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THREE-DIMENSIONAL (3D) PRINTED HALAL MEAT: DO WE NEED A NEW REGULATORY FRAMEWORK?

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ABSTRACT

The three-dimensional printing (3DP) process provides the ability to formulate innovative food ingredients that enhanced nutritional benefits as well as sensory profiles. 3DP technology is an alternative method in food processing which include the production of halal based products. Despite the rapid development of 3DP in recent years, there is still concern surrounding the technology such as quality, manufacturing process capability, taste, structure, or shape, and binding mechanism are some of the factors that can still be improved. The addition of binding components, for example, gelatin from an animal to enhance the meat processing will be subjected to debate based on the Halal guidelines. In today's world, the issues regarding food safety are discussed where the producers use inadequate instruments, unsterilized plating, and mixing non-halal based products with the halal based product. This article reviews the need for new standards and regulations for halal printed products, in particular meat-based products. Conventional standards and regulations for halal processing meat need to be revised according to the technology in food science and engineering. Consequently, other issues including ethical issues need to be addressed from different Islamic perspectives to provide strong foundations for 3DP halal meat standards and regulations. This study suggests for further in-depth research to be conducted in this field and urges scholars to view this as a fast-growing research field in Halal studies.

Keywords: *3D Printing, Halal, Food Forensics, Halal Forensics, Meat*

Introduction

In the past four decades, world-wide meat demand is projected to triple and risen by 16% relative to 2015 in 2025 (Stoll-Kleemann & O'Riordan, 2015; Lynch, Mullen, O'Neill, Drummond & Álvarez, 2018). The global meat supply is projected to surge more than double than previous 2050 to a cumulative volume of 470 million tonnes (FAO, 2009), further exacerbating the related environmental effects which are due to the demand of an approximate 9 billion population. Meat is one of the main commodities which primarily falls under Halal consideration whereby Muslims are very particular about Halal meat compared to other food products (Kabir, S, 2015). As the global market for halal foods grows, there will be increasing demand from countries that relies on others to produce sufficient quantities of their halal food.

In the current market, animal proteins account for 40% of global protein intake and will continue to rise as the population continues to expand (Sans & Combris, 2015). Present livestock productions, as primary factors in a large variety of environmental concerns, have many threats including land and water degradation, wetlands and biodiversity destruction, increased soil erosions, and greenhouse gas emissions. Introducing policies and emerging technology to reduce the environmental consequences of agriculture is only projected to be successful by 20% (Peter et al. 2008). That is why several researchers indicated that meat intake could be reduced or production practices such as cultured meat, which are more sustainable (Bhat et al. 2015, 2017; Lentz, Connelly, Mirosa & Jowatt, 2018) could be introduced.

Three-dimensional printing (3DP) could offer unique solutions for the vital issues of cultured meat production; particularly on regulating the protein, fat, and other nutritional content, along with providing realistic texture (K. Handral, H., Hua Tay, S., Wan Chan, W., & Choudhury, D., 2020). 3DP technologies attribute to positive factors in the food industry, namely customizable food design, personalized and digitalized feeding, streamlining the supply chain, and widening the source of usable food materials. This technology enables us to create complicated and delectable foods that could not be achieved by any handwork or traditional molds, based on present data files containing the list of expertise and artistic expertise cooks, nutrition specialists, and food designers (Sun, J., Zhou, W., Yan, L., Huang, D., & Lin, 2017). As to this burgeoning in 3DP, it expanded to food manufacturing. Extrusion of 3DP has successfully rendered its technique of producing foods like purées, mousses, ganache, and others by putting together sundry material. Based on recent technology in the field of 3DP, it is possible to produce 3D printed halal meat as a sustainable solution to cope with the emerging demand for halal meat. This article reviews whether there is any need for a new regulatory framework for 3DP halal meat production based on the present halal meat supply chain in Malaysia.

