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Faculty of Tropical AgriSciences

Consumers' Attitudes Towards 3D Printed Meat

MASTER'S THESIS

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DIPLOMA THESIS ASSIGNMENT

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International Development and Agricultural Economics

Thesis title

Consumers' Attitudes Towards 3D Printed Meat

Objectives of thesis

The main purpose of this study is to develop an understanding of consumers' attitudes toward 3D-printed meat. Firstly, the factors affecting the purchase and consumption of conventional meat will be identified. Then the awareness about and willingness to try 3D-printed food among Czech consumers will be explored. Furthermore, the willingness of consuming 3D printed meat among young Czech consumers will be analysed. Lastly, the influence of socio-demographic characteristics on consumer attitudes towards and awareness of 3D-printed food will be evaluated.

Methodology

The methodological approach taken in this study will be a mix of convenience sampling and snowball sampling. The data will be collected through an online questionnaire survey among Czech consumers to identify their meat consumption habits, awareness about 3D printed food products, and their willingness to try 3D printed meat and the factors affecting their willingness. The data will be processed through descriptive and explanatory analysis. Consumer attitudes towards 3D printed meat and the factors affecting it will be identified.

The proposed extent of the thesis

50 pages

Keywords

3D food products, consumer willingness to try, food consumption, meat consumption habits, the Czech Republic

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Recommended information sources

Brunner, T. A., Delley, M., & Denkel, C. (2018). Consumers' attitudes and change of attitude toward 3D-printed food.

Lupton, D., & Turner, B. (2018). "I can't get past the fact that it is printed": consumer attitudes to 3D printed food.

Manstan, T. & McSweeney, M. (2020). Consumers' attitudes towards and acceptance of 3D printed foods in comparison with conventional food products. International Journal of Food Science & Technology, 55(1), 323–331.

Tran, J. L. (2016). 3D-Printed Food. Science & Technology, 17(2), 855–880.

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Declaration

I hereby declare that I have done this thesis entitled Consumers' Attitudes Towards 3D Printed Meat independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague, 20.04.2023.

…..................................

Bc. Wahaj Muhammad

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Abstract

Although meat consumption is increasing worldwide, recent studies show that a significant proportion of European consumers are willing to reduce their meat consumption. High level of meat consumption is linked with health risks, while conventional livestock production is linked with high levels of greenhouse gas emissions, deforestation, biodiversity loss, food safety risks, and overall negative impact on the climate. 3D printed meat has the potential to offset the negatives of conventional livestock production. Given the limited literature about consumer attitudes towards 3D printed food products, the main purpose of this study is to develop an understanding of consumers' attitudes toward 3D-printed meat by young Czech consumers. An online cross-sectional survey was used in combination with convenience sampling method and a total of 182 responses were collected. Although there is a relatively large knowledge of 3D printers among the respondents, their knowledge of printed food and especially meat is significantly lower. Familiarity with the technology, previous knowledge, and previous experience were identified as important factors that influence consumer acceptance of 3D printed meat. Price and taste were found to be the most important factor determining consumer attitude towards both conventional and 3D printed meat. Overall, there is a high willingness to try 3D printed food products and a lower willingness to try 3D printed meat products among the respondents. No meat eaters expressed low willingness to try 3D printed meat which could be credited to the debate around the legitimacy of cultured meat as a viable "vegetarian" alternative to conventional meat).

Key words: 3D food products, consumer willingness to try, food consumption, meat consumption habits, the Czech Republic

Contents

List of Tables

List of Figures

1. Introduction

As per the Food and Agricultural Organization of the United Nations, meat and meat products continue to serve as the primary protein source for the global population. It is expected that consumption of animal protein will increase in the forthcoming years (FAOSTAT 2023). This is especially true in the case of the Czech Republic, as 90% of the population do eat meat. In comparison, the average proportion of such people in Europe is around 76% (Ipsos 2020).

However, the consumption of high levels of meat has been linked to a variety of health conditions such as cardiovascular diseases, type 2 diabetes, and certain forms of cancer. Additionally, it has been identified as a contributing factor to the global obesity epidemic which affects a significant proportion of the adult population worldwide (Salter 2018). Furthermore, the increasing production and consumption of meat have been identified as one of the primary drivers of environmental and social pressures. Conventional animal agriculture is highly inefficient in terms of their conversion rates of feed to meat protein and have been associated with high levels of greenhouse gas emissions, deforestation, biodiversity loss, food safety risks, and overall negative impact on the climate (Conzachi 2022).

Consequently, there has been a growing interest in understanding the advantages associated with diets that incorporate lower levels of meat and increased amounts of plant protein. This interest aims to foster the development of effective policies and strategies for reducing meat consumption or substituting meat in diets (Apostolidis & McLeay 2016). One such technology that could help reduce the negative impacts of conventional meat production is three-dimensional printing.

Three-dimensional (3D) printing (also known as additive manufacturing) is the process of guiding a digital fabricating machine to extrude materials in a layering pattern to construct items using computer software (Mohr & Khan 2015). Some see it as a disruptive and revolutionary technology that will contribute to a third industrial revolution due to the changes it will bring to manufacturing, the global supply chain, and the economy (Mohr & Khan 2015). Cartridges loaded with edible materials - pastes, purees, powders, doughs, liquids, and gels created from sugar, chocolate, cheese, wheat, fruit, vegetables, and animal proteins - are used in the 3D printing of meals. The pastes are extruded through nozzles to produce edible substances with elaborate patterns.

The first commercial utilization of such technology can be traced back to 1988 when Charles Hull's 3D Systems sold the first industrial 3D printer. Ever since, the technology evolved throughout the 1990s, and it became commercially viable to the public around 2009 once the printers started to utilize the Fused Deposition Modelling technology (Houser 2016). In terms of food being printed, the first instances of such activities can be traced back to 2006 to a group of undergraduate and graduate students from Cornell university. These students further developed the Fab@Home, the first multi-material 3D printer available to the public and used it to create a prototype that could print edible products. As a result, they were able to print foods like chocolate and cookies dough (Creative Machines Lab 2022). Around the same time another printer was being developed called CandyFab4000 that used hot air to create objects from sugar by melting and fusing sugar grains together (Oskay 2007). So far, 3D printing technologies have been used to create products such as chocolate or sugar decorations, candies and desserts, pancakes, pizza bases, biscuits, bread, pasta, and puree forms (Lupton & Turner 2016).

The general promise behind the technology is the potential to be both healthful and environmentally friendly since it enables is use of alternative materials such as proteins from algae, beet leaves, or insects into more acceptable, palatable, commercially viable foods. It also allows for meal personalization, allowing it to cater to individual requirements and tastes. Shape, colour, texture, flavour, and nutrition of the meal can all be changed, making it valuable in industries like space exploration and healthcare (Liu et al. 2017).

2. Literature Review

There is a growing interest in the field of 3D printing of food. The literature review shows that the previous studies focus primarily on the technical aspects of the process, assessing the general feasibility of the techniques, and the potential ingredients that could be used to create the final edible product. Moreover, the general practicality of the technology is explored. Benefits and challenges are identified, and over time, the consumer studies are conducted with the aim to recognize which factors are important in terms of consumer acceptance and their willingness to try and use this technology in their lives.

2.1. 3D Printing of Food

3D food printing technologies integrate computer-aided design software with advanced systems capable of producing food products with intricate patterns and forms. This is achieved through the process of extrusion, wherein layers of soft-textured food materials such as melted chocolate, sugar pastes, cheese, dough, and pureed meat, vegetables, and fruit are precisely deposited through nozzles. The ingredients used in 3D food printing can be partially cooked during printing by heating the extruder, with the temperature of both the extruder and the printing bed varying based on the material and intended printing outcome. Moreover, the printing bed may be heated, allowing the printed product to bake further after being extruded, and the food product to firm on the printing bed. Alternately, the extruder and printing bed heat functionalities can be switched off, allowing the food item to be produced at room temperature. Once the 3D printed food product is printed it can be processed like conventional food products (Sun et al. 2015).

Even though extrusion based printing is the most common technique of 3D printing, there are other techniques being developed. Inkjet-based 3D food printing, like standard inkjet printers, employs microscopic droplets of liquid food components that are precisely deposited onto a substrate to construct the finished food product layer by layer. This method is frequently used to create visually complex patterns or motifs on food products such as cake decorations or personalized meal toppers (Le-Bail et al. 2020).

In the case of binder jetting food components are in a powdered form, then layers of powder are selectively linked together using a liquid or heat to make the final 3D food product. This method is used to make food with a powdered or crunchy texture, such as crackers or biscuits (Le-Bail et al. 2020).

Another technique is called selective laser sintering which employs a laser to selectively heat and fuse powdered food components together to make the final 3D food product. Utilization of this technique enables the printing of culinary items or to include many components into a single food product (Le-Bail et al. 2020).

Food-printing methods have also been proposed for usage in 3D printed meat. Scientists have been experimenting with making meat in laboratories using tissue cultivated from animal cells using procedures like those used for growing and printing human tissue for medicinal purposes (Sun et al. 2018). 3D printed meat further provides the opportunity to reduce the emissions from conventional livestock production and the need for land clearing, as well as to alleviate animal welfare concerns related to livestock raised and slaughtered for human consumption, thereby addressing some of the moral and ethical concerns of those who choose not to eat animals or who are concerned about animal cruelty (Kira 2015).

There has been a surge in promising discourse surrounding the potential of 3D food printing technologies. Currently, certain 3D food printers are being utilized in commercial settings and nursing homes, while others are still in the developmental and experimental phases, with some remaining in the speculative stage (Lupton & Turner 2018b).

2.2. 3D Printed Food Products

The selection of ingredients is a crucial factor in determining the feasibility of 3D printing of food and plays a critical role in establishing the final products that can be produced. Typically, research studies related to ingredients can be categorized into four primary groups based on the food categories they examine, namely: meat and fish, fruits and vegetables, dairy, and non-perishable items. The overview of the recent literature focused on 3D printed food is provided in Table 1.

Recent research investigating the potential use of meat and fish as ingredients for 3D printing has demonstrated their viability as potential components. Specifically, the ability to alter the characteristics of the final product, such as its texture and structure, can lead to an overall improvement in the perceived quality of the food product (Dick et al. 2019). Secondly, the possibility of altering the nutritional contents of the final product and being able to modify it to an individual's need is noted as a highly important benefit, as through this method it is possible to provide the individuals with the nutrients, they are deficient in and need the most (Wilson et al. 2021). Since the structures of the product can be modified, it could be beneficial for people with disabilities like dysphagia as the food could be made easier for them to consume (Kouzani et al. 2017). As an alternative to traditional animal protein sources, insects are highlighted as a feasible alternative source of protein and through its use in 3D printing of snack bars can become more appealing to consumers (Soares & Forkes 2014; Severini et al. 2018). To sum up, there is evidence to suggest that beef (Dick et al. 2019), chicken (Wilson et al. 2021), pork (Dick et al. 2020), surimi (Wang et al. 2018), insects, and tuna (Kouzani et al. 2017) are all viable options for 3D printing and can utilize the benefits this technology has to offer.

