to note that production scales vary across food sectors. Considering the production scale required by SMEs versus large food processing companies could help develop technologies that meet their respective needs.

3.3.4.2 3DFP economic viability

Businesses confirmed potential users and experts' perceptions of 3DFP high cost (Rogers and Srivastava, 2021; Smith et al., 2022b); challenges usually present in technology innovations, such as novel cultured-meat (Guan et al., 2021) or 3D printing technologies (Won et al., 2022). Standard and automated production are economically advantageous, as stated by C3. While 3DFP is recognized for mass customization (Sun et al., 2015), balancing customization and mass production is crucial for viability, especially in high-volume sectors such as alternative protein and healthcare. Food customization in food service and confectionery is viable if orders meet a minimum of printed items. However, customization brings food delivery challenges due to fragile designs, requiring customized packaging solutions or limited geographic distribution, as noted by C1 and FS1.

To address profitability, businesses (FSs and Cs) offer costly products to non-price-sensitive segments or prioritize (H and PAs) scaling up technology for high throughput. Alternatively, some confectionery businesses develop and sell printers to compensate low margins selling printed products. Increasing scale and decreasing printer costs are necessary for economies of scale, making products accessible and affordable, consequently facilitating 3DFP sustainability and successful adoption.

3.3.4.3 Consumer perception of 3DFP technology

Businesses found that despite the novelty of 3DFP, consumer knowledge is lacking, and upon learning, perceptions are often negative, aligning with previous findings (Burke-Shyne et al., 2021; Lee et al., 2021). Businesses observed consumers being impressed by the printing process but expressing worries about product safety and edibility, often associating 3D-printed food with artificiality, high processing, and non-food materials, echoing previous consumer studies (Lupton & Turner, 2018c; Ross et al., 2022; Tesikova et al., 2022) which indicated that unfamiliarity with 3DFP led to food safety, taste, and health benefits assumptions. These concerns are usually seen with emerging food technologies (Siegrist & Hartmann, 2020) leading to skepticism or resistance, particularly concerning food safety.

As per businesses' experiences, it was identified that depending on food familiarity, consumer attitudes vary. Consumers express more positive feedback regarding 3DFP for confections than alternative proteins. Thus, they suggested entering markets aligned with consumer familiarity to overcome hesitancy. Leveraging consumer familiarity with complex designs has aided 3DFP adoption in the confectionery sector. Presenting 3DFP as a secure and appealing alternative to conventional food production is key to overcoming consumer skepticism (Rogers and Srivastava, 2021). Describing technology functionality using familiar methods, such as regular piping bags, can address positive consumer attitudes, as mentioned by C4.

3DFP education is important to increase 3DFP consumer acceptance (Brunner et al., 2018; Feng et al., 2022). Businesses proposed market education, communication strategies, and channels to facilitate consumer feedback and encourage positive attitudes, such as avoiding technical terminology to prevent consumers from doubting the product, creating spaces for consumers to encounter 3D-printed food and encourage technology adoption, and collaborating food service and processors for promoting 3DFP industry penetration and consumer awareness.

3.3.4.4 3DFP rate of adoption

Businesses selling the printer noted that limited sales volumes prompt higher technology pricing, impeding broader adoption across enterprises. Therefore, they are engaged in limited profitable markets (Nopparat and Motte, 2023). Technological advancements combined with large companies involved are undoubtedly necessary to accelerate adoption and reduce costs, as emphasized by (Mavri et al., 2023), who assessed 3D printing adoption. Though a few large pasta and confectionery companies are involved, more large companies and investors are needed to increase 3DFP visibility. However, high cost and unsuitable production lines were anecdotal reasons for large companies not adopting 3DFP, suggesting that 3DFP's successful adoption across the food industry relies on the scaling up of the technology.

3.3.5 3DFP network and regulations

Social norms, such as regulations, influence the spread of innovation (Rogers, 1983). Regulatory frameworks for new foods often lag behind the rapid pace of technological advancements, creating uncertainties for developers, users, and consumers (Henchion et al., 2017; Tyndall et al., 2024), now extending to 3DFP, particularly in alternative protein sectors to enter new markets across different countries. In contrast, the absence of regulations has facilitated food service using 3DFP, justifying even more the importance of such a sector in facilitating 3DFP adoption.

Moreover, even though industry experts commented that lack of regulations on intellectual property rights for 3D printing recipes constrains technology adoption (Rogers and Srivastava, 2021), businesses (C1 and FS1) expressed that sharing non-trademarked designs facilitated technological exploration and creativity, emphasizing the relevance of 3DFP network and supportive regulations to encourage technology exploration and food innovation. Active collaboration, both within and outside the 3DFP community, was instrumental in successfully implementing 3DFP, a common factor for emerging innovations (Schiefer & Deiters, 2022).

3.4 Study limitations and future work

As 3DFP is in its early stages with few businesses utilizing it, the small population of adopters resulted in a limited sample size. A small sample worked to explore 3DFP utilization in different sectors purposively. Although early adoption may not fully demonstrate a successfully established business using 3DFP, it reveals insights into the technology's early adoption stage, which is usually relevant for potential adopters (Rogers, 1983). Investigating potential adopters' perspectives of early adopters' insights in each sector could help identify the relevance of factors interfering potential 3DFP adoption.

Interviewees talked about 3DFP adopted by householders as a kitchen appliance. While some businesses considered this a promissory segment for 3DFP, others did not find it suitable for 3DFP's intended capacity. Few studies have investigated householder willingness, with varying receptiveness, either positive (Mantihal et al., 2019) or reluctant (Tesikova et al., 2022). This business model could influence 3DFP technology manufacturers (Nopparat and Motte, 2023) and shape the 3DFP scope of adoption. Future research can explore feasibility and adoption strategies, identifying suitable applications for household settings.

Lastly, limited studies have examined consumers' perceptions of 3DFP focused on specific applications, such as food service (Ross et al., 2022). Participating businesses anticipated promising 3DFP applications in food service, confectionery, and alternative protein sectors. Examining consumer perception in these sectors could uncover distinct attitudes and targeted strategies, contributing to the framework of 3DFP adoption from consumer's role.

3.5 Conclusions

This study identified factors influencing early 3DFP adoption, including technological, social, economic, and adopter-related aspects from food business experiences. Using the process-oriented adoption approach of the DOI model, businesses engaging with 3DFP showed commitment as early adopters due to their innovative mindset for implementing 3DFP. Analysis of DOI's five aspects revealed that 3DFP's relative advantage, compatibility, and complexity pertained to technical and novelty attributes, while trialability and observability of 3DFP were influenced by adopters' active collaboration, entrepreneurial behavior, and communication channels.

Operational efficiency, design complexity, versatility, customization, convenience, and support for sustainable solutions were the characteristics of technology superiority over conventional methods. Compatibility with adopters' entrepreneurial spirit, prior experience with 3D printing, and alignment with business needs were crucial for successful adoption. The applicability of 3DFP varied by the food sector, demonstrating the need to prioritize technology features based on each sector's specific requirements for successful adoption.

Technology scale-up and involvement of large organizations are paramount to improving 3DFP economies of scale, but the former is essential to evidence a large adoption rate. Strategies to address negative consumer perceptions include market education, leveraging food and technology familiarity, and labeling the technology differently. Overcoming adoption barriers is crucial for increasing awareness and interest. Successful adoption requires considering market dynamics, technological maturity, public perception, and education efforts.

This exploratory study presents insights into 3DFP adoption in the food service, confectionery, alternative protein, and healthcare food processing sectors. Further research within the assessed sectors could expand the present study findings by identifying strategies to support potential 3DFP adoption within each sector.

Chapter 4 – Readiness for adoption of 3D food printing among food industry sectors

4.1 Introduction

3D food printing (3DFP) has gained attention for its potential to disrupt food processing and consumption, offering several advantages to large-scale organizations and small and medium enterprises (SMEs) in the food processing, hospitality, and institutional sectors of the food industry. These advantages include precise control over ingredient placement, portioning, design (Sun et al., 2018), food versatility (Gholamipour-Shirazi et al., 2020), food customization (Escalante-Aburto et al., 2021), rapid product development (Derossi et al., 2023), process efficiency (Dankar et al., 2018), unique gastronomic experiences (Lupton & Turner, 2017), and the potential to address food sustainability (Yoha & Moses, 2023).

Early adoption of 3DFP has been observed among SMEs and a few large organizations in confectionery, alternative protein, pasta, healthcare food manufacturing, and hospitality food sectors (Guaqueta et al., 2024; Rogers & Srivastava, 2021). However, 3DFP's integration into the food industry is still in its early phases, necessitating increased technology adoption across food sectors to enhance 3DFP awareness (Manstan & McSweeney, 2020; Tesikova et al., 2022) and acceptance (Gosine et al., 2021; Guaqueta et al., 2024). Pro-innovation bias can cause individuals to concentrate on the advantages of an innovation while disregarding its potential adoption limitations (Rogers, 1995). Most 3DFP studies have focused on 3DFP technical and product innovative features, and consumer acceptance. However, the success of integrating innovations into the food supply chain relies on businesses' receptiveness to embrace it (Schiefer & Deiters, 2022). Uncovering perceptions of 3DFP among potential industry adopters can reveal opportunities, barriers, and strategies related to its adoption.

Our previous study assessed the adoption of 3DFP among food industry early adopters through the lens of Roger's Diffusion of Innovation (DOI) theory (Tornatzky & Klein, 1982). Through interviews with industry representatives, we identified that perceptions of the attributes of innovation of 3DFP technology, such as its advantages over previous technologies, compatibility with adopters' processes, values and needs, and the complexity of learning and utilizing 3DFP technology, influence adoption decision-making and its implementation (Guaqueta et al., 2024). Perceptions of an innovation may differ depending on potential adopters' extent of knowledge of the technology and innovativeness (i.e., attitudes toward adoption of innovations and acceptance of uncertainty) (Rogers, 1983). The DOI framework describes the adoption trajectory of an innovation based on individuals' innovativeness; 'early adopters' embrace innovations based on intuition, the 'early majority' wait for others to adopt before considering it, the 'late majority' adopt established innovations, and 'laggards' adopt innovations only when they become necessary (Yi et al., 2006). Assessing individuals innovativeness could help classify them and identify strategies for the different categories of adopters (Rogers, 1983) to encourage the adoption of 3DFP technology.

According to 3DFP early adopters' experiences, technological determinants of adoption were dependent on its food sector application (Guaqueta et al., 2024), highlighting the importance of perceptions toward the technology in a specific food application. 3DFP has the potential to alter Canada's food production system (Charlebois & Juhasz, 2018). Canada's 3DFP market is growing, representing over 5.5% and 15% of the global and North American market, respectively (BCC, 2020). In Alberta, Canada, food processing, food service, and healthcare sectors contribute to the economy (Statistics Canada, 2023). SMEs dominate the food service and manufacturing sectors (Statistics Canada, 2023), along with the provincial healthcare system, which relies heavily on patient and nutrition food services for optimal patient recovery and well-being (Alberta Health Services, n.d.). It has been suggested that bakers and restaurants (Mantihal et al., 2019), and caterers and healthcare players (Rogers & Srivastava, 2021) could drive 3DFP adoption throughout the food industry. 3DFP uptake in food processing for healthcare, confectionery, and food service has been positive in food businesses around the globe (Guaqueta et al., 2024). Opinions in these sectors can offer insights into perspectives and strategies for potential 3DFP adoption in Alberta and unexplored regions where these sectors hold relevance.

Therefore, this study aimed to investigate the readiness for 3DFP adoption by confectionary and bakery, food service, and healthcare food service sectors in Alberta, Canada. The secondary objectives of this study were to examine food sectors' 1) extent of current knowledge about and adoption of 3D printing technologies and innovativeness, 2) perceptions of 3DFP based on its benefits, features for implementation, and DOI's attributes of innovation, and 3) willingness and perceived relevance of strategies to adopt 3DFP.

4.2 Methodology

4.2.1 Participants

Individuals from confectionery, bakery, food service, and healthcare food service sectors were purposively recruited (Creswell, 2014). These sectors were included as there has been a positive uptake of 3DFP in such sectors, identified in the first study (Chapter 3). Primary food producers (e.g., businesses dedicated to oilseeds, grains, or produce) were not included as 3DFP is designed to be a processing technique, belonging to a stage ahead of primary food products. Individuals (n=815) from confectionery, bakery and food service sectors were invited through publicly available business emails, with follow-ups via email and phone calls to increase participation. Afterward, the survey invitation was disseminated through the provincial food processing association e-news, hospitality association administrative contact, the Canadian Food Innovation Network platform, and an industry workshop at the Leduc Food Processing Development Center held in January 2024.

Potential participants in healthcare organizations were identified by areas where 3DFP might be relevant based on its applicability. Individuals in healthcare food services, including procurement, meal planning, quality control, registered dietitians, food service management, and speech-language pathologists, were reached through a representative within their provincial health organization and a survey advertisement in the Canadian Nutrition Society newsletter. The survey was opened from October to January 2024. The survey was piloted by a healthcare representative and two members from the University of Alberta's sensory and consumer research group. Participants provided informed consent, and responses were anonymous. This study was approved by the Health Research Ethics Board at the University of Alberta (Pro00121507).

4.2.2 Data collection

The survey was presented using Qualtrics® and comprised three sections: participants' characteristics; perceptions of 3DFP; and receptiveness and strategies to adopt the technology (Figure 4.1; Appendix D). In the first section, participants indicated their organization's food sector, location, size, and role within their organization (So, 2022). Then, they indicated their organisation's innovativeness by their level of agreement with statements that describe DOI's adopter categories (Yi et al., 2006) using a 5-point Likert scale anchored from 'strongly disagree'(1) to 'strongly agree'(5). Prior knowledge about non-food 3D printing (3DP) and 3DFP, and the extent of 3DFP knowledge (what it is, how it works, how to operate it) were assessed using 5-point scales anchored from 'extremely'(1) to 'not at all'(5) (Brunner et al., 2018), and 'not at all'(1) to 'extremely'(5), respectively. The source of information (Steenhuis & Pretorius, 2016) and awareness of 3DFP applications were queried. Current adoption of 3DP and 3DFP were assessed using yes, no, and 'do not know' options.