3D-Printing History

In the beginning, 3DP can be integrated with metals, advanced machines, plastics, other molding materials, and can be mixed with all. 3DP technologies can be utilized effectively, with beneficial effects on the human constitution as a personalized solution such as to a person's health; this factor contributes to its geometric sophistication and mass customization, which gives virtues that differentiate it from traditional development techniques (Prerna Singh and Alok Raghav, 2018). 3DP creates a three-dimensional structure using a CAD model that uses digital 3D as a platform to produce such a structure (The Economist, 2013). This 3D creation is integration between liquid molecules and powder grains, typically fused layer by layer. Additionally, 3DP is regarded as a range of processes in which material is deposited, joined, or solidified under the operation of computer control (Excell, 2013). This 3D method was firstly created in the early 1980s by eminent Dr. Kodama, thenceforth deemed significantly ideal for the development with countless possibilities applied in numerous areas, practically or aesthetic design making, and it fits the concept at all time (Tmg-muenchen.de, n.d.). The first commercial 3D device was developed at the end of 1987, followed by a thorough review, and the first test machine was successfully produced (Joan Horvath, 2014).

Table 1: The Development of 3D-printing Timeline (Ahmad Syukran, Mohammad Amir, Aminuddin, & Abdul Rahim, 2015; Fenn, 2010)

Year	Events
1984	The birth of 3D printing
1992	Building parts, layer by layer
1999	Engineered organs bring new advances to medicine
2002	A working 3D kidney
2005	Open-source collaboration with 3D printing
2006	SLS leads to mass customization in manufacturing
2008	The first self-replicating printer, do it yourself (DIY) co-creation service launched, and a major development for prosthetics using 3D started
2009	DIY kits for 3D printers enter the marketplace, From cells to blood vessels
2011	World's first 3D printed robotic aircraft, printed car, and 3D printing in silver and gold
2012	3D printed prosthetic jaw implantation
2013	3D Systems introduced sugar sculptures
2015	A Swedish company introduces the first standardized commercial bio-ink to the market that can be used in tissue cartilage printing
2020	Fused Deposition Modelling (FDM) in 3DP has widely be used in 3DP technology 3D Printed vegan steak being introduced to the market by an Israel company

3D printing started in the early 1980s when Charles Hull invented the machine that allowed users to test a design before agreeing to invest in the manufacturing programs. In 1992, a layer-by-layer printing machine was developed which used viscosity and honey-colored liquid which is known as ultraviolet (UV) laser solidifying photopolymer to form a three-dimensional material that goes through a layer-by-layer process. The technology then evolved in 1999 when scientists at the Wake Forest Institute for Regenerative Medicine developed engineering organs and implanted a 3D-synthetic scaffold coated with patient cells for urinary bladder augmentation. This technology then has remarkably developed into a much smaller functional filterable kidney which can produce dilute urine by removing substances from the blood in animals. These experiments had not had any rejections from the recipients either in animals or humans because they were made from the recipients' cells. The 20^{th} century then demonstrates a rapid development in 3D printing technology (Coatney, 2013; Greenemeier, 2012).

In the 2000s period, starting with the engineering of a working 3D-kidney in 2002, a 3D-printer that can print from its components was created in 2005. In 2006, the first SLS (Selective Laser Sintering) machine was introduced. This machine uses a laser to fuse materials into 3D products. It then led to the development of multivariate materials manufactured. In recent years, with the substantial development in the modern world, the drawback that emerges at the initial 3DP development has already been solved where it has more accurate precision, making products faster and easier in 3D by way of an alternative of a conventional system. 3DP has improved to the extent that certain 3DP technologies reckon feasible as an advanced processing technique (Formslabs, 2020).

