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MINI REVIEW

Halal standards as elements in the legal framework of 3D/4D-printed food using source-composition-manufacturing and halal forensic concepts

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Abstract

In the coming years, it is expected that 3D-printed food will be commercialised across the globe. Previous research suggested the necessity of establishing a legal framework for 3D/4D-PF. Meanwhile, the multiplicity of halal standards across the globe nowadays has made things difficult when it comes to trading between countries, thus affecting the legal control of imported halal food in certain countries. However, until now, there is no legal framework developed especially for halal standards and certification. This study aimed to identify specific standards that should be complied with by 3D/4D-PF thus suggesting a halal legal framework based on existing halal standards. This study used the inductive method to analyse relevant standards and the compatibility with 3D/4D-PF production elements by combining the source-composition-manufacturing (SCM) conceptual model and Halal Forensics concepts. The application to 3D/4D-PF can be considered after comparing relevant standards and regulations. The study is evidence that the basic requirements related to halal 3D/4D-PF need to comply with halal standards. The halal standards analyzed in this study denote that there is a necessity for the world especially for the Muslim population to be ready for the halal issues of 3D/4D-printed food.

1. Introduction

In the last few years, there has been a huge rise in the popularity of halal products and services all over the world. Because more people are interested in halal food, more suppliers have joined the industry, and it has become a profitable business. It has expanded beyond the halal food market to include niche markets like Islamic tourism, finance, and lifestyle. Halal business development has been slowed by the COVID-19 pandemic; however, it is predicted that the worldwide halal market would increase from a USD 1.90 trillion industry in 2015 to about USD 4.60 trillion by 2030, with an optimistic scenario of potentially reaching USD 4.96 trillion (Thomas, 2022). In 2020, the OIC member countries are expected to have a halal market value of USD 3.7 trillion, which is expected to rise to USD 4.7 trillion in 2024. As a group, OIC member countries have a lot of potential for the growth of the halal industry because they already have a halal-friendly environment, more money to buy things, and more people.

Halal standards and regulations are one sort of halal product management system that ensures product quality and safety and has received a lot of attention in industry and research fields. In general, the halal sector is still expanding significantly, both in terms of supply and demand. On the supply side, a rising number of halal

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manufacturers around the world, ranging from tiny businesses to multinational corporations, have begun to incorporate the halal standard into their operations and manufacturing processes (Lever and Miele, 2012). According to the 2018/2019 State of the Global Islamic Economy Report, halal food has more enterprises than any other sector of the Islamic economy (Azam and Abdulah, 2020). It is worth noting that the increased market demand for halal products is not simply due to Muslim consumers (Wilson and Liu, 2010; Wilson, 2012; Baharuddin *et al.*, 2020).

Meanwhile, three-dimensional and four-dimensional food printing (3D/4D-FP) enables the creation of food with novel dimensions, forms, flavours and interior structures. Food made using 3D/4D-FP is made through a variety of steps and processes. Additionally, 3D/4D-FP is sustainable because creators exclusively create and print food. Food from cereals (cookies, pasta, breakfast cereals), chocolate, sugar, and almond paste, as well as dairy goods such as meat and fish products, are all being produced nowadays using three-dimensional food printing. The 3D-food printing market is estimated to account for about USD 201 million in 2022 and is projected to reach a value of nearly USD 1,941 million by 2027 (Baharuddin *et al.*, 2015; MarketsandMarkets, 2022). Figure 1 shows an example of basic 3D printing of food while Table 1 shows the types of 3D/4D-printed food available by recent technology.

Despite the advancement of technology in the field of future food, there is currently no legal framework in place to regulate 3D/4D-printed food products. Ismail *et al.* (2020) and Burhanuddin *et al.* (2023) suggest that there is a need to implement regulations and laws to protect human life, consumer interest and health. This is also to ensure fair practices in the food trade. Meanwhile, Jasper Tran (2016) in his study is concerned about the legal issues of labels for 3D-printed food with regard to the content of the products. This includes possible allergens and adulteration that might be a potential risk to the health of consumers. Therefore, the researcher proposed that a regulation for the labelling of 3D-printed food products be implemented.

