Effect of labelling and information on consumer sensory acceptance, attitude, and quality ratings of foods labelled as 3D printed

by

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Abstract

3D printing technology, also known as additive manufacturing, involves digital construction of a physical structure by depositing materials layer by layer. In the recent few years, 3D printing has expanded to the food sector enabling customized food design and personalized nutrition. Most researchers therefore hold optimistic views of this novel technology. While more research studies have focused on the optimization of, and food development using 3D food printing (3DFP), consumer acceptance, which is an equally important determinant of future market of 3DFP, remains underexplored.

The primary research objective of this study was to investigate the effect of labelling as 3D printed and product-specific positive information about 3DFP on consumer sensory acceptance of plausible 3D printed foods products. Secondary research objectives were to determine consumer attitude before and after "3D printed" food tasting with presented benefits; the effect of Food Technology Neophobia (FTN) and previous knowledge about 3D printing on overall liking and perceived quality of "3D printed" foods and attitude towards 3D printing; and preference between a food product presented as both conventional and 3D printed. Consumer food choice orientations, familiarity with digital tools, product use behaviors, and opinions of tasted "3D printed" foods were also evaluated.

A hundred and eighty-six participants participated in one of the chocolate swirl (n = 68), gummy candy carrot (n = 59), and potato Smiles® (n = 59) sensory panels. For each panel, three identical and conventionally produced food samples were presented monadically as conventional, 3D printed, and 3D printed a second time after presentation of product-specific benefits about 3DFP. Participants tasted and evaluated each product presentation for overall liking and liking of appearance, aroma, flavor, and texture on 9-point hedonic scales and perceived quality on 5-point Likert scales. Additionally, consumer attitude towards 3D printing, previous knowledge about 3D printing, FTN, and four consumer constructs (digital native and food choice orientations to health, natural content, and convenience) were assessed. Participants indicated their preference between samples previously presented as conventional and 3D printed and were invited to leave comments for each sample.

Labelling and information had limited effect on participant sensory attribute acceptance of the foods but resulted in a more positive attitude towards 3D printing. Participants (75–79%) preferred the “3D printed” to the “conventional” chocolate swirls and gummy candy carrots and increased agreement of high perceived quality when the products were first presented as 3D printed. Participant attitude towards 3D printing decreased with higher FTN and was not affected by previous knowledge about 3D printing. Overall, the mostly young and educated population had little knowledge about 3DFP but positive attitude towards 3D printing. Results of this study will contribute to the consumer and sensory science literature about 3DFP and inform 3DFP stakeholders about consumer responses to this novel food technology.

Preface

This thesis is an original work by Xiaoqin Feng under the supervision of Dr. Wendy V. Wismer. No part of this thesis has been previously published. Chapter 2 of this thesis will be submitted as Feng, X., Khemacheevakul, K., De León Siller, S., Wolodko, J., & Wismer, W. V. Effect of labelling and information on consumer sensory acceptance, attitude, and quality ratings of foods labelled as 3D printed. *Food Research International*. Dr. Wendy V. Wismer will be the corresponding author.

For the manuscript (chapter 2), I was responsible for study design, investigation, data collection and analysis, and manuscript composition. K. Khemacheevakul was involved in conceptualization, study design, investigation, and data collection and analysis. S. De León Siller performed data analysis. Dr. J. Wolodko was responsible for project administration, supervision, and funding acquisition. Dr. W. V. Wismer assisted with conceptualization, study design, project administration, and supervision. All co-authors will review and edit the manuscript draft.

The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "Consumer perceptions of the taste of 3D printed food products", Pro00089544, October 22nd, 2019.

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List of Abbreviations

3D: Three-dimensional

3DFP: Three-dimensional food printing

ANOVA: Analysis of variance

FT: Food technology

FTN: Food Technology Neophobia

Conv: Study food products presented as conventional

3DP: Study food products presented as 3D printed

3DP+Info: Study food products presented as 3D printed after presentation of benefits about 3DFP

Chapter 1 - Literature Review

Three-dimensional (3D) food printing (3DFP) is a promising novel food production technology that allows digital and custom fabrication of various foods (1.1). Extrusion-based 3DFP allows personalization of food shapes and nutrition and has been used in custom food businesses and nutrition projects proving its commercial value (1.2). Currently, 3DFP faces challenges associated with printing parameter optimization, printing efficiency, and material selection and preparation (1.2); however, research studies are emerging to tackle those challenges and contribute to the knowledge base of 3DFP (1.3). Research attention has been largely on the engineering and food development aspects of 3DFP with little consumer and sensory science research that focused on understanding consumer acceptance of this novel food technology and the products generated (1.4). As consumer approval of novel food technologies is crucial for their future acceptance in the market, the study described in Chapter 2 was designed to help fill the research gap to further understand consumer perceptions of 3DFP (1.5).

1.1 3D Food Printing (3DFP)

3D printing, also known as additive manufacturing, is a fabrication method that allows digital manufacturing of complex 3D objects in sequential layers (Yang et al., 2015). Originally created for application in the engineering field such as printing metals, plastic, and polymers (Godoi et al., 2016), 3D printing using food material emerged two decades ago, enabling customization in our food experience (Manstan & McSweeney, 2019). 3D food designs created by computer-aided design software are translated into multiple layer data in Standard Triangle Language files. Slicing software (e.g. Slic3r) then converts Standard Triangle Language files into G-code, which commands the motor of the printer enabling the printing process (Sun, Peng et al., 2015). 3DFP categories are defined by fabrication process; extrusion-based printing, selective laser sintering, binder jetting, and inkjet printing. Extrusion-based 3DFP is the most popular used among them (He et al., 2020). An extrusion-based food printer platform is typically made of a X-Y-Z three axis stage, dispensing units, a user interface, and optional heating elements. When a printing job starts, motors drive the printhead along the three axes while adding pressure on the syringe for accurate deposition of the food material (Sun, Zhou et al., 2015).

1.2 Advantages, applications, and challenges of 3DFP

Supported by computer-aided design and precise digital control, 3DFP users can customize the appearance, taste, texture, and even nutrient content of the printed food (Sun, Zhou et al., 2015), allowing culinary creativity and precise nutrient delivery. Three main advantages of 3DFP include fabricating complex and custom food geometries, lower capital cost and improved efficiency in small-scale food production as compared to conventional production methods (Lipton et al., 2015), and realizing personalized nutrition (Sun et al., 2018). The advantages of 3DFP are applied to bring culinary, sensory, nutritional, and educational benefits to niche food markets.

3D food printer companies such as Natural Machines, Print2Taste, and Wiiboox have released food printer models for producing culinary art using confections, pastry, and complementary foods while others, for instance Choc Edge, have specialized in single material printing (Choc Edge, 2021; Natural Machines, 2020; Print2Taste, 2019; Wiiboox, 2021). Hershey has partnered with 3D Systems and developed a chocolate 3D printer named Cocojet, which allowed customization of chocolate (Liu et al., 2017). In Magic Candy Factory, customers customize fruit gummy candies through a touch screen (Frost, 2017). The 3D food printer nūfood brings more possibilities to the sensory experience by fabricating flavor extracts in the form of pearls or customized shapes which can be added to drinks and dishes (Dovetailed, 2020).

Culinary arts created by 3DFP not only make food experiences enjoyable, but also help facilitate nutrient delivery by producing products that are visually appealing to consumers (Portanguen et al., 2019). The PERFORMANCE project, which involved five European countries, provided 3D printed personalized meals in nursing homes to the elderly, who generally required tailored nutrition. The preliminary results showed more positive consumer sensory acceptance of this nutritious and visually appealing alternative compared to the unappetizing pureed diet (European Commission, 2016). Similarly, Natural Machines is dedicated to providing personalized nutrition using 3DFP through designing pre-filled formulations that meet the nutritional needs of the elderly in healthcare organizations. The company Nourished allows consumers to personalize their desired nutrients and 3D prints those nutrients in the form of layered gummy candy (Nourished, 2021).

Two other populations that require extensive nutrition support are soldiers and astronauts, who go through long missions and vary in personal physical characteristics. Nutrition tailored for individuals is thus important in optimizing and sustaining their performance. The 3D printing company BeeHex has been working with the U.S army to print personalized snack bars to meet individual nutrition and energy requirements based on the biometric data of soldiers (NASA Spinoff, 2019). In order to meet personal and individual nutrient requirements of astronauts, NASA funded research to use 3DFP to change the current food system by allowing customization and easier production at lower cost (Liu et al., 2017).

3DFP, in comparison to traditional molding or cutting, produces less waste by additively depositing material, which could lower the cost of the production (Yang et al., 2015). It also provides an economical solution to the custom/specialty food industry by allowing anyone to produce intricate designs which typically require highly skilled professionals and high time input

(Lipton et al., 2015). Additionally, precise digital deposition and flexible fabrication by 3DFP allowed its application in sustainable food prototyping. Refined Meat developed a trade-marked 3D printed plant-based steak, which resembles the sensory quality of beef muscle tissues while providing adequate and sustainable nutrition (Askew, 2020). In a similar initiative, KFC will release a 3D printed plant and cell-based chicken-analog nugget in mid-2021 (Southey, 2020).

In relation to the end users, 3D food printers are largely used by foodservice professionals in restaurants and healthcare organizations, researchers and educators, event holders, businesses for customizing foods/gifts and personalizing nutrition, and new product prototyping. They are less adopted by the general populations for home use.

While the advantages of 3DFP make its future promising, it has also faced challenges which limit its applications. One of the technological challenges is related to the printing material. Traditional 3D printing is used to produce industrial material which has homogenous properties. Foods, on the other hand, are more complex in composition, have more interactions between components, and require alternating layering and processing; therefore, optimizing the printing process to accommodate the complex nature of food material is one technological challenge in 3DFP (Hanley, 2016). In addition, rheological properties of the food material, which are crucial for successful printing, are easily affected by addition of other materials, chemical reactions over time, and can vary among batches, thus causing issues in printing (Sun et al., 2018). Therefore, precise control of parameters that affect the material rheology poses another challenge.

From a consumer standpoint, preparing food materials to the correct consistency or purchasing pre-filled food capsules adds to the cost and time for home use, and the addition of additives for adjusting material consistency is becoming less desirable as consumers are increasingly health conscious (Portanguen et al., 2019). Making the material rheology adjustment easier, cheaper, and cleaner is one challenge to tackle. The current printable food materials are largely confections, spreads, or other calorie-dense substances. In response to the growing demand for healthy and nutritious foods, exploration of printing materials that are more nutrition-dense and consumed more often than confections and spreads, is needed (Piyush et al., 2020).

Another limitation of 3DFP is its low efficiency. While computerized automation will gradually lead to rapid mass production as the technology advances, the current efficiency of 3D fabrication remains low and the production remains small scale. To date, 3D food printers for large scale production have not been designed (Sun et al., 2018). Moreover, published literature (He et al., 2020) and real-life applications both point to the necessity of post-printing processes to maintain product stability or further process the 3D printed objects, which could be a limiting factor to its production efficiency. Post-printing processes include traditional drying, baking, frying, and cooling, which impair the convenience brought by 3DFP. Future research that aims to address these issues will be important to bring success to 3DFP.

1.3 Research foci of extrusion-based 3DFP

Research in extrusion-based 3DFP has mainly focused on three areas; study of printable material (e.g. material properties, printability, material interactions, and new material exploration), optimization of the printing parameters, and food prototyping using innovative or nutritious ingredients.

Printable food materials require specific rheological and/or thermoplastic properties; therefore, foods may require modification to achieve suitable consistency for printing (Godoi et al., 2016). Naturally printable food materials should be soft enough to allow smooth extrusion yet solid enough to maintain their shape after printing or stable enough for further processing. These include molten or slurry materials such as hydrogels, cake frosting, cheese, hummus, gummy candy, mashed potato and chocolates.

The texture of food materials can be modified by adding hydrocolloids or processing aids to facilitate printing (Sun, Zhou et al., 2015). For instance, the addition of magnesium stearate and plant sterols in dark chocolate, potato starch in mashed potatoes, and gums in brown rice gel improved the printability of the corresponding food matrix (Huang et al., 2020; Liu et al., 2018; Mantihal, Prakash, Godoi et al., 2019).

Material modifications before printing and further processing or preservation after printing using thermal, chemical, and physical methods have also been studied. Examples of those pre-treatments include dry heating treatment (Maniglia et al., 2020) and ozone processing of cassava starch gels (Maniglia et al., 2019), microwave and salt treatment of strawberry slurry (Fan et al., 2020), and pH modification of a protein containing matrix (Wang et al., 2018). Examples of post-treatments other than traditional cooking include vacuum microwave drying of juice gel (Yang et al., 2019) and rapid freezing and laser cooking of dough (Blutinger et al., 2018; Yang et al., 2018).

In addition to investigations of optimal printable materials, 3DFP has been studied as a prototyping tool for nutritious or innovative food development. Examples of prototyped 3D printed nutritious foods include a fruit-based snack using banana, dried mushrooms, white beans, milk powder, lemon juice, and ascorbic acid that could provide 5-10% of required energy, calcium, iron, and vitamin D to children (Derossi et al., 2018); and a fruit and vegetable smoothie made with carrot, kiwifruit, pear, broccoli, raab leaves, and avocado as a superfood (Severini, Derossi et al., 2018). Innovative food sources such as edible insects and microalgae have been successfully incorporated into a baked snack and cookie and improved the protein content and antioxidant activity of the respective products (Severini, Azzollini et al., 2018; Vieira et al., 2020). Based on current stage of 3D printed conventional meat, 3D printed cultured meat is foreseen to provide customized nutrition while bringing environmental benefits in the future (Handral et al., 2020).

