Review
Scientific and Islamic perspectives in relation to the Halal status of cultured meat

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Cultured meat is meat produced from stem cell biopsies of cattle. Stem cells were cultured in a bioreactor in the presence of serum to grow the flesh to maturity. Cultured meat technology originated from regenerative medical technology; however, it has been given a new lease of life to produce cultured meat as an innovative food source in the future without involving cattle breeding. This technology can reduce the negative environmental impacts of global warming, water use, soil, and unethical handling of animals. In the excitement of accepting this new technology, the halal status of cultured meat is in question, as it can be produced from embryonic stem cells and myosatellite cells, each of which can be disputed for their halal status. Additionally, the process of culturing and maturation of stem cells involves the use of an impure medium derived from animal blood. Thus, cultured meat is acceptable to Muslims only if the stem cells, medium and scaffold biomaterials used to manufacture it are from Halal sources and shall be in line with the six principles discussed in this study. The discussion is based on Halal and haram animals; Animal slaughtering; Not derived from a source of najs (impurity); Istihalah tammah (perfect substance change); Maslahah (public interest or benefit) and mafsadah (damage); and Darurat (exigency) of cultured meat.

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Article info
Article history:
Received 16 June 2022
Revised 13 October 2022
Accepted 10 November 2022
Available online 15 November 2022

Keywords:
Science and Islam perspective
Halal status
Cultured meat
In vitro meat
Laboratory grown meat
Clean meat

Abstract
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1. Introduction

Cultured meat, in vitro meat, laboratory-grown meat, artificial meat, clean meat, or cell-based meat is a cell-based biotechnology meat that can replace traditional animal meat products. It refers to the use of muscle-specific stem cells from animals grown with a sufficient number of cells that can differentiate into tissue tissues (Post 2014). A technology similar to the cultured meat technology has been developed for other products such as skin, seafood, and milk (Post et al. 2020). In 2013, Prof. Mark Johannes Post, a professor of tissue engineering at the University of Maastricht, Netherlands, first proved the concept of cultured meat derived from cattle by producing cultured meat burgers and demonstrating cooking and eating burgers with two panellists at Riverside Studios, London in August 2013 (The Associated Press 2013; Wurgaft 2019). The two panellists were Josh Schonwald, one of the authors of the book “The Taste of Tomorrow” and Hanni Rutzler, a nutritionist from Austria. According to Mark J. Post, cultured meat is safe to eat and tastes no different from real meat. According to him, the beef produced was not red but yellowish, and to make it look like beef, he added a small amount of red beet juice and saffron. The panellists Josh Schonwald and Hanni Rutzler were satisfied with the taste, and they noted that the taste was very similar to that of real meat (Hamdan et al. 2017; Zaraska 2013).

Mark J. Post produced cultured meat using bovine thigh stem cells in a bioreactor containing serum as the culture medium (Post 2014). Cultured meat technology originated in the field of regenerative medicine, where the objective was to restore injured tissues in the medical field, Post suggested the name cultured meat to distinguish it from edible meat. Cultured meat was once mentioned by Winston Churchill in 1932; however, the idea was believed to have come from his friend, Alexis Carrel, a scientist. Carrel (1937) successfully cultured fragments/isolates of liver cells from chicken embryos, and he maintained the cells ex vivo (outside the body of the animal) for a long time. The historical chronology of cultured meat has been described in detail by Hamdan et al. (2017).

Globally, cultured meat is gaining attention as an alternative to traditional meat protein sources obtained from slaughtering cattle, goats, or chickens. Cultured meat can potentially be used in the future as a source of non-slaughtered meat, which can be cultured in the laboratory in a bioreactor (cell culture container) to produce a large number of cultured cells. Cells are harvested and modified to produce processed products such as beef burgers, chicken nuggets, sausages, and foie gras (special food products made from duck or goose livers) and potentially as a whole cut (Kifordu et al. 2020).