Next category of ingredients are fruits and vegetables. These plant-based ingredients are explored to further determine the limits 3D printing technology. Some studies were of exploratory nature and were aimed at recognizing certain foods as agents that would be added to other ingredients to help those ingredients with 3D printing. For example, a study on lemon gel serves as a reference point for how to work with other gel product and starch products in the future (Yang et al. 2017). Another study focuses on mashed potatoes and how they can be used to modify the textural qualities and explores the possibility of multi-material and multi-colour foods (Liu et al. 2018). Similarly, it was explored how peas protein in combination with potato starch can affect the structural properties of the final product (Chuanxing et al. 2018). Furthermore, it is possible to create unique designs with predetermined shapes and dimension with novel compositions, structures, textures, and tastes. This can be achieved from a combination of different fruits and vegetables resulting in novel combinations of food products (Derossi et al. 2018). Additionally, edible blue-green algae were recognized as a prospective ingredient to boost the nutritional properties of 3D printed foods (An et al. 2019). In comparable studies, powders from the button mushrooms (Keerthana et al. 2020) and the cordyceps flowers

(Teng et al. 2019) were identified as ingredients for 3D printing that could produce healthy and nutritious food products.

The potential of customizability in terms of designs is highlighted for especially for non-perishable foods like chocolate products (Jun-yong et al. n.d.; Mantihal et al. 2019) and cereals (Noort et al. 2017). For instance, the husk of a viable ingredient like rice can be used to print into the form of packaging to reduce waste (Nida et al. 2021). Also, rice starch can be used to increase printability of other ingredients (Theagarajan et al. 2020). Additional non-perishable commercial food products like vegemite and marmite can be used in the process to add aesthetic value in the final product (Hamilton et al. 2018).

In terms of dairy products, the research indicates that ingredients such as cheese (le Tohic et al. 2018), cookie dough (Pulatsu et al. 2020), and eggs (Liu et al. 2018; Anukiruthika et al. 2020) can be used. This research on these ingredients displays various methods on how to work with more complex food products and outlines new methods on how to work such ingredients.

Table 1 Recent research on 3D printed food products

Type	Food	Key findings	Supported reference
Dairy	**Cheese**	Processed can be used to 3D print food products. The effects of the structure can lead to changes in the melting profile of the cheese.	(Le Tohic et al. 2018)
	Cookie Dough	Cookie dough without the necessity to add gums and stabilizers can be created. Modifying the milk and sugar content reflects on the structural stability of the cookies.	((Pulatsu et al. 2020))
	Eggs	The possibility of being able 3D print food product based on the egg white protein complex system is encouraging in terms of handling more complicated food products. Thus, eggs could also serve as an important ingredient in 3D food printing.	(Anukiruthika et al. 2020; Liu et al. 2019, 2020)
Fruits & vegetables	**Edible blue-green algae**	It is a suitable material for 3D printing and because of its nutritional properties it could be used when personalizing food for consumers.	(An et al. 2019)
	Fruits / Vegetables	It is possible to create innovative food with predetermined shape and dimension made from several different fruits and vegetables personalized to the consumer's liking. Hydrated vegetables with low contents of hydrocolloids are best pro 3D printing as they maintain the nutrition and flavours. It in addition reduces food wastage.	(Derossi et al. 2018; Severini et al. 2018c; Pant et al. 2021)
	Lemon	lemon gel is a suitable material for 3D printing. This can be a good reference point for other gels and starch products.	(Yang et al. 2018)
	Mashed potatoes	Through altering infill percentages, 3D printing provides the capacity to modify the textural qualities of samples. It is possible to have multi-colour multi-material foods printed.	(Liu et al. 2018; He et al. 2020)
	Mushrooms	Button mushroom powder with wheat fluor, and Cordyceps flower powder can be a base for 3D printing can produce healthy, nutritious, and customizable food products from a sustainable healthy food source.	(Teng et al. 2019; Keerthana et al. 2020)
	Peas	Balancing ingredients has a direct effect on the structural properties of the final product. When the pea protein was at 1% the final printed product was the best.	(Chuanxing et al. 2018)

Table 1 (continued) Recent research on 3D printed food products

Type	Food	Key findings	Supported reference
Meat & fish	**Beef**	Being able to modify the fat content resulted in better properties and more appealing characteristics of the final cooked beef product.	(Dick et al. 2019)
	Chicken	3D-printed chicken nuggets can be customised in terms of nutrition, micronutrients, macronutrients, and nutraceutical ingredients.	(Wilson et al. 2020)
	Insects	In combination with wheat, insect protein can be a viable component for 3D printing of customized and unique food products with increased nutritional quality. It can be a more sustainable protein source.	(Soares & Forkes 2014a; Severini et al. 2018a)
	Pork	3D printing of meat can result in a less concentrated meat structure. It can help modify the food texture.	(Dick et al. 2020)
	Surimi	Surimi gel is suitable for 3D printing. Using microwaves during the 3D printing aids the hydrogen bonds of surimi that leads to better mechanical strength and water retention capabilities. Utilizing microbial transglutaminase can help in the 3D printing process. Starch content of sweet potatoes can enhance the structure 3D printed surimi.	(Wang et al. 2018; Dong et al. 2019, 2020; Zhao et al. 2021)
	Tuna	3D printing of tuna removed reliance on skilled labour; provided with a faster, easier, and replicable method of food production that could be beneficial for people with dysphagia.	(Kouzani et al. 2017)
Non-perishable	**Cereals**	3D printing technology can produce food with more complicated shapes, with novel compositions, structure, textures, and tastes.	(Noort et al. 2017)
	Chocolate	You can change the textural characteristics and physical stability of chocolates with 3D printing. The design of the final products impacts its stability. You print chocolate with additional medicinal nutrition, which results in higher oil-holding capacity than traditional chocolates.	(Jun-yong et al. n.d.; Mantihal et al. 2017, 2019b)
	Rice husk	By mixing guar gum into risk husk, it become printable, and thus can be used in creating packaging for food, helping reduce dependency on plastics.	(Nida et al. 2021b)
	Rice starch	3D printing using starch-based materials has a large commercial and scientific potential.	(Theagarajan et al. 2020)
	Vegemite / Marmite	These products are possible to use in 3D printers at certain temperatures and can be used in food presentations to make them look better.	(Hamilton et al. 2018)

2.3. Benefits of 3D Printing of Food

There are numerous potential advantages associated with 3D printed food (Table 2). The primary benefit of this technology lies in its flexibility, as it offers the capability to customize the nutritional composition of existing food products in terms of their protein, carbohydrate, fat, vitamin, and mineral contents. Ingredients of a product can be personalized based on the requirements of the individual (Severini & Derossi 2016).

The capacity to modify the visual appearance of the final product represents a significant advantage of 3D printing technology. Furthermore, the 3D printing technology allows for the creation of unique shapes and designs, resulting in the production of innovative and novel food products which would be impossible to create otherwise (Lupton & Turner 2016; Yang et al. 2017). This ability to manipulate the shape could lead to the creation of visually appealing food products that may have otherwise been unappealing to certain consumer groups. For example, motivating children to consume healthier food items can be a challenging task. However, by leveraging 3D printing technology to create visually appealing products using nutritious ingredients such as fruits and vegetables, children may become more motivated to opt for healthier food options (Derossi et al. 2018). Another similar case could be made for the consumption of insects as a more sustainable protein alternative. For example, the stigma of and fear of eating insects could be overcome by creating a visually more appealing snack bar, a form the consumers are accustomed to in their daily consumption habits (Soares & Forkes 2014; Yang et al. 2017; Severini et al. 2018).

Research has indicated that the implementation of 3D printing technology in food production can increase efficiency by reducing input requirements and resource consumption (Galdeano 2015; Davies & Garrett 2018) Consequently, the production process can be streamlined, resulting in faster and more straightforward food production. (Tran 2016). 3D printing technology has the potential to decrease dependence on skilled labor and create a faster and more replicable method of food preparation. This, in turn, could facilitate home cooking and empower consumers to prepare their meals with greater ease and convenience, ultimately reducing barriers to cooking at home (Kouzani et al. 2017). Once such printers would be implemented at the home kitchen, it could lead to decreasing the need for traditional grocery stores and increase the quality of meals prepared and eaten at home (Hall 2013; Sun et al. 2015; Tran 2016; Caulier et al. 2020). As by-product resulting in a reduction of microwave usage and lowering the time of exposition to radio waves (Tran 2016).

Based on the existing body of research, the use of 3D printing technology in food production appears to be a more sustainable alternative to the conventional methods. This is particularly evident in the ability to incorporate alternative sources of protein such as lab-grown cultivated meat, plant-based meat alternatives, or insects into the printing process, which can reduce the carbon footprint associated with conventional meat production techniques (Phillips 2013; Foster 2013; Lupton & Turner 2016). Furthermore, 3D printing technology has the potential to support waste management practices by enabling the creation of biodegradable packaging materials from food waste or rice husks. In addition, the technology can be utilized to recycle food waste by transforming it into new food products that are safe and suitable for consumption (Boissonneault 2019; Baiano 2020).

Table 2 Benefits of 3D printed food products

Benefits	Key findings	Supporting literature
Change of appearance	By modifying the appearance of food, it can make healthier foods more appealing to kids. Protein rich Insects can be printed into a more accepting form.	(Soares & Forkes 2014; Yang et al. 2017; Derossi et al. 2018)
Convenience	For the military it can eliminate the need for grocery stores and cooks; improve their performance through specialized demand. Better meals at homes for people not able to cook. Can aid astronauts in space.	(Hall 2013; Sun et al. 2015; Tran 2016; Caulier et al. 2020)
Less resources used	Less inputs are used with 3D printing food. It can streamline the whole process.	(Galdeano 2015; Davies & Garrett 2018)
Meat Substitute	Plants and its by-products can be used to 3D print meat analogues. It can be further modified in terms of flavours, nutrient content, texture, and size.	(Carlota 2019; Ramachandraiah 2021)
More efficient food production	3D printing can create food easier and faster.	(Tran 2016)
New food designs	Foods can be customized in terms of shapes, enabling the possibility to create new designs. Used in fine dining.	(Lupton & Turner 2016; Yang et al. 2017)
Nutrition	Possible to customize the nutritional content of food. Can be personalized based on the needs of the individual.	(Severini & Derossi 2016)
Reduction of carbon footprint	Meat replacements such as lab-grown animal protein, insects, and plant based proteins can lead to reduction/elimination of traditional animal production for meat.	(Phillips 2013; Foster 2013; Lupton & Turner 2016)
Reduction of exposure to radio waves	By eliminating the need for cooking and the use of a microwave in some cases.	(Tran 2016)
Waste reduction	Creation of biodegradable packaging from agricultural and food waste. Recycling restaurant food waste into new food product. Integration of product and packaging into a single entity.	(Siegner 2017; Boissonneault 2019; Baiano 2020)

2.4. Challenges of 3D Printing of Food

In contrast to the many benefits listed in the previous sections, there are many challenges that 3D printed food faces (Table 3). Firstly, it is important to recognize that the size and dimensions of the final products are limited to the physical dimensions of the printer itself. Additionally, given how the technology works, the printers are limited to certain types of foods, due of the difficulty of establishing numerous extruder capabilities, existing 3D food printers can only use a few different materials. This restricts the kind of foods that may be 3D printed, excluding sophisticated recipes that need a range of components (Stevenson 2014). Ingredients themselves are also limiting; it is necessary to prepare the ingredients to print them. Not all possible food material is suitable for 3D printer (Stevenson 2014).

The implementation of 3D printers for mass production is limited by the speed of printing. Even though it is sufficient for personal usage and limited commercial usage in restaurants, the speed is not sufficient for factory production. For instance, simple designs take 1 to 2 minutes to complete, whereas more elaborate and complicated designs can take 3 to 7 minutes to complete, and more complex designs take even longer (Carolo 2021). Depending on the ingredients, the process can take even longer.

Ensuring food safety is a crucial consideration in the use of 3D printing technology for food production. Proper cleaning and maintenance of the entire printer is necessary to prevent the growth of bacteria from leftover food materials. Regular and thorough cleaning procedures must be implemented to prevent contamination and ensure food safety (Stevenson 2014; Godoi et al. 2018).