Optimized 3D food printing parameters include nozzle size and height, nozzle movement rate, infill level, extrusion rate, and temperature (Liu et al., 2017). Food materials evaluated include whole or modified dough, chocolate, mashed potato, fish surimi, gums, juice gel, starch gel, egg, rice, vegetable and fruit puree, spreads (Piyush et al., 2020), algae, edible insects, protein, meat, and processed cheese (He et al., 2020). Identified critical printing material properties include viscosity, elasticity, shear stress, water holding capacity, gel strength, microstructure, particle size distribution, density, dry matter content, relative volume fraction (Piyush et al., 2020), moisture content, crosslinking mechanisms (Liu et al., 2017), crystallization state, and glass transition temperature (Godoi et al., 2016).

1.4 Consumer perceptions of 3DFP and novel foods and food technologies

Little published research has explored consumer acceptance of 3DFP. Novel foods and their related technologies are susceptible to public distrust, highlighting the importance of consumer research at an early stage of process development to gauge consumer acceptance (Brunner et al., 2018). Consumer attitude towards novel food technologies and sensory perceptions of novel foods are determinants of their food acceptance and purchase decision (Mantihal et al., 2020; Tan et al., 2017). To date, consumer research of 3D printed foods involves acceptance assessment based on images, concepts, and information about 3D printed foods and sensory evaluation of 3D printed samples; methods include focus panels, online discussion panels, and consumer surveys. The following section describes consumers' current experience level with and responses to 3DFP and factors that affect consumer acceptance of 3DFP. Since consumer and sensory science research about 3DFP is limited, that of other novel food technologies and novel foods are also reviewed.

1.4.1 Consumer current knowledge, attitude, and sensory acceptance

A summary of consumer and sensory science literature on the topic of 3DFP is presented in Table 1.1. Consumer knowledge about 3D printed foods was observed to be low (Brunner et al., 2018; Lupton & Turner, 2018a; Manstan & McSweeney, 2019); attitude towards 3DFP was observed to be negative to neutral (Brunner et al., 2018; Caulier et al., 2020); and willingness to purchase and eat 3D printed foods were observed to be low (Manstan & McSweeney, 2019). On the contrary, an Australian university population was knowledgeable about 3D printing and 3DFP, and had a positive attitude towards 3DFP (Mantihal, Prakash, & Bhandari, 2019). One possible explanation is that the mostly young and highly educated university population is more familiar with, and accepting of, 3DFP than general populations.

Sensory acceptance of 3D printed foods has been overall positive and comparable to conventionally produced controls. Studied key sensory attributes included appearance, color, aroma, off-odor, taste, after-taste, flavor, off-flavor, texture, and overall liking (Caulier et al., 2020; Keerthana et al., 2020; Mantihal, Prakash, & Bhandari, 2019; Severini, Derossi et al., 2018). The appearance, taste, and texture of two 3D printed cooked snacks were "liked slightly" to "very much" (Caulier et al., 2020; Keerthana et al., 2020). The color, aroma, taste, and appearance of a 3D printed fruit and vegetable smoothie was "liked slightly" to "extremely" while the off-flavor and off-odor were perceived to be minimal. The appearance of the 3D

Table 1.1. Consumer and sensory science literature about 3DFP.

Brunner et al. (2018); Switzerland	
Main objective	To determine predictors of consumer attitude towards 3D printed foods
Methods	Participants were 260 adults randomly selected from a telephone directory. **Consumer survey** - Information: benefits of 3D food printing (3DFP) - Measurements: attitude towards 3D printed foods before and after information, and attitude change; food neophobia; Food Technology Neophobia (FTN); previous knowledge about 3D food printing; food choice orientations to health, natural content, and convenience; social-demographic variables; benefit perception; willingness to consume; perceived fun to use; cooking creativity; food involvement; preference for familiar foods (familiarity); familiarity with digital technology (digital native); nutritional knowledge
Results	1. Participant previous knowledge about 3DFP was low; initial attitude was negative, which improved after receiving benefits of 3DFP but remained negative. 2. Predictors of consumer attitude towards 3D printed foods: - Perceived fun to use, willingness to consume, FTN, food neophobia, and gender (men more positive) predicted consumer initial attitude. - Willingness to consume, FTN, benefit perception, convenience orientation, and perceived fun to use predicted consumer attitude after receiving information. - Food neophobia, benefit perception, nutrition knowledge, convenience orientation, previous knowledge, and FTN predicted consumer attitude change.
Mantihal, Prakash, and Bhandari (2019); Australia	
Main objective	To assess the preferences of texture-modified 3D printed chocolate and consumer perceptions of 3D printed foods

Methods	Participants were 30 semi-trained (preference test) and 244 untrained (consumer survey) adults recruited from university. 3D printed chocolates were made of Cadbury dark chocolate (choc1) and Callebaut dark chocolate (choc2). **Preference test** - Preference ranking of appearance, hardness, and overall preferences of 25, 50, and 100% infilled honeycomb patterned 3D printed choc2 - Paired preference between the 100% infilled rectilinear pattern 3D printed choc1 and the cast chocolate block **Consumer survey** - Information: participants watched 3DFP process, saw 3D printed chocolate samples, and were provided information about 3DFP. - Measurements: demographics, knowledge about 3DFP, perception about benefits, opinions about the 3D printed chocolate on display, attitude towards 3D printed food.
Results	Preference test: 1. Appearance of 100% infilled chocolate was considered smoother and preferred to that of 50% and 25% infilled counterparts. No preference was observed in hardness and overall preference among chocolate of three infill levels. No preference was observed between the 3D printed and cast chocolate. Consumer survey: 2. Participants had high self-assessed and objective knowledge about 3DFP. 3. Most participants perceived benefits of 3DFP in creative food design, personalized nutrition, easy preparation of foods, and waste reduction; perceptions of benefits were not affected by gender, age, or education. 4. 3D printed chocolate was perceived as attractive, intricate and respondents were willing to try. Participants considered 3DFP to be good, important, positive, and should be supported.

Manstan and McSweeney (2019); Canada

Main objective	To investigate consumer opinions of 3D printed foods as compared to conventional food products
Methods	Two focus groups (n=8; n=12) were conducted to identify consumer opinions of 3DFP for developing the consumer survey. Participants (consumer survey) were 329 Atlantic Canadian adults who had no experience in food, sensory analysis, and 3D printed industry and were recruited through research facility mailing list and social media. **Consumer survey** - Information: photos of 3D printed and conventional mashed potatoes, meatballs, pizza, and cookies - Measurements: willingness to purchase and eat; perceived healthiness; perceived level of processing; beliefs about 3D printed foods, food processing methods, 3D printing, healthy diet, and food sustainability; knowledge about 3D printing
Results	1. 3D printed foods, except for mashed potatoes, were perceived as healthier than their conventional counterparts; however, willingness to buy or eat them remained low. 2. Participants had limited knowledge about 3D printing; young participants had higher acceptance of 3D printed foods than the older participants. 3. The "interested to try 3D printed foods" group was willing to eat 3D printed foods, appreciated the benefit of 3DFP in personalized nutrition and cost reduction. The "not interested" group was not willing to buy or eat 3D printed foods, perceived them as unfit for consumption and not beneficial for people.
Caulier et al. (2020); Netherlands	
Main objective	To determine a) the effect of information about 3DFP and repeated exposure to 3D printed food on consumer attitude towards 3DFP, and b) the effect of consumer customization freedom on sensory acceptance of 3D printed food.

Methods	Participants were 12 male soldiers recruited from an airmobile brigade. 3D printed snack bars were made of 30g cookie dough filled with 25-30g filling. Conventional snack bars (control) were made of 55g vanilla cookie bar with chocolate chips. **Consumer survey** - Information: benefits of 3DFP in personalized nutrition for soldiers - Rated overall liking and liking of taste, appearance, and texture of 3D printed snack bars with increasing customization freedom 1^{st} week: no customization (the control) 2^{nd} week: customization of texture (soft/crunchy) 3^{rd} week: customization of texture and taste (sweet/savoury) 4^{th} week: customization of texture, taste, and ingredients (4 types of dough, 13 types of filling) - Measurements: initial consumer attitude towards 3D printed foods, attitude after information, and attitude after repeated tastings; food neophobia, FTN, food choice motives before and after repeated tastings **Interview** For qualitative insights
Results	1. Participants had neutral initial attitude towards 3D printed foods, and presentation of benefits of 3DFP did not affect participant attitude; however, after repeated tastings, participants perceived 3D printed foods to be better as compared to before. 2. Participants had low food neophobia and FTN scores indicating high acceptance towards novel foods and food technologies. 3. Customization freedom did not affect consumer sensory acceptance of the 3D printed snack bars. 4. Participants indicated that taste, portion size, texture, shape, colour were important in making food choices. Participants preferred a larger portion size and customization of nutritional content. They had low acceptance of 3D printed snacks as recovery product substitutes due to the limitation of current 3DFP technology to fulfill personal needs.

Lupton and Turner (2018a); Australia	
Main objective	To evaluate consumer opinions of 3D printed foods
Methods	Participants were 30 adults recruited through research company mailing list. **Online discussion panel** - Information: photos of 3D printed sweets, carrot puree, ground insects, chicken puree, pizza, pasta, and chocolates; descriptions and ingredient list of each presented food - Rated: disgusting to delicious; unhealthy to healthy; artificial to natural; willingness to eat; willingness to serve to family members - Commented: explanation of answers and comments to others
Results	1. Participants had limited knowledge and experience with 3DFP. 2. Consumer opinions of 3D printed foods were influenced by the food product type. While opinions on 3D printed chicken and vegetable meal, pizza, pasta, and chocolate were overall positive, those on 3D printed sweets and insects were overall negative. 3. Overall, familiarity, healthiness and naturalness, perceived mode or level of processing, and perceived sensory properties were aspects of the study 3D printed foods that shaped consumer opinions.
Severini, Derossi et al. (2018); Italy	
Main objective	To determine sensory attribute acceptance of a 3D printed fruit and vegetable smoothie
Methods	Participants were 20 untrained panelists; recruitment details not indicated. Smoothie ingredients were pears, carrots, kiwi fruit, broccoli raab leaves, avocado **Consumer survey** - Rated liking of appearance, colour, odour, off-odour, taste, and off-flavour of a pyramid-shaped 3D printed smoothie and a food formula control

Results	1. Participants had good sensory acceptance of 3D printed smoothie and rated the appearance of 3D printed smoothie to be higher than that of the food formula control.
Keerthana et al. (2020); India	
Main objective	To determine sensory attribute acceptance of a mushroom-based 3D printed snack in sweet and spicy flavours
Methods	Participants were 20 semi-trained adults; recruitment details not indicated**.** Snack ingredients were white button mushrooms, wheat flour, potassium metabisulphite, sodium chloride, calcium chloride. Sweet formulation: served in sugar-added milk. Spicy formulation: added salt, spice powder additionally. **Consumer survey** - Rated overall acceptability and liking of flavour, colour, taste, aftertaste, aroma, appearance, and texture of butterfly-shaped 3D printed sweet and spicy snacks
Results	1. Participants had good sensory acceptance of 3D printed sweet and spicy snacks and preferred the spicy variant to the sweet one. 2. Texture and flavour of the spicy snack were liked more than those of the sweet variant, which can be explained by the sogginess introduced by the milk in the sweet snack and lack of the compatibility of the snack with a sweet taste.

printed smoothie received higher liking than that of the conventional control (Severini, Derossi et al., 2018), indicating the advantage of 3DFP in creating appealing designs. Paired preference results suggested that equal numbers of participants preferred 3D printed or molded chocolate after sensory evaluation of both (Mantihal, Prakash, & Bhandari, 2019).

1.4.2 Perceptions of 3DFP and qualitative insights

Consumer perceptions of 3DFP remained inconclusive. Both positive and negative perceptions were documented, and the 3D printed product type also played a role in opinion formation. Some consumers perceived 3DFP as attractive and recognized its benefits in personalized nutrition, easy preparation of food, food waste reduction, and attractive presentation of soft foods (Mantihal, Prakash, & Bhandari, 2019). 3D printed meatballs, pizza, and cookies, but not mashed potatoes, were perceived to be healthier and less processed than their conventional counterparts (Manstan & McSweeney, 2019).

An online discussion panel was conducted with 30 Australians to analyze their responses to seven pictures of 3D printed foods including sugar, carrot puree, insect snack, chicken and vegetable pureed meal, pizza, pasta, and chocolates. The open-ended responses showed that consumers based their opinion of 3D printed foods on expected sensory attributes, visual cues, healthiness, naturalness, level or mode of processing, and familiarity. 3D printed pizza and pasta received positive responses due to high product familiarity, good expected taste and perceived normality. The 3D printed insect snack was perceived to be most negative by its content and appearance, and 3D printed sugar was perceived to be unhealthy, unnatural, and more as a decoration than food. Moreover, 3DFP could be perceived as another layer of processing, thus reducing the acceptance of supposedly natural foods (Lupton & Turner, 2018a). Consumer unfamiliarity of the novel food or technology, resulting in negative responses, referred to unfamiliar processing methods, nature and extent of processing, appearance, and ingredients. Researchers suggested that advertisement of 3D printed foods should emphasize the nutritional benefits and novelty of 3DFP and reduce consumer skepticism by providing them with more information about this technology (Lupton & Turner, 2018b).

In another study, Dutch military participants preferred customization of nutrient content rather than sensory customization after tasting customized 3D printed snack bars. They also expressed their reluctance to use 3DFP due to its limited development (Caulier et al., 2020).