Cultured meat is very popular among environmentalists, who believe that it can reduce the effects of environmental destruction due to large-scale farming. Global warming due to greenhouse gases is believed to be caused by the livestock sector, which releases carbon dioxide, methane, and nitrogen oxide gases, thus, increasing the temperature by 0.5–2.0 °C. Maurya et al. (2015) reported that methane, one of the major greenhouse gases after carbon dioxide, leads to 15 %-20 % of global warming. If cultured meat can be mass-produced as an alternative to conventional farming, the emissions of such greenhouse gases are estimated to be reduced by up to 96 %.

Cultured meat can also solve the growing demand for animal products owing to the increasing world population and growing wealth. Today’s world population, which is approximately 7.3 billion people, is expected to surpass 9 billion by 2050. The projection shows that by 2050, nine to ten billion people will be walking on Earth (Shapiro 2018; Hocquette et al. 2020). If most of them are lavish, a large amount of land, water, and animal welfare will be required to meet this demand. The livestock industry requires a high demand for animal shelters, pastures, manure management, water, and other infrastructure to support this industry. Additionally, cultured meat can be produced using controlled parameters (temperature and culture medium) without the use of antibiotics or pesticides (Bhat et al. 2014). Cultured meat can reduce the number of animals sacrificed for food supply, and in turn, it can improve human health by reducing the chances of infection with zoonotic diseases (animal-borne diseases)(Bhat et al. 2014; Zhang et al. 2020).

The concept of cultured meat was introduced to America in 2016 by Memphis Meats, a food technology company headquartered in Berkeley, California, USA. The company was promoting cultured meatball products by publishing videos about them, and a year later, in 2017, the company published videos for cultured chicken and duck dishes. The company had provided substantial funds for investing in the project for producing cell cultures in bioreactors, which involved substantial research and financial investment, which later involved Bill Gates as one of the project’s contributors. The biggest barrier to bringing cultured meat to the consumer market is the high cost of cell growth medium (Mizukami & Swiec 2018). However, this did not stop another cultured meat production company, Eat Just, from selling nugget-cultured chicken meat products to the public. Cultured chicken meat is being sold in a restaurant in Singapore after the Singapore government became the first country in the world to approve the sale of cultured chicken meat products (Kifordu et al. 2020).

The global halal food industry has a high economic value for halal food. Data released by the Global Islamic Economy Report 2020/21 show that consumer spending on halal food and beverages has increased by 3.2 percent as compared to 2018, with global Muslim spending totalling USD 1.17 trillion in 2019, and it is expected to continue to increase to USD 1.38 trillion by 2024 (HDC, 2021). This shows the capability of Muslim consumers to spend their income in the halal food market. Ignoring the capabil-
ities of Muslim consumers causes huge losses to the country’s halal industry. Muslim consumers strongly emphasise the halal status of food products, which has some scientific benefits. For Muslim consumers, cultured meat must comply with the standards set by MS1500:2009 (Malaysian Standard 2009), MS1500:2019 (halal food) (Malaysian Standard 2019), Shariah law, and fatwa. Cultured meat has been viewed as an opportunity for Malaysia to explore the cell-based halal food industry. Additionally, studies have been conducted on serum-free culture media for bovine myoblasts (Kolkmann et al. 2020).

2. Concept of cultured beef

Cultured meat is aimed at mimicking conventionally produced meat through stem cell and tissue culture. Stem cells and tissues obtained from the stem cell source are placed in a culture medium suitable for cell growth and must contain the nutrients needed for cells to multiply and mature. With the presence of biomaterials, the stem cells are induced to form muscle fibres, as a major component of meat (Bhat et al. 2015). The most suitable medium for stem cell/tissue proliferation (proliferation) is a medium containing 5–10% blood serum. Serum is a liquid derived from blood that does not play a role in blood clotting. It is a solution containing a mixture of complex proteins, hormones, growth factors, and other components that are essential for animal cell reproduction (Pledger et al. 1984). A brief illustration of the concept of cultured meat published by Post et al. (2020). Scaffold biomaterials are also used for the structuring and morphology of cultured meat. They serve as an integrated support network to expand and differentiate stem cells and tissues in an anchorage-dependent manner. The type of material used as scaffold-based can be derived from animal such as collagen or gelatine. Other alternative materials are polysaccharide such as cellulose, starch, pullulan, alginates, hyaluronic acid and others (Cunha & Gandini 2010, Ben-Ayre et al. 2020).