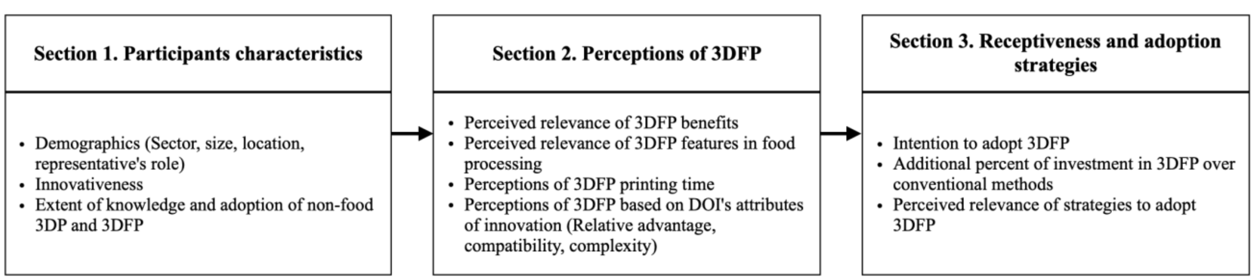


Figure 4.1. *Survey framework.*

In the second section, participants assessed potential 3DFP application within their sector-specific context: confectionery and bakery, food service, or healthcare food service. Confectionery and bakery sectors were combined due to the similar applications of 3DFP. Descriptive scenarios drawn from real business experiences with 3DFP (Guaqueta et al., 2024) were developed to highlight technology benefits and features in food processing for each sector. Images of 3D-printed foods were used to illustrate sector-specific products. The perceived relevance of 3DFP benefits and features for implementation were assessed using a 5-point scale ranging from ‘not at all’(1) to ‘very’(5) and a ‘do not know’ option (Jayaprakash et al., 2020; Won et al., 2022).

A current 3DFP adoption barrier is the slow speed of production. Therefore, perceptions of speed of production of a single-extruder 3D food printer were evaluated by presenting images of 3D printed food items with their printing time, using a scale from ‘very slow’ to ‘very fast’ with a midpoint of ‘just about right’. An image of a 3D-printed drumstick-shaped puree with a 7-minute printing time was presented to healthcare food service participants, while chocolate lettering with a 4-minute printing time was presented to individuals in the confectionery and bakery, and food service sectors.

Perceptions of 3DFP based on DOI’s attributes of innovation, relative advantage, compatibility, and complexity (Figure 4.1), were assessed through constructs describing each attribute, adapted from previous studies (Atkinson, 2012; Moore & Benbasat, 1991). Complexity was examined inversely as ease of use and learning. Participants scored their level of agreement with the constructs using a 5-point Likert scale anchored from ‘strongly disagree’(1) to ‘strongly agree’(5).

In the last section, participants indicated their interest in adopting 3DFP on a 5-point scale from ‘not at all’(1) to ‘extremely’(5) (Tesikova et al., 2022). They then indicated the additional amount (in percentage) they were willing to invest in a 3D food printer over currently implemented technology using a slider (0-100%) with a ‘not interested’ option. Participants indicating willingness to invest in 3DFP technology identified potential technology replacements. Relevance of adoption strategies was rated on a 5-point scale anchored from ‘not at all’(1) to ‘extremely’(5) (Won et al., 2022). Participants could suggest additional strategies they considered relevant.

4.2.3 Data analysis

Data were analyzed using Statistical Package for the Social Sciences (SPSS, 29.0.1.0). Participants’ sector, business size, location, representative’s role, extent of knowledge, current adoption, source of knowledge, known applications, and printing time perception of 3DFP were analyzed using descriptive statistics. Participants were grouped as knowledgeable and not knowledgeable about non-food 3DP and 3DFP. Participants were categorized based on their organization size: small (up to 49 employees), medium (50-299), and large (> 300).

Data were assessed for normality using the Shapiro-Wilk test, revealing a non-normal distribution ($p \leq 0.05$). Thus, non-parametric tests were employed to analyze participants’ responses. Participants’ innovativeness, perceived relevance of 3DFP benefits and features for implementation and adoption strategies, and perceptions of 3DFP based on DOI’s innovation attributes were statistically analyzed within each sector using the Friedman test. Differences across sectors, business size, and knowledge about 3DP and 3DFP were assessed using the Kruskal Wallis test and Mann-Whitney U-test, as appropriate. Dunn’s post-hoc test was performed for statistically different results to identify the difference

(Marino, 2018). The p-values of multiple comparisons were adjusted with Bonferroni correction. ‘Do not know’ responses were excluded from multiple variable comparison analyses. A significance level of 0.05 was used in all statistical tests. Comments regarding potential technology replacements and other adoption strategies were analyzed by content analysis (Erlingsson & Brysiewicz, 2017).

3DFP adoption in Alberta’s food sectors is an area that had not been studied previously, which required adapting constructs to assess relative advantage, compatibility, and complexity to the specific context of food sectors in Alberta. Hence, an exploratory factor analysis (EFA) was conducted using principal axis factoring to validate these constructs (Chong et al., 2009). The Kaiser-Meyer-Olkin test confirmed the data’s adequacy (0.855) (Mavri et al., 2023). An oblique promax rotation was chosen for EFA because factors aligned with simple structure criteria with correlations over 0.3 (Thurstone, 1947). Eigenvalues of factors were greater than one, and construct loadings from the EFA exceeded 0.5, indicating their significance within their respective factor and the three factors’ distinctiveness (Igbaria et al., 1995): relative advantage, compatibility, and complexity. The total variance explained by these factors was 75.17%, of which relative advantage contributed 51.64%, followed by compatibility (12.53%) and complexity (11%) (Appendix E). Factors Cronbach’s alpha exceeded 0.85, indicating good reliability of the constructs. Spearman’s rho correlation coefficients were employed to evaluate correlations between factors and the intention to adopt 3DFP.

4.3 Results

4.3.1 Participant characteristics

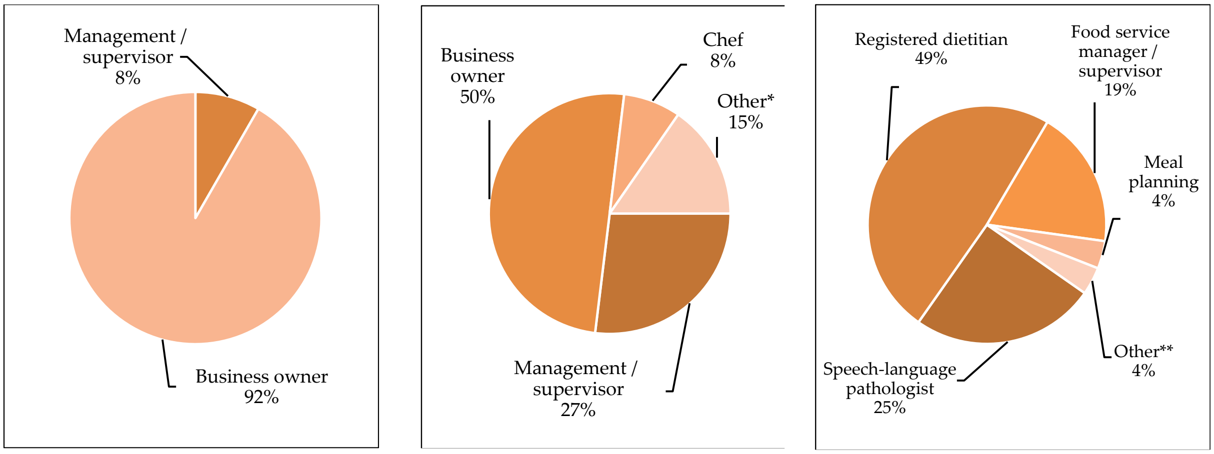
4.3.1.1 Participant demographics and innovativeness

Appropriate number of responses for a purposive sample is based upon the research questions and researchers’ criteria; Sample sizes ranging from greater than 30 to less than 500 are deemed appropriate (Sekaran, 2003). Of 195 initial participants, a total of 118 respondents completed the survey, with high participation from healthcare food service (68%), followed by food service (22%), and confectionery and bakery sectors (10%) (Table 4.1; Appendix F). All or nearly all (89-100%) confectionery and bakery, and food service businesses were SMEs. The majority (85%) of participants in healthcare food service indicated working in large organizations, reflecting Alberta’s province-wide healthcare system. Most confectionery and bakery, and food service businesses (92-96%) were concentrated in the metropolitan areas of Edmonton and Calgary, mirroring the province’s population density distribution. Healthcare food service organizations were evenly distributed across Edmonton, Calgary, and the central area between the two cities. Over three-quarters of food service (77%) and all the confectionery and bakery (100%) businesses were represented by owners and managers, while nearly half of healthcare food service participants were dietitians (49%), followed by speech-language pathologists (25%) and food service supervisors (19%) (Figure 4.2).

Table 4.1. *Participant demographics, adoption, knowledge of non-food 3DP and 3DFP technologies, and innovativeness in confectionery and bakery (n=12), food service (n=26), healthcare food service (n=80) sectors.*

	Confectionery and Bakery	**Food service**	**Healthcare food service**
		n (%)	
Size of Organization (Number of Employees)			
1 - 9	8 (67)	11 (42)	-
10 - 29	3 (25)	8 (31)	1 (1)
30 - 49	1 (8)	2 (8)	4 (5)
50 - 99	-	2 (8)	3 (4)
100 - 299	-	-	4 (5)
300 or more	-	3 (12)	68 (85)
Location			
Northern Alberta	-	-	9 (11)
Edmonton and area	6 (50)	14 (54)	28 (35)
Central Alberta	-	1 (4)	19 (24)
Calgary and area	5 (42)	10 (38)	17 (21)
Southern Alberta	1 (8)	1 (4)	7 (9)
Current adoption of a non-food 3D printer			
Yes	1 (8)	3 (12)	7 (9)
No	11 (92)	23 (88)	25 (31)
Do not know	-	-	48 (60)
Current adoption of 3DFP			
No	12 (100)	26 (100)	54 (68)
Do not know	-	-	26 (32)
Current knowledge about non-food 3DP[1]			
Knowledgeable	6 (50)	9 (35)	12 (15)
Current knowledge about 3DFP[2]			
Knowledgeable	4 (33)	9 (35)	16 (20)
Current extent of knowledge about 3DFP[3,4]		Mean (sd)	
Know what 3DFP is	4.5 (0.6)	4 (0.7)	3.5 (1.1)
Know how 3DFP works	4 (1.4)	3.7 (0.5)	3.3 (1.3)
Know how to use 3DFP	2.5 (1.3)	1.9 (1.1)	1.4 (0.9)
Innovativeness[4,5]			
Early adopters	2.3 (1.4)	3 (1.3)	2.2 (1.1)^{A}
Early Majority	3 (1.4)	3.5 (1.3)	3.7 (0.9)^{B}
Late Majority	3.3 (0.9)	3.6 (1.5)	4.2 (1.0)^{C}
Laggards	3 (1.2)	3.4 (1.4)	4.1 (1.0)^{C}

[1]Knowledgeable is "extremely" to "moderately" on a 5-point scale. [2]Knowledgeable is "extremely" to "slightly" on a 5-point scale. [3]Responses from participants knowledgeable about 3DFP. [4]Agreement to each item characterizing willingness when adopting innovations on a 5-point scale anchored from "strongly disagree"(1) to "strongly agree"(5). [5]Different superscripted letters within a sector indicate statistical difference ($p \leq 0.05$).



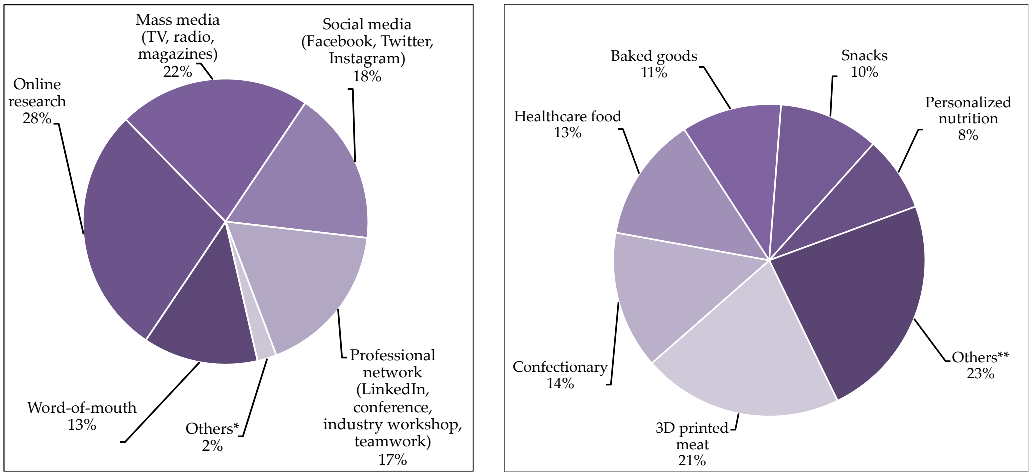
(a) **(b)** **(c)**

Figure 4.2. *Study participant organizational role by food sector. (a) Confectionery and Bakery (n=12); (b) Food service (n=29); (c) Healthcare food service (n=80). *Marketing, production, and research working areas. **Administrative, R&D, and management positions*

Healthcare food service participants indicated significantly higher agreement with statements characteristic of 'late majority' and 'laggard' adopters than 'early adopters' and 'early majorities' (Table 4.1.). This indicates that participants generally adopt established innovations. There were no significant differences in the innovativeness among food service, and confectionery and bakery participants.