1.4.3 Food Technology Neophobia (FTN)

Low acceptance of 3DFP, a novel food technology, could result from consumer fear and skepticism (Cox & Evans, 2008). Resistance to new foods produced by new technologies has been described as Food Technology Neophobia (FTN) and is quantified on the Food Technology Neophobia Scale (FTNS), designed and validated by Cox and Evans (2008). The scale is composed of 13 items related to food technology evaluated on 7-point Likert scales from 1 = totally disagree to 7 = totally agree (total score range = 13–91). A higher score indicates a higher FTN and a lower acceptance towards novel food technologies. FTNS has been proven to be a reliable tool to predict consumer acceptance of novel food technologies (Evans et al., 2010). FTN was negatively associated with consumer acceptance of shelf-life extension technology in packaged fish fillets (Demartini et al., 2019), vacuum packaging of fresh beef (Chen et al., 2013), nanotechnology to treat cherry tomatoes and ice cream (Kuang et al., 2020), mushroom powder fortified flat bread (Proserpio et al., 2019), general use of pasteurization, selective breeding of animals, fortification, bioactives, triploidy, genetic modification, nanotechnology (Evans et al., 2010), and 3DFP (Brunner et al., 2018). In the context of 3DFP, FTN was observed to be low in the Dutch military setting (Caulier et al., 2020) and negatively associated with consumer attitude towards 3D printed foods both before and after presentation of positive information (Brunner et al., 2018). Previously, geographical differences in FTN scores were observed. Canadian consumers were found to have a relatively higher mean FTN score (58.5) than Brazilian (47.0) and Australian (55.0) consumers, suggesting a relatively more food technology neophobic population (Cox & Evans, 2008; Matin et al., 2012; Vidigal et al., 2015).

1.4.4 Factors that affect consumer acceptance of 3DFP and novel foods and food technologies

Both consumer constructs and the presentation of information have been studied to understand their effect on consumer acceptance of 3DFP and novel foods and food technologies. Consumer constructs that predicted consumer initial attitude towards 3DFP included perceived fun to use, willingness to consume, FTN, Food Neophobia, and participant gender. Benefit perception and food choice orientation to convenience also predicted consumer attitude after receiving positive information about 3DFP. Food choice orientations to nutrition and convenience and agreement of the presented benefits were predictors of attitude change. Consumer food choice orientations to natural content, familiarity with digital technology, and previous knowledge about 3DFP did not predict consumer attitude before and after receiving positive information about 3DFP (Brunner et al., 2018); however, in a study of functional foods, participants who reported a higher self-assessed knowledge about lycopene were willing to pay a higher price for the health benefits of lycopene-enriched tomatoes (La Barbera et al., 2016). Consumer objective knowledge about benefits and risks of genetically modified foods increased attitude ratings towards them (Zhu & Xie, 2015).

Interest in 3DFP is another consumer construct that affected acceptance of 3DFP products. Results of stratification by interest in 3DFP suggested that the “interested” group were interested in purchasing and eating 3D printed foods and perceived its benefit in personalization and decreased cost. In contrast, the “not interested” group showed low willingness to purchase and eat 3D printed foods and perceived they were unsafe and unacceptable (Manstan & McSweeney, 2019).

In addition to consumer constructs, the effect of customization freedom, infill level, and formulations of the printed products on sensory acceptance of 3D printed foods have been evaluated (Caulier et al., 2020; Keerthana et al., 2020; Mantihal, Prakash, & Bhandari, 2019).

Results from the three studies suggested that increasing freedom of customization did not improve consumer sensory liking of a 3D printed snack bar (Caulier et al., 2020). The appearance of a 100% infilled 3D printed chocolate bar was smoother and preferred to that of 50% and 25% infilled counterparts, whereas no preference was found in the texture and overall liking among products of the three infill levels (Mantihal, Prakash, & Bhandari, 2019). The texture and flavor of a savory 3D printed mushroom snack were liked more than the sweet formulation, while liking of color, taste, after-taste, aroma, appearance, and overall liking of the two formulations were not different. An explanation for the lower liking of the texture of the sweet snack was the sogginess introduced by the addition of milk (Keerthana et al., 2020).

Labelling and information have been studied, either individually or combined, as interventions to improve consumer acceptance of novel foods and food technologies. The presentation of benefits of 3DFP increased consumer attitude towards it in one study (Brunner et al., 2018) while had no effect in another (Caulier et al., 2020). In a study of fish fillets packaged with a shelf-life extension technology, participants were allocated to one of four information conditions; no information (control), information of 'no adverse effect' of using the technology, information about 'economic and environmental benefits' of the technology, and presentation of both information pieces. Results suggested that the presentation of 'no adverse effect' and both information pieces improved consumer acceptance of taste and smell of the fish fillets, and the latter condition additionally improved consumer perception of naturalness of the product, suggesting that both content and quantity of positive information affected consumer acceptance (Demartini et al., 2019).

Willingness to purchase increased after participants were informed about the novel foods. Presentation of positive information about vacuum packaging increased consumer willingness to pay for beef packaged by this technology as compared to no information (Chen et al., 2013). Participant willingness to purchase insect-based foods increased after being informed about its benefits on either individual health or community (e.g. food security) while the individual health benefits had a greater effect (Lombardi et al., 2019).

Labelling with the benefits of a functional cookie fortified with blueberry pomace improved consumer expected liking before, but not actual liking after tasting (Curutchet et al., 2019). In a study of consumer acceptance of cultured meat, conventionally made beef hamburgers labelled as either conventional or cultured were rated by three groups of participants after receiving one of social, personal, or sensorial benefits of cultured meat. Researchers observed that after receiving positive information about cultured meat, consumer liking of taste, out of six tested sensory attributes, was improved for the "cultured" hamburger as compared to the "conventional" counterpart (Rolland et al., 2020). In another study of consumer acceptance of food nanotechnology, labelling as nanotechnology produced with presented benefits did not affect sensory attribute acceptance of cherry tomatoes and chocolate ice cream (Kuang et al., 2020).

1.4.5 Summary of consumer perceptions of 3DFP and novel foods and food technologies

Consumer knowledge about 3DFP was low and attitude was negative to neutral in general populations, but higher and more positive in university populations. Sensory perceptions of 3D printed foods were overall positive and were comparable to, or higher than, conventionally produced controls. Depending on consumer interest and the 3D printed food type, 3DFP are perceived as attractive, useful, healthy and less processed, but may also be perceived as unhealthy, unnatural, and non-food like. FTN, a determinant of consumer acceptance of novel food technologies, was observed to be relatively higher in Canadian populations as compared to other countries and negatively associated with consumer attitude towards 3DFP.

In addition to FTN, the effect of consumer previous knowledge, food choice orientations (health, convenience, natural content), familiarity with digital technology, positive information, and labelling plus positive information on consumer acceptance of novel foods or food technologies have been previously studied. Positive information generally increased consumer acceptance of novel foods and food technologies, while the effect of the other aforementioned variables was limited or unique to the study products. Since few studies investigated their effect on consumer acceptance of 3DFP, understanding how these variables affect sensory and attitudinal acceptance of 3D printed foods will benefit the stakeholders of 3DFP to assist in the development of strategies to enhance their acceptance and will contribute to the limited knowledge of consumer acceptance of this novel technology.

1.5 Current study and its significance

3DFP has been viewed positively by researchers; news sources have described this technology as “futuristic; creative; healthy; efficient; sustainable” (Lupton, 2017). To date, research has emphasized material and printing process optimization and innovative or functional food prototyping; consumer acceptance, which primarily determines the future success of 3DFP, remains under investigated. In fact, novel foods and related technologies are prone to failure in the early development stages if consumer opinions of them are not understood (Brunner et al., 2018; Verbeke et al., 2015). Regarding 3DFP, some studies investigated consumer and sensory acceptance briefly and as a secondary objective, while others that focused on consumer research often used imaginary scenarios or pictures for acceptance testing. Sensory evaluation, an important process in food experience, was adopted by few studies.

To fill the research gap, the current study aimed to determine consumer sensory acceptance of "3D printed" foods under labelled and informed conditions, and consumer constructs that affect their acceptance. Three conventionally made products, chocolate swirl, gummy candy carrot, and potato Smiles® were evaluated in three sequential presentations; conventional (*Conv*), 3D printed (*3DP*), and 3D printed after receiving product specific positive information about 3DFP (*3DP+Info*). Key sensory attribute acceptance (appearance, aroma, taste, texture, overall liking) and perceived quality were measured after each presentation, and attitude towards 3D printing was measured before and after evaluation of products presented as 3D printed. Measured consumer constructs included FTN, previous knowledge about 3D printing and 3DFP, familiarity with digital technology, and food choice orientations to health, natural content, and convenience. Overall, findings of this study will provide insights on consumer sensory and attitudinal acceptance of 3D printed foods and 3D printing to support enhanced consumer acceptance of food products introduced by the 3DFP industry.

1.6 Research objectives and hypotheses

The *primary research objective* was to investigate:

1. the effect of labelling as 3D printed and presentation of positive information about 3DFP on consumer sensory acceptance of three food products.

Secondary research objectives were to determine:

2.1 consumer attitude towards 3D printing before and after tasting "3D printed" foods with presented benefits;

2.2 consumer preference between identical products labelled as conventional or 3D printed;

2.3 the effect of FTN and previous knowledge about 3D printing on overall liking and perceived quality of "3D printed" foods and attitude towards 3D printing.

Consumer characteristics and their comments on tasted products were also described.

Consumer attitude towards 3D printing but not 3DFP was evaluated as the authors anticipated high novelty of 3DFP thus low consumer familiarity to form a valid attitude towards it. Consumer familiarity with the general 3D printing is foreseen to be higher, so the associated attitude was expected to carry more practical meaning than attitude towards 3DFP specifically.

Hypotheses

Study hypotheses were generated based on the reviewed literature and with considerations of the advantages and applications of 3DFP (1.3). It was hypothesized that labelling as 3D printed and product-specific positive information about 3DFP would increase consumer sensory acceptance of three study food products, and consumer attitude towards 3D printing would become more positive. Higher FTN and previous knowledge about 3D printing were hypothesized to negatively and positively affect consumer overall acceptance, respectively. It was hypothesized that participants would prefer the "3D printed" product presentation over the "conventional".

Chapter 2 - Effect of labelling and information on consumer sensory acceptance, attitude, and quality ratings of foods labelled as 3D printed

2.1 Introduction

Three-dimensional (3D) printing is a production technology that allows successive deposition of materials layer by layer based on computer-aided design (Mantihal et al., 2020). The main applications of 3D food printing (3DFP) include creative design of confections (Print2Taste, 2019; Sun, Peng et al., 2015) through customization of intricate food geometries (Burke-Shyne et al., 2020), personalized nutrient delivery (Lipton et al., 2015; Nourished, 2021), and appealing presentation of pureéd diets for individuals with chewing and swallowing challenges (Dick et al., 2020; Kouzani et al., 2017). Considering these benefits, there is great optimism about the future of this pioneering food technology (Lupton, 2017; Sun, Peng et al., 2015).

Recent 3DFP research has focused on technological advancement and product prototyping or development; however, consumer acceptance, an important determinant of the future success of 3DFP, remains under-investigated (Brunner et al., 2018; Manstan & McSweeney, 2019). Knowledge of consumer opinions of novel food technologies early in the development stage is a crucial step to future success (Brunner et al., 2018; Verbeke et al., 2015). Most published consumer and sensory science research to date has evaluated consumer acceptance of the concept of 3DFP or pictures of 3D printed foods (Brunner et al., 2018; Lupton & Turner, 2018a; Manstan & McSweeney, 2019) with few tasting experiences of the products.

In the limited sensory science research that incorporates tasting of 3D printed foods, Caulier et al. (2020) observed that participant overall liking and liking of appearance, taste, and texture of 3D printed snack bars were not significantly different under varying degrees of customization freedom and were lower than the conventionally produced control. Participants showed more interest in customization of nutrition rather than taste. Participants in the study by Mantihal, Prakash, and Bhandari (2019) preferred the appearance of the 3D printed honeycomb-patterned chocolate with 100% infill level, which had a smooth texture, to those with 50% and 25% infill levels. No preference was found in hardness and overall preference among 3D printed samples with different infill levels and between the molded and the 3D printed sample. Sensory evaluation of novel foods was therefore adopted to generate higher acceptance than using imaginary scenarios (Kuang et al., 2020).

Several recent publications have described the effect of food product labelling and positive information about foods or food technologies on consumer sensory acceptance. Labelling with quality, brand, and production methods influenced consumer sensory acceptance of various food products (Kongstad & Giacalone, 2020; Liem et al., 2016; Lu et al., 2016; Silva et al., 2017) while labelling with meat type did not affect consumer sensory acceptance of the meat (Meier-Dinkel et al., 2013). Rolland et al. (2020) observed that after receiving positive information about cultured meat, participants rated the taste of identical and conventionally made hamburgers labelled as "cultured" to be better than those labelled as "conventional". In contrast, no difference was observed in sensory attribute acceptance between identical cherry tomatoes and chocolate ice-cream presented as either not nanotechnology produced or nanotechnology produced with benefits of the technology, except for "creaminess" of the ice cream, which could be a result of melting over time (Kuang et al., 2020).