3D printed foods technologies would have many beneficial effects and endless possibilities for food printing by addressing problems linked to food shortages, eliminating hunger, mitigating climate change, eliminating no longer needed businesses, and even addressing the food scarcity dilemma for astronauts and military forces at length (Jasper L. Tran, 2016). Fused deposition modeling (FDM) is the most common 3DP technology in use since 2020 (Su, A., & Al'Aref, S. J., 2018). The first design is the Virtuoso Mixer, which monitors number, form, and source, blends, and mixes different ingredients. This mixer is divided into three parts, on the top-layer configuration of storage containers for controlling temperature, humidity, and weight. Meanwhile, in the middle part are for manufacturing chambers devoted to mixing, whisking, and grinding. Secondly, DigitalFabricator is a type of machine with the combination of model and cook ingredients into unique types with specified dimensions. The concept involves refrigerated food canisters, a three-axis printing head on the printing surface, and a fabricator processing chamber. Thirdly, RoboticChef- transforms current products into modern patterns of taste and style. It consists of two robotic arms with five degrees of movement, an instrument head for localizing transformations such as drilling, cutting, distribution, and a heating bed for cutting, cooking, and sintering.

Commercialization of 3D-Printed Meat

One of the latest technology created in 2020, the first 3D-printed vegan steak globally, was brought out by a company located in Israel. Redefine Meat, an Israeli company based in Rehovot, has launched an 'Alt-Steak' a device that, through the 3D-printing process, successfully replicates the texture, taste, and appearance of real meat. The new Alt-Steak is composed of natural colors and tastes, mainly made up of proteins of soya and pea, coconut fat, and sunflower oil. The steak imitation has high protein content to recreate beef's muscle composition and has zero cholesterol as it originates from the plant (Salama, 2020).

On the other hand, Aleph Farms has recently produced a system that mimics the normal muscle regeneration process within the cow's body. In contrast with plant-based 3D printed meat, this approach uses bovine cells to mimic the meat's flavor, texture, and appearance. Their groundbreaking approach includes combining cells – fat cells, muscle fibers, blood cells, and others –to produce bio-ink for use in the 3D bioprinting process (Aysha M., 2020). 3DP products such as custodial pasta, pie, pancakes, and burgers are laden in the market being marketed for its capacity to create a food product, such as in unique shapes or customized images, and for its ability to provide customized food for individuals with specific dietary requirements, such as elderly patients, pregnant mothers, athletes, and people with diabetes (Venlo Nesli Sözer, 2017; Kathy Holliman, 2015).

In the meantime, MeaTech is one of the current players in the 3D best meat printed race. This Israeli start-up is pivoting on 3D meat printing on a scale that focuses on the industrial industry. The business strives to manufacture fast and build one unit of product for every few seconds. According to their CEO and co-founder, Sharon Fima stated that "We are aiming to demonstrate that 3D meat printed industrially." (Aysha M., 2020).

One of the world's most extensive industrial-quality 3D printers, 3D Systems producers, and Hershey (a major producer of chocolate and desserts), has developed an extrusion-based chocolate printer called Cocojet, enable for the product to be print into assorted chocolate shape (Millen, 2012). Another outstanding engineer and inventor, Hans Fouche, innovated eight nozzle Cheetah 3D chocolate printer and experimented with various chocolate where most of the 3D chocolate created by using a melted extrusion-based printer; meanwhile, four students from the University of Waterloo have designed low-cost selective laser sintering based printers to build 3D chocolate structures using chocolate powder named 3D Chocolateering (Victor, 2015)

A legend in the 3D world of printing pastries, Dinara Kasko has captured the eye of the world with her sculptural pastries with this operation. Then again shows that 3DP is not only restricted to printing food but also suitable to create delightful intricate culinary art. The next scenario illustrates how edible food revamps from the utility to the kitchen top. The world-renowned Italian company, Barilla, has partnered with the Dutch research institute to bring the world's first fresh 3D pasta printer to life. Instead of using filament, 3D pasta processing uses the optimal combination of traditional pasta to manufacture it.

Into the bargain, Dutch company ByFlow has developed a 3D printer that does precisely printing 3D plates. However, the organization took the concept of creating a whole restaurant around with 3D technology even further. Their Focus 3DP system can produce food and shape some geometric or abstract shapes of a dish that they can think of because of their busyness. Moreover, in partnership with engineering tech powerhouse Microsoft, the company has developed a type of molecular 3DP technique called spherification to create fruity designs in split seconds where natural flavors are added and adjusted with a particular combination of fruit juice and sodium alginate powder.