In summary, the potential impact of 3D printing technology on the food supply chain is significant, as it could enable a more sustainable and efficient food production process. This could result in easier access to healthier food options for consumers, potentially reducing reliance on traditional food production methods and reducing food waste. However, it is important to consider the potential implications for all stakeholders involved in the food supply chain, including farmers, producers, and consumers. Careful consideration must be given to ensure that the adoption of this technology aligns with sustainable development goals and that its benefits are widely shared (Dabbene et al. 2018). Furthermore, it is crucial to consider the legal implications of this novel technology. As with any new technology, new laws and regulations may need to be established to ensure safe and ethical use. (Vogt 2017; Baiano 2020).

Table 3 Challenges of 3D printed food products

Challenges	Key findings	Supporting literature
Design limitations	Printing is limited in terms of physical and geometrical limits, and in terms of ingredients possible to use.	(Stevenson 2014)
Ingredients	Current technology is limited in terms of ingredients.	(Stevenson 2014)
Legal framework	Legislation is complex and slow to implement. Copyright law could be another issue. New regulations may be required.	(Vogt 2017; Baiano 2020)
Safety	Food is processed through machines that could be open to bacteria growth and other food safety concerns.	(Godoi et al. 2018; Stevenson 2014)
Speed	3D printing not fast enough for mass production.	(Carolo 2021)
Systematic changes	Disrupting technology that may need complex system changes to fully integrate and replace the current system.	(Dabbene et al. 2018)

2.5. Consumer Attitudes towards 3D Printed Foods

Factors thought to be influencing consumer attitudes towards 3D printed foods have been explored in several studies (Table 4). However, to our knowledge, the research is quite limited. The first serious discussion and analyses of it is the preliminary work of Lupton & Turner (2016) as it is the first instance of such research being conducted was later formally published in a form of two articles (Lupton & Turner 2018a, 2018b). One of these studies included consumer attitude towards the idea of 3D printed meat and the finding can be concludes as that few people expressed an interest in or support for trying or serving 3D-printed food products created from cultured meat (Lupton & Turner 2018b). Most of the later studies can track their origin to these original findings. The generalisability of much published research on this issue can be problematic as they use different methods to conclude their results. However, there are general trends in factors influencing the attitudes across all the studies. These trends could be divided into the following categories: factors influencing willingness to consume, purchasing factors, quality parameters, and socio-economic factors.

Factors that influenced the willingness to consume were determined to be the content of the food products, environmental impact, nutritional value, impact on health, and level of processing. It was important for the consumer to be aware that the ingredients being used to create the 3D printed food product were natural, healthy, fresh, something that they were familiar with and would consider tasty (Lupton & Turner 2016). If the nutrient content is perceived not to be the best, it could be negative in terms of willingness to consume (Lupton & Turner 2016). The general perceived impact on health is important for the consumers to know (Lupton & Turner 2016). Regardless of the potential positive environmental impact of the technology, the consumers were not concerned with this aspect of the technology (Lupton & Turner 2016).

In terms of purchasing factors, previous research further suggests that previous knowledge and experience is crucial in terms of acceptance and general attitude toward 3D printed food. When consumers are not familiar with food product, they usually tend to dislike it (Tan et al. 2015). Previous experience with consumption of 3D printed food products leads them to be more willing to try other 3D printed food products (Caulier et al. 2020). Previous general knowledge about the technology of 3D printing of food could lead to higher willingness to try 3D printed food products, and the opposite of such could decrease their willingness to try (Lupton & Turner 2016; Brunner et al. 2018; Caulier et al. 2020; Manstan & McSweeney 2020). Level of processing is taken in consideration for willingness to try. If the food product is not perceived to be fresh than it lowers the acceptance of the food product (Lupton & Turner 2016).

When discussing the quality parameters of the final food products, its general appearance was determined to be highly important. If the final product appears unnatural or artificial it is perceived negatively (Lupton & Turner 2016). Additionally, the more the final food product differs from the expected taste and texture, the more negatively it is perceived(Lupton & Turner 2016).

Regarding socio-economic characteristics of the consumers, factors like age, education, gender, household size, income, nationality, occupation, and residence area were examined. As to the factor of the age, it was mentioned that there was no difference between age groups (Brunner et al. 2018). In contrast, in the study by Manstan & McSweeney (2020). Age did matter with younger consumers being more welcoming towards 3D printed foods and newer technologies in general when compared to older individuals. Similarly, gender was another conflicting factor. One study evaluated that there were no differences between the genders (Manstan et al. 2020), whereas in another it stated that women were more sceptical towards novel food technologies like 3D printed food (Brunner et al. 2018). In terms of income, the richer people were less willing to try 3D printed foods, however this could maybe be explained by the fact that older people were also earning more (Manstan & McSweeney 2020). While education, household size, nationality, occupation, and residence area were determined to not be significant factors (Brunner et al. 2018).

Table 4 Factors effecting consumer attitudes towards 3D printed food products

Type	Factor	Key findings	Supporting literature
Factors influencing willingness to consume	**Content of the food products**	To what extent its ingredients were considered tasty, healthy, familiar, and natural. Freshness of the ingredients is also important	(Lupton & Turner 2016)
	Environmental impact	Perceived positive environmental issues seemed unimportant in terms of food consumption choices	
	Impact on health	Consumers think about the health benefits when they make food consumption choices. It is important for them if the food is considered healthy or tasty.	
	Nutritional value	If the food is perceived to lose the nutrient content, it negatively impacts the acceptance	
	Social influence	Consumers favour different foods given what people around them accept as food	
Purchasing factors	**Familiarity**	When consumers are unfamiliar with food, they usually dislike it	(Tan et al. 2015)
	Previous experience	Prior experience of eating 3D printed food products seemed to positively impact the general attitude towards 3D food printing	(Caulier et al. 2020)
	Previous knowledge	Previous knowledge can lead to better consumer acceptance of 3D printed foods, lack of it led to worse acceptance	(Lupton & Turner 2016; Brunner et al. 2018; Caulier et al. 2020; Manstan & McSweeney 2020)
	Freshness	Level of processing; the more people think that the food is process, the less fresh, the less likely to consume. How fresh it is, the degree of processing	(Lupton & Turner 2016)

Table 4 (continued) Factors effecting consumer attitudes towards 3D printed food products

Type	Factor	Key findings	Supporting literature
Quality parameters	**Appearance**	If food appeared to be artificial or unusual then the final product is perceived more negatively. Food that looked too artificial, unusual, or slimy was viewed more negatively. Physical parameters as colour of the food product were mentioned.	(Lupton & Turner 2016)
	Taste	The taste or flavour of the final product is an important factor in terms of acceptance for 3D printed food products	
	Texture	The texture of the final product is an important factor in terms of acceptance for 3D printed food products	
Socio-economic factors	**Age**	Not a significant factor	(Manstan & McSweeney 2020)
		Younger consumers are more accepting of new food technologies	(Brunner et al. 2018)
	Education level	Not a significant factor	(Brunner et al. 2018; Manstan & McSweeney 2020)
	Gender	No differences based on gender	(Manstan & McSweeney 2020)
		Women have more reserved attitudes towards novel foods	(Brunner et al. 2018)
	Household members	Not a significant factor	(Brunner et al. 2018)
	Income	People with higher incomes were less willing to try 3D printed foods	(Manstan & McSweeney 2020)
	Nationality	Not a significant factor	(Brunner et al. 2018)
	Occupation	Not a significant factor	(Brunner et al. 2018)

2.6. Consumer Attitudes towards Cultured Meat

As there is insufficient research on consumer attitudes towards 3D printed meat and a version of 3D printed meat is a direct product of cultured meat, it is beneficial to explore the consumer attitudes towards cultured meat. Factors deriving from this review were categorized similarly as the studies about consumer attitudes towards 3D foods into three general categories: factors influencing willingness to consume, purchasing factors, and socio-economic factors (Table 5).

If consumers perceive the technology as having harmful outcomes for society, acceptance of it may decrease (Wilks & Phillips 2017). A real life example of such concern is the right-wing government of Italy that supported a proposed legislation that aims to prohibit the production and sale of laboratory-generated meat and other synthetic food products. The legislation's proponents assert that it upholds the nation's cultural and culinary legacy while safeguarding public health (Kirby 2023). Surprisingly, animal welfare was not proved to be create a higher preference for cultivated meat (Slade 2018). Consumers distinguish cultivated meat to be less health than conventional meat (Verbeke et al. 2015b; Wilks & Phillips 2017).

There is evidence to suggest that vegetarians and vegans are more receptive of the benefits of cultured meat, although they are less inclined to try it than meat eaters (Wilks & Phillips 2017). Additionally, the vegetarian community is divided on cultured meat, with some claiming that lab generated meat does not qualify as "vegetarian" because the original cells needed to cultivate the meat are obtained from animals (Slade 2018).

One of the barriers for consumer acceptance of meat are religious teachings about food intake. Religions like Islam and Judaism have specific rules about meat consumption. Even though religion is not the fundamental motivation for advocating or supporting cultured meat (Bryant 2020), according to (Hamdan et al. 2021), many religions are likely to embrace cultured meat if the production adheres to their religious meat dietary doctrine. The final acceptance from religious perspective could rely on the origin of the cells used to grow cultivated meat. Limited taste was identified as a concern (Slade 2018).

In term of the purchasing factors, consumer acceptance will determine by how the cultured meat is prepared, if it is available and affordable (Verbeke et al. 2015a). Two out of three participants claimed to be willing to try cultured meat if it was available to them (Verbeke et al. 2015b). Consumers are not willing to pay more than what they would pay for conventional meat. If the prices would be the same, there would be higher acceptance among consumers (Verbeke et al. 2015b). Some evidence suggests that increased familiarity with cultured meat is associated with increased acceptance (Bekker et al. 2017; Wilks & Phillips 2017).

The socio-economic trends display that people's acceptance of cultured meat are consistent with those seen in people's reactions to other revolutionary food technologies and theories (Bryant & Barnett 2018). Younger consumers and consumers with higher level of education have a more open stance towards cultivated meat (Slade 2018). Men showed to more receptive to the technology in comparison with women (Slade 2018).

Table 5 Factors effecting consumer attitudes towards cultured meat

Type	Factor	Key findings	Supporting literature
Factors influencing willingness to consume	**Animal Ethics**	Animal welfare did not correlate towards preference for cultivated meat	(Slade 2018)
	Conventional meat eating habits	Vegetarians more likely to perceive the benefits, less likely to try than meat eaters. Some don't consider lab grown meat vegetarian.	(Wilks & Phillips 2017; Slade 2018)
	Effects on society	Consumers worried about the negative effects on the farmers and other effects on the economy.	(Verbeke et al. 2015b; Wilks & Phillips 2017)
	Environmental impact	Being aware of the positive environmental impacts increases consumers' claimed willingness to try and purchase	(Verbeke et al. 2015b; Slade 2018)
	Impact on health	Consumers believe cultured meat to be less healthy than conventional meat.	(Verbeke et al. 2015b; Laestadius & Caldwell 2015)
	Religious reasons	Not a fundamental motivation for acceptance, could be acceptable if certain preparation methods are followed	(Bryant 2020; Hamdan et al. 2021)
	Taste	Concerns about taste	(Wilks & Phillips 2017)
Purchasing factors	**Previous knowledge**	Increased familiarity with cultured meat is associated with increased acceptance	(Verbeke et al. 2015b; Bekker et al. 2017; Wilks & Phillips 2017)
	Availability	Consumers are willing to try cultured meat if available to them	(Verbeke et al. 2015b, 2015a)
	Origin	Consumer acceptance depends on how cultured meat has been produced	(Verbeke et al. 2015a)
	Price	Preference for cultured meat was significantly higher when its price was lower	(Verbeke et al. 2015a; Slade 2018)
	Technology familiarity	Higher acceptance among individuals with better technology familiarity.	(Huang et al. 2006)

Table 5 (continued) Factors effecting consumer attitudes towards cultured meat

Type	Factor	Key findings	Supporting literature
Socio-economic factor	**Age**	Younger consumers have a stronger preference for cultivated meat.	(Slade 2018)
	Education level	More educated consumers have a stronger preference for cultivated meat.	
	Gender	Men are more likely to adopt cultivated meat	

3. Aim of the Thesis

The technology of 3D printed meat is maturing and is now slowly being spun out into commercial applications. As consumer acceptance is a crucial aspect to any market implementation, it is important to identify it a single out the main components that influence it. Whilst some research has been carried out on consumer attitudes towards 3D printed food, there have been no studies focusing on 3D printed meat particularly.