3. Embryogenesis and stem cells

Embryogenesis and the subsequent growth of an entire organism starts with fertilisation and the development of cells into new organisms through a complex and progressive series of events, leading to the formation of various types of cells, tissues, and organ systems. Fertilisation is the result of fusion between male (spermatozoa) and female gametes (oocyte) that form the zygote. Once the zygote reaches the two-cell stage, it undergoes cleavage with a series of mitotic cells (cell division) to increase the number of cells. These cells are small in size, and they are known as blastomeres (Sadler 2003). Following the third fission, blastomeres maximise contact with each other by forming dense cell balls and removing blastomere boundaries (Sadler 2003). These dense cells divide further up to the level of 16 cells, known as the morula. Centric cells of the morula form the inner cell mass (ICM) while the surrounding cells comprise the outer cell mass. ICM forms embryonic tissues, and the outer cell mass forms a trophoblast that penetrates the uterine mucosa. Gradually, the space between the cells forms a single cavity known as the blastocyst. At this stage, the embryo is called the blastocyst. The ICM, now called the embryo, is in a single pole, and the outer cell mass or trophoblast flattens and forms the epithelial wall of the blastocyst. The inner cell mass of the blastocyst can be isolated and propagated to produce ESC lines. Stem cells are pluripotent because they can grow into any conceivable body tissue, other cells, or tissues such as muscle cells, nerves, bones, and other tissues.

On forming tissues and tissue-specific stem cells, cells lose their pluripotency and become more tissue-specific. Some of these cells form adult stem cells while most cells fully differentiate into tissue cells. Adult stem cells are undifferentiated cells that reside between different cells in a tissue or organ. They can multiply (proliferate) and self-renew by maintaining at their specialized cell types. This technology is widely used in medicine to treat injured or dysfunctional organs. The concept of this technology was used by Post (2014) to produce cultured beef using muscle stem cells. Biopsy is performed (tissue is removed from the body of a living animal) to obtain satellite cells (muscle-specific stem cells) and adipose tissue. Satellite cells multiply and combine to form primitive myotubes in the serum media. During this phase, the serum concentration is reduced from 20% to 2%. Differentiation is typically initiated by serum withdrawal, although it is not completely removed. When these myotubes are cultured around the gel loop, they produce more proteins to form burger meat tissue, and it looks like a donut as its growth surrounds the loop. The demonstration of cooking and eating cultured beef in London in 2013 gave three main messages: technically, meat can be cultured in the laboratory; cultured meat is an alternative to traditional beef production; and beef culture is an ethical and environmentally-friendly method to produce beef (Post 2014).

4. Cultured meat technology

4.1. Cell selection

There are two types of stem cells: ESCs and adult stem cells (ADSCs/non-ESCs). ESCs are pluripotent stem cells that can multiply in different tissues; however, they lose pluripotency once they are isolated from blastocysts. ESCs are the best choice for cultured meat production due to their ability to reproduce and grow without limit (Bhat et al. 2014). However, the use of ESCs for cultured meat raises ethical issues regarding the use of embryos or foetuses for formation of cultured meat.