In addition to sensory acceptance, consumer attitude towards 3DFP also determines its success. Consumer skepticism of novel food technologies is a challenge to their widespread application (Brunner et al., 2018; Demartini et al., 2019). The reasons for skepticism, mistrust, or fear towards novel food technologies or novel foods include a lack of knowledge (Giordano et al., 2018; Lupton & Turner, 2018a; Lusk et al., 2014), a lack of perceived benefits of the technology (Henson et al., 2008; Vidigal et al., 2015), food neophobia, a phobia of novel foods (Pliner & Hobden, 1992), and Food Technology Neophobia (FTN), described as consumer reluctance to accept foods produced by new technologies (Cox & Evans, 2008). Providing positive information about novel foods or related food technologies has been identified as a strategy to improve consumer attitude through increased knowledge (Zhu & Xie, 2015).

Consumer knowledge, FTN, benefit perceptions, and the effect of positive information on consumer attitude have been evaluated in the context of 3DFP. Consumer knowledge about 3D printed foods was low in a Swiss sample (Brunner et al., 2018) and an Atlantic Canadian sample (Manstan & McSweeney, 2019); however, two-thirds of Australian university participants had high self-assessed knowledge about 3D printing and 3DFP, and around half showed a clear understanding of 3DFP, suggesting a high knowledge level in the young and highly educated population (Mantihal, Prakash, & Bhandari, 2019). A lower FTN predicted a more positive consumer initial attitude towards 3D printed foods and attitude after presentation of positive information (Brunner et al., 2018), and the low FTN in the Dutch military environment indicated a food technology neophilic population (Caulier et al., 2020). While some participants perceived 3D printed meatballs, pizza, and cookies to be healthy (Manstan & McSweeney, 2019) and acknowledged benefits of 3DFP in creating appealing designs, simplifying food preparation, and providing solutions to swallowing difficulties and food waste issues (Mantihal, Prakash, & Bhandari, 2019), others have described 3D printed foods as unfamiliar, unnatural, unhealthy, and non-food like (Lupton & Turner, 2018a). Brunner et al. (2018) observed a more positive consumer attitude towards 3DFP after receipt of positive information about 3DFP, although attitude ratings after information remained negative. Caulier et al. (2020) did not observe a difference in attitude of Dutch soldiers before and after presenting information about 3DFP and its benefit to personalized nutrition in the military setting; however, attitude ratings increased after repeated tastings of 3D printed foods.

Consumer food choice orientations and familiarity with digital technology have also been associated with acceptance of 3DFP in prior research. Brunner et al. (2018) tested the effect of consumer perceived importance of having healthy food (*health*), food that contains *natural content,* food that can be prepared easily (*convenience*), and familiarity with digital technology (*digital native*) on attitude towards 3D printed foods before and after receiving positive information about 3DFP. Their results suggested that orientation to *convenience* predicted a positive attitude and attitude change towards 3D printed food.

This study assessed consumer sensory acceptance of three plausible 3D printed foods in labelled and informed conditions. The primary aim of the study was to investigate the effect of labelling and product-specific positive information about 3DFP on consumer sensory acceptance of foods labelled as 3D printed. Secondary objectives were to determine consumer attitude towards 3D printing before and after tasting "3D printed" foods with presented benefits; the effect of FTN and previous knowledge about 3D printing on overall liking, perceived quality of "3D printed" foods, and attitude towards 3D printing; and consumer preference between identical products labelled as conventional or 3D printed. Consumer orientations to *health, natural content, convenience*, and *digital native* and comments on tasted products were also collected.

2.2 Materials and methods

2.2.1 Study design

Milk chocolate swirls (Carnaby Sweet, Toronto, ON), gummy candy carrots (Bulk Barn Foods Ltd., Aurora, ON), and baked potato Smiles® (McCain Foods Ltd., Florenceville, NB) were each evaluated in one of three sensory panels. All food products were purchased from local grocery stores; none were 3D printed. Each of the three food products was selected to represent an established benefit of 3DFP; creative designs (chocolate swirl), personalized nutrition (gummy candy carrot), and appealing presentation of pureéd foods (potato Smiles®). Additionally, these products have limited availability and would have been unfamiliar to many participants, and the unique product shapes lent credibility to their presentation as 3D printed foods.

Participants were seated in individual sensory booths under natural white lighting and completed all tastings and surveys presented on Compusense Cloud software using a tablet (Figure 2.1) (Surveys see Appendix C). Participants first completed a Food Technology Neophobia Scale (FTNS) and indicated their previous knowledge about and attitude towards 3D printing. Participants then tasted and evaluated three samples of the same food, presented monadically as conventional (*Conv*), 3D printed (*3DP*), and 3D printed again after the presentation of product-specific benefits about 3DFP (*3DP+Info*). Overall liking and liking of appearance, aroma, flavor, and texture of food samples were evaluated on 9-point hedonic scales anchored from “dislike extremely” to “like extremely”. Agreement of high product quality was evaluated on 5-point Likert scales anchored from “strongly disagree” to “strongly agree”. Participants were invited to provide comments about each food sample. After sensory evaluations were completed, participants indicated their preference between samples labelled as conventional and 3D printed, attitude towards 3D printing again, and answered questions regarding their orientations to *health, natural content, convenience*, and *digital native*.

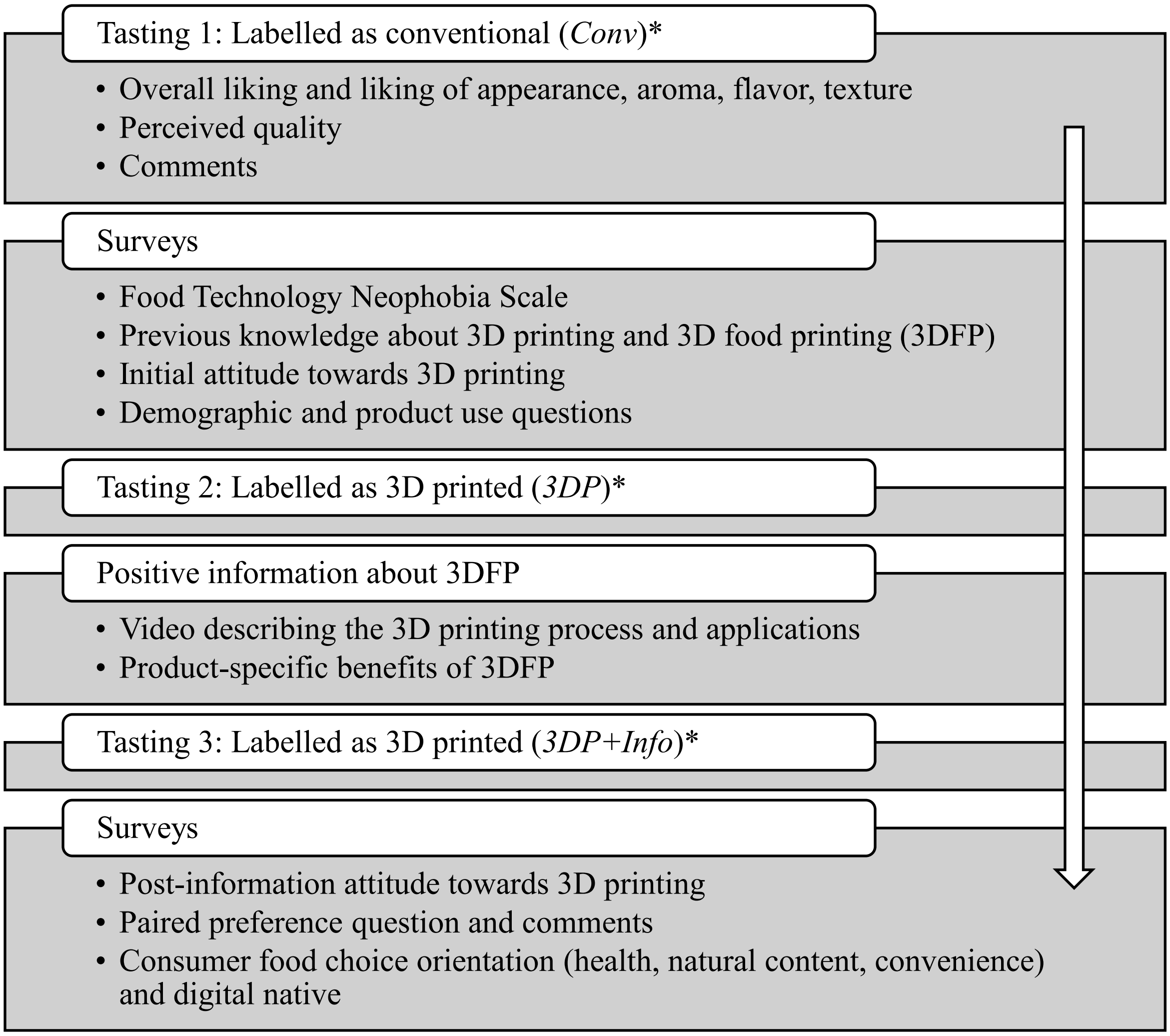

Figure 2.1. Study procedures.

*Same attributes were evaluated at each tasting.

2.2.2 Participants

Adults who liked and regularly consumed the general type of study product were recruited from the University of Alberta community (Edmonton, AB) and invited to participate in one of three panels. Participants completed written informed consent and received a $5 gift card at the end of the study. The study protocol was approved by a Research Ethics Board at the University of Alberta (Pro00089544). After all data collection, participants were debriefed via email about the true identity of the study samples (i.e. none were 3D printed) and could withdraw from the study within one week.

2.2.3 Food sample preparation

Chocolate swirls and gummy candy carrots were stored in air-tight containers at room temperature, and potato Smiles® were stored in a freezer (−18 °C) until preparation. Chocolate swirls or gummy candy carrots were served directly in 15mL plastic cups with lids at room temperature. Potato Smiles® were baked as per manufacturer instructions. Prepared potato Smiles® were served in 237 mL Styrofoam cups with lids, and the samples were kept warm until serving. Misshapen samples of any product were discarded.

2.2.4 Surveys

2.2.4.1 Previous knowledge and consumer attitude towards 3D printing

Assessment of consumer previous knowledge and attitude was adapted from Brunner et al. (2018). Self-assessed previous knowledge about 3D printing and 3DFP were evaluated using 5-point categorical scales anchored from "not at all" to "extremely". Attitude towards 3D printing before and after tastings and receipt of positive information about 3DFP were evaluated on 7-point semantic differential scales anchored from "negative" to "positive".

2.2.4.2 FTNS

Food Technology Neophobia was quantified on the FTNS (Cox & Evans, 2008). Participants rated their agreement to 13 items about new food technologies on 7-point Likert scales from "totally disagree" to "totally agree".

2.2.4.3 Consumer orientations

Four constructs including the degree to being a *digital native* and consumer food choice orientations to *health, natural content,* and *convenience* were assessed using the question items adapted by Brunner et al. (2018) for their study of 3DFP, previously developed and validated (Candel, 2001; Steptoe et al., 1995; Teo, 2013). Participants rated their agreement to each item on 7-point Likert scales from “strongly disagree” to “strongly agree”.

2.2.4.4 Product-specific beneficial information about 3DFP

All participants were presented with a short video (Mashable, 2014) to introduce the process of 3D printing, followed by product-specific text to describe the benefits of 3DFP associated with the panel food product (Appendix A). Combined images of real 3D printed and molded foods were presented with the text as examples.

2.2.4.5 Preference

After the three tastings, participants performed a paired preference of samples labelled as conventional and 3D printed for chocolate swirls and potato Smiles®. Participants were invited to provide comments about their preference.

2.2.4.6 Demographics and product use

Participant age, education, income level and household size data were collected. Participants identified their frequency of consumption of the general type of the test product; special occasion chocolate (chocolate swirl panel), nutritional supplements (gummy candy carrot panel), and familiarity with pureéd diets (potato Smiles® panel).

2.2.5 Data analysis

Data were analyzed using R statistical language (R Core Team, 2020) and Compusense Cloud sensory software (Compusense, Guelph, ON). Within-Subjects Analysis of Variance

(ANOVA) and pairwise t-test with Bonferroni correction were used to determine differences in sensory acceptance scores among three tastings, and paired two sample t-test was used to compare attitude scores before and after "3D printed" food tasting with presented benefits about 3DFP. Median scores and were used to stratify participants by FTN (neophilic, less neophilic); collapsed categories were used to stratify participants based on previous knowledge about 3D printing (knowledgeable, not knowledgeable). Results from One-way ANOVA showed no difference in FTN scores but significant differences in participants' previous knowledge across three panels. As participants of the three panels were a homogeneous university population, their data were merged for stratification by FTN and previous knowledge to evaluate overall opinion, perceived quality, and attitude scores of each product between the food technology neophilic and less neophilic groups, and between the knowledgeable and not knowledgeable groups (unpaired two sample t-tests). Demographic and product use information, consumer orientations, FTN, previous knowledge, and change of liking rating between two adjacent sample presentations were analyzed using descriptive statistics. Participant comments regarding sensory perceptions and preference between samples were analyzed by content analysis (Erlingsson & Brysiewicz, 2017) by three authors (XF, KK, SS). Only word categories that received 5% and 10% frequency of mention were included in the analysis for preference and sensory perception comments, respectively. Preference comments for the gummy candy carrot panel were not collected due to an error in questionnaire design. A significance level of 0.05 was used in all statistical tests.