As previously mentioned, there have been only a several studies focusing on consumer acceptance towards 3D printed food. As far as we know, no previous research has investigated consumer acceptance towards 3D printed meat specifically, nor the Czech Republic have been the focus of such research. Thus, the aim of the thesis was to explore the attitudes of Czech adult consumers towards 3D printed food, in general and with special focus on 3D printed meat. The results of this study could be used as launch pad for further investigation. Taking these key elements into consideration the following key research questions were formed:

- What are consumers' attitudes towards 3D printed food and meat products?
- What is the level of consumers' awareness with the concept of 3D printed food and meat products?
- Are consumers willing to try, and/or willing to buy 3D printed food and meat products?
- Would people with meat restricting diets (vegans, vegetarians) be willing to try and/or willing to buy 3D printed meat?
- Which factors are important in terms of consumers' conventional and 3D printed meat eating habits, their purchasing habits, and the quality parameters?
- Which factors have a significant influence on the willingness to try 3D printed food and meat products?

4. Methodology

4.1. Survey design

Exploratory survey was chosen as the method to gain the information required to determine the consumer attitudes. This was inspired by previous studies with the same goals mentioned in the chapter 2.5.

Given the novel nature of 3D meat printing as a technology it was decided to focus on the younger generations as they are more open to accept new food technologies (Vidigal et al. 2015). The focus on younger age group, more specifically millennials and generation Z, was also considered because of their tendency to be more aware about the climate and are also more open to reduce traditional meat product because of the impact conventional livestock production has on the climate (Young 2021). In terms of age groups, respondents ages 18-40 years old would be considered in the final evaluation of the results. This is further supported by a study commissioned by the Česká veganská společnost (Czech vegan society), according to which the younger generations are more open to alter their eating habits, such as having to limit their use of meat or milk. According to the reported data, while 33% of poll respondents are inclined to consume less meat or replace alternatives in some meals, this number ruses to 42% among those aged 18 to 26 (Ipsos 2020).

As the intended target audience of the study are younger adults it was then decided that the best option would be for the data to be gathered through an online survey. Google forms were used to create the online survey. As Czech consumers are the focus of this research and only Czech national would be accepted for the data analysis.

To explore the meat eating habits of the participants we would be dividing their habits into three categories: meat eaters, partly meat eaters, and no meat eaters. This categorization further enables us to determine if people with meat restricting diets (vegans, vegetarians) will be willing to try 3D printed meat. The meat eaters are frequent consumer of meat and other animal products with minimal or not meat restrictions. Partly meat eaters are consumers that have meat in their diets but are actively trying to reduce their general consumption or remove certain types of the meats from their diets. Such category would include pescatarians and pollotarians among others. No meat eaters are people that do not consume meat or any other animal based products like eggs, milk, etc. Such category includes vegetarians and vegans.

Factors important in terms of consumers´ attitudes towards meat were determined based on the literature review and author´s expectations and assumptions. These factors were categorized into three main categories: factors influencing willingness to consume conventional, purchasing factors influencing consumption of conventional meat, and quality parameters influencing consumption of conventional meat. Same categories and factors would be explored for 3D printed meat. Furthermore, socio-economic factors were chosen based on the literature review. These factors were gender, age, education level, number of household members, type of area of living, and monthly household disposable income.

Animal ethics, economic value/benefits, environmental impact, impact on health, nutritional value, religious reasons, social influence, and taste were chosen to be the factors influencing the willingness to consume conventional and 3D printed meat. Availability, freshness, origin/traceability, previous easting experience, and price were chosen to be the purchasing factors influencing consumption of conventional meat. Aroma, colour, taste, texture was finalised as the quality parameters influencing consumption of conventional meat.

To assess the level of awareness it was important to determine the current knowledge of the respondents of 3D printing, 3D printed food, and 3D printed meat. Respondents were asked to determine if they knew about the technology itself and if they knew about the methods behind these technologies. The approach in this section was in general inspired by how previous research was done by Lupton and Turner (2018). The question regarding the willingness to try was divided into two parts: first focusing on 3D printed food products, and the second one focusing on 3D printed meat. Keeping in mind the objectives of the research, proposed research questions and the literature review a conceptual design of consumer attitudes to 3D printed meat was formed (Figure 1).

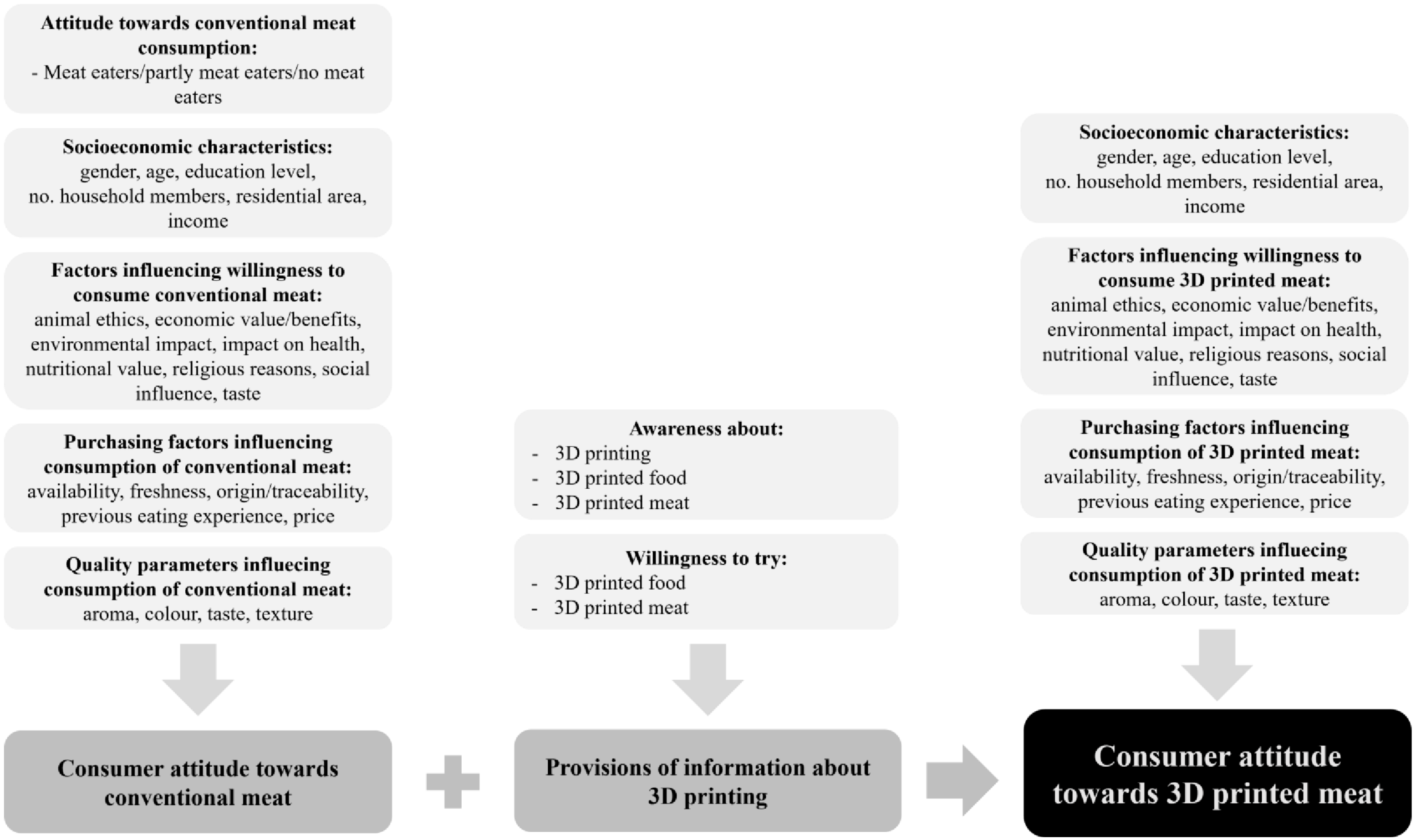

Figure 1 Conceptual design of consumer attitude towards 3D printed meat

4.2. Data collection instrument

The survey began with a brief description of the research (Annex 1). The purpose of the survey, the intended use, and estimated time of fill the survey was explained. The questionnaire was divided into three sections: section one focusing on traditional meat eating habit and previous knowledge of 3D printed food, section two was about exploring the factors and attitudes towards 3D printed meat, and section three collecting socio-economic factors.

In the first section, the respondents were asked a series of questions about their general conventional meat consumption. The consumer attitudes towards conventional meat and their habits were determined in this section. Collecting information about traditional meat consumption was done as a means of contextualising their later responses to 3D printed meat. Section one then moved on to what the participants thought about 3D printing technology.

In the second section, the respondents were provided with a list of benefits of 3D printed meat and with an infographic that explained how the 3D printed meat was created. The respondents were provided with an infographic that provided an example of how a steak would be printed by harvesting stem cells from a living animal. This method was chosen instead of a plant based source one as up to 90% of Czech population consumes food without considering if it is of animal or vegetable origin and only 28% of Czechs wish to replace animal products in their diet with more plant based alternatives (Ipsos 2020). Additionally, it was determined that cultured meat based 3D printed meat provided

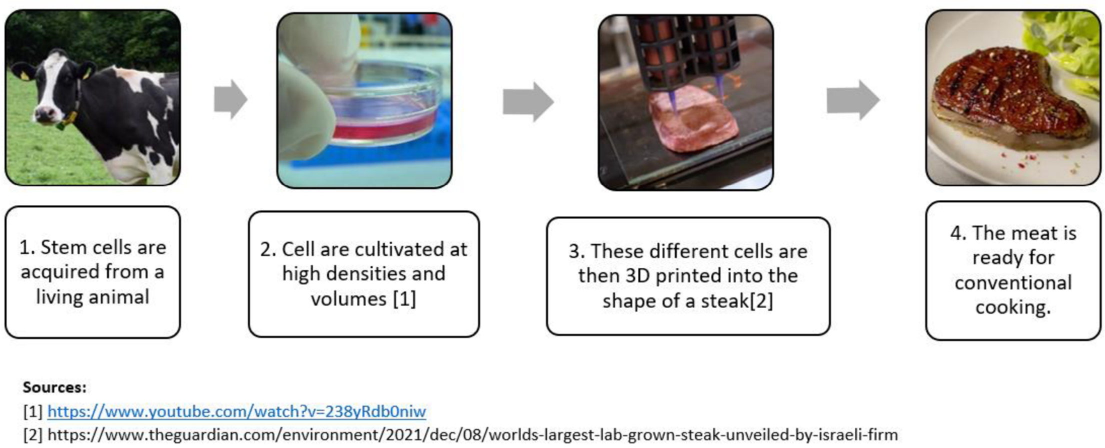

Figure 2 Infographic from the survey about how a 3D meat streak is made

the best comparison with conventional meat. Afterwards a series of question focused on factors determining consumer attitudes toward 3D meat consumption.