Dankar *et al.* (2018) highlighted the value of establishing specific regulations for 3D food printing facilities and workers where there are four major hurdles in the printing process: rules and guidelines, food shelf life, ingredient constraints and post-processing. On the

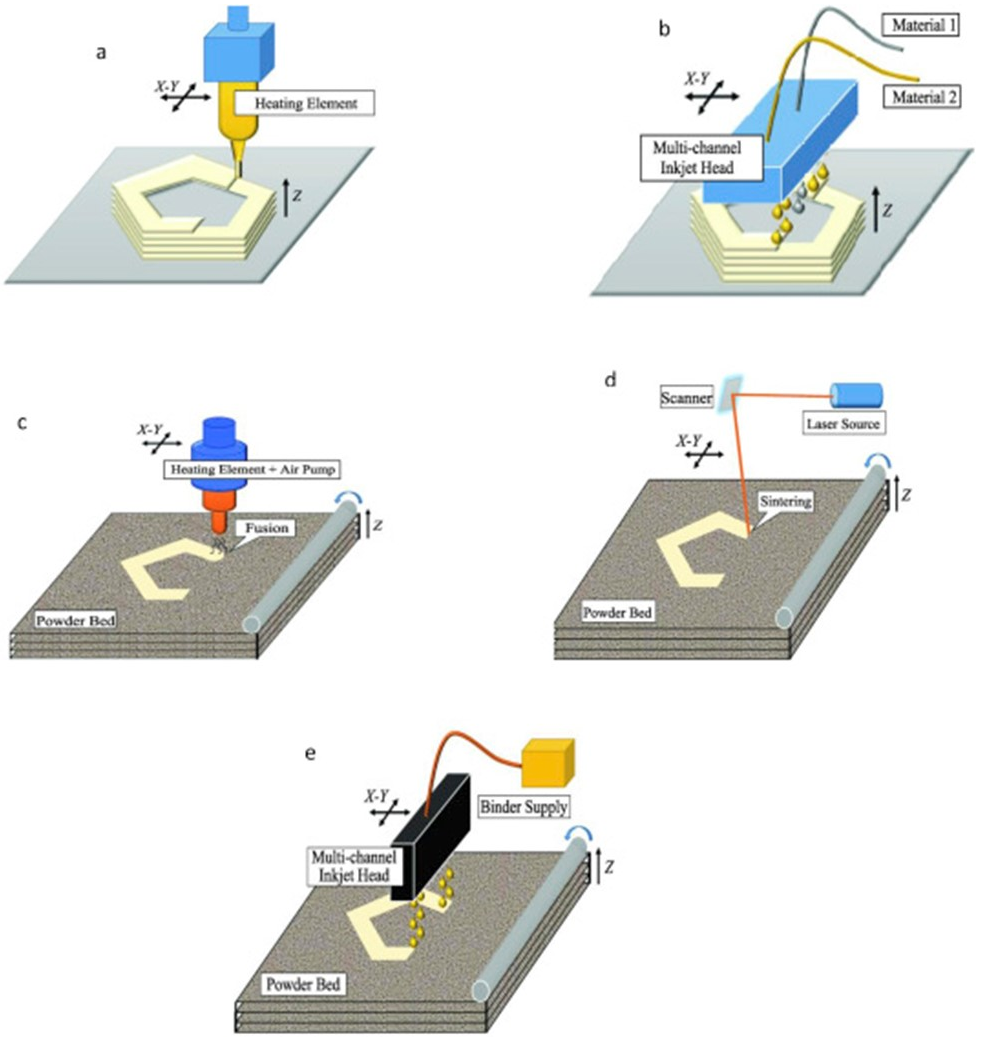

Figure 1. A schematic representation of the different technologies applied in 3D food printing: direct printing through extrusion (a), inkjet printing (b), selective sintering technology through hot air (c) and laser (d) and binder jetting (e) (Dankar *et al.*, 2018)

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Table 1. Recent technology available for 3D/4D food printing adapted from Li *et al.* (2022)

		Hot melt/ room temperature extrusion	Selective laser sintering/ hot air sintering	Binder spraying	Inkjet printing
Food materials		• Pasty food materials such as dough, gel, chocolate • Phase change gel materials • Phase change hot melt materials.	• Powdered food materials that are melted by heating, such as chocolate.	• Food-grade adhesives • Powdered materials, such as starch, powdered sugar.	• Low-viscosity food materials, such as tomato sauce.
Factors	Material properties	• Rheological properties Thermodynamic properties • Mechanical properties,	• Particle size • Melting temperature • Fluidity • Wettability	• Particle size • Fluidity • Viscosity • Surface tension.	• Rheological properties • Surface energy • Compatibility.
	Printing parameters	• Nozzle diameter, • Printing speed • Layer height • Extrusion speed.	• Heat source type • Nozzle diameter • Scanning speed • Energy density.	• Printing speed • Nozzle type • Nozzle diameter • Layer height.	• Printing speed • Nozzle diameter • Printing temperature.
	Post-processing	• Baking • Steaming • Frying.	• Removing unsintered powder • Surface polishing.	• Heating • Removing excess powder.	
Advantage		• Wide range of available ingredients • Simple equipment • Low cost.	• Printing hollow and intricate food structure.	• Printing complex food structure • Colouful printing.	• Wide range of available ingredients • Fast speed.
Limitation		• Poor mouldability of food structure.	• Limited available ingredients • Poor compatibility.	• Limited available ingredients • Poor compatibility.	• Poor stability • Plane structure.

other hand, Antonietta Baiano (2020) provides an extensive overview of safety standards for 3D-printed foods and highlights possible opportunities for 3D business expansion. In their opinion, 3D food printing can be used as an avenue to build innovative market models as well as to improve the sustainability of the food supply chain. Other research has also been conducted on legal concerns and regulations of 3D-printed products and meat alternatives. Table 2 briefly traces the research on legal concerns and the regulatory framework of 3D/4D-printed food based on a preliminary overview.