2.3 Results

2.3.1 Participant characteristics

A total of 186 individuals participated in the chocolate swirl (n = 68), gummy candy carrot (n = 59), and potato Smiles® (n = 59) panels. The majority of participants (53–75%) in all panels were between the age of 18–25 years (Table 2.1), and nearly all (93–96%) had some or completed university or higher level of education, reflecting recruitment on a university campus. Nearly half or more of participants (49–73%) were knowledgeable ("somewhat" to "extremely") about 3D printing at the start of the panel, while the majority (80–93%) had little knowledge ("not very" or "not at all") of 3DFP. The average FTN score (43.8–45.7) was lower than the midpoint of FTNS (52) indicating a tendency towards food technology neophilia. Participants were highly oriented to health, natural content, and convenience in their food choice and were digital natives. Half of the participants (50%) in the chocolate swirl panel frequently consumed special occasion chocolates and roughly half (54%) in the gummy candy carrot panel frequently consumed nutritional supplements. The majority of participants (66%) in the potato Smiles® panel were familiar with pureéd diets.

2.3.2 Sensory acceptance of "3D printed" foods and content analysis of open-ended comments

The effects of labelling and information on sensory attribute acceptance and perceived quality.

All sensory attributes of chocolate swirls, gummy candy carrots, and potato Smiles® over the three product presentations were liked slightly to moderately (Table 2.2). Appearance liking of chocolate swirls and the perceived quality of chocolate swirls and gummy candy carrots were not different between the *3DP* and *3DP+Info* presentation and were rated higher than those attributes of the Conv counterparts. The aroma of gummy candy carrots was liked more when samples were presented as *3DP+Info* as compared to *3DP*, but no difference in liking was observed between the two 3D printed (*3DP* and *3DP+Info*) and *Conv* presentations. The aroma of potato Smiles® was liked more when samples were presented as *Conv* as compared to *3DP+Info*, but no difference in liking was observed between the *Conv* or *3DP+Info* and the *3DP*

Table 2.1. Participant characteristics in three food panels.

Variable	**Chocolate swirl (n = 68) n (%)**		**Gummy candy carrot (n = 59) n (%)**		**Potato Smiles® (n = 59) n (%)**	
Age (years)						
18–25	36 (53)		44 (75)		35 (59)	
26–35	18 (26)		8 (14)		22 (37)	
36 and older	14 (21)		7 (12)		2 (3)	
Education						
Some or completed high school	3 (4)		4 (7)		3 (5)	
Some or completed university/college/ technical training	42 (62)		33 (56)		29 (49)	
Some or completed postgraduate university study	23 (34)		22 (37)		27 (46)	
Annual Income[1]						
Less than $36,600	18 (26)		24 (41)		30 (51)	
$36,601–$71,000	13 (19)		9 (15)		9 (15)	
$71,001–$115,000	15 (22)		9 (15)		8 (14)	
more than $115,000	8 (12)		3 (5)		2 (3)	
I prefer not to disclose	14 (21)		14 (24)		10 (17)	
Household size						
1–2	34 (50)		26 (44)		31 (52)	
3–4	27 (40)		21 (36)		25 (43)	
≥ 5	7 (10)		12 (20)		3 (5)	
Consumption of special occasion chocolate[2]						
Frequent (once or more per month)	34 (50)					
Consumption of nutritional supplements[2]						
Frequent (once or more per week)			32 (54)			
Familiarity with pureéd diets[2]						
Familiar					39 (66)	
Previous knowledge about 3D printing[2]						
Knowledgeable (somewhat to extremely)	33 (49)		33 (56)		43 (73)	
Previous knowledge about 3D food printing[2]						
Knowledgeable (somewhat to extremely)	5 (7)		12 (20)		12 (20)	
Variable[3] (scale range; midpoint)	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
FTN *(13–91; 52)*	45.1 (10.3)	24–71	45.7 (9.9)	26–73	43.8 (9.7)	23–68
Orientation to health *(6–42; 24)*	35.7 (3.7)	26–42	34.6 (5.5)	11–42	34.1 (5.6)	7–42
Orientation to natural content *(3–21; 12)*	14.5 (3.9)	6–21	14.6 (4.3)	4–21	14.8 (4.3)	3–21
Orientation to convenience *(5–35; 20)*	23.5 (7.6)	8–35	24.1 (5.2)	13–35	22.2 (7.8)	5–35
Digital native *(8–56; 32)*	45.7 (6.0)	32–56	45.5 (5.7)	32–56	45.6 (7.8)	15–56

[1] Categories reflect tax brackets in Canadian dollars.
[2] Results for infrequent, unfamiliar, not knowledgeable groups not shown.
[3] Evaluated on 7-point Likert scales from 1 = "totally disagree" to 7 = "totally agree".

Table 2.2. Mean[1] sensory attribute acceptance[2] and perceived quality[3] scores ± SD for chocolate swirls (n = 68), gummy candy carrots (n = 59), and potato Smiles® (n = 59) when presented as conventionally produced (*Conv*), 3D printed (*3DP*), and 3D printed with product benefit information (*3DP+Info*).

	Conv	*3DP*	*3DP+Info*
Appearance			
Chocolate swirl	6.7 ± 1.5^{a}	7.2 ± 1.3^{b}	7.1 ± 1.2^{b}
Gummy candy carrot	6.7 ± 1.5	6.8 ± 1.5	6.9 ± 1.4
Potato Smiles	7.3 ± 1.1	7.3 ± 1.2	7.4 ± 1.2
Aroma			
Chocolate swirl	7.0 ± 1.2	7.2 ± 1.3	7.2 ± 1.1
Gummy candy carrot	5.6 ± 1.3^{ab}	5.5 ± 1.2^{a}	5.8 ± 1.2^{b}
Potato Smiles	7.2 ± 1.1^{a}	6.9 ± 1.3^{ab}	6.8 ± 1.4^{b}
Flavor			
Chocolate swirl	7.2 ± 1.4	7.4 ± 1.3	7.3 ± 1.1
Gummy candy carrot	6.6 ± 1.5	6.8 ± 1.4	6.9 ± 1.2
Potato Smiles	6.8 ± 1.3	6.7 ± 1.4	6.7 ± 1.4
Texture			
Chocolate swirl	7.2 ± 1.5	7.3 ± 1.1	7.3 ± 1.1
Gummy candy carrot	6.0 ± 1.8	6.0 ± 1.7	6.2 ± 1.7
Potato Smiles	6.4 ± 1.6	6.0 ± 1.7	6.3 ± 1.7
Overall opinion			
Chocolate swirl	7.1 ± 1.3	7.4 ± 1.3	7.4 ± 1.1
Gummy candy carrot	6.5 ± 1.2	6.5 ± 1.3	6.8 ± 1.3
Potato Smiles	6.8 ± 1.2	6.7 ± 1.4	6.7 ± 1.5
Perceived quality			
Chocolate swirl	3.2 ± 1.0^{a}	3.7 ± 0.9^{b}	3.7 ± 0.8^{b}
Gummy candy carrot	3.2 ± 1.0^{a}	3.6 ± 0.8^{b}	3.7 ± 0.8^{b}
Potato Smiles	3.6 ± 0.8	3.7 ± 0.9	3.8 ± 0.9

[1] Mean scores with different superscript letters in the same row are significantly different ($p \leq 0.05$).
[2] Evaluated on 9-point hedonic scales from 1 = "dislike very much" to 9 = "like very much".
[3] Agreement of high product quality evaluated on 5-point Likert scales from 1 = "strongly disagree" to 5 = "strongly agree".

presentations. There were no significant differences in liking scores of flavor, texture, and overall opinion of the three food products among the three presentations.

Mean sensory acceptance scores are presented reflecting an increase, decrease or no change between evaluations as *3DP* and *Conv*, and between *3DP+Info* and *3DP* for each product (Appendix B). The majority of sensory attribute acceptance ratings between two successive tastings were unchanged except for the texture of potato Smiles®. Over the three product presentations between two successive tastings, participants who decreased their acceptance ratings reduced acceptance scores by 1–2.3 points, and participants who increased their acceptance ratings increased acceptance scores by 1–1.9 points.

Participants comments about the sensory attributes of food samples presented as *Conv* and *3DP* were grouped around the five dimensions of texture, taste/flavor, appearance, quality, and similar/same; texture, taste/flavor, and two samples being similar/same were the most frequently mentioned dimensions (Table 2.3). Comments for samples presented as *3DP+Info* were not analyzed due to the limited responses received. *Smooth mouthfeel* was mentioned more frequently when the chocolate swirls were presented as *3DP* as compared to *Conv,* while negative textural perceptions including *greasy/waxy* and *dry/grainy* were no longer mentioned. Chocolate swirls presented as *Conv* were described as *too sweet*, *positive, milky* and of *average* and *low quality,* while the same product presented as *3DP* had *rich chocolate flavor* and was *tasty,* but for some was *bland.* The texture of the *Conv* gummy candy carrots was described as *chewy/hard*; when presented as *3DP* it was perceived to be *less chewy*. The taste/flavor of gummy candy carrots was perceived to be *stronger* by some participants when presented as *3DP*, and *appealing* and having *good taste/flavor* in both presentations. The dominant texture perception of *Conv* potato Smiles® was *not crispy*, which was less frequently mentioned when presented as *3DP*. A *good/less mushy* texture and *tasty* were only mentioned when the potato Smiles® was presented as *3DP*.

For all three products, participants were neutral or “agreed” that the product was of high quality when presented as *Conv*. The agreement of high quality when presented as *3DP* and *3DP+Info* reflected a significant increase in quality perception relative to *Conv* for the chocolate swirls and potato Smiles®.

Table 2.3. Participant comments[1] on sensory perceptions of food samples presented as conventional (*Conv*) and 3D printed (*3DP*).

Conv			*3DP*		
Chocolate swirl[2]					
Dimensions	**Categories**	**Frequency of mention (%)[3]**	**Dimensions**	**Categories**	**Frequency of mention (%)[3]**
Texture		38	Texture		39
	Greasy/waxy	13		Smooth mouthfeel	29
	Dry/grainy	13		Good	10
	Smooth mouthfeel	13			
Taste/flavor		55	Taste/flavor		35
	Too sweet	18		Rich chocolate flavor	14
	Positive taste/flavor attributes	15		Tasty	10
	Tasty	13		Bland	10
	Milky	10			
Quality		45	Similar/same		35
	Low quality	23		Similar/same taste/flavor	18
	Average	23		Similar/same overall	16
Gummy candy carrot[2]					
Texture		81	Texture		56
	Chewy/hard	70		Less chewy	26
	Good hardness/mouthfeel	11		Chewy/hard	21
				Better	10
Taste/flavor		19	Taste/flavor		28
	Appealing	19		Good taste/flavor	18
				Stronger	10
Appearance		11	Appearance		10
	Attractive	11		Impressed	10
			Similar/same		69

				Similar/same appearance	23
				Similar/same overall	18
				Similar/same taste/flavor	15
				Similar/same texture	13
Potato Smiles®[2]					
Texture		72	Texture		45
	Not crispy	44		Not crispy	27
	Crispy	14		Good/less mushy	18
	Dry/grainy	14			
Taste/flavor		17	Taste/flavor		27
	Bland	17		Bland	16
				Tasty	11
			Similar/same		30
				Similar/same overall	30

[1] Categories mentioned by least 10% of commenting participants were included for content analysis.
[2] Participants providing comments in each panel were: chocolate swirl (*Conv*: n = 40; *3DP*: n = 49); gummy candy carrot (*Conv*: n = 37; *3DP*: n = 39); and potato Smiles® (*Conv*: n = 36; *3DP*: n = 44).
[3] Each respondent could enter multiple responses therefore frequency percentages total more than 100%.

The effect of FTN and previous knowledge about 3D printing on overall liking and perceived quality.

Compared to the food technology (FT) neophilic group, the less FT neophilic group rated perceived quality and overall liking higher for products presented as *3DP* and *3DP+Info* (Table 2.4). Additionally, the FT neophilic group rated the overall liking of products presented as *3DP* and *3DP+Info* to be the same and higher than that of products presented as *Conv* while the ratings of the less FT neophilic group did not change. There were no significant differences in overall liking and perceived quality between participants that were previously knowledgeable and not knowledgeable about 3D printing.

2.3.3 Consumer attitude towards 3D printing

Participant initial attitude towards 3D printing was positive (mean = 5.2; SD = 1.0–1.2) and was more positive (mean = 5.9–6.0; SD = 0.9–1.0) ($p < 0.001$) at the conclusion of the study for all three products. Both FT neophilic and less FT neophilic groups had a positive initial attitude; however, the FT neophilic group had a higher attitude score compared to the less neophilic group at both timepoints (Table 2.4). There was no significant difference in attitude between groups that were knowledgeable and not knowledgeable about 3D printing.

2.3.4 The effect of labelling and information on paired preference for samples labelled as conventional and 3D printed

In the paired preference test, chocolate swirls and gummy candy carrots labelled as 3D printed were preferred to their *Conv* counterparts while there was no preference for potato Smiles® (data not shown). The majority of participants in chocolate swirl and potato Smiles® panels described perceived product differences motivating their preference (Table 2.5). A *good/better* sensory profile was most frequently mentioned when explaining preference for

Table 2.4. Mean[1,2] overall liking and perceived quality scores ± SD for chocolate swirls, gummy candy carrots, and potato Smiles® (N = 186) when presented as conventionally produced (*Conv*), 3D printed (*3DP*), and 3D printed with product benefit information (*3DP+Info*), and mean attitude towards 3D printing ± SD before *3DP* and after *3DP+Info* between and within stratified groups.