4.3.1.2 Extent of adoption and knowledge of 3DP and 3DFP

Half of participants (50%) did not have a non-food 3D printer and over three-quarters (78%) did not have a 3D food printer. Over two-fifth (41%) and one-third (32%) of participants in healthcare food service were unsure whether their organization owned a non-food 3D printer and a 3D food printer, respectively (Table 4.1). Nearly one-quarter of participants were knowledgeable about 3DP (23%) and 3DFP (25%); knowledge about 3DP did not vary by sector. Among those knowledgeable about 3DFP, most (93%) had slight knowledge, and only two individuals (in the confectionery and bakery sector) self-identified as extremely knowledgeable. Knowledgeable individuals across sectors shared the pattern of having a good understanding of what 3DFP is and how it works with notably lower confidence in knowing how to operate the technology.



(a) **(b)**

Figure 4.3. *Among all participants (n=118) (a) Source of knowledge about 3DFP; (b) Identified 3DFP applications. *at school. **pasta, fine dining, catering, beverages.*

Awareness of new technologies relies on communication channels and social interactions (Rogers, 1983). Internet sources, mass and social media, and professional and personal networking have played a key role in informing about 3DFP across the food sectors (Figure 4.3a). The most known 3DFP applications by participating food sectors were 3D printed meat, confectionary, and healthcare food (Figure 4.3b).

4.3.2 Perceptions of 3DFP

4.3.2.1 Perceived relevance of 3DFP benefits

There were statistically significant differences in the relevance of 3DFP benefits within confectionery and bakery, and healthcare food service sectors. In confectionery and bakery, the importance of the 3DFP benefits of using natural ingredients, achieving consistent and precise food items, and creating visually appealing and customized designs was greater than the use of food-by products ($p \leq 0.05$) (Table 4.2).

In healthcare food service, improving patient appetite and eating experience, food visual appeal, texture customization, and food attribute preservation were the most important technology benefits. Nutrition customization was similarly important to texture customization, but texture customization was significantly more important than design customization. Moreover, the benefit of using fresh ingredients was more important than the use of pre-prepared foods ($p \leq 0.05$). The novelty of 3DFP was one of the less relevant benefits in healthcare food service, and confectionery and bakery sectors.

In the food service sector, 3DFP benefits were statistically similarly relevant ($p > 0.05$), ranging from neutral to somewhat important (Table 4.2). The relatively high importance of repurposing food by-products or unappealing produce in this sector contrasts with the low relevance given to food by-product utilization in confectionery and bakery.

Table 4.2. *Mean[1,2] of the relevance of sector-specific 3DFP benefits in confectionery and bakery (n=12), food service (n=22-26)[3], and healthcare food service sectors (n=73-77)[3].*

Confectionery and Bakery		**Food service**		**Healthcare food services**	
3DFP Benefit	Mean (sd)	3DFP Benefit	Mean (sd)	3DFP Benefit	Mean (sd)
Use of natural ingredients	4.5 (1.2)^{c}	Use of fresh ingredients	3.9 (1.6)	Improvement of patient eating experience	4.8 (0.7)^{b}
Precise and consistent production	4.1 (1.5)^{bc}	Consumer experience	3.9 (1.5)	Improvement in patient appetite	4.8 (0.7)^{b}
Food design customization	4.1 (1.5)^{bc}	Use of natural ingredients	3.8 (1.6)	Make visually appealing food	4.8 (0.7)^{b}
Visually appealing and memorable products	4.1 (1.5)^{bc}	Food ingredient versatility	3.8 (1.5)	Food texture customization	4.7 (0.7)^{ab}
Product innovation	3.7 (1.5)^{ab}	Repurposing food by-products or visually unappealing produce	3.7 (1.6)	Preservation of food taste, aroma, and color	4.7 (0.8)^{ab}
Fast customization	3.5 (1.6)^{ab}	Plastic reduction by creating edible utensils	3.6 (1.4)	Food nutrition customization	4.5 (0.9)^{ac}
Food ingredient versatility	3.3 (1.8)^{ab}	Food design versatility	3.5 (1.5)	Present pureed foods in their original shape	4.4 (0.9)^{ac}
Delicate food designs	3.1 (1.9)^{ab}	Elevate menu offerings	3.4 (1.7)	Food ingredient versatility	4.4 (0.9)^{ac}
Complex food designs	3 (1.8)^{ab}	Fast customization	3.3 (1.6)	Use of fresh ingredients	4.3 (0.9)^{ac}
Saving storage space for food designs in SD card	2.9 (1.8)^{ab}	Food design customization	3.3 (1.5)	Food design versatility	4.2 (0.9)^{acd}
Food design versatility	2.8 (1.7)^{ab}	Technology novelty	3.1 (1.3)	Food design customization	4 (1.1)^{cd}
Technology novelty	2.6 (1.2)^{ab}	Delicate and aesthetic food designs	3 (1.5)	Use of natural ingredients	4 (1.2)^{acd}
Use of food additives	2.3 (1.5)^{ab}	Showcase 3D food printer on-site	3 (1.3)	Use of pre-prepared food	3.6 (1.2)^{de}
Use of food by-products	2 (1.2)^{a}	Complex designs	2.7 (1.4)	Use of food additives	3.1 (1.2)^{e}
				Technology novelty	2.6 (1.3)^{e}

[1]Mean of relevance from 'not at all' to 'very' on a 5-point scale. [2]Different superscripted letters within a sector indicate statistical difference ($p \leq 0.05$); lit-wise comparison excluding 'do not know' responses: confectionery and bakery n=12, food service n=22, healthcare food service n=65. [3]Range of responses excluding 'do not know' responses.

4.3.2.2 Perceived relevance of 3DFP features for implementation

There were statistically significant differences in the relevance of 3DFP features for implementation in the healthcare food service sector. The most important features were cost per serving, printing time, equipment maintenance, large quantity production, ease of cleaning, and technical support ($p \leq 0.05$) (Table 4.3). Ingredient sourcing, whether developed on-site or purchased from a third party, was the least important feature for 3DFP implementation in healthcare food service.

Although there were no significant differences in the perceived relevance of 3DFP features within food service, and confectionery and bakery sectors, their opinions were not significantly different from healthcare food service, except for the relevance given to large-quantity production and printing time. For healthcare food service, large production quantity was significantly more important than for food service and confectionery and bakery, and printing time was significantly more important than for food service ($p \leq 0.05$).

In addition, organization size had a significant effect on the relevance of large quantity and production speed. For participants in large-sized organizations, large quantity production and processing time of 3DFP was significantly more relevant than for small businesses ($p \leq 0.05$). Based on the images of 3D-printed food items presented with their respective production time, 3DFP's printing time was categorized across sectors as very slow. Current knowledge about 3DP and 3DFP did not influence the perceived relevance of technology features ($p > 0.05$).

Table 4.3. *Mean[1,2,3] relevance of 3DFP features for implementation in confectionery and bakery (n=11-12)[4], food service (n=22-26)[4], and healthcare food service sectors (n=66-75)[4].*

	Confectionery and Bakery	**Food service**	**Healthcare food service**
3DFP Feature		Mean (sd)	
Ability to purchase 3D printed items from a third-party	3 (1.7)	3.4 (1.5)	3.7 (1.1)^{dcb}
Autonomous process	2.9 (1.6)	3.5 (1.5)	3.6 (1.2)^{dcb}
Cost per serving	4 (1.7)	4 (1.6)	4.6 (0.9)^{ae}
Ease of cleaning process	4.1 (1.8)	3.9 (1.5)	4.4 (1)^{ae}
Equipment maintenance	4 (1.7)	3.9 (1.6)	4.4 (1.1)^{ae}
Ingredients developed on-site	2.7 (1.7)	3.3 (1.7)	3 (1.2)^{d}
Ingredients purchased from a third-party	2.8 (1.6)	3.3 (1.4)	3.2 (1.2)^{d}
Large quantity production	3.3 (1.5)^{A}	3.5 (1.6)^{A}	4.4 (1)^{aeB}
Level of expertise	3.8 (1.7)	4 (1.5)	4.1 (1.2)^{cbe}
Possibility of food experimentation	3.7 (1.7)	3.7 (1.6)	3.6 (1.1)^{dcb}
Post-processing required	3.3 (1.5)	3.4 (1.5)	3.5 (1.3)^{dcb}
Printing time	3.9 (1.7)^{AB}	3.6 (1.5)^{A}	4.5 (0.9)^{aeB}
Required food preparation	3.2 (1.8)	3.5 (1.5)	4.1 (1.1)^{cbe}
System refill and cleaning by personnel	3.7 (1.8)	3.6 (1.5)	4.1 (1.1)^{cbe}
Technical support	4 (1.7)	4 (1.6)	4.3 (1.1)^{ae}
	Local delivery 4 (1.7)	Packaging customization 3.2 (1.6)	Delivered frozen food 3.5 (1.2)^{dcb}
	Special packaging needed 2.9 (1.7)	Process waste 3.6 (1.4)	Production on-site 3.3 (1.2)^{dc}

[1]Mean relevance from 'not at all' to 'very' on a 5-point scale. [2]Different lowercase superscripted letters indicate statistical difference within a sector ($p \leq 0.05$); lit-wise comparison: confectionery and bakery n=9, food service n=23, healthcare food service n=56 excluding 'do not know' responses. [3]Different uppercase superscripted letters indicate statistical differences across sectors ($p \leq 0.05$). [4]Range of responses excluding 'do not know' responses.

4.3.2.3 Perceptions of 3DFP based on DOI attributes of innovation

There were no significant differences among sectors in the perceptions of 3DFP based on the DOI attributes of innovation; relative advantage, compatibility, and complexity (ease of use and learn) (p>0.05). Participants' perceptions of 3DFP's relative advantage over conventional food processing methods ranged from somewhat disagree to a neutral stance (Table 4.4), except for healthcare food service participants, who indicated a slight but statistically significant increase in the agreement of 3DFP improving the quality of work over conventional food processes. Food service participants agreed more on the ease of learning than utilizing the technology ($p \leq 0.05$). Nonetheless, participants generally were neutral toward 3DFP's relative advantage, compatibility, and easiness.

Perceptions of 3DFP relative advantage, compatibility, and ease of use and learning were positively correlated to the intention to adopt 3DFP (Table 4.4). The correlation of 3DFP compatibility and intention to adopt was moderate and stronger (0.669) than with the perceived relative advantage (0.430) and complexity of 3DFP (0.389). This potentially contributed to the significantly higher agreement of healthcare food service participants with 3DFP compatibility with their organization's vision, values, and needs, than existing operations ($p \leq 0.05$). Current knowledge of 3DP and 3DFP did not influence perceptions of 3DFP relative advantage and compatibility but had a statistically significant effect on the perceived ease of use and learn ($p \leq 0.05$); knowledgeable participants agreed more on the ease of learning and utilizing the technology than not knowledgeable individuals.

Table 4.4. *Mean[1,2,3] agreement by food industry sector with constructs describing DOI attributes of innovation, and correlation of factors (attributes) with 3DFP adoption.*

Factor, Mean[1] (sd)	Confectionery and Bakery (n=12)	Food service (n=26)	Healthcare food service (n=80)
	Mean (sd)		
Relative advantage, 2.8 (1.2)			
Using 3DFP would enable organization efficiency over conventional food processing.	2.7 (1.4)	3.1 (1.3)	2.6 (1.1)[a]
Using 3DFP would make it easier for your organization's employees to do their job over conventional food processing.	2.5 (1.3)	3.1 (1.3)	2.5 (1.1)[a]
Using 3DFP would reduce your organization's cost structure over conventional food processing.	2.3 (1.4)	3.1 (1.2)	2.5 (1)[a]
Using 3DFP would give your organization's employees greater control over their work over conventional food processing.	2.7 (1.3)	3.2 (1.3)	2.8 (1.1)[ac]

Using 3DFP would improve your organization's quality of work over conventional food processing.	2.9 (1.6)	3.4 (1.3)	3.3 (1.1)^{bc}
Compatibility, 3.3 (1.2)			
3DFP would be compatible with the vision of your organization.	2.8 (1.5)	3.2 (1.4)	3.7 (1.1)^{b}
3DFP would fit with the values of your organization.	2.8 (1.4)	3.4 (1.3)	3.8 (1.0)^{b}
3DFP would fit your organization's need	3.0 (1.2)	3.2 (1.5)	3.6 (1.1)^{b}
3DFP would be compatible with existing operations in your organization.	2.7 (1.3)	3.0 (1.4)	2.8 (1)^{a}
Complexity (Ease of Use and Learning), 3.1 (1.0)			
Learning to operate 3DFP would be easy for my team and I.	3.3 (1.0)	3.5 (1.0)^{b}	3.0 (0.9)
3DFP would be easy to use.	3.4 (1.0)	3.2 (1.1)^{a}	2.9 (0.9)

[1]n=118. [2]Mean of level of agreement from 'extremely disagree' to 'extremely agree' on a 5-point scale. [3]Different superscripted letters indicate statistical differences within each factor per sector ($p<0.05$).

4.3.3 Intention and strategies to adopt 3DFP

4.3.3.1 Intention to adopt 3DFP

Over two-thirds (63%) of participants were moderately to extremely interested in adopting 3DFP (Figure 4.4). No significant differences were found across the sectors. Current knowledge of 3DP and 3DFP did not impact adoption intentions ($p>0.05$), while the size of the organization did ($p\leq0.05$). The moderate to high interest in adopting 3DFP in participants from large-sized organizations (3.2±1.3) was statistically similar to small-sized organizations (2.8±1.4) ($p>0.05$), but significantly different from the slight interest of medium-sized organizations (2.0±1.0) ($p\leq0.05$). Over two-thirds (64%) of participants indicated willingness to invest at least 1% more in 3DFP over the technology they currently use, while the remaining 36% confirmed their disinterest in adopting 3DFP. Of 57 participants moderately to extremely interested in adopting 3DFP, 47% were willing to invest an additional 1 to 25% over a conventional method they use, 28% of participants from 26% to 50%, 18% from 51 to 75%, and lastly 7% from 75 to 90%.