The last part of the survey is used to collect socio-economic data about the respondents. These factors were gender, age, education level, number of household members, type of area of living, and monthly household disposable income.

4.3. Data Collection

The study employed a non-random convenience sampling method, with respondents being asked to refer the survey to others using the snowball technique. The use of voluntary sampling may have also affected the study's outcomes. The questionnaire was originally developed in English and translated into Czech. It was pre-tested with a small group of volunteers and based on their recommendation some items were re-formulated and clarified.

The survey was initially shared with 43 Czech nationals through Facebook Messenger, of which 37 provided responses. These individuals were requested to share the survey with other Czechs in their immediate surroundings, resulting in 60 completed surveys. The survey was then disseminated through the personal Facebook profile of the author. At the time of distribution, the author had 113 "friends" on Facebook, which is a feature that allows users to see each other's activity in Feed, Stories, and Photos(Facebook, 2022). As a result, only 6 questionnaires were completed through this method.

Table 6 List of Facebook groups approached to fill out the survey

Facebook group name	Members as of 04.08.2022	Link
Dotazníky k vyplnění	5889	https://www.facebook.com/groups/308364969266339
Vegetariánství	219	https://www.facebook.com/groups/315959078528087
Veganství	12335	https://www.facebook.com/groups/veganstvi/
Zdravý flexitarian	114	https://www.facebook.com/groups/Ceskyflexitarian/
Vegetarian CZ & SK	8863	https://www.facebook.com/groups/vegetarianczsk/
10 Týdnů Veganství	685	https://www.facebook.com/groups/233346568940517/

Subsequently, the survey was shared in various Facebook groups (Table 6) that catered to individuals following meat-restricted diets, including vegetarianism, veganism, and flexitarians. While some of these groups permitted immediate posting of the survey, others required manual approval by a moderator.

The post in the "Veganství" Facebook group elicited four comments. The first commenter was uncertain about how to respond to question five, "What factors are important for you when deciding to buy meat (if you buy meat)?" as they did not consume meat and therefore did not purchase it. They realized that the appropriate response was to select the "not relevant" option. The second commenter requested clarification on the definition of 3D printed meat at the beginning of the survey and initially expressed reluctance to continue until it was clarified that the definition was provided later in the survey. The third commenter stated their unwillingness to consume cultured meat, citing their ethical beliefs that the use of cells from living animals is still not ethical. They expressed dissatisfaction with the lack of an option to convey this belief in the survey. The fourth commenter suggested that an option to select "not relevant" in all questions regarding 3D printed meat consumption would be more suitable for vegans. They felt that the absence of such an option made the survey unsuitable for vegans. In total, posting the survey in Facebook groups focused on people with meat-restricted diets yielded 70 responses.

In the next phase, acquaintances of the author were approached again and requested once again to fill out the survey if they had not already. They were further requested to reach out to their family members to fill out the survey. This effort resulted in an additional 46 responses.

A total of 232 surveys were completed using a non-random sampling method, resulting in respondents from various age groups and nationalities. However, for the purposes of this study, responses from non-Czech nationals and respondents over 40 years of age were excluded. As a result, the final dataset comprised 182 responses for further analysis.

4.4. Data Analysis

The collected data was downloaded from Google form, inserted into Microsoft Excel. Following, the data was then cleaned and prepared for further analysis. Basic statistical data analysis was done through Microsoft Excel, and more complex testing was done using SPSS Statistics, which is a statistical software suite developed by IBM.

Descriptive statistics were employed to analyse the socio-economic information as well as the data related to meat consumption habits and purchasing behaviours. To assess the importance of factors, willingness to try, and awareness about, a 5 scale Likert scale was chosen. The scale represented the following statements: 1-Strongly disagree, 2-Disagree, 3-Neither agree nor disagree, 4-Agree, 5-Strongly agree. This scale of chose because of its simplicity to understand for both the researcher and the respondents. Means and standard deviations were calculated to assess the responses.

To determine if there was a statistically significant difference between two Likert scale means, the statistical test of Wilcoxon matched pared test was used. The Kruskal-Wallis test was used to determine if there is statistically significant difference in the case when we were testing more than two means. Given the confidence level of 95%, if the p-value is under 0.05 it can be stated that the difference between the means is statistically significant.

To determine which factors effected the willingness to try 3D printed food and meat products four linear regression models were created. The first one explains the influence of factors determining consumer attitudes towards conventional meat on willingness to try 3D printed food products, the second one explained the influence of factors determining consumer attitudes towards conventional meat on willingness to try 3D printed meat products, the third one explains the influence of factors determining consumer attitudes towards 3D printed meat on willingness to try 3D printed food products, the fourth one explained the influence of factors determining consumer attitudes towards 3D printed meat on willingness to try 3D printed meat products. Given the confidence level of 95%, if the p-value is under 0.05 it can be stated that the factor is statistically significant in terms of the model.

5. Results

5.1. Eating Habits of Conventional Meat

The details of the socio-economic characteristics of the respondents are provided in the Table 7. Most of the respondents were females with 61% and the rest being male with 39%. Similar trend is apparent in all meat eating habit categories with biggest difference being for no meat eater with 72.9% of them being female and the smallest difference being for meat eaters with 53.5% of them being females.

Most of the respondents were on the younger side with 65.4% were between the ages of 18-30 and the rest were between the ages of 31-40. In terms of meat eating habits the data shows that most of the meat eaters were in the age category of 18-30 with 72.3%. Similarly, most of the partial meat eaters are also between the age category of 18-30 with 77.3%. On the other hand, the no meat eaters are more balanced in term of the age categories, with the age category of 31-40 having slightly higher representation with 50.9% in this meat eating habit category. The education question was divided into two categories based on if they had university level education or not. Most of the respondents had university level education with 57%. This was reflected in the meat eating categories as well except for partial meat eaters where most of the respondents had university level education with 72.7%.

Most of the respondents were from two or three members' households with 41.2% from 2 member households and with 24.2% from 3 member households. In terms of the living situation, 75.3% of the respondents were living in an urban area. Same trends are apparent in all meat eating habits categories.

As regards to income, most of the respondents were in the 24,001 – 50,000 CZK range with 35.2%, and with the 50,001 – 75,000 CZK range coming in second with 25.8%. Most of the meat eaters were in the 24,001 – 50,000 CZK range with 38.6%. In the case of partial meat eaters, the range of ≤ 24,000 CZK is the most common with 31.8%. As for no meat eaters up to 66.1% of the respondents were in the 24,001 – 75,000 CZK.

Table 7 Socio-demographic variables, and meat consumption and purchase frequency and its distribution in meat eating habits

	Total Sample		Meat	Partly Meat	No Meat
Variable	**N**	**%**	**%**	**%**	**%**
Gender					
Female	111	60.99	53.47	63.64	72.88
Male	71	39.01	46.53	36.36	27.12
Age					
18-30	119	65.38	72.28	77.27	49.15
31-40	63	34.62	27.72	22.73	50.85
Education					
Non-university	79	43.41	46.53	27.27	44.07
University	103	56.59	53.47	72.73	55.93
Household Members					
1	24	13.19	13.86	18.18	10.17
2	75	41.21	31.68	54.55	52.54
3	44	24.18	29.70	9.09	20.34
4	25	13.74	15.84	13.64	10.17
5+	14	7.69	8.91	4.55	6.78
Residential Area					
Urban	137	75.27	76.24	72.73	74.58
Rural	45	24.73	23.76	27.27	25.42
Income					
≤ 24 000	38	20.88	19.80	31.82	18.64
24 001 – 50 000	64	35.16	38.61	22.73	33.90
50 001 – 75 000	47	25.82	23.76	18.18	32.20
75 000+	32	17.58	17.82	27.27	15.25
Consumption Frequency					
Daily	31	17.03	80.65	19.35	0
Several times per week	44	24.18	90.91	9.09	0
1-2 x per week	21	11.54	85.71	14.29	0
Occasionally	26	14.29	69.23	34.62	0
Never	60	32.97	0	0	100
Purchase Frequency					
Several times per week	12	6.59	83.33	16.67	0
1-2 x per week	38	20.88	86.84	10.53	2.63
Occasionally	30	16.48	73.33	16.67	10
Rarely	47	25.82	65.96	17.02	17.02
Never	55	30.22	9.09	5.45	85.45

1 EUR = 23.60 CZK (as of 8.3.2023)

In terms of the frequency of the meat consumption the data shows that 17% consume meat daily, 24.2% consume meat several times per week, 11.5% consume meat 1-2 times per week, 9.3% consume meat occasionally, 5.5% consume meat rarely, and 32.4% never consume meat.

When asked about the frequency of meat purchase the data indicates that 6% purchase meat daily, 20.9% purchase meat several times per week, 16.5% purchase meat one to two times per week, 25.8% purchase meat occasionally, and 0.6% rarely purchase meat.

5.2. Awareness about 3D Printing

The awareness of respondents about 3D printing of food was examined through asking about 3D printing in general, 3D printed food product, and 3D printed meat products. The respondents were asked to express their general awareness about the technology and if they were familiar with how it works.

The data gathered from the survey suggest that most of the respondent are highly aware of what a 3D printer is (M = 4.30) and moderately aware of how it works (M = 3.53). In terms of 3D printed food products, the respondents are moderately aware of the technology (M = 3.73). However, they are not sure about how it works (M = 2.49). Comparable result is for 3D printed meat (M = 3.31), however the awareness of how 3D printed meat works is noticeably the lowest (M = 2.09). The overall sentiment is similar across all meat eating habits categories with no significant outlier.

In terms of their willingness to try 3D printed products the data suggests that there is a high willingness among the respondent to try such products (M = 4.25). The trend of high willingness is the case across all meat eating habit categories; however, the willingness declines from meat eaters being the highest (M = 4.5), partly meat eaters in the middle (M = 4.09) and no meat eaters the lowest (M = 3.86). This difference is statistically significant. This is the case for 3D printed meat too. Even though there is a moderate level of willingness (M = 3.46), the willingness is noticeably different across the meat eating habits with the meat eaters having a high willingness to try (M = 4.14), partial meat eaters having moderately high willingness (M = 3.45), and the no meat eaters having noticeably the lowest willingness (M = 2.29). This difference in means is also statistically significant.

There is a statistically significant difference in means in the case of all respondents, meat eaters, and no meat eaters, while there was no statistically significant difference in mean for partly meat eaters. The details about the awareness and willingness to try of the respondents are provided in the Table 8.

Table 8 Awareness and willingness to try for 3D printed food products

	All respondents	**Meat eaters**	**Partly meat eaters**	**No meat eaters**	
N	182	101	22	59	
	M ± SD	M ± SD	M ± SD	M ± SD	p-value
Awareness					
3D printed products	4.30 ± 0.98	3.00 ± 1.07	4.45 ± 0.51	4.22 ± 0.97	0.392
Method of 3D printing	3.54 ± 1.18	3.67 ± 1.18	3.18 ± 1.26	3.46 ± 1.13	0.137
3D printed food products	3.73 ± 1.23	3.72 ± 1.30	3.77 ± 1.15	3.71 ± 1.16	0.907
Method of 3D food printing	2.49 ± 1.29	2.50 ± 1.35	2.54 ± 1.37	2.46 ± 1.18	0.994
3D printed meat products	3.31 ± 1.47	3.29 ± 1.54	3.50 ± 1.37	3.27 ± 1.39	0.836
Method of 3D meat printing	2.09 ± 1.23	2.06 ± 1.32	2.14 ± 1.21	2.12 ± 1.08	0.668
Willingness to try					
3D printed food products	4.25 ± 1.02	4.50 ± 0.77	4.09 ± 1.15	3.86 ± 1.21	**0.001**
3D printed meat products	3.46 ± 1.53	4.14 ± 1.08	3.45 ± 1.57	2.29 ± 1.47	**0.000**
Willingness to try 3D printed food vs. 3D printed meat (p-value)	**0.000**	**0.000**	0.059	**0.000**	

5.3. Factors Determining Conventional and 3D Printed Meat Consumption

In this part factors determining consumer attitudes towards conventional and 3D printed meat were identified. These factors were further compared between the two types. How these factors differ across different meat consumption habits are then explored (Table 9).