3D Printed Cultured Meat Production vs Conventional Meat Production: Challenges and Issues

According to Harish K. Handral, et. al. (2020), there are several differences between cultured meat production and conventional meat production. In conventional meat production, animals will be grown until matured and ready for processing. This is time-consuming and requires resources based on the animals' types compared to cultured meat production that takes only a few weeks for harvesting. The cultured meat production process will save time and resources as there is a possibility of in vitro replication of complex in vivo tissue growth. Also, Cultured meat could be 3D printed as a paste (which is called "meat paste" Dick et al. 2019). Moreover, contamination may occur during the conventional meat production process. Pollution, foodborne and zoonotic diseases may become the biggest challenge in dealing with conventional meat production.

Hygiene and cleanliness of slaughterhouse facilities may affect produced meat through microbial contamination. Cultured printed meat is carried out with stringent inspection and quality controls in place under sterile conditions, thereby reducing the chance of microbial infection during the meat processing stage (Ben-Arye and Levenberg 2019). Besides, conventional meat production utilizes large resources and consumes a specific unit/lot of land. This will involve manpower depending on the space and resources needed. On the other hand, cultured printed meat utilizes bioreactors and specifically 3DP equipment which are space-efficient and can minimize the need for manpower. But it requires skilled expertise and sufficient facilities such as laboratory well-equipped laboratory. Also, the slaughter-free method in cultured meat harvesting ensures an efficient way of managing and treating waste-water from production.

Due to the tremendous prospect of 3DP used in the food industry, some possibilities need to be contemplated as the machine that runs the food can attract foreign substances. Short-term consumption of 3D printed foods may lead to adulterated foods, causing food poisoning problems, although this issue can be avoided (Jasper L. Tran, 2016). Referring to a scenario, particularly where one or only a few people are poisoned by eating 3D-printed food. This sporadic situation will only exist in the case of people with severe food allergies. Due to that, the authority currently demands food producers to declare food allergens on their packaging, where present regulation includes labeling or disclosing eight main dietary allergens: milk, egg, fish, shellfish, tree nuts, wheat, peanuts, soybeans. Another situation may occur where one or more batches of food printing materials contain infected substances, a possible occurrence in all scenarios that may betide 3D food printing. If this occurs, individuals responsible for the contamination will be held accountable. For instance, if the parties negligently to take precautions; the government should interfere and mandate the company to disclose ingredients containing harmful or deleterious compounds (Jasper L. Tran, 2016).