This study will review the possibilities of halal standards across the world to be applied to 3D/4D-printed food, combining the source-composition-manufacturing (SCM) conceptual model and halal forensic concepts in order to obtain a detailed analysis.

2. Halal forensics (HF) element and source-composition-manufacturing (SCM) conceptual model

Halal forensics is a concept that combines several components, such as product testing in labs to establish whether or not the product is acceptable and permissible in Islam (Hassan, 2018). Numerous halal-related situations can be addressed with this relevant framework (Baharuddin, *et al.*, 2015; Mohd Fadzli, *et al.*, 2021). To date, halal concerns have mostly focused on the use of questionable raw materials (for example, the processing of gelatin into capsules); the addition of ingredients and food additives during manufacturing; logistic conditions; and production line issues. The usage of the halal logo is a further essential aspect of halal requirements. The risk of being deceived by false halal logos led to the development of authenticity criteria for halal logos (Razali *et al.*, 2015). Therefore, the halal forensics concept covers a wide range of topics, particularly those pertaining to food and pharmaceutical

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Table 2. Legal concerns and regulatory framework of 3D/4D printed food based on a preliminary overview

Source	Legal Concerns of 3D Printing and Additive Manufacturing (AM)	Regulatory Framework for Meat Alternatives and Other Food Products
Antonietta Baiano (2020)	X	
Bhat *et al.* (2019)		X
Daly *et al.* (2020)	X	
Dankar *et al.* (2018)	X	
Etxabide *et al.* (2018)		X
Faustman *et al.* (2020)		X
García-Oliveira *et al.* (2020)	X	
Hallman and Hallman (2020)		X
Hamdan *et al.* (2018)		X
Horst and McDonald (2020)	X	
Horst *et al.* (2019)	X	
Ismail *et al.* (2020)	X	
Kirillova *et al.* (2020)	X	
Jasper (2016)	X	
Lee *et al.* (2020)		X
Li *et al.* (2020)	X	
Melzener *et al.* (2020)		X
Milanesi *et al.* (2020)	X	
Oberweis *et al.* (2020)	X	
Seehafer and Bartels (2019)		X
Stephens *et al.* (2019)		X
Verzijden and Buijs (2020)		X
Warner (2019)		X

products.

To the idea of halal forensics, Hassan (2018) added Syariah law, halal standards and acts, halal science, and halal management. Islamic law should be discussed as the first component of halal forensics. Islamic law, which outlines what is permitted and what is not, serves as its foundation. Acts and standards make up the second part. The Trade Description Act of 2011 for example, has indirectly outlined the characteristics of halal food that are significant to Muslims in Malaysia. The specifications of this law must be met by any halal food or product. Upon conviction for any violation of any provision outlined in the Trade Description Act (Definition of Halal) Order 2011, the offender shall be subject to a fine not to exceed MYR 1 million (USD 220,000) or to a term of imprisonment not to exceed 3 years or both. A corporation violating the same provision shall be subject to a fine not to exceed MYR 5 million (USD 1.1 mil.). If a person violates the Trade Description (Certification and Marking of Halal) Order 2011, the penalty upon conviction is a fine not to exceed MYR 100,000.00 (USD 22,300.00) or imprisonment for a term not to exceed three years or both. If a corporate body violates the same offence, the penalty upon conviction is a fine not to exceed MYR 250,000.00 (USD 55,700.00).

Halal science is another element included in HF. The identification of suspicious ingredients in halal foods or products is the subject of this component. All products intended for human consumption must be completely safe and approved by a recognised agency (Hassan, 2018; Roslin *et al.*, 2022). The fourth HF element is halal management. This element is essential for figuring out whether the finished product complies with all halal requirements, from the food source and production until its distribution to the consumer. If any lack in the production lines contravenes the halal product regulation, the manufactured items will be scrutinised, and their halal certification may be revoked (Hassan, 2018). Baharuddin *et al.* (2019) included one extra element which is health implications. This element pertains to food safety and is advantageous to one's bodily, emotional, and spiritual well-being. Numerous health problems might result from consuming hazardous food or products.