The most important factors in terms of determining consumer attitudes toward 3D printed meat, ranked accordingly to their means, are environmental impact, price, taste, animal ethics, and availability. For conventional meat the most important factors are freshness, taste in terms of quality parameters, price, taste in terms of factors influencing willingness to consume, and texture. Noticeably, environmental impact is significantly more important for 3D printed meat than conventional meat, which is explained by the varying differences in terms of its importance between meat eaters and no meat eaters.

The most important factors for meat eaters in terms of determining consumer attitudes toward 3D printed meat, ranked accordingly to their means, are price, taste, availability, environmental impact, and economic value/benefits. For conventional meat the most important factors are taste in terms of quality parameters, freshness, taste in terms of factors influencing willingness to consume, price, and aroma.

The most important factors for partly meat eaters in terms of determining consumer attitudes toward 3D printed meat, ranked accordingly to their means, are environmental impact, price, animal ethics, impact on health, and availability. For conventional meat the most important factors are taste, freshness, texture, animal ethics, and environmental impact.

The most important factors for no meat eaters in terms of determining consumer attitudes toward 3D printed meat, ranked accordingly to their means, are animal ethics and environmental impact. For conventional meat the most important factors are also animal ethic and environmental impact.

Table 9 Important factors determining consumer attitudes towards conventional and 3D printed meat

	All respondents			Meat eaters			Partly Meat Eaters			No Meat Eaters		
	Meat	3D Meat		Meat	3D Meat		Meat	3D Meat	Δ	Meat	3D Meat	
	M	M	p	M	M	p	M	M	p	M	M	p
Factors influencing willingness to consume												
Animal ethics	3.80 ± 1.25	3.89 ± 1.32	0.330	3.20 ± 1.12	3.92 ± 1.14	**0.000**	4.05 ± 1.21	4.05 ± 1.40	1.000	4.75 ± 0.78	3.78 ± 1.57	**0.000**
Economic value/benefits	2.97 ± 1.35	3.56 ± 1.35	**0.000**	3.31 ± 1.21	4.03 ± 1.02	**0.000**	3.00 ± 1.27	3.73 ± 1.42	**0.047**	2.37 ± 1.40	2.69 ± 1.41	0.112
Environmental impact	3.78 ± 1.23	4.07 ± 1.22	**0.006**	3.21 ± 1.15	4.21 ± 0.91	**0.000**	4.04 ± 1.09	4.50 ± 1.22	0.061	4.66 ± 0.80	3.68 ± 1.55	**0.000**
Impact on health	3.62 ± 1.09	3.71 ± 1.20	0.316	3.50 ± 0.94	3.99 ± 0.90	**0.000**	3.91 ± 1.15	4.00 ± 1.23	0.802	3.73 ± 1.28	3.14 ± 1.42	**0.010**
Nutritional value	3.25 ± 1.29	3.59 ± 1.19	**0.001**	3.57 ± 1.11	3.79 ± 0.94	**0.047**	3.64 ± 1.26	3.86 ± 1.28	0.473	2.56 ± 1.33	3.14 ± 1.41	**0.015**
Religious reasons	1.35 ± 0.91	1.46 ± 0.98	**0.014**	1.33 ± 0.93	1.47 ± 1.05	**0.010**	1.68 ± 1.13	1.86 ± 1.25	0.102	1.27 ± 0.76	1.29 ± 0.67	0.773
Social influence	2.62 ± 1.28	2.65 ± 1.27	0.730	2.71 ± 1.19	2.85 ± 1.24	0.331	2.82 ± 1.22	2.86 ± 1.04	0.841	2.37 ± 1.43	2.22 ± 1.31	0.383
Taste	3.89 ± 1.33	3.90 ± 1.24	0.899	4.34 ± 0.90	4.32 ± 0.81	0.683	4.27 ± 0.83	4.00 ± 1.23	0.473	2.98 ± 1.61	3.14 ± 1.48	0.437
Purchasing factors determining consumption												
Availability	3.78 ± 1.15	3.88 ± 1.23	**0.002**	3.94 ± 1.01	4.31 ± 0.86	**0.004**	3.89 ± 0.99	4.00 ± 1.15	0.305	2.69 ± 1.49	3.10 ± 1.42	0.389
Freshness	4.25 ± 1.03	3.47 ± 1.29	**0.000**	4.41 ± 0.79	3.78 ± 1.07	**0.000**	4.44 ± 0.92	3.86 ± 1.17	0.077	3.18 ± 1.55	2.78 ± 1.42	0.537
Origin/traceability	3.67 ± 1.29	3.46 ± 1.31	0.139	3.65 ± 1.25	3.59 ± 1.14	0.558	3.84 ± 0.96	3.59 ± 1.30	0.284	3.59 ± 1.80	3.17 ± 1.54	0.265
Previous eating experience	3.84 ± 1.14	3.42 ± 1.31	0.211	4.00 ± 1.02	3.71 ± 1.16	0.143	3.80 ± 0.83	3.91 ± 1.15	0.439	3.00 ± 1.71	2.73 ± 1.34	0.478
Price	3.95 ± 1.24	4.01 ± 1.31	**0.003**	4.10 ± 1.14	4.47 ± 0.86	**0.002**	3.89 ± 1.15	4.27 ± 1.20	0.281	3.13 ± 1.63	3.14 ± 1.55	0.653
Quality parameters determining consumption												
Aroma	3.83 ± 1.20	3.27 ± 1.26	**0.015**	4.09 ± 0.99	3.50 ± 1.15	**0.001**	3.47 ± 1.33	3.64 ± 1.18	0.859	2.43 ± 1.34	2.76 ± 1.34	0.172
Colour	3.84 ± 1.20	3.15 ± 1.27	**0.000**	4.02 ± 1.02	3.37 ± 1.20	**0.000**	3.94 ± 1.18	3.55 ± 1.30	0.606	2.43 ± 1.50	2.64 ± 1.26	0.755
Taste	4.29 ± 1.10	3.35 ± 1.33	**0.000**	4.52 ± 0.78	3.57 ± 1.24	**0.000**	4.45 ± 1.05	3.77 ± 1.27	0.070	2.50 ± 1.45	2.81 ± 1.36	0.473
Texture	3.88 ± 1.11	3.21 ± 1.24	**0.002**	4.01 ± 0.98	3.49 ± 1.16	**0.003**	4.16 ± 0.83	3.55 ± 1.22	0.110	2.57 ± 1.40	2.63 ± 1.17	0.234

p = p-value of Wilcoxon matched paired test. M = Mean of Likert scale answers, SD = standard deviation of mean

5.4. Willingness to Try 3D Printed Food and Meat Products

Firstly, the influence of factors determining consumer attitudes towards conventional meat on willingness to try 3D printed food and meat products were identified (Table 10). It was revealed that none of the factors determining consumer attitudes towards conventional meat had any statistically significant effect on the willingness to try 3D printed food products. In regards of the influence on willingness to 3D printed meat for the same factors, only the purchasing factor of price was determined to be significant in the model. The beta coefficient for price was -0.341, indicating that increase in animal ethics by 1 was associated with a 0.341 decrease in willingness to try 3D printed meat products.

Afterwards, the of factors determining consumer attitudes towards 3D printed meat on willingness to try 3D printed food and meat products were identified (Table 11). It was determined that none of the factors determining consumer attitudes towards 3D printed meat had any statistically significant effect on the willingness to try 3D printed food products. In regards of the influence on willingness to 3D printed meat for the same factors, animal ethics, environmental impacts, religious reasons, and availability were determined to be significant in the model. The beta coefficient for animal ethics was -0.231, indicating that increase in animal ethics by 1 was associated with a 0.231 decrease in willingness to try 3D printed meat products. The beta coefficient for environmental impact was 0.29, indicating that increase in animal ethics by 1 was associated with a 0.29 increase in willingness to try 3D printed meat products. The beta coefficient for religious reasons was -0.246, indicating that increase in animal ethics by 1 was associated with a 0.246 decrease in willingness to try 3D printed meat products. The beta coefficient for price was 0.461, indicating that increase in animal ethics by 1 was associated with a 0.461 increase in willingness to try 3D printed meat products.

Table 10 Influence of factors determining consumer attitudes towards conventional meat on willingness to try 3D printed food and meat products

	3D printed food products				3D printed meat			
	B	Std.Er.	t	p-val	B	Std.Er.	t	p-val
Factors influencing willingness to consume conventional meat								
Animal ethics	-0.025	0.172	-0.143	0.887	-0.114	0.218	-0.524	0.602
Economic value/benefits	0.113	0.123	0.924	0.359	0.142	0.155	0.919	0.361
Environmental impact	-0.112	0.164	-0.681	0.498	-0.049	0.208	-0.236	0.814
Impact on health	0.139	0.140	0.992	0.325	0.280	0.177	1.580	0.118
Nutritional value	-0.024	0.122	-0.199	0.843	0.045	0.154	0.291	0.772
Religious reasons	0.040	0.144	0.276	0.783	0.005	0.182	0.030	0.976
Social influence	0.124	0.109	1.139	0.259	0.067	0.138	0.484	0.630
Taste	0.012	0.129	0.096	0.924	-0.085	0.163	-0.524	0.602
Purchasing factors determining conventional meat consumption								
Availability	-0.033	0.139	-0.237	0.813	0.123	0.175	0.700	0.486
Freshness	0.291	0.161	1.806	0.075	0.294	0.204	1.446	0.153
Origin/traceability	-0.092	0.114	-0.807	0.422	-0.003	0.144	-0.021	0.983
Previous eating experience	-0.160	0.135	-1.186	0.239	-0.216	0.171	-1.262	0.211
Price	-0.152	0.133	-1.147	0.255	-0.341	0.168	-2.034	**0.046**
Quality parameters determining conventional meat consumption								
Aroma	-0.049	0.178	-0.277	0.783	-0.130	0.225	-0.580	0.564
Colour	-0.016	0.128	-0.124	0.902	-0.073	0.162	-0.447	0.656
Taste	0.154	0.177	0.868	0.388	0.298	0.224	1.331	0.188
Texture	-0.007	0.132	-0.052	0.958	0.047	0.167	0.281	0.780
Socio-economic variables								
Age	-0.280	0.277	-1.010	0.316	-0.439	0.350	-1.255	0.214
Education level	0.122	0.264	0.464	0.644	-0.070	0.333	-0.209	0.835
Gender	0.039	0.260	0.148	0.882	-0.007	0.328	-0.022	0.983
Household size	-0.079	0.116	-0.675	0.502	-0.111	0.147	-0.756	0.452
Household type	-0.051	0.293	-0.175	0.861	0.091	0.369	0.247	0.806
Income	0.059	0.130	0.457	0.649	0.120	0.164	0.730	0.468