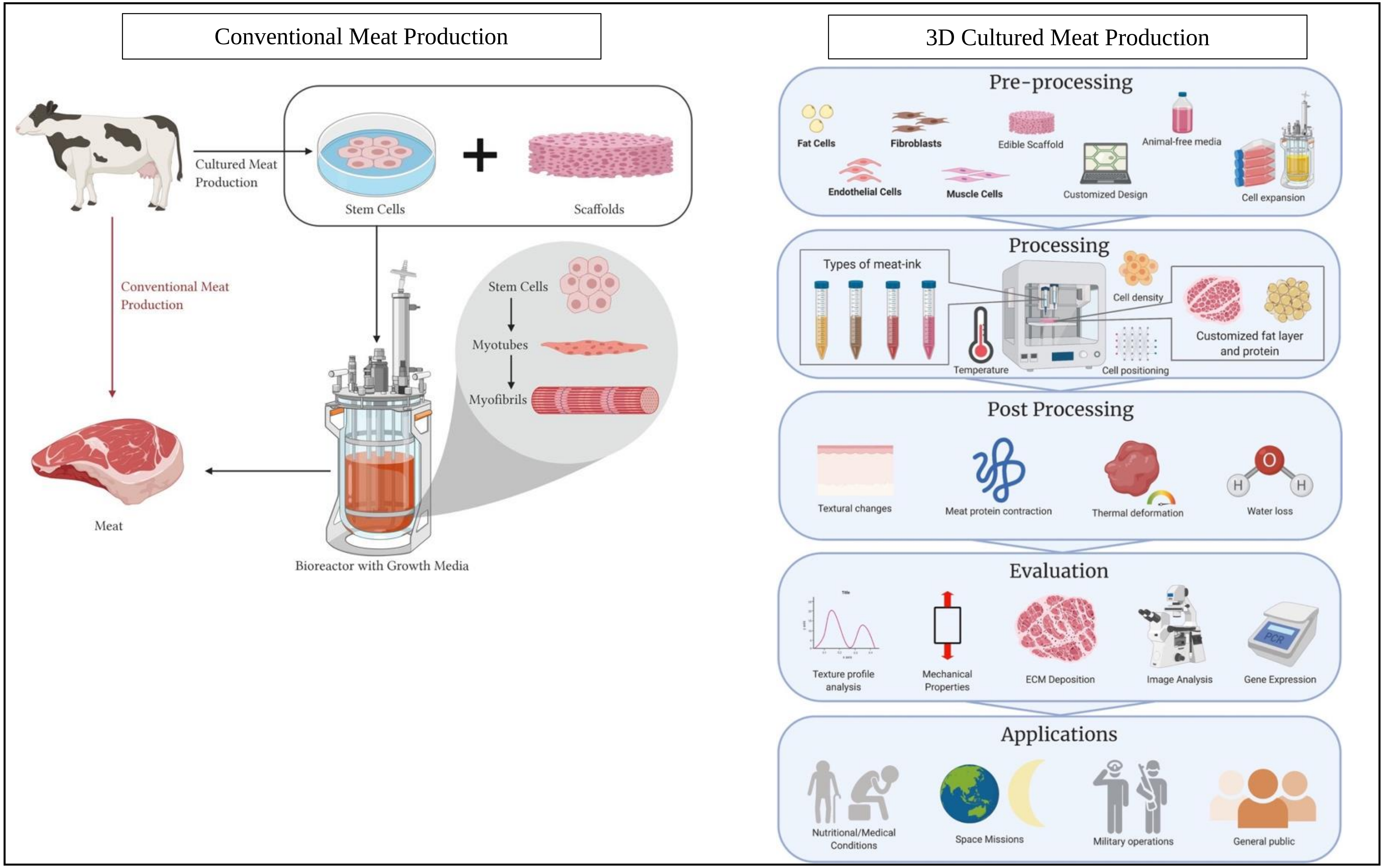

Figure 1: 3D Printed Cultured Meat Production vs. Conventional Meat Production Process (Harish K. Handral, Shi Hua Tay, Weng Wan Chan & Deepak Choudhury, 2020)

Following the novelty of 3D-printed food, there have been no long-term and well-controlled demographic studies of the food printing industry. Accordingly, without a comprehensive study regarding this new technology, it is out of the question to draw a legal inference. Hitherto, there are no predictable regulatory problems with the long-term use of 3D-printed food. Although no one knows what reaction will occur without reliable evidence, preventive measures, and a well-defined payment mechanism for injured patients are needed if only a few, not all, individuals who have consumed 3D-printed food encounter health problems.

By labeling all traces of materials, the liability and risk shifted to the customers who had an allergy when making the purchases, and they can avoid the product at all costs. As a result, parties participating in the food printing process may deny the liability. A person is likely to be responsible for themselves by selectively not eating food to which they are allergic. In the event of a mislabeling that resulted in food poisoning from allergies, the person responsible for the mislabeling will be accountable for damages arising from food poisoning since the harm was inevitable.