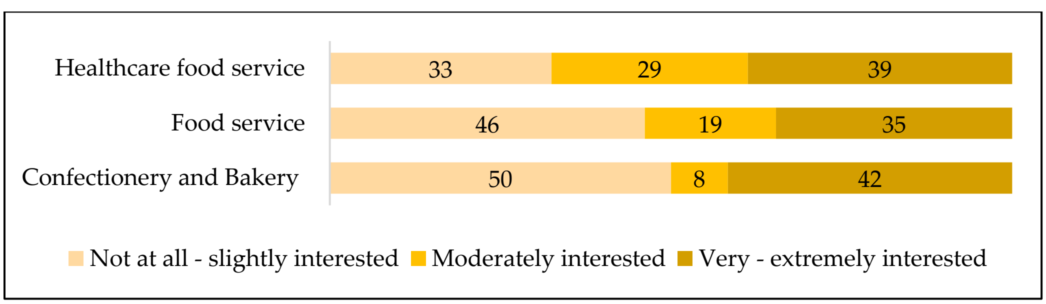


Figure 4.4. *Distribution (%) of respondents' intention to adopt 3DFP in participating industry sectors; confectionery and bakery (n=12), food service (n=26), and healthcare food service (n=80).*

Participants provided diverse perspectives on the role of 3DFP as an alternative to current practices, including 3DFP as a substitute for traditional tools such as blenders, molds, and handmade methods or as a replacement for currently sourced foods such as pre-pureed and pre-molded foods. Others believed 3DFP would not replace existing technology but rather be an additional kitchen tool or potentially replace human labor. Additionally, others dismissed the need for current technology replacement, citing the requirement of cooking ingredients or reliance on pre-prepared foods, overlooking the capacity of 3DFP to use prepared foods. The common compared method to 3DFP in confectionery and bakery was hand-made sculpting and decorations. Similarly in food service 3DFP was identified as a potential replacement of cooking methods made by the personnel or regular cooking equipment, whereas in healthcare food service 3DFP was compared to molds, blenders, pre-made frozen foods, and staff labor.

4.3.3.2 Perceived relevance of strategies to support 3DFP adoption

There were no statistical differences in the relevance of adoption strategies across food sectors ($p>0.05$) (Table 4.5). Trials of full-scale implementation projects, government initiatives, and promoting knowledge and training were rated moderate to very important by participants from all three sectors. Organizational size and current knowledge of 3DP and 3DFP did not affect the perceived relevance of adoption strategies, except for the effect of current 3DP knowledge on the importance of promoting successful case studies; participants who were not knowledgeable considered case studies as more important (3.8±1.1) than those who were knowledgeable (3.2±1.4) ($p \leq 0.05$).

Some participants proposed supplementary strategies for 3DFP adoption, including ensuring printer availability, demonstrating research-backed success and scalability for adoption in large organizations, showcasing evidence of benefits in their sector, and comprehensive cost analyses covering labor, food preparation time, and maintenance. Lastly, some participants shared their apprehensions regarding the societal implications of 3DFP and the food quality perceived as artificial, unnatural, or not tasty.

Table 4.5. Mean[1,2] relevance of strategies to support 3DFP adoption across the food sectors of confectionery and bakery (n=12), food service (n=26), and healthcare food service (n=80).

Strategy	Confectionery & Bakery	Food service	Healthcare food service
	Mean (sd)		
Promoting successful case studies	3.3 (1.4)	3.4 (1.3)	3.9 (1.1)[a]
Collaboration around 3DFP	3.3 (1.4)	3.3 (1.5)	3.7 (1.1)[a]
Training in 3DFP	3.9 (1.4)	3.6 (1.3)	3.9 (1.2)[a]
Promoting knowledge of 3DFP	3.5 (1.4)	3.6 (1.3)	3.8 (1.1)[a]
Government incentives	3.5 (1.7)	3.7 (1.4)	3.9 (1.3)[a]

A trial project to commence full-scale implementation	3.7 (1.4)	3.7 (1.4)	4 (1.2)[a]
Private financial support	3.1 (1.7)	3.5 (1.4)	2.9 (1.3)[b]

[1]Mean relevance from 'not at all' to 'extremely' on a 5-point scale. [2]Different superscript letters within a sector indicate statistical difference ($p<0.05$)

4.4 Discussion

Representatives from food service, confectionery and bakery, and healthcare food services sectors were surveyed about their knowledge, perceptions, and receptiveness towards 3DFP, resulting in the identification of opportunities and current barriers to the readiness to adopt 3DFP by these food industry sectors. No study participants had adopted 3DFP, and three-quarters of respondents were not knowledgeable about 3DFP, indicating that the perspectives about 3DFP of participants in this study represented those of novice individuals. 3DFP 'self-assessed' knowledgeable individuals identified applications not widely adopted in the food industry, such as 3DFP for alternative proteins and healthcare food, as well as the more well-known application in confectionery. This indicates a growing awareness of 3DFP industry applications among these individuals. That aligns with current trends such as the rise of alternative protein sources, increasing demand for health-conscious products (Galanakis, 2024), and the enduring popularity of indulgent treats (Barry Callebaut, 2023).

3DFP offers a variety of benefits to the food industry, but their relevance differs based on sector-specific needs and priorities (Guaqueta et al., 2024). Professionals in healthcare food service highlighted 3DFP's ability to improve patients' eating experience and appetite, customize food textures, visual food appeal, and conservation of food taste, aroma, and color. This echoes healthcare practitioners' opinions on 3DFP capabilities in creating visually appealing food (Hemsley et al., 2022), improving patients' quality of life through texture-modified foods (Smith et al., 2022b) and bringing back the joy of eating(Burke-Shyne et al., 2021). While some healthcare professionals acknowledged customization of food design (Hemsley et al., 2022; Smith et al., 2022b) and food texture (Burke-Shyne et al., 2021), for healthcare food service participants, food texture customization was more important than food design customization.

Confectionery and bakery participants underscored 3DFP's use of natural ingredients, precision in production, food design customization, and creation of memorable products. The latter two benefits concur with the value proposition in a potential business model for chocolate manufacturers proposed by 3DFP experts (Jayaprakash et al., 2020). In food service, 3DFP benefits were all similarly important, including natural and fresh ingredients, consumer experience, food customization, versatility, and intricate designs. In addition, the importance of sustainability, particularly in reducing food waste, was emphasized in the food service sector, indicating a growing awareness of environmental concerns (Lins et al., 2021). This concurs with individuals' viewpoints from the 3DFP supply chain (Rogers & Srivastava, 2021). Relevant 3DFP benefits across sectors aligned with early adopters' perspectives (Guaqueta et al., 2024), confirming sectors' different priorities of 3DFP applicability. Innovations are more likely to be adopted when they meet a genuine need, making them meaningful to adopters (Rogers, 1983). 3DFP offers a wide range of potential applications in the food industry, but the possibilities of being successfully adopted rely on the match of useful technology attributes to an unsolved or need-for-improvement need.

Key technology features for 3DFP implementation among sectors are cost per serving, technical support, technology ease of cleaning, maintenance and efficiency. It has been found that the learning curve required and the high investment and processing cost of the technology may pose challenges for adopting 3DFP in healthcare (Hemsley et al., 2022), food businesses (Guaqueta et al., 2024; Rogers & Srivastava, 2021), and educational settings (Gosine et al., 2021). Thus, developments of 3DFP should consider improving the affordability and usability of the technology to become a technology for mainstream production where high volume and low cost of products are often prioritized. This may encourage adoption among the ‘early majority’ who prioritize practicality when considering adopting innovations (Yi et al., 2006). While the speed of production of 3DFP depends on the food item formulation, size and design (Rogers & Srivastava, 2021), it is a concern for food sectors, reaffirming viewpoints of 3DFP early adopters (Guaqueta et al., 2024), nutrition and 3DP experts (Burke-Shyne et al., 2021), and educators (Gosine et al., 2021). The healthcare food sector highlighted the relevance of the need for high production capacity, given the usual demand of large-size organizations; thus, addressing 3DFP capacity limitation is necessary to resonate with food sector needs.

Participants’ perceptions of 3DFP relative advantage, compatibility, and complexity were neutral, contrasting 3DFP early adopters’ positive perspectives (Guaqueta et al., 2024). Participants’ neutral positions can result from their lack of knowledge, as found in previous studies on consumer attitudes (Ng et al., 2022). Lack of knowledge can influence perceptions and acceptance of the technology (Brunner et al., 2018; Ross et al., 2022) and could explain the participants’ undefined position towards these aspects. Consumer lack of acceptance about 3DFP coming from product quality concerns, such as product edibility, tastiness and naturalness, were similarly found in food sectors representatives’ comments at the end of the survey. This indicate potential barriers that are similarly found in other 4.0 technologies such as cultured meat or precise fermentation (Hassoun et al., 2024) and may stem from a lack of knowledge or new food technology neophobia (Brunner et al., 2018; Feng et al., 2022; Ng et al., 2022).

Additionally, some participants expressed their concerns about effect of 3DFP in food business dynamics such as the perceived replacement of human labor, a factor that is usually negatively perceived (Tesikova et al., 2022). Educational efforts are needed to address concerns about the societal impact of 3DFP and determine its value in businesses where human involvement in food production is highly valued by food businesses and end consumers. The real-world descriptive scenarios used in this study helped to raise awareness about 3DFP benefits and features for implementation, but they may have not been sufficient to sway participants' stances about 3DFP's DOI innovation attributes. Unlike previous studies in which introduction to the 3DFP concept resulted in consumers' positive perceptions of the technology (Jayaprakash et al., 2020), perceptions of participating food industry sectors in this study require more convincing venues to convey 3DFP harmonization with business requirements, operations, effectiveness, and usability to increase the motivation for 3DFP adoption.

Organizational innovativeness emerged as a factor influencing perceptions toward 3DFP. Organizations driven by innovation tend to perceive technology novelty as highly important (Cunningham et al., 2023). While 3DFP early adopters valued technology novelty (Guaqueta et al., 2024), the surveyed food sectors (healthcare food service, and confectionery and bakery) of this study perceived this aspect as one of the less important characteristics of 3DFP. Thus, communication strategies to encourage 3DFP integration in these sectors should focus on effective technology application rather than its novelty, a focus which could be counterproductive to its adoption. Healthcare food service participant characterization as 'late majority' adopters indicated a preference for established innovations, resonating with the high importance given by participants in this sector to the promotion of successful case studies. Thus, until not evidencing a wide use of the technology, this group may be reluctant to adopt 3DFP.

It is essential to increase 3DFP visibility to support adoption among consumers (Gosine et al., 2021; Jayaprakash et al., 2020), food nutrition educators (Gosine et al., 2021), and 3DFP businesses (Guaqueta et al., 2024). Identifying 'early majority' adopters might support a high rate of adoption (Rogers, 1983), such as industry stakeholders or regions where novel but practical technologies are of interest and are positively accepted; the hubs focused on promoting a food innovation ecosystem could help accelerate awareness and adoption of 3DFP.

The successful integration of 3DFP into the participating food sectors requires a collaborative effort from food stakeholders and researchers to promote awareness and practical knowledge, and demonstrate 3DFP's tangible benefits. Even though 3DFP 'self-assessed´ knowledgeable individuals indicated knowing what 3DFP is and how it works, there is a gap of expertise in knowing how to operate it, which could be a barrier to adoption (Hemsley et al., 2022). Engaging food industry stakeholders in practical demonstrations could increase hands-on knowledge and mitigate usability barriers. Proving that 3DFP is actually beneficial and economically viable over conventional used methods by providing measured data could provide practical information for adoption decision-making. Therefore, readiness for adoption in participating sectors necessitates real-world implementation and proven effectiveness. Regions interested in exploring receptiveness toward 3DFP, and where the same food sectors are key and knowledge about 3DFP is similarly lacking, may benefit from this study's insights to establish strategies for increasing awareness and encouraging adoption.

4.4.1 Future studies

Using real-world scenarios favored understanding sector-specific perceptions about 3DFP, which are valuable insights for market strategies, technology developers, and stakeholder decision-making. Further studies could use the described benefits and technology features identified in this study to explore adoption in similar food sectors in unexplored regions. Applying DOI's aspects of innovation and individual innovativeness helped identify that food sectors require evidence of 3DFP capabilities. Further research could explore the effect of 3DFP demonstrations on attitudes and receptiveness for adopting 3DFP by implementing focus groups or interview methods. Moreover, participants' comments on the edibility, tastiness, and naturalness of 3D-printed food indicate hesitancy about the resulting products, which may stem from lack of knowledge or new food technology neophobia (Brunner et al., 2018; Feng et al., 2022; Ng et al., 2022). Assessing personal traits, such as new food technology neophobia, among industry stakeholders could add to the explanation of their attitudes toward 3DFP adoption.

4.4.2 Study limitations

The small sample size of confectionery, bakery and food service sectors was a study limitation. Participation from the confectionery and bakery sectors was limited by the number of local businesses established in Alberta and, similar to food service sector (Whitehouse et al., 2023), representatives' limited availability due to the business demands resulted in a hard-to-engage population. Participants from these sectors were recruited through their contact email and phone number, limiting the contact list to those using this communication method for non-commercial purposes. However, their presence in metropolitan areas and small-size businesses reflected sectors' characteristics of high SMEs presence (over 90%) in these areas (Statistics Canada, 2022). Industry leaders working towards innovation in these food sectors could help gauge interest in 3DFP and consequently, strengthen adoption of 3DFP in the sector.