Stratified groups (n)	Overall liking			Perceived quality			Attitude	
	Conv	*3DP*	*3DP+Info*	*Conv*	*3DP*	*3DP+Info*	Before	After
Food Technology Neophobia								
FT neophilic (n = 94)	6.9 ± 1.2^{a}	7.2 ± 1.3^{bx}	7.3 ± 1.2^{bx}	3.4 ± 0.9^{a}	3.9 ± 0.8^{bx}	3.9 ± 0.8^{bx}	5.8 ± 0.9^{ax}	6.4 ± 0.8^{bx}
Less FT neophilic (n = 92)	6.8 ± 1.3	6.6 ± 1.4^{y}	6.7 ± 1.4^{y}	3.2 ± 0.9^{a}	3.4 ± 0.9^{by}	3.5 ± 0.8^{by}	4.6 ± 1.0^{ay}	5.5 ± 1.0^{by}
Previous knowledge about 3D printing								
Knowledgeable (n = 109)	6.9 ± 1.2	6.9 ± 1.3	7.0 ± 1.4	3.4 ± 0.9^{a}	3.7 ± 0.9^{b}	3.7 ± 0.9^{b}	5.4 ± 1.1^{a}	6.0 ± 1.0^{b}
Not knowledgeable (n = 77)	6.7 ± 1.4	6.8 ± 1.5	7.0 ± 1.3	3.3 ± 0.9^{a}	3.7 ± 0.9^{b}	3.6 ± 0.8^{b}	5.0 ± 1.1^{a}	5.9 ± 1.1^{b}

[1] Mean scores with different superscript letters (a, b) in the same row are significantly different within stratified groups; mean scores with different superscript letters (x, y) in the same column are significantly different between stratified groups ($p \leq 0.05$).

[2] Overall liking was evaluated on 9-point hedonic scales from 1 = "dislike very much" to 9 = "like very much"; agreement of high product quality was evaluated on 5-point Likert scales from 1 = "strongly disagree" to 5 = "strongly agree"; attitude towards 3D printing was evaluated on 7-point semantic differential scales from 1 = "negative" to 7 = "positive".

Table 2.5. Participant comments on their preference choices for "3D printed" or conventional products[1].

		Frequency of mention (%)[2]	
Dimensions	**Categories**	**Chocolate swirl (n = 66)**	**Potato Smiles® (n = 54)**
Preferred 3D printed			
Sensory profile		59	31
	Good/better texture	24	19
	Good/better taste and flavor	24	13
	Good/better appearance	11	
No difference		30	15
	Same/similar	24	15
	No preference	6	
Support novel technology		20	13
	Support new technology	6	
	Interesting	9	6
	Novel	5	7
Perceived benefits		18	6
	Creative, custom, appealing design	8	6
	Cost effective	6	
	More efficient production	5	
Preferred conventional			
Sensory profile		12	43
	Good/better taste and flavor	8	11
	Good/better texture	5	26
	Better aroma		6
Find 3DFP acceptable			17
	Not opposed to 3D printed food		9
	Recognize benefits of 3DFP/ may become interested in the future		7
No difference		11	13
	Same/similar	11	13

Perceived benefits of the conventional product			9
	Conventional product is more natural/healthy		9
Knowledge and familiarity		9	
	Lack of knowledge about 3DFP/ more knowledge about the conventional product	9	
Lack of visual appeal of the 3D printed product		5	
	3D design is not cool enough	5	

[1] Categories mentioned by at least 5% of participants were included for content analysis.
[2] Qualitative input by participants was optional. Each respondent could enter multiple responses therefore frequency percentages add up to more than 100%.

samples of either label. For both products, some participants that preferred the "3D printed" samples also mentioned their support for novel technology that is *interesting* and *novel* and perceived benefits of 3DFP in fabricating *creative, custom, appealing design*. Perceived benefits of 3DFP specific to chocolate swirls were related to food production (*cost effective* and *more efficient production*). Participants that preferred the *Conv* sample perceived benefits of the conventional product, lack of visual appeal of the 3D printed product, and knowledge and familiarity. The *Conv* potato Smiles® was described as *more natural/healthy*; some participants who preferred the *Conv* chocolate swirls mentioned that the *3D design was not cool enough* and that they had a *lack of knowledge about 3DFP* or *more knowledge about the conventional product*. Regardless of product or preference, there were frequent mentions of no difference (*similar/same* or *no preference*) between the food samples presented as *Conv* and 3D printed. Some participants who preferred the *Conv* potato Smiles® also found 3DFP acceptable indicating an accepting rather than negative attitude.

2.4 Discussion

The effect of labelling and positive information on sensory acceptance of foods has varied outcomes and may be unique to the product and information type. In this study, both labelling as 3D printed and product-specific positive information about 3DFP had limited effect on sensory attribute acceptance of the three foods that represent applications of 3DFP. However, there was greater agreement of high product quality after labelling, and as observed in the literature, attitude towards 3D printing became more positive. The limited change in sensory attribute acceptance between samples presented as *Conv* and *3DP* is supported by frequent participant mentions of them perceived as similar or same. As samples were identical for all three tastings, our findings suggest that the label of being 3D printed and positive information about 3DFP were not effective in increasing consumer sensory acceptance of foods when objective sensory differences were absent. Development of 3D printed foods should therefore aim for a superior sensory quality to their conventionally made counterparts for higher sensory acceptance. As labelling and information resulted in a more positive attitude towards 3D printing and higher perceived quality, the opportunity to taste 3D printed foods with presentation of benefits that resonate with consumers could increase consumer acceptance of 3DPF through attitude change.

Perceived sensory attributes that differed among the product presentations were observed in open-ended comments, yet associated attribute acceptance ratings did not differ. For example, the texture of foods presented as *3DP* was described more positively than foods presented as *Conv,* although differences in acceptance ratings between the two product presentations were not observed. Overall, positive sensory attributes such as *smooth mouthfeel* for chocolate swirls and *good/less mushy* texture for potato Smiles® were mentioned more frequently, and negative sensory attributes such as *chew/hard* for gummy candy carrot and *not crispy* for potato Smiles® were mentioned less frequently when the samples were presented as *3DP*. This finding suggests that consumer impressions of 3DFP could have a positive influence on the sensory experience of 3D printed foods.

After the sensory evaluation of all three product presentations, participants completed a paired preference test between food products presented as 3D printed and conventional. Preference for identical food samples labelled as 3D printed over those labelled as *Conv* for 2 of the 3 study food products suggests a positive influence of labelling and positive information about 3DFP on overall product preference. Participants preferred chocolate swirls and gummy candy carrots presented as 3D printed over those labelled as *Conv*; however, overall acceptance ratings of the two products presented as *3DP* and *3DP+Info* were not different from their *Conv* counterparts in the sensory evaluation. This is congruent with the observation that hedonic ranking results in better hedonic discriminability than hedonic rating when hedonic differences are small (Barylko-Pikielna et al., 2004).

Participant open-ended comments revealed that preference for “3D printed” chocolate swirls and potato Smiles® was associated with the novelty and creativity of 3DFP food products. Reasons for preferring the *Conv* presentations included perceived healthiness and higher familiarity with the technology and products and lack of visual appeal of the 3D printed food. Similarly, in previous studies, perceived fun to use, healthiness, and familiarity aspects of 3DFP shaped consumer acceptance (Brunner et al., 2018; Lupton & Turner, 2018a). Our finding suggests that emphasizing the novelty and creativity aspects of 3DFP could appeal to consumers who have a positive attitude towards 3D printed foods. Meanwhile, communication strategies that aim to improve perceived healthiness and familiarity of 3D printed foods may increase product acceptance by consumers who initially do not prefer them to conventionally made foods.

3D printed food designs are typically more visually complex and appealing than the products presented in this study, thus participant comments about *lack of visual appeal* suggests expectations of the greater visual complexity. For example, Severini, Derossi et al. (2018) found that the overall appearance of a 3D printed fruit and vegetable puree was highly appreciated, and the rating was higher than that of the non-3D printed control.

Consumer constructs relevant to the acceptance of 3DFP were measured. The mostly young and educated participants were knowledgeable about 3D printing technology but less knowledgeable about the application of 3D printing to food products. Mantihal, Prakash, and Bhandari (2019) observed a high knowledge level of both 3D printing and 3DFP in a university population. A high knowledge level of novel food technologies increases consumer acceptance of the related food products (Manstan & McSweeney, 2019) emphasizing the importance of designing education strategies for consumers who have little knowledge about 3DFP to gain greater acceptance.

Our university community participants had a positive initial attitude towards 3D printing and sensory acceptance of “3D printed” foods. The positive initial attitude was observed in another university population (Mantihal, Prakash, & Bhandari, 2019). In contrast, non-university populations were found to have a negative to neutral attitude towards 3D printed food (Brunner et al., 2018; Caulier et al., 2020). Regarding consumer Food Technology Neophobia, our university participants were relatively more neophilic (mean = 44.9) than non-university Canadian (mean = 58.5) (Matin et al., 2012), Brazilian (mean = 47.0) (Vidigal et al., 2015), and Australian participants (mean = 55.0) (Cox & Evans, 2008). Generally, our university participants were oriented to health, natural content, and convenience in their food choices and were digital natives. Half or more had consumed special occasion chocolate and nutritional supplements and were familiar with pureéd diets. Benefits generated by the enhancement of these products by 3DFP could therefore be relevant to the majority of this population.

Participants were stratified by FTN and previous knowledge level of 3D printing into FT neophilic and less FT neophilic; and knowledgeable and not knowledgeable groups, respectively. Overall liking and perceived quality of three product presentations and attitude towards 3D printing were compared between groups and within groups among three product presentations. Previous knowledge level of 3D printing did not affect overall liking, perceived quality, and attitude. Brunner et al. (2018) also observed that initial knowledge level of 3D printed foods did not predict consumer attitude before and after receiving positive information about 3DFP;

compared to other significant predictors, higher initial knowledge level was associated with smaller attitude change after receiving positive information. One explanatory mechanism is that high consumer initial knowledge could indicate high confidence in existing positive or negative attitude and high resistance towards attitude change after receiving new information (Zhu & Xie, 2015). In contrast, FTN affected all three acceptance variables. Compared to the FT neophilic group, our less FT neophilic group had a less positive attitude towards 3D printing both before and after tasting "3D printed" foods with presented benefits about 3DFP; and lower overall liking and perceived quality of products presented as *3DP* and *3DP+Info*. This suggests that FTN decreases consumer overall acceptance of 3D printing and "3D printed" foods in a relatively FT neophilic population; therefore, it is important to understand the FTN formation processes and explore interventions to reduce it for greater acceptance of 3DFP.

The following strengths of this study were noted. The primary research aim was achieved through sensory acceptance evaluation of identical food products presented sequentially as *Conv*, *3DP*, and *3DP+Info*. Consistent sensory properties of the products evaluated ensured that any differences in sensory acceptance, attitude ratings, and preference choice were due to the effect of 3D printed labels and positive information about 3DFP. The inclusion of three plausible 3D printed foods, each representing one application of 3DFP, allowed comprehensive assessments of consumer acceptance in three main applications of 3DFP. Additionally, this study included a qualitative component to describe participant acceptance ratings and preference decisions for a thorough investigation in consumer opinion formations. Findings of this study help fill the research gap and contribute to our knowledge about consumer acceptance of 3DFP and its determinants. Implications generated from consumer sensory and attitudinal responses to "3D printed" foods and 3D printing yield marketing and communication strategies for 3DFP stakeholders.

We note two limitations to this study. Cessation of research due to the COVID-19 pandemic prevented completion of this study with off-campus participants, thus our sample represents a university rather than a general population. This population, however, is representative of the younger and more educated population who show greater acceptance towards new technologies (Chen et al., 2013; Kuang et al., 2020; Manstan & McSweeney, 2019) and are more likely to be the early adopters of 3DFP. Unlike the other two study products, the potato Smiles® did not receive a higher perceived quality rating and preference when presented as *3DP+Info* as compared to *Conv*. This may be the result of quality changes in the warming method.

Based on observations and findings of this study, several future recommendations are generated. In this study, *health, natural content, convenience, digital native,* and *experience with conventionally made products relevant to the benefits of 3DFP* were used as descriptive variables. Inferential statistical analysis of the relationship between those constructs and acceptance of tasted 3D printed foods could be performed in future studies. Moreover, since evidence suggests that Food Technology Neophobia decreases consumer overall acceptance of 3D printing and 3D printed foods, future studies could also investigate psychosocial determinants of FTN and interventions for its reduction in the context of 3DFP. Comprehensive tools could be used to assess knowledge and attitude, as used previously (Brunner et al., 2018; Manstan & McSweeney, 2019; Mantihal, Prakash, & Bhandari, 2019), and a more demographically diverse sample could be included.

3DFP is a promising novel food technology that is expected to bring more possibilities to the consumer food experience in the near future. In preparation, attention must be directed to improve its consumer sensory and attitudinal acceptance and understand intrinsic factors that lead to consumer acceptance or rejection of this technology. In this study, labelling as 3D printed and positive information about 3DFP both had a minimal effect on sensory attribute acceptance of three food products, but when combined had a positive influence on consumer attitude towards 3D printing and perceived quality and preference for the "3D printed" foods. Two implications were generated from this main finding. First, superior sensory quality of 3D printed as compared to conventionally made foods is required as labelling and information alone were not effective in improving sensory attribute acceptance. Second, 3D printed food tasting combined with presentation of benefits of 3DFP could be an effective strategy that leads to more positive attitude towards 3D printing and preference for 3D printed as compared to conventionally made foods. Additionally, based on observations in FTN and qualitative insights, communication strategies should be informative, relevant to consumers, and product specific. 3DFP stakeholders should advertise the novelty, artistic creation, and/or healthiness aspects of 3DFP depending on its applications. Currently, the university population has a low FTN, predicting a high acceptance of novel food technologies; however, interventions to reduce FTN in the less neophilic population need to be explored.