Commonly used 3D food applications are based on extrusion technologies such as staple food like cereal and chocolate. However, the use of substitute materials to produce the food, such as insulated proteins and fibers, algae, microorganisms, and agri-food residuals, is fascinating. There can be microbiological degradation and migration from printer elements of hazardous substances, but successful cleansing procedures and usage of food contact-approved materials can ensure safety-related requirements by using those organisms (Antonietta Baiano, 2020)

Accordingly, their unique shape strongly affects them as a central plight in dealing with 3D printed foods' acceptability. 3D food printing can be seen as an avenue to build innovative marketing models and enhance the food supply chain's quality. The potential opportunities for 3D food printing include integrating 3D food printing and cooking on a single computer and advancing 4D printing (Antonietta Baiano, 2020).

Along with the first concern for food protection printed on 3D, even the most smoothly looking prints have tiny gaps and cracks where the germs and bacteria can grow. This should not be an issue in preparing a cup, platform, or utensil for disposable use. However, for goods to be used often, the company must make deliberate choices, whether it is a good thing to implement 3D. If not taken care of carefully, a printed 3D component will become a bacterial petri dish in a few weeks.

Although bacterium aggregation may not concern disposable goods, it is strongly recommended to use food-safe coating if the corporations intend to build a long-term component. Since particles may move from 3D printer elements to 3D printed components, it is vital that any item comes into contact with or is food-grade and contains no hazardous chemicals (Anatol Locker, 2017)

Another aspect to be considered concerning the machine component is the ABS filament (Lyndsey Gilpin, 2014). It is commonly considered hazardous for food connections since ABS contains poisonous compounds that can contaminate food. Natural PLA is made of maize starch and is typically considered healthy for foodstuffs. It can be turned another way and becomes complicated where suppliers can mix with another color, power, or other additives that render the filament unhealthy (Anatol Locker, 2017).

Moreover, desktop FDM printers using ABS and PLA plastic are "high emitters" of ultrafine particles (UFPs), according to a report in 2015 by the Illinois Institute of Technology. These particles can occur on the surface of the printed product, and adverse health consequences may arise from prolonged inhalation or absorption of these UFPs.

If in the machine printer, bacteria are abundant, which need to be washed up. It may become deformed and twisted when the prototype is placed in hot water or with the dishwasher. PLA is more thermal-sensitive and certainly not safe for washing. Not all FDM 3D printers are extruder of the same kind. Others are made of titanium, aluminum, or metal, whereas a brass extruder could contain lead, creating specific unhealthy issues with lead pollution. Extruders in 3D brass may contain lead, and some severe health concerns may be caused by contamination. It is unclear exactly how much lead is in the cube and whether a large lead is moved from the nozzle during the printing process. Some people seemed to think that this was a big concern; others argued that it was insignificant how much lead would be applied to the final product (Anatol Locker, 2017). This means its required to safeguard when using different materials as certain items main contain toxic and can attract foreign substances when it comes into contact with the component.

Reviews of 3DP Halal Cultured Meat through Halal Meat Supply Chain Regulatory in Malaysia