4.5 Conclusions

The study survey revealed that professionals in food service, confectionery and bakery, and healthcare food services sectors in Alberta, Canada, lacked knowledge and adoption of 3DFP. Organization representatives highlighted 3DFP benefits relevant to their respective sectors. For healthcare food service participants, key 3DFP benefits were improvements in patient eating experience, food texture customization and visual appeal, while confectionery and bakery representatives identified the benefits of using natural ingredients, precision in production, and food design customization. In food service, all 3DFP benefits were similarly important, including natural and fresh ingredients, food waste and plastic use reduction, consumer experience, food customization and versatility. Relevant 3DFP features for implementation across sectors include costs per serving, technical support, and technology maintenance, ease of cleaning and efficiency.

Two-thirds of participants were interested in adopting 3DFP, but hesitancy was evidenced by the perceived 3DFP potential impact on food quality and participants' neutral position toward 3DFP usability, capabilities over conventional technologies, and compatibility with current processes. Demonstrated success and tangible information that support the effective application of 3DFP, in addition to full-scale projects, government initiatives, and promotion of awareness and training, is needed for fostering readiness for adopting 3DFP among food industry sectors.

Chapter 5 – General discussion and conclusions

5.1 Main findings and implications

The aim of this thesis was to analyze the factors influencing the adoption of novel 3DFP technologies in the food industry. In the initial research phase, the focus was on examining existing literature regarding the acceptance of 3DFP. This review showed that most studies have looked at 3DFP acceptance from consumers' viewpoints, paying little attention to how industry players perceive 3DFP and the factors affecting its adoption in real-world scenarios within various food sectors. In the second and third phases of this research, factors influencing adoption were studied by interviewing current adopters in food businesses around the globe and surveying industry perspectives in Alberta food sectors, respectively. These two phases revealed that the sustainable and potential adoption of 3DFP in food sectors is impacted by technical, economic, social, and personal factors.

In the second phase, 3DFP early adopters' innovative mindset and prior experience with 3DP technologies, and alignment of 3DFP capabilities with business needs, were identified as supporting factors to 3DFP adoption. 3DFP early adopters acknowledged technology advantages over conventional processing methods, such as operational efficiency, versatility, intricate food design and customization, and support for food sustainability. However, the relevance of these benefits varied depending on the specific food sectors' needs and priorities. Technology developments should consider specific sector opinions for successful 3DFP applicability in food business processes.

Challenges hindering 3DFP implementation in food businesses are technology's limited scale and economic viability issues, negative consumer perceptions of the technology and the end-products, and low involvement of large companies. Overcoming these interconnected barriers requires breakthroughs in technology efficiency, including faster processing and cost-effective solutions. Improving the cost-effectiveness of 3DFP could support successful adoption among current adopters, potentially expanding available products in the market and raising awareness and acceptance of 3DFP among consumers and potential industry stakeholders.

In the third phase of this research, based on descriptive scenarios developed using early adopters' sector-specific insights, Alberta food sectors indicated the relevant 3DFP benefits according to their sector. For confectionery and bakery, natural ingredient usage, consistent and precise production, and customized designs benefits prevailed. Healthcare food service prioritized 3DFP benefits for patient eating experience, food visual appeal and texture customization. In the broader food service sector, all 3DFP benefits were deemed important. These included using natural and fresh ingredients, reducing food waste and plastic use, enhancing consumer experience through food customization and versatility, and promoting food sustainability by repurposing food waste. The distinct relevant 3DFP benefits among participating sectors confirmed early adopters' insights regarding that despite the wide range of 3DFP benefits, application of 3DFP should focus on the alignment of business needs with the technology capabilities. Moreover, essential factors for potential adoption in Alberta food sectors include cost per serving, technical support, and technology maintenance, ease of cleaning and efficiency (printing time and large quantity production).

According to the DOI theory, innovativeness influences the sequence of adoption, which was observed as the difference in mindset of current adopters around the globe compared to potential adopters in Alberta food sectors. The initial stages of 3DFP adoption in the food industry were confirmed. Early adopters were motivated by 3DFP novelty, compatible with their entrepreneurial drive, whereas Alberta food sectors need evidence of successful use and benefits before considering adoption. Utilization of the DOI model indicated that the 3DFP relative advantage over conventional technologies, compatibility with business needs and values, and complexity of using and learning about 3DFP were determinants in the adoption by early adopters. For potential adopters in Alberta food sectors, their position towards these aspects was neutral, which might have been caused by the low awareness about and lack of evidence of 3DFP application in their respective sectors. Interest in adopting 3DFP was noted in Alberta food sectors, but adoption strategies are necessary to support adoption readiness, including trials of full-scale projects, government support, knowledge-sharing venues, and training programs. Moreover, educating about the evidence-based benefits of 3DFP to prove its effective and economically viable application is essential to support credibility towards 3DFP and encourage adoption among food sectors.

Collaboration and support networks were identified as crucial in facilitating the adoption of 3DFP among current adopters and increasing awareness in potential adopters. 3DFP businesses have benefited from visibility, facilitating knowledge sharing and technology demonstrations. Word-of-mouth, the media, and personal and professional platforms have supported diffusion of 3DFP existence among Alberta's food sectors. Observing 3DFP becoming more commonly used was identified as a supporting factor to encourage technology awareness and utilization by 3DFP early adopters. Additional strategies, such as showcasing early adopters' experiences in demonstrations and informative forums with potential stakeholders, could further enhance awareness and foster trust in the relevance of this technology over conventional technologies.

Furthermore, the adoption of novel technologies, such as 3DFP, relies heavily on how it is perceived by consumers. Individuals that embrace innovation in food preparation may be more open to experimenting with 3DFP as a novel way to create customized dishes and unique dining experiences. However, people often feel apprehensive about new technologies, especially when it comes to something as fundamental as food. 3DFP shares with other 4.0 technologies or products, such as fortified foods, cultured meat, and precision fermentation, to respond to current consumer demands for sustainable and healthy food options, but consumers lack acceptance coming from naturalness, safety, and healthiness concerns and lack of knowledge are challenging these emerging food trends (Hassoun et al., 2024).

Cultures that value culinary traditions may be hesitant to adopt 3DFP and other 4.0 food technologies due to concerns about the authenticity of the food. It is reasonable to imagine that concerns stemming from the fear of the unknown about this novel technology may lead to unease about losing the culinary identity that is often tied to traditional cooking methods or reluctance to change established habits. Embracing 3DFP requires a shift in how people perceive and interact with food, which can lead to resistance and reluctance to try something new. The idea of consuming food that is printed rather than traditionally prepared can be unsettling for many consumers, particularly for those consumers who prioritize the quality and cost of the product over the technology that is used.

Additionally, affordability and accessibility of 3DFP can influence adoption rates across different socio-economic groups within a society. Current solutions are designed for a premium market, which might be a challenge for large-scale production where lower cost is desired to obtain profitability and resonate with food pricing accessibility by broader consumer segments. Thus, the application of this technology might continue to be segmented for premium niche markets rather than for mainstream production and daily food consumption. Otherwise, the technology needs to offer a value that is not already solved by current methods or disrupt the food industry dynamics targeting underserved or overlooked segments while offering more convenient or more affordable products (Christensen, 1997).

Despite 3DFP's promising benefits in the food industry, technological, economic, and societal barriers need to be tackled to ensure the successful adoption of this novel technology in the food industry and become an ever-present part of consumers daily lives. These barriers encompass technology production limitations and high costs in the hardware and the end products as well as consumer lack of acceptance about 3DFP. Overcoming these barriers necessitates addressing technical challenges, enhancing consumer education and awareness, adding value over conventional food cooking or processing methods, building trust in the technology's significance, capabilities, and safety, and navigating regulatory landscapes to ensure seamless integration of 3DFP into everyday life.

5.2 Study limitation and strengths, and future directions

Four limitations of this study were identified. Firstly, stakeholders who adopted the technology but eventually discontinued its use were not included in this thesis. Gathering their viewpoints could add or confirm barriers of adoption of 3DFP in food businesses. Conversely, understanding the perspectives of those who overcame challenges and continued using the technology is crucial, as they contribute to its diffusion and can guide future stakeholders. Second, implementation of the DOI model might have limited the exploration of external factors of the adoption process that might potentially intervene in the adoption of 3DFP. The Technology Acceptance Model (TAM) is often used to understand users' perceptions and attitudes towards a technology, making it particularly relevant for understanding individual-level acceptance and usage behaviors (Davis, 1989). On the other hand, the Disruptive Innovation Model focuses on how new technologies disrupt existing markets and create new ones, making it valuable for analyzing industry-level dynamics and strategic decision-making (Christensen, 1997). While the Diffusion of Innovation Model provided insights into the process of adoption of 3DFP and the factors intervening in the adoption decision-making, the TAM and the Disruptive Innovation Model might offer focused perspectives on the understanding of individuals' behavior toward 3DFP or how the technology could eventually change how food is produced and consumed, displacing established production methods or food consumption habits, and transforming the industry landscape. Thus, further studies might consider utilizing these other models to complement the understanding of the integration of 3DFP in the food industry and consumer daily life.

Thirdly, the survey sample has limited participation from non-healthcare food sectors. Food industry stakeholders are a hard-to-engage population, especially as their business dynamic limits their availability. Conducting a follow-up study interviewing representatives from the Alberta food sector could provide deeper insights into rationale behind the acceptance of 3DFP. Fourth, the presentation of descriptive scenarios in the survey may have been insufficient to influence industry stakeholders' viewpoints towards 3DFP competitiveness and compatibility. However, participants gained valuable knowledge regarding current applications, technological advantages, and features of 3DFP, which may support future adoption strategies to embrace this innovative technology successfully. Further focus groups that include in-person demonstrations could be conducted to showcase applicability and identify motives and concerns about the technology adoption, including personal and organizational beliefs and characteristics that may favor or limit adoption.

This research has four strengths. First, considering consumers attitudes in the context of food industry is essential as they are the last key in the supply chain that will determine the acceptance of 3D printed food. This research did not directly study consumer attitudes towards 3DFP, but findings from early adopters in the food sector supported findings in previous studies on consumer attitudes, including lack of knowledge and concerns of food naturalness and edibility (Chapter 2). Moreover, it was discovered that potential adopters in surveyed Alberta food sectors shared some of the consumers concerns about food taste and naturalness. This might have resulted from Alberta food sectors lack of knowledge or new food technology neophobia, similar to previous study findings involving consumers. Understanding the effect of personal traits, such as new food technology neophobia, could add to the understanding of industry stakeholders' conservative attitudes toward 3DFP.

Second, in the literature review (Chapter 2) the effect of food type on the acceptance of 3DFP was identified; 3DFP is more accepted when used in food applications that are compatible with 3DFP capabilities such as confectionery for its common aesthetic appearance. Use of 3DFP for 3D printed meat was the most acknowledged application among Alberta food sectors and was considered as the most promising application of 3DFP by early adopters. Using 3DFP for unconventional protein sources requires explanation and mindset change, akin to the adoption process seen with plant-based proteins processed with other technologies. Addressing negative perceptions in this area is crucial for wider acceptance of 3DFP and the resulting products.

Third, the qualitative study with 3DFP early adopters helped to distinguish the distinct applicability of 3DFP technology among food sectors despite its wide range of described benefits. Moreover, it presents the practical limitations of 3DFP application often overlooked because of the significant emphasis placed on the technology's advantages. The distinct relevant 3DFP benefits across various food sectors indicates that its application must be purposeful and responsive to specific sectors priorities. Further developments of 3DFP might be tailored to respond to the capacity and technology characteristics suitable for the distinct food sectors to meet their specific consumer demands and unsolved needs. Fourth, this research revealed the distinct contrast in mindset between the novelty-driven early adopters and the conservative attitude toward innovations among Alberta healthcare food service sector. The conservative mindset might represent the current state of various food businesses which limits widespread adoption. Investigating food sector readiness in other geographic areas could help in identifying regions where the technology might be delayed or promptly accepted.

5.3 Conclusions

This thesis delved into factors impacting the uptake of novel 3DFP technologies in the food industry. Through interviews with 3DFP food businesses the study identified key factors influencing early adoption of the technology: early adopters' innovative mindset, alignment of sector-specific technology benefits with business needs, and technology advantages over conventional methods. However, current barriers for successful implementation include lack of economies of scale, negative consumer perceptions, and low rate of adoption of large companies. Proposed solutions from businesses emphasized the breakthrough on technology capacity and market education. On the other hand, a survey in confectionery and bakery, healthcare food service, and food service sectors in Alberta revealed general low awareness about 3DFP. Alberta food sectors indicated relevant 3DFP benefits from the wide range of benefits applicable to their sector, confirming the relevance of technology alignment with business priorities. Two thirds of participating Alberta food sectors indicated an interest in adopting the technology. Key identified technology features for implementation were related to serving costs, technology support, maintenance, and efficiency.

Application of Rogers' DOI theory helped to note differences between current and potential 3DFP adopters in the willingness of adopting innovations, such as 3DFP; early adopters were driven by their enthusiasm in adopting novel 3DFP, whereas Alberta´s healthcare food service sector indicated being more conservative in adopting innovations. Strategies identified for potential adoption readiness include trials of full-scale projects, government support, knowledge-sharing, and training programs. Moreover, evidence on 3DFP technology effectiveness and viability was also suggested as a strategy to support adoption. Collaboration and visibility of the technology were seen as vital for adoption, with word-of-mouth, media playing, and successful application by other food organizations playing key roles. This thesis revealed the need for evidence-based benefits, sector-specific strategies, and collaborative efforts to promote successful 3DFP adoption in the food industry. Moreover, from a broader perspective, to integrate 3DFP into consumers daily life successfully, technological, societal, and economic barriers should be overcome, including production capacity limits, technology and product high costs, consumer lack of acceptance, and demonstrate its value over existing food processing methods and products.