2.5 Conclusion

Labelling and information about 3DFP improved consumer attitude towards 3D printing but had limited effect on consumer sensory attribute acceptance of foods labelled as 3D printed. Food products labelled as 3D printed were preferred to those labelled as conventional. The young and highly educated study participants had low initial knowledge about 3DFP but a positive initial attitude towards 3D printing. Food Technology Neophobia was low, and a lower FTN was associated with a higher overall sensory acceptance of "3D printed" foods and a more positive attitude towards 3D printing.

Chapter 3 - General discussion and conclusions

3DFP is a novel food production technology with uncertain consumer acceptance in its future commercial applications. This research incorporated sensory evaluation and quantitative and qualitative consumer surveys to 1) investigate consumer sensory and additional acceptance of “3D printed” foods and 3D printing under labelled and informed conditions, and 2) describe consumer constructs relevant to acceptance and opinions of 3DFP. The study results shed light on the effect of labelling and positive information about 3DFP on consumer sensory acceptance of three food products that can benefit from 3DFP; attitude before and after labelling and information; preference for foods prepared with 3DFP and conventional food technologies; general acceptance of novel food technologies (FTN); consumer constructs that influenced overall acceptance; and qualitative insights on tasted “3D printed” foods. Findings of this research add to the limited consumer and sensory science research of 3DFP and provide practical information to stakeholders of 3DFP.

3.1 Main findings and implications

The primary research objective was to determine the effect of labelling as 3D printed and positive information about 3DFP on consumer sensory acceptance of three plausible 3D printed foods. Key sensory attributes and perceived quality of conventionally made food products were evaluated under three product presentations; conventional (*Conv*), 3D printed (*3DP*), and 3D printed after presentation of positive information about 3DFP (*3DP+Info*). Labelling as 3D printed and positive information about 3DFP had limited individual and combined effect on consumer sensory attribute acceptance of foods when there was a lack of objective sensory differences among presentations. This finding suggests that 3D printed foods must have more appealing sensory attributes than conventionally made foods to gain higher sensory acceptance.

This observation aligns with the previously observed limited effect of labelling and information on sensory attribute acceptance of meat and foods presented as cultured and nanotechnology produced, respectively (Kuang et al., 2020; Rolland et al., 2020).

The hypothesized positive effect of labelling and positive information was observed on the following two sensory attributes, respectively. Labelling as 3D printed increased acceptance rating of the appearance of the chocolate swirl, and positive information about 3DFP increased the acceptance rating of aroma of the gummy candy carrot; however, this effect was minimal and generates little practical messages considering the lack of observed effect in other key sensory attributes and consistency across three food products. Labelling, however, increased perceived quality of chocolate swirls and gummy candy carrots. This observation in 2 of 3 study products suggests that positive impression of 3DFP could improve perceived quality of 3D printed foods.

Secondary objective 2.1 was to explore consumer attitude change after tasting “3D printed” foods and receiving positive information about 3DFP, as consumer attitude also plays an important role in product acceptance. Despite a limited effect of labelling and information on consumer sensory acceptance, in this study, a more positive consumer attitude towards 3D printing was observed. This finding is consistent with the observed overall positive effect of positive information on consumer attitude towards novel foods (Brunner et al., 2018; Chen et al., 2013; Demartini et al., 2019; Lombardi et al., 2019) and in agreement with the hypothesis that consumer attitude towards 3D printing would become more positive. As benefit perception was associated with positive consumer attitude change (Brunner et al., 2018), this finding suggests positive perception of the presented benefits that consisted of an introduction to 3D printing (video), product specific benefits and applications of 3DFP (text), and visual presentation of 3D designs (images). It is postulated that beneficial information combined with fundamental knowledge implementation, appealing visual messages, and tastings may be a valuable educational approach to improve consumer attitude towards novel food technologies.

Preference between food products labelled as 3D printed and conventional was also explored as objective 2.2 of this study. After sensory evaluation of all three product presentations, participants were asked to indicate their preference between the “conventional” and “3D printed” food products. Preference for “3D printed” food products over the conventional counterparts was observed for two of three study food products, suggesting a positive influence of labelling and information on consumer preference. This finding aligns with the hypothesis that the participants would prefer the “3D printed” product presentation over the “conventional”.

Overall, study participants showed positive attitude towards 3D printing and low FTN. Similarly, a positive attitude towards 3DFP was observed in an Australian university population. In contrast, Swiss non-university and Dutch male military populations exhibited a negative and neutral attitude, respectively. The Canadian university population in this study had a lower FTN score (44.9) as compared to a more demographically diverse Canadian population (58.5), suggesting a relatively higher food technology neophilia. Positive attitude and low FTN are important determinants of consumer willingness to purchase foods produced by novel food technologies (Evans et al., 2010; Mantihal et al., 2020); therefore, findings of this study suggest a positive future prospect of 3DFP in the mostly young and educated university populations.

In objective 2.3, FTN and consumer self-assessed previous knowledge about 3D printing were hypothesized to negatively and positively affect overall acceptance of 3D printing and “3D printed” foods, respectively. Participants from three panels were merged and stratified by FTN into Food Technology (FT) neophilic and less FT neophilic, and by previous knowledge into knowledgeable and not knowledgeable groups. Overall liking and perceived quality of “3D printed" foods and attitude towards 3D printing were compared between stratified groups. Higher FTN lowered consumer overall acceptance of 3D printing and "3D printed" foods in the highly neophilic population, providing further evidence that FTN is associated with reduced acceptance of new food technologies.

This finding also suggests 3DFP stakeholders should form approaches to lower FTN for higher 3DFP product acceptance. Including 3DFP, novel food technologies have been applied to enhance food safety and nutrition and reduce cost and food waste (Giordano et al., 2018). From a broad perspective, reduction of FTN, identified as a predictor of the acceptance of various novel food technologies (Evans et al., 2010), is beneficial for the acceptance of novel food technologies collectively. Potential approaches to increase consumer novel food technology acceptance could aim to improve the sensory quality of associated foods and perceived benefits in health, utility, and convenience, while addressing mistrust in science and risk perceptions in negative health outcomes (Giordano et al., 2018).

Consumer previous knowledge level about 3DFP, on the other hand, did not affect overall acceptance of 3D printing and "3D printed" foods. It's possible that consumers with higher initial knowledge about 3DFP did not have more positive opinions about it than those who self-assessed as having a low level of knowledge. The results suggest that only the hypothesis regarding the negative influence of FTN on consumer overall acceptance is supported.

Participants were invited to leave open-ended comments on their sensory perceptions of identical food products under three presentations. Perceived differences in some sensory attributes between identical food products presented as *Conv* and *3DP* were observed even though associated sensory attribute acceptance ratings did not differ. Positive texture perceptions were mentioned more frequently, and negative texture perceptions were mentioned less frequently when food products were presented as *3DP* as compared to *Conv*. This observation suggests that consumer impression of 3DFP could influence the sensory perceptions of 3D printed foods.

Participants were invited to explain their preference choices between the “conventional” and the “3D printed” food products. Some participants that preferred the “3D printed” presentation mentioned their support for novel technology and perceived benefits, suggesting the potential to engage this consumer group by highlighting the novelty aspect and communicating benefits of 3DFP. Meanwhile, some consumers that preferred the “conventional” presentation mentioned their higher knowledge, familiarity, and perceived healthiness of the conventional product despite the receipt of benefit information about 3DFP. For this consumer group, communication could focus on education about the available healthy food materials used for 3DFP and establishing the connection between extrusion-based 3DFP and familiar food production technologies (e.g. industrial production of pasta). Some participants who preferred the conventional potato Smiles® were not opposed to trying 3D printed foods in the future, suggesting an accepting attitude towards 3DFP in this neutral group once benefits are communicated effectively.

Two limitations of this study were observed. First, the COVID-19 pandemic prevented the recruitment of off-campus participants. Findings of this study therefore apply to the university population with limited extrapolation to the general populations. Nevertheless, previous research suggests that the younger and more educated population are more accepting of new technologies (Chen et al., 2013; Kuang et al., 2020; Manstan & McSweeney, 2019) thus the university students are likely to be among the early adopters of 3DFP. Second, potato Smiles®

was the only study product that did not receive a higher perceived quality rating and was not preferred when presented as *3DP+Info* as compared to *Conv*. Considering the lower acceptance rating of aroma when presented as *3DP+Info* as compared to *Conv,* and that more participants lowered the acceptance rating of texture than those increased and remained the ratings when presented as *3DP* as compared to *Conv*, the quality loss in “3D printed” potato Smiles® caused by the warming method used to maintain sample temperature prior to serving was identified to negatively influence participant sensory acceptance.

Two strengths of this study were noted. Participant qualitative insights obtained by open-ended comments provided insights into hedonic ratings and allowed exploration of their opinion formation processes. Moreover, the within-subjects design and use of identical conventionally produced food products presented differently as *Conv*, *3DP*, and *3DP+Info* minimized the confounding effect of objective sensory differences on consumer sensory acceptance.

A good understanding of consumer interest and skepticism is crucial for strategy development in the 3DFP industry. This study aimed to help 3DFP stakeholders understand consumer acceptance of plausible 3D printed foods under labelled and informed conditions and consumer constructs associated with acceptance. Overall, results of this study suggest a positive impression of 3DFP in the mostly young, educated, and digital savvy population.

3.2 Future directions

In this study, participants were highly health-oriented when making food choice decisions, which is consistent with the trend of growing global consumer consciousness in health (Portanguen et al., 2019; Sun et al., 2018). Current extrusion-based 3DFP extensively uses calorie-dense and nutritionally incomplete food materials and texture modifying additives, raising the research question about what “consumer approved” ingredients are under growing health orientation. Future studies could aim to understand consumer demands for healthy printable food materials. Results from such consumer demand assessment could further guide research in healthy printable food material selection and food development. In addition to health, study participants were oriented to natural content and convenience in their food choices and were digital natives. Food choice orientations and familiarity with digital technology are consumer constructs that may affect acceptance of 3D printed foods. Half or more of participants in this study either frequently consumed or were familiar with special occasion chocolate, nutritional supplements, and puréed diets, which are conventional products that could be enhanced by 3DFP. High involvement in those products indicates high relevance to the benefits of 3DFP and is postulated to predict high likelihood of accepting 3DFP. Due to the foci of this study, consumer food choice orientations, familiarity with digital technology, and experience with conventional foods were not statistically analyzed. Future studies could perform quantitative assessments to explore the effect of those consumer constructs on acceptance of tasted 3D printed foods.

In this study, consumers with higher FTN had lower overall acceptance of 3D printing and "3D printed" foods. Future studies could address drivers of FTN in relation to 3DFP and develop interventions for its reduction. Preference for "conventional" or "3D printed" in this study were generated based on the tasting experience and positive information about 3DFP. How additional key information (e.g. price and availability) affects consumer preference for 3D printed foods among alternatives could be a future research question. Furthermore, intentions do not imply purchase behaviors. Preference and willingness to purchase could be assessed under realistic scenarios, such as by the auction method, used by La Barbera (2016).

Similar studies could also improve upon the methodology of the current study by including a demographically diverse sample, objective and comprehensive measurement of knowledge and attitude, and different labelling methods and education approaches. Including older adults in 3DFP studies will add value to 3DFP research as one of its main applications of appealing presentation of puréed food mainly targets the elderly, who are more likely to experience chewing and swallowing difficulties. An older and/or less educated sample may also provide different perspectives on 3DFP than the university sample that is young and knowledgeable about 3D printing, rendering more representative findings. Additionally, stratified random sampling methods could be used for recruiting specific demographic groups while reducing bias as compared to convenience sampling.

In this study, a single item was used to measure each of consumer self-assessed knowledge about 3D printing and 3DFP and attitude towards 3D printing. Future measurements could include multiple items that focus on various aspects of knowledge and attitude constructs for comprehensive assessment, as used in previous research (Brunner et al., 2018; Manstan & McSweeney, 2019; Mantihal et al., 2019). Moreover, consumer objective understanding of 3DFP could be measured to reduce bias in self evaluation of the level of 3DFP knowledge.

Labelling and positive information about the food technology or the food have been observed to influenced sensory acceptance of several identical foods in previous research, while a limited effect was observed in this study. In the current study, food products were labelled as 3D printed or conventional; presented information included a description of 3D printing in a video plus beneficial applications of 3DFP in text and images. Future studies could continue to formulate science-driven labelling and education approaches in relation to 3DFP for perceived sensory improvement. Furthermore, studies could include information that reflects consumer interests and concerns about novel foods. New information content, such as the cost and safety of 3D printed foods, benefits of 3DFP in food waste reduction and sustainability, and other utilities of 3DFP could be examined, as those aspects may contribute to consumer opinion formation about novel food technologies (Giordano et al., 2018).

3.3 Conclusions

This research investigated consumer acceptance of 3DFP with an emphasis on sensory acceptance of chocolate swirls, gummy candy carrots, and baked potato Smiles® presented as 3D printed and with benefits of 3DFP. Labelling as 3D printed and product-specific positive information about 3DFP together improved consumer attitude towards 3D printing; labelling improved perceived quality of chocolate swirls and gummy candy carrots. Both interventions had limited effect on sensory attribute acceptance of the three study products. Food Technology Neophobia lowered consumer overall liking and perceived quality of “3D printed” foods and attitude ratings of 3D printing, while previous knowledge about 3D printing had no effect on those variables. Consumers preferred food products presented as 3D printed over those presented as conventional, except for potato Smiles®. Consumers who preferred the “3D printed” products mentioned their support for a novel technology and perceived benefits of 3DFP in enabling creative, custom, and appealing design; and those who preferred the conventional product mentioned their perceived benefits of the conventional product in naturalness and healthiness, lack of familiarity with and knowledge about 3DFP, and lack of visual appeal of the 3D printed product. Overall, the university participants had positive attitude towards 3D printing, were highly oriented to health, natural content, and convenience when making food decisions, and were digital natives. Half or more had experience with conventionally made food products that could be enhanced by 3DFP, indicating a high possibility of accepting 3DFP in the future.