Table 11 Influence of factors determining consumer attitudes towards 3D printed meat on willingness to try 3D printed food and meat products

	3D printed food products				3D printed meat			
	B	Std.Er	t	p	B	Std.Er.	t	p
Factors influencing willingness to consume 3D printed meat								
Animal ethics	-0.112	0.089	-1.257	0.211	-0.231	0.102	-2.255	**0.026**
Economic value/benefits	0.039	0.078	0.501	0.617	0.161	0.090	1.783	0.077
Environmental impact	0.140	0.107	1.309	0.192	0.290	0.123	2.365	**0.019**
Impact on health	-0.100	0.117	-0.854	0.395	0.095	0.134	0.710	0.479
Nutritional value	0.158	0.111	1.428	0.155	0.202	0.127	1.587	0.115
Religious reasons	-0.091	0.091	-1.006	0.316	-0.246	0.104	-2.356	**0.020**
Social influence	0.005	0.067	0.070	0.944	0.000	0.077	-0.001	0.999
Taste	0.111	0.097	1.144	0.254	0.215	0.111	1.931	0.055
Purchasing factors determining 3D printed meat consumption								
Availability	0.092	0.120	0.764	0.446	0.461	0.138	3.333	**0.001**
Freshness	0.013	0.098	0.129	0.897	-0.139	0.113	-1.223	0.223
Origin/traceability	-0.061	0.081	-0.753	0.453	-0.116	0.093	-1.251	0.213
Previous eating experience	0.017	0.078	0.221	0.826	0.103	0.090	1.150	0.252
Price	0.105	0.112	0.931	0.353	0.023	0.129	0.180	0.857
Quality parameters determining 3D printed meat consumption								
Aroma	-0.168	0.115	-1.460	0.146	-0.132	0.132	-0.994	0.322
Colour	-0.118	0.091	-1.306	0.193	-0.021	0.104	-0.206	0.837
Taste	0.182	0.105	1.741	0.084	-0.029	0.120	-0.239	0.812
Texture	0.059	0.118	0.506	0.614	0.042	0.135	0.311	0.756
Socio-demographic variables								
Age	-0.171	0.169	-1.009	0.314	-0.072	0.195	-0.372	0.710
Education level	0.186	0.160	1.163	0.247	-0.101	0.184	-0.550	0.583
Gender	-0.046	0.172	-0.265	0.791	-0.169	0.198	-0.852	0.396
Household size	0.046	0.076	0.614	0.540	0.108	0.087	1.238	0.218
Household type	-0.054	0.179	-0.301	0.764	-0.114	0.205	-0.555	0.580
Income	-0.046	0.082	-0.562	0.575	0.030	0.094	0.319	0.750

6. Discussion

6.1. Awareness about 3D Printing

The results showed that the Czech respondents were aware of 3D printed products, and had comparatively lower awareness about 3D printed food, and the lowest about 3D printed meat. The awareness about the printing methods is quite low. People have low awareness about how 3D printed food works and even lower for 3D printed meat. This could be explained by the availability of the technology. It is evident that the less prevalent the technology is, the less familiar with it the respondents are. The first commercial 3D printer was available in 1988 (BCN3D 2020). The first 3D food printer was available in 2006 (Creative Machines Lab 2022). 3D meat printing is still a proprietary technology that is still not readily available in the Czech Republic. Given the declining trend in the means of awareness we can observe that the newer the technology, the less people are aware about it. The level of awareness is important to recognize as familiarity (Tan et al. 2015), previous knowledge (Lupton & Turner 2016; Brunner et al. 2018; Caulier et al. 2020; Manstan & McSweeney 2020), and previous experience (Caulier et al. 2020) were all identified as factors that lead to better acceptance of 3D printed food products, and the lack of them lead to worse acceptance and consumers disliking the final product. The same is true for consumer attitude towards cultured meat; increased familiarity is associated with increased acceptance (Verbeke et al. 2015b; Bekker et al. 2017; Wilks & Phillips 2017). Lack of knowledge regarding how the printing technology works is another concerning factors as technological familiarity led to higher acceptance (Huang et al. 2006).

There is no statistically significant difference across meat consumption habits when it comes to the awareness about 3D printing, 3D printed food products, and 3D printed meat products. We can deduce that awareness is not dependant on meat eating habits.

Based on the previous research, the varying level of awareness regarding 3D printing is shared around the world. While some studies showcase their respondents having relatively low knowledge about the technology (Brunner et al. 2018), there are other where the knowledge is higher. Being familiar with the technology, having trust in it, the product being perceived more natural than artificial, and gaining knowledge all led to more positive consumer acceptance (Brunner et al. 2018; Lupton & Turner 2018; Manstan et al. 2021). Repeated consumption of food produced by 3D printing enhanced customer acceptability of these items, according to a prior study (Caulier et al. 2020).

6.2. Factors Determining 3D Meat Consumption

Price was deemed to be overall the most important factor determining consumer attitude towards both conventional and 3D printed meat. While the importance is quite high for conventional meat, it is even higher for 3D printed meat. This is true across all meat consumption habits. This is in accordance with the literature that states that price plays a role in consumer acceptance and that consumers are not willing to pay more than what they would pay for conventional meat. The acceptance would be higher if the consumers were expected to pay the same for conventional meat (Verbeke et al. 2015b).

Taste, both in terms of factors influencing willingness to consume meat and quality parameters determining consumption, was identified as an important factor, especially for meat eaters. The importance of taste is backed for both 3D printed food product (Lupton & Turner 2016), and cultured meat (Wilks & Phillips 2017).

Environmental impact and animal ethics were identified as important factors determining consumer attitudes especially for consumers restricting their diets. These factors were the most important factors for both partly meat eaters and no meat eaters. Even though for no meat eaters there is significant difference between means for conventional meat and 3D meat, these factors are still the most important for them. This in line with expectations as these are one of the main reasons why people decide to restrict their meat consumption (Fluckiger 2018). Even though previous research recognizes that consumers reflect positively there were some concerns raised. While customers acknowledged the environmental benefits, others were concerned that it would be less efficient than conventional meat, and that existing quantities and methods of cultured meat production were unsustainable in terms to the current demand for conventional meat (Laestadius & Caldwell 2015). Furthermore, some questioned what would happen to farm animals if they were no longer needed for food production, while others supported animal slaughter as a necessary component of the natural order. For both meat eaters and vegetarians, the main recognized advantage of cultured meat was the avoidance of animal murder (Laestadius & Caldwell 2015).

Availability of 3D printed meat products was important across all meat eating habits. This is in line with expectations as consumers would be willing to try cultured meat if they had a way to procure it (Verbeke et al. 2015b, 2015a).

There were significant differences in terms of importance of all factors grouped under quality parameters determining consumption. Importance was higher for conventional meat in comparison with 3D printed meat. This was the case across all meat eating habits. This could be explained by the fact that conventional meat is readily available in the market and all the respondents have had some sort of experience with conventional meat. This is not the case for 3D printed meat as it no readily available.

Religious reasons were expressed to be the least significant factors in determining customer attitudes towards conventional and 3D printed meat products. This can be explained by the fact that around seven out of ten Czechs (72%) do not identify with a religious group (Evans 2017).

6.3. Willingness to Try 3D Printed Food and Meat Products

There is high willingness to try 3D printed food products and moderate willingness to try 3D printed meat products. This moderate willingness to try 3D printed meat is in order with the research done by Wilke & Phillips (20017) that stated there is an overall positive view of cultured meat with about 65.3% of the respondents willing to try cultured meat. This could also be since respondents were given information about the benefits of 3D printed meat and the infographic providing information about how a steak would be made. It was discovered that self-reported willingness to try for cultured meat increased when participants were given additional information about the benefits for the environment and impact on health, compared to when they only had basic information (Bryant & Barnett 2018). Regardless of the high willingness to try, it should be made clear that in a study about cultured beef it is stated that even though consumers may express willingness to try cultured meat in the future there were notable worries expressed about unknown impact on health and concerns about lower nutritional value (Post 2014).

There is statistically significant disparity between willingness to try 3D printed food and meat product which could be explained by the different levels of awareness. Respondents were more aware about the 3D printed food products which resulted in higher willingness to try them, whereas lower 3D printed meat product awareness resulted in lower willingness to try it. This is supported by multiple sources that state that previous knowledge and familiarity with the technology would lead to increased acceptance and general positive attitude towards 3D printed food products and cultured meat (Tan et al. 2015; Verbeke et al. 2015b; Lupton & Turner 2016; Bekker et al. 2017; Wilks & Phillips 2017; Brunner et al. 2018; Caulier et al. 2020; Manstan et al. 2020). This is further consistent with the experimental data, which implies that acceptance scores are reflective of information provided (Verbeke et al. 2015b). Even if customers are prepared to try a novel product, this does not guarantee repeat purchases or a long-term change in eating habits (Grunert et al. 2011).

Willingness to try is significantly different across the different meat eating habits. The more meat restricting diet, the less willingness to try. While no meat eaters are moderately willing to try 3D printed food products, they have low willingness to try 3D printed meat products. This could be explained by the fact that the vegetarian community is divided on cultured meat, with some claiming that lab generated meat does not qualify as "vegetarian" because the original cells needed to cultivate the meat are obtained from animals (Slade 2018). Such sentiments were also expressed by the vegetarian and vegan Facebook group members that were approached to fill out the questionnaire. Also, regardless of if the meat is conventional or cultured, vegetarian customers may still perceive meat of any kind as harmful. Vegetarian customers are typically content with the alternatives they have chosen and are accustomed to, and hence see little or no need to consume meat of any kind again (Verbeke et al. 2015b).

With regards to the factors that influence consumer attitudes towards conventional meat, only price had a significant influence on willingness to try 3D printed meat. Higher price would result in lower willingness to try 3D printed meat. This is accordance with expectations of higher preference if the price was lower for cultured meat (Verbeke et al. 2015a; Slade 2018).

In terms of factors determining consumer attitudes towards 3D printed meat; animal ethics, environmental impact, religious reasons, and availability had a significant influence on willingness to try 3D printed meat. Animal ethics has a negative influence on willingness to try. This is not according to the expectations as it did not correlate towards preference for cultivated meat (Slade 2018). Environmental impact has a positive impact, which is according to expectation as being aware of the benefits of environmental impact ends up increases the willingness to try (Verbeke et al. 2015b; Wilks & Phillips 2017). Religious reasons have a negative influence on 3D printed meat. The literature states that while it is not a fundamental motivation for acceptance, but if the right protocols are followed then people should not face a religious reasoning that prevents them from trying. Positive influence of availability is in line with expectations that states that people are willing to consume cultured meat if it is feasible for them (Verbeke et al. 2015b; 2015a).

Even though there is evidence in the literature that states that some socio-economic variable indeed has an influence on the general consumer acceptance of 3D printed food product and cultured meat, there was no significant influence identified in this study.

The results of this research can be basis for entrepreneurs and current conventional meat related business owners who are interested in working with 3D printed meat and other more environmentally friendly, cruelty free alternatives to conventional livestock production. Given the results, it is important to consider the price of the final product. The closer the price of the final price of 3D printed meat products is to conventional meat products the higher acceptance we can expect (Verbeke et al. 2015b). It is further crucial to ensure that the 3D printed meat products are readily available for consumers, ideally near the conventional meat products in supermarkets and other grocery shops that sell conventional meat products.

Regarding the proprietary nature of the technology and general limited product experience to date, positioning is crucial for boosting acceptability among the potential consumers. It is reasonable to assume that consumers will build expectations based on the information they get and how it is delivered. Customers are likely to look to goods with a comparable positioning in the market when generating product-related expectations, the positioning of 3D printed meat products as a replacement or as a supplement to conventional meat products will be crucial. This would be in line with the expectation identified by Verbeke for cultivated meat products.