The source-composition-manufacturing (SCM) conceptual model, which is used to determine whether a food product complies with halal standards, was suggested by Abdallah *et al.* (2021). The first step is to determine whether the food product originates from an animal, a vegetable, a microbial, a chemical synthetic or a biotechnological source. In the second step, the

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composition must be examined in order to classify ingredients, additives, adjuvants and processing aids as essential or not for halal status. The third step entails inspecting the production facilities to ascertain whether the production lines are only used to produce halal food products or if they are also used to produce non-halal certified goods. Another requirement is that the production line must be sanitised (free from pollutant-*najis*) before halal products can be made.

This study combined these two concepts to get a detailed overview of 3D-printed food in terms of halal standards and certification. Figure 2 shows the combination of HF and SCM to be applied as the foundation of the study.

3. Current standards and regulations for 3D-printed food

The expansion of 3D printing has led to a surge in unlawfully created items that violate intellectual property, patent, and copyright regulations. Food printing uses food-based materials to make food. In the future, 3D food printing may be used to produce unique cuisines utilising chemical molecules instead of food. Epidemiological studies on the short and long-term health consequences of food types will be crucial for specific policies.

Like any other type of food, 3D-printed food could contain allergens, be tampered with, or cause food poisoning if they are made or stored incorrectly. There are already rules about these kinds of concerns at the national, federal, and international levels. The labelling of 3D-printed food brings up another interesting legal issue. 3D-printed food could be considered imitation foods and should be labelled differently than the foods they are based on. On the other hand, if making traditional foods cost more than 3D printing and the printed and traditional foods look the same, selling 3D-printed food without specific labels would be a form of food fraud. However, even if 3D-printed food looks different from regular foods and can be easily told apart from them, they should be labelled differently, as is already done with foods that contain or are made from genetically modified organisms (GMO). Labelling rules for 3D-printed food should also cover the case where only some of the ingredients used to make the food are printed on the label.

The foundation of Malaysia's food safety policy is provided by the Food Act 1983 and the Food Regulations 1985. The Sale of Food and Drug Ordinance and Regulations 1952 is repealed by these laws. The term "food" is defined broadly in the Food Act 1983 as including "every article manufactured, sold or represented for use as food or drink for human consumption or which enters into or is used in the composition, preparation or preservation of any food or drink and includes confectionery, chewing substances and any ingredient of such food, drink, confectionery or chewing substances." Food additives and their proportions are specified under the Regulations. Food additives, processing aids, vitamins, minerals, novel food ingredients and nutritive substances must be approved by the Regulations. When allowed, such substances must be used within the regulations' limits. So far, the 3D/4D-PF is subject to these Regulations in general. On the labelling issue, 3D/4D-PF engages with at least eleven rules of labelling according to the Food Act. illustrations, logos, brand and product name, the quantity of the product, ingredients, nutrition facts, importer/ manufacturer, expiration date, barcode, description of the product and also instructions should be cleared on the packaging of the 3D/4D-PF. What matters here as the

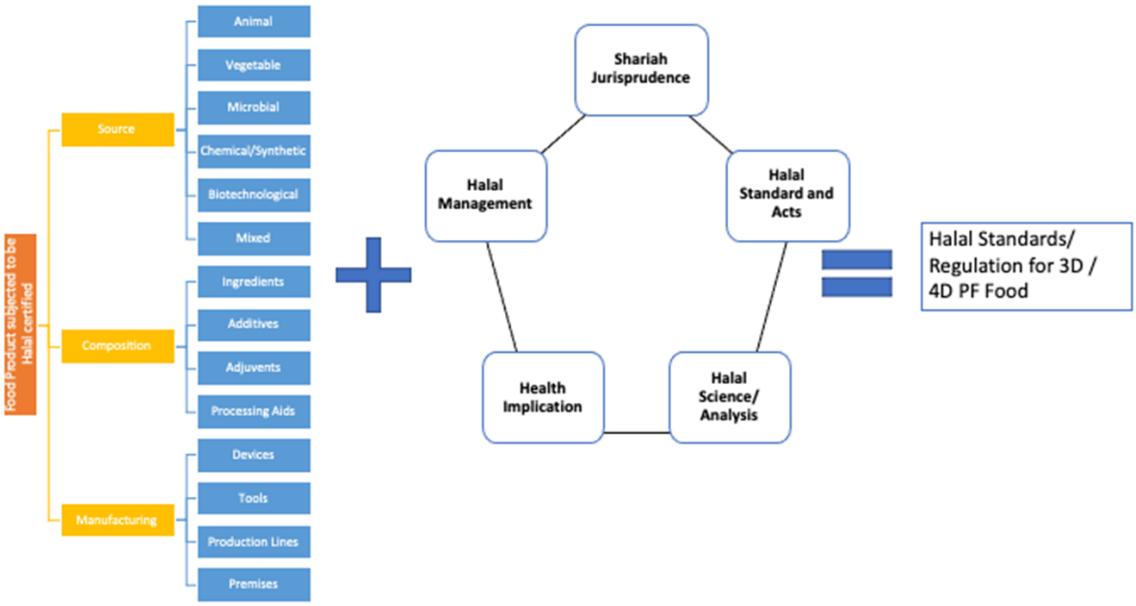

Figure 2. HF and SCM concepts as the foundation of this study adapted from Abdallah *et al.* (2021) and Roslin *et al.* (2022)

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focus of this study is the halal logo obtained is subject to specific halal regulations as 3D/4D-PF can be considered as 'novel foods'. Another issue occurs if it is imported from other countries that have their own halal certification/governing body/organisation since there is no generic halal regulatory framework yet established with regard to the 3D/4D-PF.