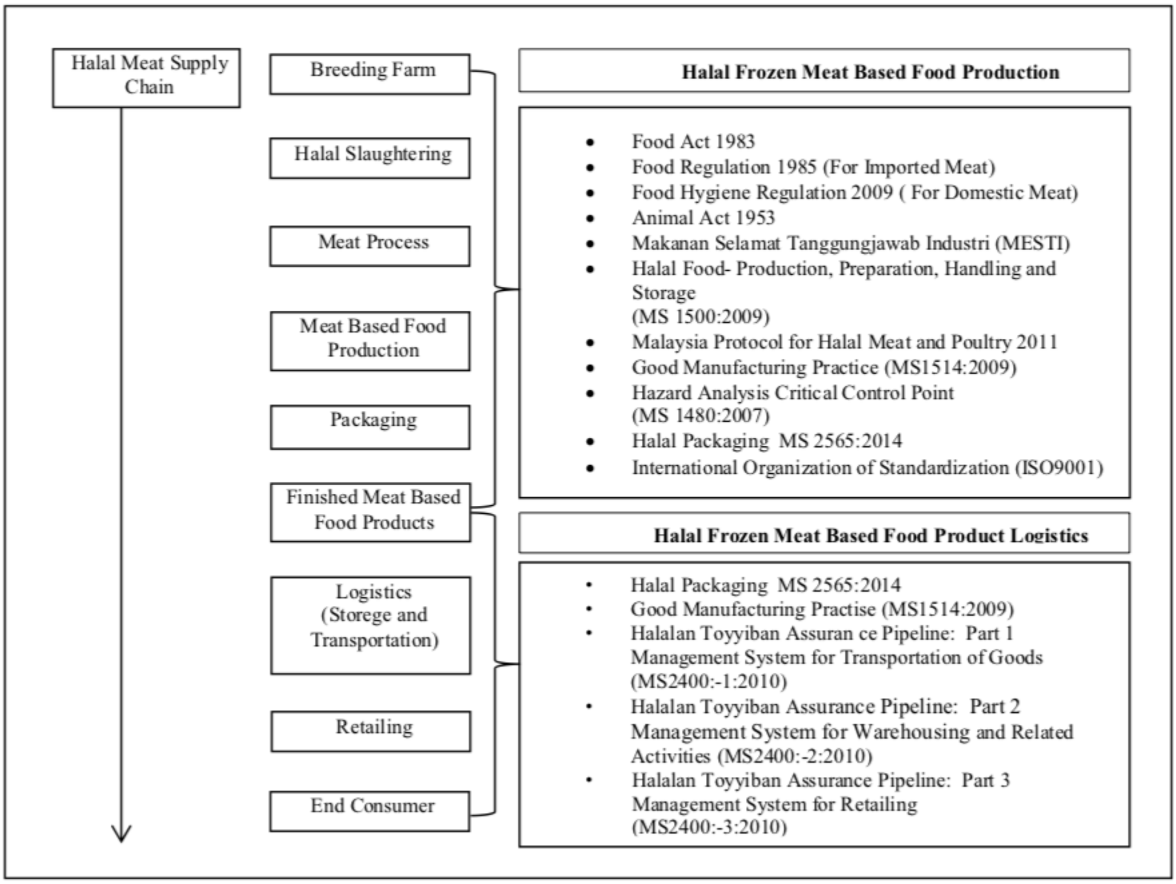

Figure 2: Halal Meat Supply Chain Regulatory Framework in Malaysia (Yaacob, T. Z., Jaafar, H. S., & Rahman, F. A., 2016)

Figure 2 displays the halal meat supply chain regulatory framework. This framework is specifically to be followed by the producer of Halal meat products. This framework consists of standards and regulations that control halal meat production from the beginning until the end of the production. This figure works for conventional meat production, but it can be amended in the way 3DP halal meat being produced. 3DP halal cultured meat does not involve a breeding farm. However, the main stage of the 3DP production should be addressed through Islam's views on the sources of the meat-ink. Therefore, the halal status of 3DP meat can be determined from the way it is produced. This is as there are several possible ways of printing meat based on previous researches.

Table 2: Islamic Ruling on Possible 3DP Halal Meat Based on Meat-Ink Sources, Culture Medium, and Technique

Islamic Ruling Based on Sources of Meat Ink	
Islamic Ruling	Sources of Meat-Ink
Forbidden (Haram)	Matured cultured tissue sourced from Embryonic Stem Cell (ESCs) from non-slaughtered & permissible animals
Permissible (Halal)	Matured cultured tissue sourced from Embryonic Stem Cell (ESCs) from slaughtered permissible animals
Forbidden (Haram)	Matured cultured tissue sourced from Embryonic Stem Cell (ESCs) from non-permissible animals
Permissible (Halal)	Cultured Adult Stem Cell (ADSCs/Non-Embryonic Stem Cell) from slaughtered permissible animals
Forbidden (Haram)	Cultured Adult Stem Cell (ADSCs/Non-Embryonic Stem Cell) from non-slaughtered permissible animals (taken alive)
	Cultured Adult Stem Cell (ADSCs/Non-Embryonic Stem Cell) from non-permissible animals (taken alive)
Permissible (Halal)	Seafood/Fish based meat
	Slaughtered permissible animal meat paste
Forbidden (Haram)	Non-slaughtered animals/non-permissible animal meat paste
Islamic Ruling Based on Meat Ink Culture Medium	
Islamic Ruling	Culture Media
Forbidden (Haram)	Blood Serum (Centrifuged)
	Fetal Bovine Serum
Permissible (Halal)	Non-Toxic/ Non-Harmful Serum-Free Media/Additives
	Non-Toxic/ Non-Harmful Mushroom Extract
	Non-Toxic/ Non-Harmful Chemical Artificial Based
Islamic Ruling Based on Meat Ink Culture Technique	
Islamic Ruling	Culture Technique
Depends on the medium and sources of cells used in the process	Bioreactor culture
	Self-organizing culture