Moreover, Siegrist et al. (2018) discovered that when participants were given a simple and non-technical explanation of cultured meat as opposed to a technical one, they showed a considerably greater acceptance rate. It is advised that it is beneficial to emphasize the similarities rather than the differences in the manufacturing process by using straightforward language to describe the two types of meat.

It is noteworthy that consumer preferences are not immutable and can change over time. Bekker et al's research (2017) demonstrates that views may be altered by new knowledge, implying that marketing efforts or societal norms may shift people's preferences for plant-based protein or cultivated meat. Keeping this in mind and the results of this research, if marketing efforts are made pushing the positive environmental impacts of 3D printed meat are put in the forefront they may lead to higher acceptance among consumers. If the consumer had a chance to taste 3D printed meat, the product experience it could lead to a higher acceptance and willingness to try in the future.

If the intention is to cater to individuals with specific religious practices, it is essential to show respect towards their methods of preparing conventional meat. There is evidence that indicates that adhering to their established practices can promote acceptance among this demographic (Hamdan et al. 2021). For instance, if the goal is to create 3D printed meat products for Muslim people, it would help if the cells used to create the cultured meat is taken from an animal that was slaughtered according to their traditional methods (Hamdan et al. 2021).

6.4. Limitations of Research

Taking into consideration the results of the current research it is apparent that previous knowledge plays a major role when it comes to customer acceptance of novel concepts. Best case scenario participants of the study would be presented with real life examples of 3D printed meat for consumption, ideally having the option to compare it with conventional meat. Unfortunately, 3D printed meat is currently not readily available, if at all, in the Czech Republic, thus this method is not possible to choose. As a result of the exploratory nature of the research with the intent of gathering information about the participants' previous experiences and their current perceptions it as opted to go with a quantitative approach.

The chosen non-random convenience voluntary sampling method utilizing the snowball method resulted in a population set not representative of the general Czech population. This could further be caused by using only the target group of 18-40 years old and utilizing only Czech nationals. Furthermore, by targeting the specialized Facebook groups focusing on meat restricting dietary practices the final data set ended up having 44.5% of people somehow restricting their meat intake (partly meat eaters and no meat eaters), while the Czech estimate is around 10% (Ipsos 2020). However, considering that there is a lack of studies focused on this issue, the results represent an important insight into the issue and can serve as a pilot survey for follow-up research.

Only the positive benefits of the 3D printed meat technology were provided to respondents in the survey, which could have caused bias to the results. In a similar study focused on cultured meat, it was stated that by highlighting only potential advantages while leaving out potential risks or uncertainties, and that the way some of the questions were worded may have skewed some of the results (Verbeke et al. 2015b).

The survey did not provide the respondents did not have the option to express the opinion that they would not consider it as a substitute. In related research, the respondents argued that cultured meat is not required since there is a better way to solve any problems related to the consumption of conventional meat and the conventional livestock production. They also suggested that individuals should consume less or no meat altogether, or if that is not possible then they should opt for options like local, organic, or wild meat over cultured meat. A small minority of commentators generally favoured switching to a more natural diet (Wilks & Phillips 2017).

The favourable responses from most of the participants may be since a written poll does not necessarily correspond to actual circumstances (Manstan & McSweeney 2020). Additionally, the participants completed the questionnaire on their personal computer devices in an uncontrolled environment.

6.5. Suggestion for Future Research

For future research the scope of the study should expanded for all age categories. It could be beneficial to explore how the individual factors are impacting different age groups and if there are any difference in their level of awareness and willingness to try.

To be able to generate findings that would be more realistic for real life implementation in the Czech Republic, it would be beneficial to have a more representative population set of the Czech Republic.

Utilizing quantitative research methods like individual interviews and focus group discussion could diversify the information available further providing additional context for the qualitative data. Long-term studies should be conducted as they allow us to examine and keep track of how attitudes evolve over time.

Additionally, it may be advised to use obtain a real life sample of a 3D printed meat product for live demonstration and the possibility of comparison with conventional meat products. This could be an interesting method of gaining further insights for the development of the product. The possibility to compare the attitude before the experience and after it could provide a deeper understanding of which quality parameters determined the acceptance of consumers.

Further research may concentrate on exploring how cultural and sociological aspects affect consumer attitudes towards 3D printed meat and food products. It would be beneficial to explore any potential ramifications for sustainability and ethical concerns in the food and hospitality industry.

7. Conclusion

3D printed meat was proposed to be a more ethical and environmentally friendly alternative to offset the negative impacts of conventional livestock production and health risks associated with high consumption of conventional meat. Given the novel nature of the technology and limited research on the consumer attitude towards it, the aim of the study was to identify the consumer attitudes towards 3D printed meat.

This study found that consumers have varying levels of awareness about 3D printing, 3D printed food, and 3D printed meat. Awareness is lower for new technologies such as 3D printed food and 3D printed meat, which can be attributed to their limited availability in the market. Familiarity with the technology, previous knowledge, and previous experience were identified as important factors that influence consumer acceptance of 3D printed meat.

Price was found to be the most important factor determining consumer attitude towards both conventional and 3D printed meat, with taste being another important factor, especially for meat eaters. Environmental impact and animal ethics were also identified as important factors, particularly for consumers who restrict their meat consumption. Availability of 3D printed meat products was considered important across all meat eating habits, indicating that consumers would be willing to try cultured meat if it were readily available.

Overall, there is a high willingness to try 3D printed food products and a moderate willingness to try 3D printed meat products among the respondents. No meat eaters expressed low willingness to try 3D printed meat which could be credited to the debate around the legitimacy of cultured meat as a viable "vegetarian" alternative to conventional meat.

These findings provide insights for future research and suggest that further investigation into consumer awareness, attitudes, and preferences towards 3D printed food and meat products would be valuable as they can be beneficial to entrepreneurs who are interested in working with 3D printed meat. Positioning 3D printed meat as a better alternative to conventional meat in terms of environmental impact, while ensuring the final price in comparable to conventional meat and the 3D printed meat is readily available is the best strategy for real market implementation.

As the idea of 3D printed meat move closer to a viable point of commercialization, it is reasonable to expect that the perception of consumer attitude towards 3D printed meat will develop over time. Inevitability of progress would lead to realities of commercial availability of products, rising media attention, growing familiarity among the general population, in addition to the opportunity to test and taste 3D printed meat products, are all elements that would immensely and positively contribute to the consumer attitudes towards 3D printed meat.

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Appendix 1: Survey

Consumers' attitudes towards 3D printed meat
Dear Madam, dear Sir,

We would like to ask you to fill out a short questionnaire focused on consumer attitudes towards 3D printed meat in Europe. This research is conducted under the Czech University of Life Sciences Prague and is intended for scientific purposes only. All data will be treated anonymously in accordance with EU GDPR regulations. It will take you a maximum of 10 minutes to complete the questionnaire. You can share the survey.

Thank you for your answers.

1. How frequently do you consume meat?

Daily	**Several times per week**	**1-2 x per week**	**Occasionally**	**Rarely**	**Never**

2. How would you describe your meat consumption habits?

Meat Easter	eating (red) meat, fish and chicken	
Flexitarian	consciously reducing meat intake, but eating meat now and then	
Pollotarian	eating no red meat, but eating fish, chicken and other poultry	
Pescatarian	eating no red meat or chicken, but eating fish and shellfish	
Vegetarian	no meat or fish, but eating either eggs and/or dairy products	
Vegan	eating no meat and no products of animal origin	

3. What factors affect your meat consumption habits?

Factors	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Economic value/benefits					
Taste					
Nutritional value					
Impact on health					
Environmental impact					
Animal ethics					
Social influence					
Religious reasons					

4. How frequently do you purchase meat (either for yourself or for someone else)?

Daily	Several times per week	1-2 x per week	Occasionally	Rarely	Never

5. What factors are important for you when deciding to buy meat (if you buy meat)?

Factors	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Not relevant
Price						
Availability						
Origin/traceability						
Previous experience						
Freshness						

6. What factors are important for you when you are consuming meat?

Factors	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Not relevant
Colour						
Aroma						
Taste						
Texture						

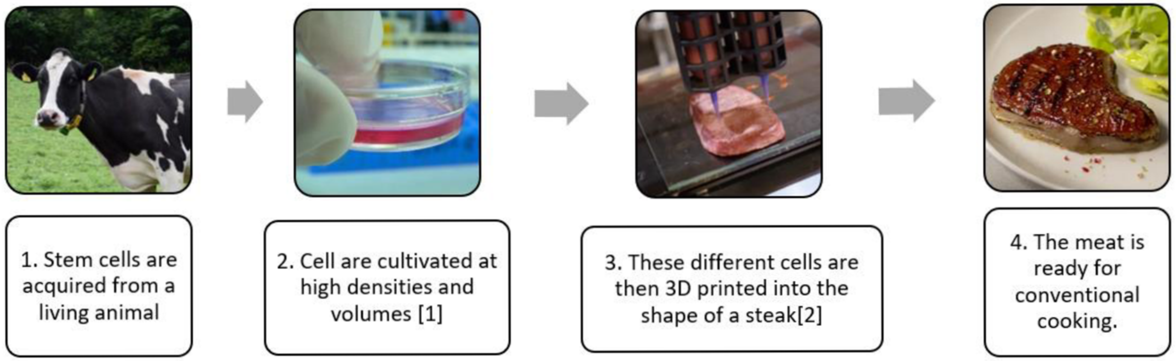
7. Are you aware of 3D printed products?

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I have heard about 3D printed prodcuts					
I know how a 3D printer works					
I have heard about 3D printed food					
I know how 3D printed food works					
I have heard about 3D printed meat					
I know how 3D printed meat works					

Benefits of 3D printed meat

- Nutritional value (customization of nutritional composition e.g., fat reduction)
- Reduction of health risks (control of diseases transmission from animal production and meat processing)
- Environmental impact (reduction of greenhouse gas emissions, land and water use, food waste)
- Animal ethics (reduced number of slaughtered animals)
- Product quality (uniformity of size and sensory properties, decreased pre-cooking handling)

Procedure for preparing meat from a 3D printer



Sources:

[1] https://www.youtube.com/watch?v=238yRdb0niw

[2] https://www.theguardian.com/environment/2021/dec/08/worlds-largest-lab-grown-steak-unveiled-by-israeli-firm

8. Are you interested in trying 3D printed products?

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I would try 3D printed food					
I would try 3D printed meat					

9. What factors would influence your decision to consume 3D printed meatr?

Factors	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Economic value/benefits					
Taste					
Nutritional value					
Impact on health					
Environmental impact					
Animal ethics					
Social influence					
Religious reasons					

10. What factors would affect your willingness to buy 3D printed meat?

Factors	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Price					
Availability					
Origin/traceability					
Previous experience					
Freshness					

11. What factors would be important in terms of your consumption of 3D printed meat?

Factors	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Colour					
Aroma					
Taste					
Texture					

12. Socio-economic factors of the respondents

Nationality	Czech
	Other
Gender	Men
	Women
	Other
Age category	18 – 30
	31– 40
	41 – 50
	51 – 60
	61 – 70
	≥71
Highest level of education	Elementary school (primary)
	High school (secondary)
	University (tertiary)

Number of household members	1
	2
	3
	4
	5
	≥ 6
Religion	Christianity
	Islam
	Hinduism
	Budhism
	None
	Other
Residential area type	Rural
	Urban
Net monthly household income (in EUR)	≤ 1 000
	1 001 – 2 000
	2 001 – 3 000
	3 001 – 4 000
	≥ 4 000