3D-printed food may be classified as 'novel foods' in the European Union because they were not widely consumed by the population prior to 15 May 1997, the date when the first regulation on novel foods was enacted in the European Union. The new Novel Food Regulation 2015/2283 governs the term "novel foods" which only encompasses innovative foods, foods made with new technology and production processes, and foods that are or have been traditionally consumed outside of the European Union (European Parliament and the Council of the European Union, 2015). Under this regulation, new foods are required to be safe for consumers, clearly labelled to avoid consumer confusion and, if they are intended to replace existing foodstuffs, not nutritionally deficient to these foodstuffs. Novel foods in the European Union are based on the notion that they must be edible and properly labelled so that consumers are not misled. If a new food is meant to replace another food, it cannot be so different that eating the new food would be bad for the person eating it. Novel foods need to be evaluated based on the above principles before they can be put on sale.

The Food and Drug Regulations in Canada define "novel foods" as substances without a history of safe use that have been produced, processed, preserved or packaged using a method that has never been used before on these foods (Food Directorate Canada, 2006). Prior to marketing or selling, 3D printing would need pre-market approval from Health Canada due to its novel nature and lack of safety data. The duration of the approval process might range from six months to two years.

4. Global halal standards and certification

The International Organization for Standardization (ISO) defines a "standard" as "a document that establishes rules, standards, or characteristics" (International Organization for Standardization, 2015). A competent halal certification body certifies a company's products and/or services as halal. Technical and Shariah auditors verifies each stage of food manufacturing to certify it as halal. When an organisation meets the standard's requirements, it receives a halal certificate and can use the halal logo on its products. If a company's products are halal, Muslims can be sure they are Shariah-compliant. Halal certification promotes consumer confidence and clarifies halal status (Latif, 2020). Halal certification has been an effective tool for Muslim consumers, offering them an informed option; for industries, giving them a marketing tool; and for regulatory bodies, for legal enforcement. Numerous attempts have been made to harmonise halal standards, certification, and accreditation. Despite these attempts to envision a global cooperative organisation, no unification has yet been achieved because many of these organisations have previously been founded. A unified halal standard is still in view. Figure 3 displays the multiplicity of the halal logo that represents the variety of halal certification bodies across the world.

Figure 3. Variety of halal certification logos resembles halal certification bodies across the world. Source: Saipullah *et al.* (2015)

According to Abdallah *et al.* (2021), there is a multiplicity of halal standards across the globe. Some standards are issued by single countries like Malaysia and Indonesia, while most of the Organization of Islamic Cooperation (OIC (OIC) members use the standard issued by the OIC Standards and Metrology Institute for Islamic Countries (SMIIC). Others use the standard issued by the Standardization Organization of the Gulf Cooperation Council (GCC). In terms of halal certification and standards that may be involved in the production of 3D/4D-printed food, the application depends on the production stages of the product. At the moment, the multiplicity of halal standards and the fact that there is no consensus across the globe creates uncertainty for producers to get their product authorized for the market and requires producers from non-Muslim nations or Muslim countries with different standards to seek separate certificates for each export market. The variety of standards (and multiple halal logos on food labels) confuses customers and may reduce their trust in certificates. The implementation of halal standards differs from country to country corresponding to the geographical area, issuing organization and purpose. Some countries have previously developed their own and led others - including the OIC, Malaysia (Latif, 2020) and Indonesia - to develop theirs. Other countries depend on the OIC/SMIIC and Arab Gulf in terms of

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Table 3. Halal standards implementation countries for halal food

Halal Standard Code	Title	Implementation
GSO 2055-1: 2015	Halal foods. Part 1: General requirements.	Saudi Arabia, Qatar, Kuwait, Oman, Bahrain, United Arab Emirates
OIC/SMIIC 1:2019	General requirements for halal food	56 member countries including Egypt, Iran, Saudi Arabia, Turkey, Indonesia, Pakistan, Nigeria, Bangladesh, and Algeria
MS 1500: 2019	Halal food. Production, preparation, handling, and storage. General requirements.	Malaysia
HAS 23201: 2012	Requirements of halal food material	Indonesia

implementation. Table 3 shows general standards for halal foods and their implementation in countries.