Despite having livestock of animals in a minimum amount, the cells taken for meat culturing process should be suggested to adhere with Halal Food-Production, Preparation, Handling, and Storage Malaysia Standard of MS1500:2009. It is to ensure that the cells are taken from animals that have not been fed with filth or hormone that makes the animals to be considered as *jallalah* animals. On the surface, 3DP halal meat does not involve the slaughtering process as no livestock will be needed. However, the halal slaughtering regulatory framework needs to be applied to the source of meat-ink. Two possible products can be printed out based on the sources of the meat-ink:

1. Printed meat from cultured meat production.
2. Printed meat from conventional meat production.

In both ways, the sources of the meat for the 3DP production are subject to permitted slaughterhouse endorsed by the Department of Islamic Development of Malaysia (JAKIM) that complies with Malaysian Protocol for the Halal Meat and Poultry Productions 2011 and Halal food-production, preparation, handling and storage (MS 1500:2009). These standards are enacted based on legislation in the Food Safety Act 1983 and Food Hygiene Regulation 2009. Moreover, all sources of meat before and during printing should have been controlled and monitored continuously to maintain its quality and sterile condition. This is one of the aspects of Malaysian Standard MS1500:2004, MS ISO 17025:2017, and Sistem Akreditasi Makmal Malaysia (SAMM).

3DP halal meat will involve the regulatory framework of packaging the products. Besides Hazard Analysis Critical Control Points (HACCP) and Good Manufacturing Process (GMP) that control the production of food from A-Z, food suppliers and customers must adjust to and comply with global requirements such as ISO 9001, Codex Alimentarius, Quality Assurance, Good Hygiene Practice (GHP) and the Standard of Operating Procedure (SOP) of the organization. Halal logo is for sure to be displayed on the packaging together with another label such '3D Printed Cultured Meat' or '3D Printed Halal Meat Product' or any label that can explain the nature of the meat (Mouat, Prince, & Roche, 2019). This is important to address the nutritional concerns among consumers especially Muslims (Kasapila, W., & Shaarani, S. M., 2016). Apart from the marketing value to increase the confidence, it adheres with the Trade Description Act 2011. Proper labels affixed to identify the halal markings according to the standards of Halal Packaging (MS 2565:2014) and Halalan Toyyiban Assurance Pipeline: Part 1 Management System for Transportation of Goods (MS2400:-1:2010) (Teh Zaharah Yaacob, 2016).

Conclusion

The future of 3DP halal meat will be blooming in the coming years. Equally, the industry is ready for such a significant transition, and technology is proliferating to catch up with the changes. However, the time will come where this 3DP halal meat will need its regulatory framework for commercial purposes. There is an urgent requirement for setting up a suitable regulatory framework to rule out the possibility of any risks and deviations in the production to safeguard the health of the consumers. Current standards and regulations of halal processing meat need to be revised according to the technology in food science and engineering. Basic issues including ethical concerns and Islam's views on 3DP halal meat need to be addressed neatly from different angles to provide strong foundations for 3DP halal meat standards and regulations. This study suggests for further in-depth research to be conducted in this field and urges scholars to view this as a fast-growing research field in future halal studies.

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