This research is unique in its approach to analyzing 3DFP adoption in the food industry, using the DOI model for the first time in this context. It addresses a knowledge gap in the factors influencing 3DFP adoption across food sectors, including perspectives from current and potential adopters. This research serves as a valuable reference for stakeholders considering 3DFP in the food industry, policymakers, and academia to leverage the opportunities presented and address identified challenges related to 3DFP adoption.

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Appendix

Appendix A – Existing literature on 3DFP acceptance by consumers and users

Table A1. *Studies assessing acceptance of 3DFP by examining perceptions of 3DFP, product tastings, or both.*

Source	**Study aim**	**Research method**	**Participants profile**	**Presentation of 3DFP concept/product**
(Burke-Shyne et al., 2021)	To understand the opportunities and challenges from a nutritional point of view of using 3D Food Printing.	Semi-structured interviews	10 3DFP experts. 5 with previous experience in 3D printing and 5 nutrition experts.	No information introduced
(Jayaprakash et al., 2020)	To gain technical and economical 3DFP perspectives from industry, academia, and potential consumers.	Mixed methods approach: Exploratory phase: Group 1 and 2 were interviewed Evaluation phase: Academia and industry conducted an online survey, and consumers were interviewed in focus groups.	**Exploratory phase:** Group 1: 15 experts on 3DFP (academic, tech developers, tech distributor) and food businesses (processors, ingredient processors, and food distributor) Group 2: 10 individuals from research and industry sectors in Finland **Evaluation phase:** 50 participants from academia and industry (62% from Finland, 72% from academia/research) Consumers: 6-8 participants in 4 groups. Aged 24-65 years. From Finland and Belgium.	No information was introduced to industry or academic experts. Potential uses of 3DFP verbally explained during consumer focus groups
(Rogers & Srivastava, 2021)	To assess the risks, opportunities, and challenges of 3DFP from a sustainable food supply chain perspective.	Semi-structured interviews	12 3DFP experts - industry and academia: Individuals who actively worked on the 3DFP (industry managers and academic researchers)	No information introduced
(Smith et al., 2022a)	To examine health professionals' views on 3D food printing for improving dysphagia patients' quality of life	Focus groups	15 health professionals with experience in dysphagia diets	Pictures and video about the 3DFP process
(Gosine et al., 2021)	To investigate teachers, students, and dietitians' views on 3DFP for food and nutrition education.	Focus groups	Teachers(6), dietitians(6), and students(11)	Pictures and a video of printing a cookie.

(Hemsley et al., 2022)	To examine 3DFP feasibility and usability to make attractive food for people with dysphagia.	Individual interviews and focus groups	15 participants - support workers, managers, or researchers in the field (e.g., speech pathologist, dietitian, food engineer, marketing business, interaction designer, or 3D printer) and one person with dysphagia.	In-person and online presentation of 3DFP
(Brunner et al., 2018)	To assess consumers' attitudes considering the influence of provided information about 3DFP.	Survey	260 consumers, residents of Switzerland Aged 19 - 80 years old	Written descriptions
(Kocaman et al., 2022)	To assess interested users' attitudes towards 3DFP technology in their home kitchens	An online survey (Group 1) followed by interviews (Group 2).	Group 1: 146 participants Group 2: 7 participants from the survey Employees of a kitchen appliance company. Individuals with an early interest in 3DFP.	Images of products already in the market and description of 3DFP advantages and disadvantages. A video demonstrating 3DFP processing steps.
(Lee et al., 2021)	To identify how specific 3D printed food attributes affect the perceived value, attitudes, and behaviors of consumers	Hand-written and online survey	343 participants that had some knowledge of 3D-printed food. 66.1% Female. 75.8% were 20-29 years old. 79% with a college degree	No information introduced
(Lundén et al., 2020)	To uncover consumers' viewpoints regarding novel ingredients and some traditional but underutilized ones, including 3D printed foods.	Two online surveys	Finnish householders across Finland from 18 to 80 years old. Survey 1: 380; Survey 2: 1014	Only technology name
(Lupton & Turner, 2018b)	To assess the attitudes towards various 3D printed foods.	Online discussion groups and close-ended questions	30 householders aged 18 years or older	Images
(Lupton & Turner, 2018a)	To assess attitudes about 3DFP combined with alternative protein ingredients	Online focus group	30 residents from different areas of Australia with different backgrounds. Aged 18 years and over. 63% Women and the rest men.	Information and images of printed products
(Manstan & McSweeney, 2020)	To investigate consumers' beliefs about 3DFP and attitudes towards 3DFP compared to conventional products	Focus groups (Group 1) followed by an online survey (Group 2)	Group 1: 20 participants Group 2: 329 participants Atlantic Canada residents without experience in the food industry, sensory analysis, or 3D printing.	3DFP description, 3D printer picture, and photographs of baked/cooked foods (conventional and 3D printed versions)

(Motoki et al., 2022)	To study social companions' influence and venue's influence on the anticipated willingness to try novel or unfamiliar foods, including 3D-printed foods.	Three surveys	Survey 1: 117 participants Survey 2: 108 Participants Survey 3: 120 Participants Japanese participants; half of female participants in all three studies.	Category name and descriptive names. Experimental design of 3D printed food presentation in 5 different companions and five separate venues.
(Ng et al., 2022)	To assess consumers' knowledge and factors that influence attitudes about 3DFP	Survey	394 householders, residents in Klang Valley, Malaysia, aged 24 - 55 years old	Infographic on 3D food printing, food examples, process, and benefits
(Piwowar et al., 2023)	To investigate factors that influence Poland consumers' acceptance of novel food products, including 3D-printed personalized food products	Survey	500 residents in the largest cities of Poland. 20-44 years old.	Not specified
(Ross et al., 2022)	To investigate determinants of 3D printed food acceptance in the food service context.	Online survey	1045 adult Irish population without food production, marketing, or home appliances background. Even distribution between males and females. Aged from 24 to 65 years.	Not specified
(Smith et al., 2022b)	To comprehend dysphagia patients and their healthcare caregivers' perspectives towards using 3DFP to improve food visual aspect and mealtime experience.	Interviews	9 people needing texturized food in their diet. 4 supporters of dysphagia patients	Online virtual experience: participants chose food ink and the end-product shape.
(Tesikova et al., 2022)	To assess Czech consumer perception of 3DFP and identify how demographics affect their responses	In-person and online survey	1156 Czech Republic residents	No information introduced
(Talens et al., 2022)	To assess consumer perception and acceptability of a breakfast bar produced by integrating three cooking devices, including a 3D food printer.	1. Survey (2055), Focus groups (9), Interviews (8), Online community (40) 2. Sensory panel	1. 2104 participants with different cultural breakfast habits Eight stakeholders from aged care and hospitality 2. 80 participants (65% women, 35% men) aged 45-75 years. Seniors and Spain residents, of which 90% have breakfast every day.	1. Images, verbal and written information, depending on if it was an interview or a survey. 2. Breakfast bar (In sensory panel)
(Mantihal et al., 2019)	To assess consumer attitudes and knowledge about 3DFP	Sensory panel and survey	244 participants, 84.8% university students Aged 20 - 39 years old. Mostly Australians.	3D-printed product

(Manstan et al., 2021)	To analyze the product's sensory acceptability and attributes before assessing consumer attitudes toward 3D-printed labeled cookies	Sensory panel and survey	133 participants	3D-printed labeled product
(Feng et al., 2022)	To examine how labeling and providing positive information about 3DFP influence consumers' sensory preferences for foods labeled as 3D printed compared to their conventional counterparts	Sensory panel and survey	186 participants from university community. 18-25 years old (53-75%)	3D-printed labeled product
(Caulier et al., 2020)	To analyze military soldiers' acceptability of 3D-printed bars	Sensory panel, one-on-one interviews, and focus group	12 male elite air assault soldiers with a mean age of 32.1 +/- 7.6.	3D-printed product
(Bracken et al., 2022)	To assess the acceptability of placebo 3D printed solid tablets in children and young people.	Sensory panel	30 patients and healthy volunteers with 4-12 years old.	3D-printed product
(Bulut & Candoğan, 2022)	To assess the sensory acceptability of the 3D printed products interfered by gelatin addition and baking process.	Sensory panel	15 trained panelists	3D-printed product
(Burkard et al., 2023)	To investigate the effect of the cream cheese and chocolate structure on the acceptability and temporal perception of the attributes.	Sensory panel	120 participants from a university community; 8-10 trained panelists, all women aged 24-59 years	3D-printed product
Chirico Scheele et al	To assess the effects of adding protein and lipids to mashed potatoes on sensory acceptability and the perceived fidelity and desirability of 3D printed products.	Sensory panel	80 participants	3D-printed product
Chirico Scheele et al	To investigate consumer response on shape, taste, and fidelity for 3D printed food designs.	Sensory panel	28 mechanical engineering students(27 male, 1 female), aged 21-37 years	3D-printed product
(Chow et al., 2021)	To investigate the effect of gelatine citric acid and whey protein isolate levels in lemon mousse formulations on sensory properties.	Sensory panel	Test 1: 10 trained panelists (9 female, 1 male) Test 2: 30 participants (21 female, 9 male) with an average age of 35 years old	3D-printed product
(Fahmy et al., 2021b)	To investigate the influence of inhomogeneous NaCl distribution on sensory perception.	Sensory panel	16 trained participants, aged 24–31 years, and with no taste or olfactory disorders	3D-printed product

(Feng et al., 2021)	To assess the effect of postprocessing methods on the sensory attributes.	Sensory panel	Undisclosed	3D-printed product
(Ghazal et al., 2019)	To evaluate the sensory acceptability of 4D-printed foods	Sensory panel	30 participants with 20-35 years old	3D-printed product
(Keerthana et al., 2020)	To assess the acceptability of snacks containing mushroom powder and wheat flour.	Sensory panel	20 semi-trained participants, aged 25-45 years.	3D-printed product
(Khemacheevakul et al., 2021)	To evaluate the temporal sensory profile, perceived sweetness intensity, and acceptance of prototype sugar-reduced and non-sugar-reduced 3D printed chocolates	Sensory panel	75 participants from university staff and students. 68% female, 58% 18-25 years old, and 86% consume one or more times per week. Trained before analysis.	3D-printed product
(Krishnaraj et al., 2019)	To evaluate the postprocessing effect on the sensory acceptability of fibre-enriched snacks.	Sensory panel	20 semi-trained panelists	3D-printed product
(Lille et al., 2020)	To assess the intensity of sensory attributes influenced by whole milk powder and wholegrain rye flour in the snack formulation.	Sensory panel	10 trained panelists	3D-printed product
(Liu et al., 2020)	To analyze the sensory acceptability as a score for assessing the optimization of the 3D printed product formulation.	Sensory panel	30 participants (15 male, 15 female) trained before the analysis. 25-30 years old	3D-printed product
(Mantihal et al., 2019)	To assess the consumers' preference for 3D printed chocolate.	Sensory panel	30 trained panelists (21 women, 9 male) and familiar with chocolate tasting. 28-55 years old	3D-printed product
(Mirazimi et al., 2023)	To determine the correlation between the instrumental and sensory evaluation of 3D-printed protein-fortified puree potatoes	Sensory panel	8 trained panelists (6 female, 2 male), aged 25-45 years	3D-printed product
(Muthurajan et al., 2021)	To identify the formulation with potato peel powder and wheat flour based on sensory acceptability.	Sensory panel	20 participants with undisclosed profile	3D-printed product

(Oliveira et al., 2022)	To evaluate the influence of Chlorella vulgaris (*C. vulgaris*) additions on the printability of cereal-based doughs in sensory acceptability, descriptors, and consumer preference.	Sensory panel	30 participants (20 female, 10 male), aged 18-50 years	3D-printed product
(Phuhongsung et al., 2020)	To investigate stimulation at different pH to alter the color, texture, and flavor of soy protein isolate, pumpkin, and beetroot mixture.	Sensory panel	12 participants from university community, aged 22-34 years	3D-printed product
(Riantiningtyas et al., 2021)	To investigate the potential sensory modulation of a protein-enriched food by creating 3D-printed yogurt gels with a multisensory layered design.	Sensory panel	Test 1: 7 trained panelists through 2 sessions (5 female, 2 male) Test 2: 30 participants (21 female, 9 male) with an average age of 35	3D-printed product
(Shahbazi et al., 2022)	To assess the sensory intensity profile of a reduced-fat 3D-printed meat analogue using microcrystalline cellulose	Sensory panel	10 participants (5 female, 5 male), aged 20-35 years old	3D-printed product
(Thangalakshmi et al., 2022)	To assess the effect of steaming on the sensory acceptability of a traditional Indian snack compared to the traditionally made.	Sensory panel	25 semi-trained participants from university students and staff	3D-printed product
(Theagarajan et al., 2021)	To identify the suitable postprocessing technique for the rice-based products in terms of stability and sensory acceptability	Sensory panel	20 semi-trained participants, aged from 24-45 years.	3D-printed product
(Tsai & Lin, 2022)	To evaluate the sensory attributes of artificial steak.	Sensory panel	25 participants with undisclosed profile	3D-printed product
(Zhu et al., 2021)	To assess the effect of the macroscopic structure on texture and sensory attributes of 3D printed protein bars	Sensory panel	70 participants (63% women and 37% males), aged 26 +/- 5 years.	3D-printed product

Appendix B – Interview guide
Duration: 45 minutes – 60 minutes

Warm-up and introduction

- Introducing the interviewer and the research
- Confirmation of informed consent
- We would like to know about your business: Business food sector, size, location, and your role there.

Getting to know about 3DFP

- Could you tell me about how the story of 3D food printing and your business began?
    - o How long has your business been using 3DFP?
    - o How did you get to know about 3DFP?
    - o Would you consider the use of the technology was visible/ noticeable within the food sector/groups/associations/conferences that you are part of?
    - o Is there a specific place or site where you observed 3DFP being used?
    - o Before adopting the technology, did you have the possibility to test it?
- How would you describe the value proposition for using 3DFP in your business? And how would you consider 3DFP compared to other conventional technologies?