5. Halal standards and certification: a case study of 3D/4D-Printed Food

The basic requirements related to 3D/4D Printed Food are common to all the major halal standards. In order to accept 3D/4D-PF as a halal product, there are standards needed to be complied with. Due to the variety of standards around the world, there might be possibilities for the 3D/4D-PF to follow certain requirements of standards according to the implementation countries. However, this depends on the halal critical control point whereby the 3D/4D-PF must be accompanied with, if they are critical, a halal certificate; if not, a halal statement is sufficient as shown in Figure 4.

Firstly, depending on the importance of the ingredients, additives and adjuvants, certain documents are needed during the halal certification process for 3D/4D-PF. Because these processing steps involve the use of components or adjuvants that are crucial for the halal status, fermentation, and enzymatic coagulation both represent a halal Critical Control Point (CCP). Every ingredient, additive and adjuvant needed for each processing step must be accompanied by a halal certificate if it is necessary, or just a halal statement if it is not. Due to the use of non-halal meat ink (paste) in the production of 3D/4D printed meat, for example, the criticality is still high. The source of the ink must be permissible and not affiliated with forbidden elements. Table 4 simplifies the possibility of meat ink source and the Islamic ruling (Baharuddin *et al.*, 2021).

Secondly, all additives, adjuvants, colourants serum, gelatine, filaments, and any binder composition have to be halal-approved. They have to be added to optimize and improve the efficiency pre- and post-printing process (Riaz and Chaudry, 2003). Other than that, a halal statement is adequate. The culture medium and technique must also be permissible to become acceptable for 3D/4D printed meat. The halal certifier should examine the media used in the culture process as it might be

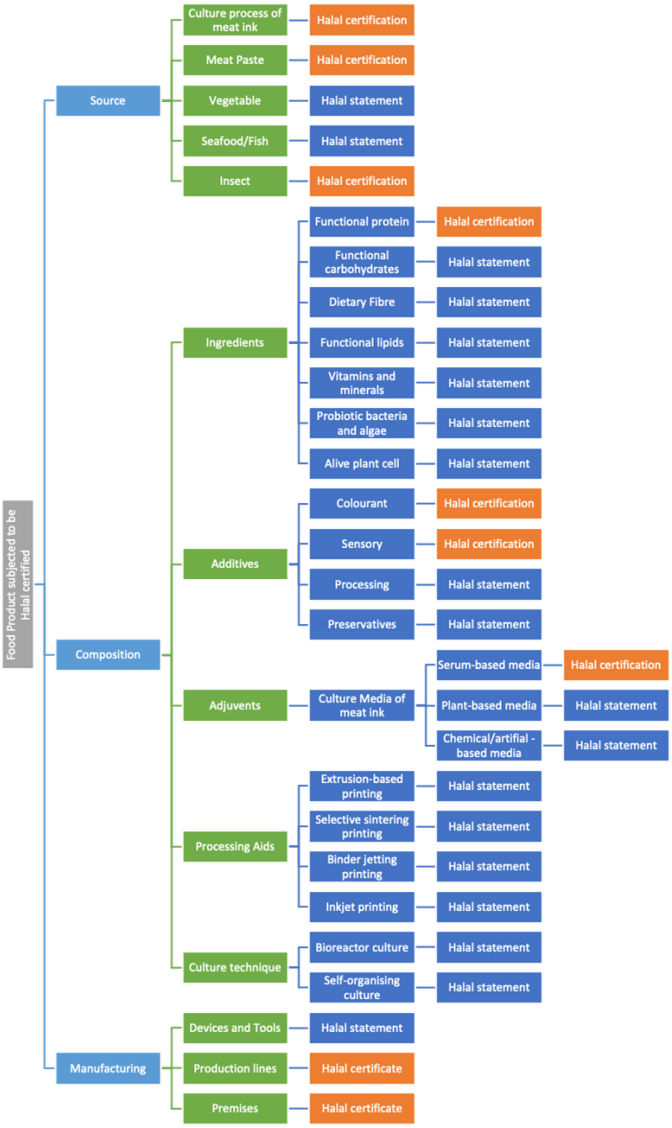

Figure 4. Halal critical point in accepting 3D/4D-PF

sourced from a forbidden medium such as centrifuged blood serum or bovine fetal serum. The technique used in the culturing process is another processing stage connected to a halal CCP, and the first commercial producers must hold a halal certification. Halal-approved cleaning methods must be used along production lines to avoid any cross-contamination with non-halal products. The halal audit should also be done at all stages of the lines where both the producer and the packing company are checked. The food technologist should also find out what ingredient will be used to determine whether it will be eaten directly or not and whether it is a semi-finished or finished product. This will help in specifying the

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Table 4. The possibility of meat ink source and the Islamic ruling. Source: Baharuddin *et al*. (2021)