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Appendices

Appendix A. Product-specific positive information about 3DFP

Chocolate for art and creativity

3D printers can easily and efficiently create interesting, novel, and complex designs that would be difficult and time-consuming to replicate by hand. These complex designs are highly customizable through digital design software, providing an opportunity for anyone to create their own designs. This aspect of 3D printing is very appealing to chocolatiers and confectioners who are constantly looking to create innovative chocolates for their consumers, but also for any user who desires to create their own unique and personalized chocolates.

Gummy candy for nutrient delivery, and creating novel and complex designs

3D printed foods can potentially create personalized foods containing the correct percentage of nutrients for a particular age or gender. It is important for individuals of all ages to meet their daily nutritional needs, but especially for children in order to have proper growth and development. A 3D printed gummy candy can be formulated to meet the nutritional needs - in terms of energy, vitamins and minerals - of children within a certain age range and at the same time create attractive and complex designs that would peak their curiosity to consume the food.

Mashed potatoes for attractive shaping of soft foods

3D food printing can be beneficial for the elderly or individuals that suffer from dysphagia; a medical condition in which people have difficulty chewing and swallowing food. Their meals usually consist of soups, liquids, or unappealing pureed globs of food. With a 3D printer, pureed meats and vegetables can be shaped into attractive designs that resemble the original food the material was pureed from. These printed foods could increase appetite, improve nutritional intake and quality of life for those suffering from dysphagia.

Appendix B. Supplementary Table 1.

Table S1. Changes in sensory acceptance ratings (increased, decreased, unchanged)[1] between two successive tastings in chocolate swirl (n = 68), gummy candy carrot (n = 59), and potato Smiles® (n = 59) panels.

	Comparing 3DP to Conv					*Comparing 3DP+Info to 3DP*				
	Increased		**Decreased**		**Unchanged**	**Increased**		**Decreased**		**Unchanged**
	Mean increase	n (%)	Mean drop	n (%)	n (%)	Mean increase	n (%)	Mean drop	n (%)	n (%)
Appearance										
Chocolate swirl	1.5	24 (35)	−1.0	8 (12)	36 (53)	1.0	10 (15)	−1.8	9 (13)	49 (72)
Gummy candy carrot	1.3	14 (24)	−1.1	10 (17)	35 (59)	1.1	9 (15)	−1.2	5 (8)	45 (76)
Potato Smiles	1.3	10 (17)	−1.2	13 (22)	36 (61)	1.1	13 (22)	−1.4	5 (8)	41 (69)
Aroma										
Chocolate swirl	1.4	23 (34)	−1.7	10 (15)	35 (51)	1.5	8 (12)	−1.2	12 (18)	48 (71)
Gummy candy carrot	1.4	15 (25)	−1.4	16 (27)	28 (47)	1.4	17 (29)	−1.0	6 (10)	36 (61)
Potato Smiles	1.3	10 (17)	−1.6	19 (32)	30 (51)	1.2	8 (14)	−1.6	10 (17)	41 (69)
Flavor										
Chocolate swirl	1.5	24 (35)	−1.5	14 (21)	30 (44)	1.8	12 (18)	−1.7	14 (21)	42 (62)
Gummy candy carrot	1.4	19 (32)	−1.1	16 (27)	24 (41)	1.4	13 (22)	−1.3	6 (10)	40 (68)
Potato Smiles	1.3	16 (27)	−1.6	16 (27)	27 (46)	1.3	15 (25)	−1.3	13 (22)	31 (53)
Texture										

Chocolate swirl	1.5	20 (29)	−1.5	15 (22)	33 (49)	1.2	11 (16)	−1.1	12 (18)	45 (66)
Gummy candy carrot	1.5	17 (29)	−1.6	16 (27)	26 (44)	1.4	21 (36)	−1.5	12 (20)	26 (44)
Potato Smiles	1.9	15 (25)	−2.3	23 (39)	21 (36)	1.5	23 (39)	−1.6	10 (17)	26 (44)
Overall opinion										
Chocolate swirl	1.6	23 (34)	−1.8	12 (18)	33 (49)	1.8	12 (18)	−1.6	13 (19)	43 (63)
Gummy candy carrot	1.2	18 (31)	−1.5	13 (22)	28 (47)	1.5	13 (22)	−1.2	4 (7)	42 (71)
Potato Smiles	1.5	13 (22)	−1.6	17 (29)	29 (49)	1.2	16 (27)	−1.5	11 (19)	32 (54)
Quality										
Chocolate swirl	1.4	27 (40)	−1.0	1 (1)	40 (59)	1.2	8 (12)	−1.3	11 (16)	49 (72)
Gummy candy carrot	1.2	22 (37)	−1.0	4 (7)	33 (56)	1.0	11 (19)	−1.3	6 (10)	42 (71)
Potato Smiles	1.1	15 (25)	−1.2	10 (17)	34 (58)	1.0	11 (19)	−1.3	6 (10)	42 (71)

[1]All attributes except quality were evaluated on 9-point hedonic scales from 1 = "dislike very much" to 9 = "like very much"; agreement of high product quality was evaluated on 5-point Likert scales from 1 = "strongly disagree" to 5 = "strongly agree".

Appendix C. Questionnaires

Sensory Evaluation

Please evaluate the sample of in front of you.

Please clear your palate before you begin with a sip of water.

Sample <u>"Conventional product"</u>

- Appearance

Overall, what is your opinion of the appearance of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Aroma

Overall, what is your opinion of the aroma of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Texture

Overall, what is your opinion of the texture of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Flavor

Overall, what is your opinion of the flavor of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Overall opinion

Overall, what is your opinion of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremel y	Dislike very much	Dislike moderate ly	Dislike slightly	Neither like nor dislike	Like slightly	Like moderate ly	Like very much	Like extremel y

- Quality

Considering all aspects of this product, in your opinion, is this a high quality product?

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree

Please take another sip of water to clear your palate.

Additional comments about the product (why you like or dislike the product):

Food Technology Scale

Please indicate your agreement with the following statements by ticking the box under the appropriate number on the scale. When responding we ask you to think about new food technologies in general rather than one specific technology.

		Totally disagree 1	2	3	Neither agree nor disagree 4	5	6	Totally agree 7
1	There are plenty of tasty foods around so we don't need to use food technology to produce more	☐	☐	☐	☐	☐	☐	☐
2	The benefits of new technologies are often grossly *overstated*	☐	☐	☐	☐	☐	☐	☐
3	New food technologies *decrease* the natural quality of food	☐	☐	☐	☐	☐	☐	☐
4	There is no sense trying out high-tech food products because the ones I eat are already good enough	☐	☐	☐	☐	☐	☐	☐
5	New foods are *not* healthier than traditional foods	☐	☐	☐	☐	☐	☐	☐
6	New food technologies are something I am *uncertain* about	☐	☐	☐	☐	☐	☐	☐
7	Society should *not* depend heavily on technologies to solve its food problems	☐	☐	☐	☐	☐	☐	☐
8	New food technologies may have long term *negative* environmental effects	☐	☐	☐	☐	☐	☐	☐
9	It can be risky to switch to new technologies too quickly	☐	☐	☐	☐	☐	☐	☐
10	New food technologies are *unlikely* to have long term negative health effects	☐	☐	☐	☐	☐	☐	☐
11	New products produced using new food technologies can help people have a balanced diet	☐	☐	☐	☐	☐	☐	☐
12	New food technologies give people *more* control over their food choice	☐	☐	☐	☐	☐	☐	☐

13	The media usually provides a *balanced* and unbiased view of new food technologies	☐	☐	☐	☐	☐	☐	☐

- Previous knowledge

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

☐	☐	☐	☐	☐
Not at all	Not very	Somewhat	Very	Extremely

How knowledgeable would you say you are about 3D <u>food</u> printing?

☐	☐	☐	☐	☐
Not at all	Not very	Somewhat	Very	Extremely

- Attitude

What is your attitude towards 3D printing?

Negative ☐ ☐ ☐ ☐ ☐ ☐ ☐ Positive

Demographic and Product Use Questions

1. What is your age range?

☐	18 – 25 years
☐	26 – 35 years
☐	36 – 60 years
☐	Greater than 60 years

2. How much do you like milk chocolate/gummy candy/potato?

☐	Like extremely
☐	Like very much
☐	Like moderately
☐	Like slightly
☐	Neither like nor dislike
☐	Dislike slightly
☐	Dislike moderately
☐	Dislike very much
☐	Dislike extremely

3. How often do you consume milk chocolate/gummy candy/potato?

☐	Daily
☐	3 – 4 times per week
☐	Once per week
☐	Once a month
☐	A few times per year
☐	Never

4. How often do you consume special occasion chocolates/nutritional supplements? OR
   Are you familiar with pureed diet? (Y/N).

☐	Daily
☐	3 – 4 times per week
☐	Once per week
☐	Once a month
☐	A few times per year
☐	Never

5. What is your level of education?

☐	Some or completed high school
☐	Some or completed university/college/technical training
☐	Some or completed postgraduate university study

6. What is your average yearly household income before taxes?

☐	Less than $36,600
☐	$36,600 - $71,000
☐	$71,001 - $115,000
☐	more than $115,000

7. How many people are there in your household?

☐	None
☐	1
☐	2
☐	3
☐	4

☐	5 or more

8. How many children between 0-12 years old do you have in your household?

☐	None
☐	1
☐	2
☐	3
☐	4
☐	5 or more

9. How many teenagers between 13-17 years old do you have in your household?

☐	None
☐	1
☐	2
☐	3
☐	4
☐	5 or more

Sensory Evaluation

Please evaluate the sample of in front of you.

Sample <u>"3D printed"</u>

- Appearance

Overall, what is your opinion of the appearance of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Aroma

Overall, what is your opinion of the aroma of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Texture

Overall, what is your opinion of the texture of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Flavor

Overall, what is your opinion of the flavor of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Overall opinion

Overall, what is your opinion of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremel y	Dislike very much	Dislike moderate ly	Dislike slightly	Neither like nor dislike	Like slightly	Like moderate ly	Like very much	Like extremel y

- Quality

Considering all aspects of this product, in your opinion, is this a high quality product?

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree

Please take another sip of water to clear your palate.

Additional comments about the product (why you like or dislike the product):

Information Provided

At this point, a general video about different kinds of 3D printing is shown to the participant. After the video, the written paragraph explaining the advantages of 3D printing chocolate/gummy candy/pureed foods will be shown, along with supporting images (Appendix A).

Sensory Evaluation

Please evaluate the sample of in front of you.

Sample <u>“3D printed”</u>

- Appearance

Overall, what is your opinion of the appearance of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Aroma

Overall, what is your opinion of the aroma of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Texture

Overall, what is your opinion of the texture of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Flavor

Overall, what is your opinion of the flavor of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Overall opinion

Overall, what is your opinion of the product?

☐	☐	☐	☐	☐	☐	☐	☐	☐
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

- Quality

Considering all aspects of this product, in your opinion, is this a high quality product?

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree

Please take another sip of water to clear your palate.

Additional comments about the product (why you like or dislike the product):

- Attitude

Now, what is your attitude towards 3D printing?

Negative ☐ ☐ ☐ ☐ ☐ ☐ ☐ Positive

Additional Questions

Please indicate your agreement with the following statements by ticking one box for each statement.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Health					
It is important to me that the food I eat on a typical day:					
Contains a lot of vitamins and minerals	☐	☐	☐	☐	☐
Keeps me healthy	☐	☐	☐	☐	☐
Is nutritious	☐	☐	☐	☐	☐
Is high in protein	☐	☐	☐	☐	☐
Is good for my skin, teeth, hair, nails, etc.	☐	☐	☐	☐	☐
Is high in fibre and roughage	☐	☐	☐	☐	☐
Natural Content					
It is important to me that the food I eat on a typical day:					
Contains no additives	☐	☐	☐	☐	☐
Contains natural ingredients	☐	☐	☐	☐	☐
Contains no artificial ingredients	☐	☐	☐	☐	☐
Digital native					
I use computers for many things in my daily life	☐	☐	☐	☐	☐
I use the computer for leisure every day	☐	☐	☐	☐	☐
I am able to communicate with my friends and do my work at the same time	☐	☐	☐	☐	☐
I am able to use more than one applications on the computer at the same time	☐	☐	☐	☐	☐
I use a lot of graphics and icons when I send messages	☐	☐	☐	☐	☐

I use pictures to express my feelings better	☐	☐	☐	☐	☐
I expect quick access to information when I need it	☐	☐	☐	☐	☐
I expect the websites that I visit regularly to be constantly updated	☐	☐	☐	☐	☐
Convenience orientation					
The less physical energy I need to prepare a meal, the better	☐	☐	☐	☐	☐
The ideal meal can be prepared with little effort	☐	☐	☐	☐	☐
Preferably, I spend as little time as possible on meal preparation	☐	☐	☐	☐	☐
I want to spend as little time as possible cooking	☐	☐	☐	☐	☐
At home, I preferably eat meals that can be prepared quickly	☐	☐	☐	☐	☐