The rationale behind deciding on adopting

- What were the main reasons for adopting the technology in your business?
- Would you consider there was any factor that influenced your business' decision to adopt the technology?

Implementation

- Could you tell me about the food products you produce with 3D food printing and who your target market is?
- What benefits and barriers would you highlight of the technology in your business?
- How would you describe the challenges of using the technology?
    - … In terms of economic viability?
    - … In terms of consumer desirability?
    - … in terms of technical feasibility?
- Was the technology difficult to use or learn? If so, what did you do to overcome that difficulty?
- Considering that you might have a previous standardized process, how was the transition to fit the technology in your process? Was it easy? Or challenging?

Reflections on the use of 3DFP

- What are the main advantages and disadvantages of 3D printing for food?
- Is there anything you wish you would have known about 3DFP before adopting it?
- What would you think is essential to move forward with the adoption of 3DFP throughout the food industry?
- What is the main contribution of 3DFP to the food industry/businesses?

Wrap-up – Future perspective of 3DFP

- How do you envision the use of 3DFP in the food industry in the next five years?

Appendix C – 3DFP DOI attributes of innovation per sector

Catering	Restaurant	Confectionery		Healthcare		Alternative proteins
Traditional cooking	Molding	Molding	Depositing	Molding	Blending	Single extrusion
Product design ✓ Aesthetic and unique food items ✓ Intricate designs impossible to make by hand. **Sustainability** ✓ Food up-cycling and reduced plastic utilization **Versatility** ✓ Multi-material	**Convenience** ✓ Support dishes' creativity with new designs **Customization** ✓ Faster and whenever it is needed	**Production cleanliness** ✓ Easy and cleaner **Product design** ✓ Complex designs ✓ Addition of sensory experience through intricate structures. **Convenience** ✓ Digitized designs ✓ Time-saving for new design creation **Customization** ✓ Faster and whenever it is needed ✓ Less expensive in the long term ✓ Recipe alteration **Production capacity and setting** ✓ Low-volume and autonomous **Sustainability** ✓ Reduced plastic utilization **Versatility** ✓ Various designs and multi-material	**Production capacity** ✓ Low-volume **Product design & technology functionality** ✓ Detailed 3D structures **Versatility** ✓ Multi-material	**Convenience & product quality** ✓ Unique solution for texture-modified food closer to a fresh product **Product design** ✓ Replication of food forms **Customization** ✓ Individual nutritional needs **Versatility** ✓ Various designs.	**Convenience & product quality** ✓ Unique solution for texture-modified food closer to a fresh product ✓ Retain original color, smell, and taste **Product design** ✓ Appealing food appearance ✓ Replication of food forms **Versatility** ✓ Various designs	**Customization** ✓ Tailored sensory experience ✓ Custom-made shapes **Product design** ✓ Mimicry of sensory attributes of animal-based counterparts **Food quality** ✓ Nutrient retention **Technology functionality** ✓ 3D internal structure ✓ Multiple ingredients at once for muscle-like recreation ✓ Low resolution for uneven appearance **Production capacity** ✓ Scalable and efficient **Versatility** ✓ Multi-material

Figure C1. 3DFP's relative technology advantages over conventional technologies among participating food sectors.

	Catering	Restaurant	Confectionery	Healthcare	Alternative proteins
Need	To create new things beyond confectionery products and offer something aligned to business artistic concept.	To offer an amusement consumer experience and to level up the restaurant.	To offer novel, customized, appealing and tasty products	To enhance individuals' health and restore joy in food	To rely less in animals for health and sustainability, and to offer alternatives mimicking animal-protein appearance and taste.
Compatibility	✓ Integrative technology for food customization ✓ Use of non-trademarked designs for design creation ✓ Scheduled production for large quantities.	✓ Easy adaptable in the workplace ✓ Low-volume, high-mix and vice versa. ✓ Use of high-quality and natural ingredients ✓ No regulations applied ✓ Large quantities by continuous production.	✓ Aesthetic products ✓ Shareable digital designs ✓ Portable printer	✓ Fresh and tasty food instead of ´high-processed' food. ✓ Frozen products with spoonable texture when warmed up. ✓ Appealing food with original taste and smell. ✓ Food shape and nutrition content customization ✓ Suitable for other health conditions.	✓ Animal-protein texture obtained ✓ Integrated with technologies to recreate animal-protein structure ✓ New product prototyping ✓ Transferable capacities for other applications

Figure C2.Compatibility of 3DFP technology attributes with food sector needs.

Catering	Restaurant	Confectionery	Healthcare	Alternative proteins
Software-use ✓ Time demanding developing designs ✓ Lack of digital design skills **Product development** ✓ Time-demanding experimentation to find suitable recipes and creative foods ✓ Limited feasible designs ✓ Balancing design creativity vs. tastiness ✓ Creating printable and stable food **Printer-use** ✓ Initial failures ✓ Long learning curve ✓ Difficulties navigating the printer	**Software-use** ✓ Lack of digital design skills ✓ Difficult to use **Product development** ✓ Time-consuming experimentation to create feasible designs ✓ Required food expertise **Printer-use** ✓ Long learning curve ✓ Challenging self-training ✓ Matching digital designs with the actual print	**Software-use** ✓ Difficult to learn ✓ Long learning curve **Product development** ✓ Time-consuming experimentation with new ingredients ✓ Required chocolate expertise ✓ Creating stable food items ✓ Understanding relation of food with printing parameters **Printer-use** ✓ Hands-on learning curve ✓ Control of temperature ✓ Matching digital designs with the actual print	**Product development** ✓ Finding suitable recipe for a stable product ✓ Complex recipe for non-sticky but swallowable food ✓ Limited design due to limited usable ingredients **Printer-use** ✓ Product resistant to post-process temperature	**Product development** ✓ Recreation of animal-based texture with plant-based ingredients ✓ Lack of food expertise **Printer-use** ✓ Hands-on experience

Figure C3. Complexity factors in using and learning 3DFP technology in participating sectors.

Appendix D – Survey questionnaire

Participant background and organization demographics

1. Please select the food sector that best describes your organization.
    - o Confectionery
    - o Bakery
    - o Restaurant
    - o Catering
    - o Restaurant in a Hotel
    - o Other in Hospitality: _______________ (please specify)
    - o Healthcare (acute and long-term care)

2. How many employees are in your organization?
    - o 1 – 9
    - o 10 – 29
    - o 30 – 49
    - o 50 – 99
    - o 100 – 299
    - o 300 or more

3. Where is your organization located?
    - o Northern Alberta
    - o Edmonton Area
    - o Central Alberta
    - o Calgary Alberta
    - o Southern Alberta

4.a. Healthcare food service participants: What is your primary role at your organization ?

- o Speech-language pathologists
- o Registered dietitian
- o Food service managers/supervisor in patient food services.
- o Food procurement
- o Meal planning
- o Food quality control
- o Other: _______________

4.b. Non-healthcare food service participants: What is your primary role at your organization?

- o Management / supervisor
- o Business owner
- o Marketing
- o Chef
- o Registered dietitian
- o Food production / processing / preparation
- o Other_____________ (please specify)

Organization' level of innovativeness

To what extent do you agree or disagree with the following statements?

a) We buy new technologies early in their lifecycle and base our purchasing decisions on our vision for their potential benefits rather than past experiences or established references.

☐	☐	☐	☐	☐
Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree

b) We share, to some extent, the previous description but prioritize practicality and wait to see how other organizations fare before making substantial investments, preferring reliable references.

☐	☐	☐	☐	☐
Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree

c) We only invest in new technology when we are confident in our organization' ability to utilize it. Thus, we prefer to wait until it becomes an established standard and requires substantial support. Additionally, we tend to purchase from reputable and large organizations.

☐	☐	☐	☐	☐
Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree

d) We are very cautious about investing in new technology. We will only purchase when we feel it has become a necessity.

☐	☐	☐	☐	☐
Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree

Previous knowledge and extent of adoption of 3D printing and 3D food printing.

How knowledgeable would you say you are about 3D printing?

☐	☐	☐	☐	☐
Not knowledgeable at all	Slightly knowledgeable	Moderately knowledgeable	Very knowledgeable	Extremely knowledgeable

How knowledgeable would you say you are about 3D food printing?

☐	☐	☐	☐	☐
Not knowledgeable at all	Slightly knowledgeable	Moderately knowledgeable	Very knowledgeable	Extremely knowledgeable

To what extent do you agree or disagree with the following statements?

a. I know what 3D food printing is.

☐	☐	☐	☐	☐
Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree

b. I know how 3D food printing works.

☐	☐	☐	☐	☐
Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree

c. I know how to use a 3D food printer.

☐	☐	☐	☐	☐
Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree

Which of the following 3D food printing application(s), if any, are you aware of? (Check all that apply)

- Confectionary (e.g., chocolate, candies)
- Baked goods
- Pasta
- Snacks
- 3D-printed meat
- Fine dining at a restaurant
- Catering
- Personalized Nutrition
- Healthcare food (e.g., food for people with swallowing difficulties)
- None
- Other(s): _______________

From which of the following sources did you learn about 3D food printing?

- Word-of-mouth
- Online research
- Mass media (TV, radio, magazines, etc.)
- Social media (Facebook, Twitter, Instagram)
- Professional network (Linked In, conferences, industry workshops, teamwork)
- Other: ___________________(Please specify)

Does your organization have a non-food 3D printer (e.g., for plastics)?

- Yes
- No
- I don't know

Does your organization have a 3D printer for food?

- Yes
- No
- I don't know

3DFP applicability in the organization

Scenario 1. **3DFP in food service (restaurant and catering)**

3D food printing (3DFP) is versatile in food applications, with potential uses in restaurants, catering, and hotels. 3DFP allows fast personalization, creating delicate, complex , and aesthetic designs which would be difficult or impossible to achieve by traditional means. 3DFP can be implemented in restaurants to elevate menu offerings with a wow factor that delights customers, whether with printed food or showcasing the printing process. In catering services, 3DFP is particularly useful for events where a large quantity and customized food designs are needed, such as weddings, parties, and corporate events. In restaurants, decorative pieces, side dishes, or customized shapes can be offered. Lastly, it has the potential to reduce plastic utilization and repurpose food by changing plastic to edible utensils and using food by-products or visually unappealing produce to create appealing items. **Some examples are illustrated below.**

Natural and fresh food ingredients can be used to print, including charcuterie, chocolate, crackers dough, cookie dough, cream cheese, butter, pasta dough, pâté, and vegetables, among others.

Source: Link

Source: Link

We would like you to rate the level of importance of 3D food printing benefits in the context of your organization. Please, tick the box under the appropriate scale.

	I do not know	Not important at all	Somewhat unimportant	Neutral	Somewhat important	Extremely Important
Delicate and aesthetic food designs						
Complex designs						
Elevate menu offerings						
Food design customization						

Food nutrition customization						
Fast customization						
Use of natural ingredients						
Use of fresh ingredients						
Technology novelty						
Consumer experience						
Showcase 3D food printer on-site						
Food ingredient versatility						
Food design versatility						
Plastic reduction by creating edible utensils						
Repurposing food by-products or visually unappealing produce						

Food ingredients can be formulated and prepared on-site or purchased pre-prepared from an ingredient supplier. Then, the prepared food must be loaded onto the printing system. The food printing process might vary from 5 to 20 minutes or even more depending on the design and size of the print. Several food pieces can be produced through continuous printing, or to speed up production, multiple printers can be set up to print simultaneously. Products that need a cooking process will require to be post-processed, which could be through baking, frying, steaming, or boiling.

Moreover, some food products would need to be frozen or adequately packaged to ensure safe delivery. Depending on the food design, packaging might also need to be customized to ensure the safe delivery of the products. Lastly, the printer can be programmed to work by itself, so there is no need to have personnel working full-time with it, except for the food refill and clean-up of the printer. Process waste might be around 10% of the used ingredients. Lastly, 3DFP utilization might require learning to use the printer and experimenting with food ingredients and formulations to optimize product quality.

Based on the information provided, we would like you to rate the level of importance of 3D food printing features in the context of your food organization. Please, select the response under the appropriate scale.

	I do not know	Not important at all	Somewhat unimportant	Neutral	Somewhat important	Extremely Important
Ingredients developed on site						

Ingredients purchased from a third-party						
Required food preparation						
Printing time						
Large quantity production						
Autonomous process						
Required post-processing						
Process waste						
Packaging customization						
System refill and cleaning by personnel						
Ease of cleaning process						
Level of expertise on 3DFP						
Possibility of food experimentation						
Ability to purchase 3D printed items from a third-party						
Cost per serving						
Equipment maintenance						
Technical support						

Now, if you were to make the item below (Chocolate future word) with a 3D food printer, how would you rate the printing time of 1 piece in 4 minutes?