Islamic Ruling Based on 3D/4D Printed Food Sources of Meat Ink	
Islamic Ruling	Sources of Meat-Ink
Forbidden (Haram)	Matured cultured tissue sourced from Embryonic Stem Cell (ESCs) from non-slaughtered and 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 paste
	Slaughtered permissible animal meat paste
	Plant based meat paste
	Permissible insect-based meat paste
Forbidden (Haram)	Non-slaughtered animals/non-permissible animal/insect meat paste
Islamic Ruling Based on Meat Ink Culture Medium	
Islamic Ruling	Culture Media
Forbidden (Haram)	Blood Serum (Centrifuged)
	Foetal Bovine Serum
	Toxic/ Harmful Chemical Artificial Based
Permissible (Halal)	Non-Toxic/ Non-Harmful Serum-Free Media/Additives
	Non-Toxic/ Non-Harmful Mushroom Extract/ Plant Based
	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

technical documents needed to meet the halal requirements. 3D/4D-printed food should also comply with food safety standards.

Thirdly, at the level of manufacturing, devices, tools, production lines and premises should also be emphasized through OIC/SMIIC 17-1:2020, OIC/SMIIC 6:2019, MS 1500: 2019, HAS 23000: 2012, GSO 2469:2021, and GSO 2468:2021 standards. Any cross-contamination should be avoided by any means. Therefore, the requirements by major standards at this level for a halal-approved cleaning technique are essential. Some tools, devices or printers may have come into contact with pollutants (*najis*). Proper cleansing is subject to the sensitiveness of the mechanical elements.

Lastly, the premises of 3D/4D-printed food must also be halal-certified. For instance, the MS 1500:2009 and HAS 23103:2012 standards mandate that the industrial site and the pig farms be kept apart. Then, according to the HAS 23103:2012 standard, the nearest pig farm, if any, must be at least five kilometres away from the halal premises. Additionally, according to the OIC/SMIIC 1:2019 standard, the slaughtering facility must be exclusively used for halal farming purposes. Lastly, in the phase of labelling and packaging, standards for halal logos/ halal marks or statement states that their 3D/4D-printed food must also be included in the food label. This is to avoid any confusion among consumers and increase their trust in the product through the recognition or certifications on the label and packaging of the 3D/4D-printed food. This is complied with the halal packaging standards and also tallies with the existing food regulations. Connecting the dots, Table 5 indicates major halal standards that may be involved in the A-to-Z production of a halal-certified 3D/4D-printed food.

As illustrated in Table 5, 3D/4D-printed food may involve GSO 2055-1:2015 Part 1 of animals as a source of 3D/4D-printed food. GSO 2055-1:2015, and GSO 993: 2015 may involve the 'Source' and 'Composition' elements except for processing aid. While GSO 2652:2021 may involve labelling and packaging, GSO 2670:2021 may involve ingredients, additives and adjuvants. As for the HAS issued by the Lembaga Pengkajian Pangan, Obat-obatan, dan Kosmetika — Majelis Ulama Indonesia (LPPOM MUI), the 3D/4D-printed food may incorporate 'Source – animal' for HAS

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Table 5. Major halal standards that may involve in the A-to-Z production of a halal certified 3D/4D-PF

Standard Code and Title	Issuing Organization and Implementation Countries	Source Composition Manufacturing Model Potential Application in 3D/4D-printed food													
		Source					Composition					Manufacturing			
		a	b	c	d	e	f	g	h	i	j	k	l	m	n
GSO 2055-1:2015: Halal Food - Part 1: General Requirements	Issuing organization: GCC Standardization Organization (GSO) (being GCC = Gulf Cooperation Council) Implementation Countries: Saudi Arabia, Qatar, Kuwait, Oman, Bahrain, United Arab Emirates	X													
GSO 2055-1:2015: Halal foods. Part 2: Guidelines for halal foods certification bodies.		X					X	X	X						
GSO 993: 2015: Animal slaughtering requirements according to Islamic law		X					X	X	X						
GSO 2468:2021: Halal Food-Management System Requirements For Transportation Of Goods And/Or Cargo Chain Services													X	X	
GSO 2652:2021: Halal Packaging-General Guideline															X
GSO 2469:2021: Halal Foods-Management System Requirements for Warehousing and Related Activities													X	X	
GSO 2670:2021: Halal Products- Usage Of Animal Bone, Skin And Hair- General Guidelines							X	X	X						
HAS 23000: 2012 - 1: Requirements of halal certification	Issuing organization: Lembaga Pengkajian Pangan, Obat-obatan, dan Kosmetika — Majelis Ulama Indonesia (LPPOM MUI), for example, “The Assessment Institution for Food, Drugs and Cosmetics of the 23000: Indonesian Council of Ulama”. Implementation Country: Indonesia	X													
HAS 23000: 2012 - 2: Halal Certification Requirements for Meat Processing Industry							X	X	X						
HAS 23000: 2012 - 5: Halal Certification Requirements for Logistic Industry													X	X	
HAS 23103: 2012: Guidelines of halal assurance system criteria on slaughterhouses		X					X	X	X						
HAS 23201: 2012: Requirements of halal food material		X	X	X	X	X	X	X	X						

a: animal, b: vegetable, c: microbial, d: chemical synthetic, e: biotechnology, f: ingredients, g: additives, h: adjuvants, i: processing aids, j: devices, k: tools, l: production lines, m: premises, n: labelling and packaging.

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Table 5 (Cont.). Major halal standards that may involve in the A-to-Z production of a halal certified 3D/4D-PF

Standard Code and Title	Issuing Organization and Implementation Countries	Source Composition Manufacturing Model Potential Application in 3D/4D-printed food													
		Source					Composition					Manufacturing			
		a	b	c	d	e	f	g	h	i	j	k	l	m	n
MS 1500: 2019: Halal food. Production, preparation, handling and storage. General requirements.	Jabatan Kemajuan Islam Malaysia (JAKIM), i.e., "Department of Islamic Development Malaysia" — Department of Standard Malaysia (DSM). Implementation Country: Malaysia												X	X	
MS 2565: 2014: Halal Packaging: General Guidelines															X
OIC/SMIIC 1:2019: General requirements for halal food	Organization of Islamic Cooperation (OIC) — Standards and Metrology Institute for Islamic Countries (SMIIC)	X	X	X	X	X									
OIC/SMIIC 6:2019 Particular requirements for the application of OIC/SMIIC 1 to places where Halal food and beverages are prepared, stored and served													X	X	
OIC/SMIIC 17-1:2020 Halal Supply Chain Management System - Part 1: Transportation/ Part 2: Warehousing/ Part 3: Retailing – General Requirements													X	X	
OIC/SMIIC 22:2021 Halal Edible Gelatine – Requirements and Test Methods							X	X	X						
OIC/SMIIC 24:2020 General Requirements for Food Additives and Other Added Chemicals to Halal Food							X	X	X						
OIC/SMIIC 37: 2022 Halal Products- Usage of Animal Bone, Skin and Hair- General Guidelines							X	X	X						
Hazard Analysis Critical Control Points (HACCP)	US Food and Drug Administration (FDA)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Good Manufacturing practices (GMP)	May varies depending to countries	X	X	X	X	X	X	X	X	X	X	X	X	X	X

a: animal, b: vegetable, c: microbial, d: chemical synthetic, e: biotechnology, f: ingredients, g: additives, h: adjuvants, i: processing aids, j: devices, k: tools, l: production lines, m: premises, n: labelling and packaging.

23000: 2012 – 1, HAS 23000: 2012 – 2 for ingredients, additive and adjuvants, and HAS 23000: 2012 – 5 for premises, labelling and packaging. HAS 23103: 2012 may be involved in 'Source – animals', 'Composition - ingredients, adjuvants and additives' while HAS 23201: 2012 may comprise the 'Source' and 'Composition' elements except processing aid. Malaysian Standards of MS 1500: 2019 and MS 2565: 2014 may comprise the production line, premises, labelling and packaging in the halal certification of 3D/4D-printed food product. In terms of the standards issued by the OIC Standards and Metrology Institute for Islamic Countries (SMIIC), they will involve specific standards for a certain part of the 3D/4D-PF. OIC/SMIIC 1:2019. General requirements for halal food may involve all 'Source' parts of the 3D/4D-PF from animal, vegetable, microbial, chemical/ synthetic, to biotechnology; while OIC/SMIIC 22:2021, OIC/SMIIC 24:2020 and OIC/SMIIC 37: 2022 may involve the 'Manufacturing' part which are ingredients, additives and adjuvants. As for the OIC/SMIIC 6:2019 and OIC/SMIIC 17-1:2020, both may implicate the certification process involving premises and production lines. Most certainly, the HACCP and GMP may involve in each aspect of SCM's potential application for 3D/4D-printed food product halal standards and certification.

6. Conclusion

Overall, there seems to be some evidence to indicate that a specific legal framework needs to be established for halal 3D/4D-printed food. 3D food printing could help feed the rising population. In the future, 3D/4D-printed food will help address the world food issue without animal suffering, wasting water, or generating carbon thereby helping to protect and preserve the environment. More research should be conducted for the betterment of this technology. Although experts in nutrition and 3D technology believe that 3D food printing has the potential to address specific health and environmental issues, its prolonged effect on health has never been studied. Halal standards analyzed in this study denote that there is a necessity for the world, especially for the Muslim population, to be ready for the halal issues of 3D/4D-printed food. A further study with more focus on the halal legal framework in specific countries is therefore suggested.

Conflict of interest

The authors declare no conflict of interest.

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