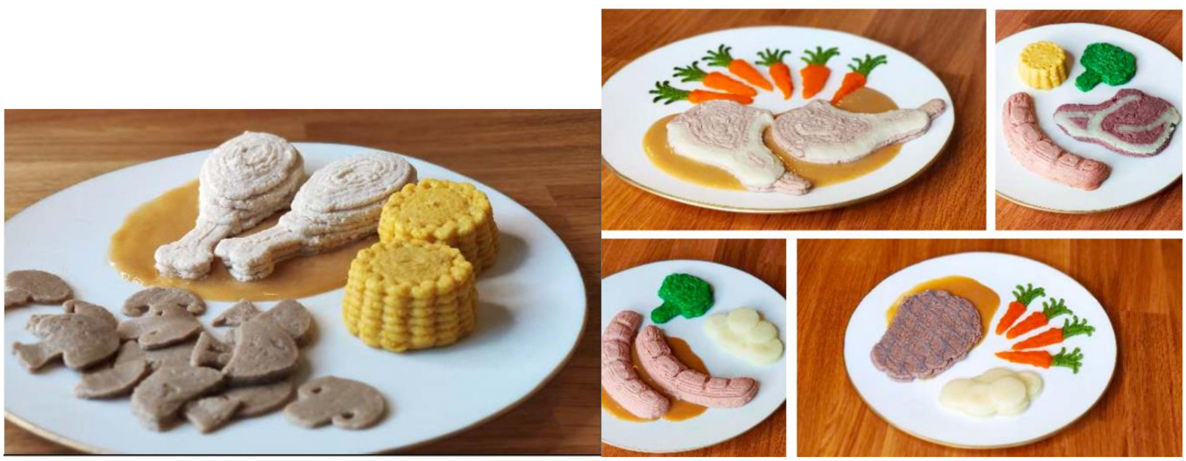
Source: [Link]

☐ Extremely long ☐ Long ☐ Just about right ☐ Fast ☐ Extremely fast

Scenario 2. **3DFP in healthcare**

3D food printing (3DFP) is used in healthcare to benefit patients with dysphagia, the elderly, children, and oncology patients. It provides flexibility in food design and ingredients, allowing personalized nutrition based on individual needs and preferences. Compared to traditional methods, 3DFP can enhance the appeal of meals by presenting food in different shapes and preserving the original color, aroma, and taste while focusing on desired food textures. Based on that, 3DFP has the potential to positively affect patients' emotional responses and appetite, improving their quality of life. Furthermore, 3DFP can support patients with taste disorders by printing customized recipes, further enhancing their overall quality of life.

Potential food products created through 3DFP include any food paste, including fresh vegetable or protein pastes, customized recipes to tailor the nutritional content or designed to bring back food's authentic taste and aroma, and customized vitamin gummies. Printed products could be vegetables or proteins in their original shapes or any desired shape. (**Some examples in pictures below**)



Source: link

We would like you to rate the level of importance of 3D food printing benefits in the context of your organization. Please, tick the box under the appropriate scale.

	I do not know	Not important at all	Somewhat unimportant	Neutral	Somewhat important	Extremely Important
Food ingredient versatility						
Food design versatility						
Use of fresh ingredients						
Use of natural ingredients						
Use of food additives						

Use of pre-prepared food						
Food texture customization						
Food design customization						
Food nutrition customization						
Technology novelty						
Improvement of patient's eating experience						
Patient's improvement in appetite						
Make visually appealing food						
Present food in their original shape						
Preservation of food taste, aroma, and color						

Food ingredients can be formulated and prepared on-site or purchased pre-prepared from an ingredient supplier. Then, the prepared food must be loaded onto the printing system. The food printing process might vary from 10 to 20 minutes or even more depending on the design and size of the print. While 3DFP can create various food shapes, food designs depend on food consistency limited by process temperature and product formulation. Several food pieces can be produced through continuous printing, or to speed up production, multiple printers can be set up to print simultaneously. Food cooking could be done before or after printing, depending on the recipe and desired food texture. Moreover, products could be frozen to ensure safe delivery to healthcare facilities to thaw and warm the product, or the printer can be used in situ.

The printer can be programmed to work by itself, so there is no need to have personnel working full-time with it, except for the food refill and clean-up of the printer. Lastly, 3DFP utilization might require learning how to use the printer and experimenting with food ingredients and formulations to optimize product quality.

Based on the information provided, we would like you to rate the level of importance of 3D food printing features in the context of your food organization. Please, select the response under the appropriate scale.

	I do not know	Not important at all	Somewhat unimportant	Neutral	Somewhat important	Extremely Important
Ingredients developed on-site						
Ingredients purchased from a third-party						
Required food preparation						
Printing time						

Large quantity production						
Delivered frozen food						
Production on-site						
Autonomous process						
Required post-processing						
System refill and cleaning by personnel						
Ease of cleaning process						
Level of expertise						
Possibility of food experimentation						
Ability to purchase 3D printed items from a third-party						
Cost per serving						
Equipment maintenance						
Technical support						

Now, if you were to make the item below (drumstick-shaped food) with a 3D food printer, how would you rate the printing time of 1 piece in 7 minutes?

Source: Link

☐ Extremely long ☐ Long ☐ Just about right ☐ Fast ☐ Extremely fast

Scenario 3. **3DFP in confectionary and bakery**

3D food printing (3DFP) technology can give a modern touch to bakeries and confectionaries as it creates intricate and customized food items with precision and consistency. With 3D printers, shapes can be effortlessly reproduced, enabling a new level of creativity of visually captivating and deliciously memorable treats. Customized products can be offered for events, giveaways, company logos, personal gifts, in situ treats, or messages on baked goods **(See examples below).** 3D food printing is more efficient and convenient for designing new creations than traditional techniques like molding. It can store numerous designs in an SD card, saving storage space, and it generates complex and unique shapes whenever needed. Furthermore, 3DFP encourages product innovation, enabling the exploration of new textures, flavors, and ingredient combinations due to its versatility in using different ingredients and the wide range of designs it can make.

Food products that can be printed are doughs, batters, chocolate, fondant, sugar, and icing, among others. In addition, food thickeners, colorants, and flavors can be added to enhance the appearance and taste of the 3D-printed confectionary and bakery items. Also, food by-products can also be reused to create added-value, edible products, which help to reduce food waste.

3D printed confections

Source: Link

3D printed tiramisu

Source: Link

3D-printed cake decoration and lettering

Source: Link

We would like you to rate the level of importance of 3D food printing benefits in the context of your organization. Please, tick the box under the appropriate scale.

	I do not know	Not important at all	Somewhat unimportant	Neutral	Somewhat important	Extremely Important
Delicate food designs						
Complex food designs						
Precise and consistent production						
Food design customization						
Fast customization						
Technology novelty						
Visually appealing and memorable products						
Saving storage space for food designs in SD card						
Product innovation						
Food ingredient versatility						
Food design versatility						
Use of food by-products						
Use of natural ingredients						
Use of food additives						

Food ingredients can be formulated and prepared on-site or purchased pre-prepared from an ingredient supplier. Then, the prepared food must be loaded onto the printing system. Depending on the design, the processing time might vary from minutes to hours. For example, while for a 1 cm height piece, printing time may vary from 15 to 20 minutes, a taller shape might take up to 2 to 5 hours. While 3DFP can create various food shapes, food designs depend on food consistency.

Several food pieces can be produced through continuous printing, or to speed up production, multiple printers can be set up to print simultaneously. Control of temperature during printing can guarantee well chocolate temperate or other required food conditions. Post-processing is necessary for foods that have to be cooked. Special packaging or local delivery shall be needed to guarantee safe delivery of the products because of their delicacy.

The printer can be programmed to work by itself, so there is no need to have personnel working full-time with it, except for the food refill and clean-up of the printer. Lastly, 3DFP utilization might require learning how to use the printer and experimenting with food ingredients and formulations to optimize product quality.

Based on the information provided, we would like you to rate the level of importance of 3DFP features in the context of your food organization. Please, select the response under the appropriate scale.

	I do not know	Not important at all	Somewhat unimportant	Neutral	Somewhat important	Extremely Important
Ingredients developed on site						
Ingredients purchased from a third party						
Required food preparation						
Printing time						
Large quantity production						
Required post-processing						
Special packaging needed						
Local delivery needed						
Autonomous process						
System refill and cleaning by personnel						
Ease of cleaning process						
Level of expertise on 3D food printing						
Possibility of food experimentation						
Ability to purchase 3D printed items from a third-party						
Cost per serving						
Equipment maintenance						
Technical support						

Now, if you were to make the item below (Chocolate future word) with a 3D food printer, how would you rate the printing time of 1 piece in 4 minutes?

Source: [Link]

☐	☐	☐	☐	☐
Extremely long	Long	Just about right	Fast	Extremely fast

Perceptions about 3DFP based on DOI five attributes of innovation

In this section, you will find statements about 3D food printing's relative advantage over conventional food processing. Please indicate to what extent you agree or disagree with the following statements.

- Using 3D food printing makes it easier (or would make it easier) for your organization's employees to do their job over conventional food processing.

☐	☐	☐	☐	☐
Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree

- Using 3D food printing gives (or would give) your organization's employees greater control over their work over conventional food processing.

☐	☐	☐	☐	☐
Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree

- Using 3D food printing improves (or would improve) your organization's quality of work over conventional food processing.

☐	☐	☐	☐	☐
Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree

- Using 3D food printing enables (or would enable) your organization's efficiency over conventional food processing.

☐ Strongly disagree	☐ Somewhat disagree	☐ Neither agree nor disagree	☐ Somewhat agree	☐ Strongly agree

- Using 3D food printing has reduced (or would reduce) your organization's cost structure over conventional food processing.

☐ Strongly disagree	☐ Somewhat disagree	☐ Neither agree nor disagree	☐ Somewhat agree	☐ Strongly agree

In this section, you will find statements about 3D food printing compatibility with your organization. Please indicate to what extent you agree or disagree with the following statements.

- 3D food printing is (or would be) compatible with existing operations in your organization.

☐ Strongly disagree	☐ Somewhat disagree	☐ Neither agree nor disagree	☐ Somewhat agree	☐ Strongly agree

- 3D food printing is (or would be) compatible with the vision of your organization.

☐ Strongly disagree	☐ Somewhat disagree	☐ Neither agree nor disagree	☐ Somewhat agree	☐ Strongly agree

- 3D food printing fits (would fit) with the values of your organization.

☐ Strongly disagree	☐ Somewhat disagree	☐ Neither agree nor disagree	☐ Somewhat agree	☐ Strongly agree

- 3D food printing fits (would fit) your organization's need.

☐ Strongly disagree	☐ Somewhat disagree	☐ Neither agree nor disagree	☐ Somewhat agree	☐ Strongly agree

The following statement is about the importance of testing 3D food printing in your organization. Please indicate your level of agreement or disagreement.

- Trying out 3DFP is (or would be) important in adopting 3D food printing for your organization.

☐ Strongly disagree | ☐ Somewhat disagree | ☐ Neither agree nor disagree | ☐ Somewhat agree | ☐ Strongly agree

The next two statements are about the complexity of using and learning 3D food printing. Please indicate your level of agreement or disagreement in each statement.

- 3D food printing is (or would be) easy to use.

☐ Strongly disagree | ☐ Somewhat disagree | ☐ Neither agree nor disagree | ☐ Somewhat agree | ☐ Strongly agree

- Learning to operate 3D food printing is (or would be) easy for my team and I.

☐ Strongly disagree | ☐ Somewhat disagree | ☐ Neither agree nor disagree | ☐ Somewhat agree | ☐ Strongly agree

Level of receptiveness in adopting 3DFP.

For those non-owners

After learning and assessing how 3D food printing (3DFP) might apply to your organization, we would like you to tell us your level of interest in adopting 3DFP by rating the following statement.

How interested would you be in buying a 3D food printer in the next 12 months if priced within your budget?

☐ Not interested at all | ☐ Slightly interested | ☐ Moderately interested | ☐ Very interested | ☐ Extremely interested

Please utilize the slider to express the additional amount (in percentage) you are willing to invest in a 3D food printer compared to the existing technology currently present in your organization, which the 3D food printer may potentially replace.

- 0-100%
- We would not invest in a 3D food printer.

Which technology might a 3D food printer potentially replace?

For those owners

After giving your perspectives on 3D food printing attributes and applicability in your organization, we would like you to tell us the likelihood of recommending 3DFP adoption by rating the following statement.

I would recommend my organization community acquire a 3D food printer.

☐	☐	☐	☐	☐
Very unlikely	Somewhat unlikely	Neutral	Somewhat likely	Very likely

Strategies to encourage 3DFP adoption

We would like your opinion regarding the importance of strategies to support 3D food printing adoption. Please, tick the box under the appropriate scale number to rate each strategy.

	Not important at all	Somewhat unimportant	Neutral	Somewhat important	Extremely Important
Promoting successful case studies					
Collaboration around 3D food printing					
Getting training in 3D food printing					
Promoting knowledge of 3DFP					
Government incentives					
A trial project to commence full-scale implementation					
Getting private financial support					

- Other____________

Appendix E – Exploratory factor analysis

	Factor		
	1	2	3
Factor, Mean[1] (sd)	Construct loadings		
Relative advantage, 2.8 (1.2)			
Using 3DFP would enable organization efficiency over conventional food processing.	0.919		
Using 3DFP would make it easier for your organization's employees to do their job over conventional food processing.	0.892		
Using 3DFP would reduce your organization's cost structure over conventional food processing.	0.841		
Using 3DFP would give your organization's employees greater control over their work over conventional food processing.	0.739		
Using 3DFP would improve your organization's quality of work over conventional food processing.	0.659		
Compatibility, 3.3 (1.2)			
3DFP would be compatible with the vision of your organization.		0.998	
3DFP would fit with the values of your organization.		0.97	
3DFP would fit your organization's need		0.815	
3DFP would be compatible with existing operations in your organization.		0.557	
Complexity (Easiness), 3.1 (1.0)			
Learning to operate 3DFP would be easy for my team and I.			0.891
3DFP would be easy to use.			0.845
Cronbach's alpha	0.911	0.925	0.87
% Variance	51.64	12.53	11.00
% Cumulative variance	51.64	64.17	75.17

Appendix F - Number of dropouts responses[†] across survey sections

Survey section and concept queried	Confectionery and bakery	Food service	Healthcare food service
Section 1			
Demographics (Organization's sector, size, and location, and representative's role)	8	2	26
Innovativeness	0	0	1
Prior knowledge about 3DFP	0	1	1
Current adoption of non-food 3DP and 3DFP technologies	4	5	10
Section 2			
Perceptions of 3DFP benefits	2	3	8
Perceptions of 3DFP features for implementation	0	1	3
Section 3			
Interest in adoption 3DFP	0	1	1
Total	**14**	**13**	**50**

[†]195 initial responses