Myosatellite cells (MCs) or satellite cells are adult stem cells that have maintained the ability to self-renew and proliferate; however, they can only differentiate into muscle cells (categorised as ADSCs). MCs can be extracted from adult animal tissues, and they can develop into muscle cells (Wagers & Weissman 2004). MCs are considered the best choice for cultured meat production because no external signals are required to promote transformation into muscle cells. MCs can be isolated from farm animals, such as cattle (Dodson et al. 1987), pigs (Wilschut et al. 2008), chickens (Yablokova-Reuveni et al. 1987), turkeys (McFarland et al. 1988), fish (Powell et al. 1989), and sheep (Dodson et al. 1986). In MCs culture, medium conditions such as serum composition can be adjusted to support the proliferation and differentiation of cells to form immature muscle fibres called myotubes. However, MCs have some drawbacks. Adult stem cells have limited proliferative capacity, typically up to 50 doublings. Prolonged cell expansion and fission can cause a cellular phenomenon known as Hayflick limitation, that is, a long period of cell fission, during which MCs lose the ability to separate due to telomere shortening (Lazennec & Jorgensen 2008). Additionally, isolating them from animals is difficult and usually requires biopsy (Datar & Betti 2010).

4.2. Techniques in cultured meat production

There are roughly-three culture-meat production techniques: scaffold-based, self-organising, and 3D printing.

4.2.1. Scaffold-based

In scaffold-based techniques, embryonic myoblasts or MCs proliferate and attach to scaffolds or carriers, such as collagen meshwork or microcarrier beads, and they are then cultured in a culture medium in a stationary or rotating bioreactor (Edelman et al. 2005; Bhat et al. 2014). Various environmental cues have
been introduced, leading to the fusion of these cells into myotubes and their differentiation into myofibers. Stem cells were grown and suspended together with collagen spheres used as a substrate or scaffold onto which myoblasts can attach and differentiate. Myoblasts form myotubes on collagen spheres. Myotubes differentiate into myofibers in the bioreactor, and they can be harvested, cooked, and consumed as meat (Wolfson 2002). The other approach used is collagen meshwork as scaffold-based. The culture medium was refreshed occasionally or percolated through the porous surface. After differentiation into myofibers, the muscle cell embedded in the collagen can be harvested and used as meat (Van Eelen 1999). Scaffolding techniques are also used by growing muscle tissues on large sheets of edible separable material, in which muscle tissues can be processed after being rolled up to a suitable thickness. The scaffold-based approaches mentioned above may be appropriate for producing ground processed meats, such as hamburgers or sausages. They are not highly structured meats such as steak; however, the cells can be cultured in substrates that allow 'self-organising constructs', producing more rigid structures (Bhat et al. 2014).

Fresh meat does not comprise only one type of muscle tissue but also includes fat and connective tissues (Ben-Arye & Levenberg 2019). A combination of more tissues grown separately and then fused using a tissue engineering approach is required for full thickness complex tissue engineering (Post et al. 2020). The production of complex tissues requires muscle, fat, connective tissue, and vascular cells using the scaffolding method improves the production of complex meat products from muscle, fat, connective tissue, and vascular cells using the scaffolding method improves tissue, and vascular cells using the scaffolding method improves the productivity of cultured meat on a large scale. The productivity of cultured meat depends on the medium composition, which determines the final characteristics of the meat product (Post et al. 2020).

The medium for cell proliferation must be different at different stages of flesh development. The cell differentiation stage, with changes in the major metabolic activity in terms of energy and nutrient utilisation, leads to the production of specific proteins. For example, complex tissues comprising muscle and fat tissues require different media compositions to continue their development until maturity (Post et al. 2020). The cultured meat medium used for meat culturing is usually sourced from animals, for example, foetal bovine serum (FBS), which takes up to 20% of FBS at the maximum, and the rest of the medium contains water, glucose, amino acids, minerals, and vitamins. However, its use is limited as FBS faces the risk of bacterial, viral, and endotoxin contamination (Fang 2017) and unknown chemical elements in the serum. Additionally, FBS violates the ethical principles of animal use for meat culture (Post et al. 2020). Therefore, the use of serum is unsustainable. FBS can be replaced with chemicals such as growth factors to support the germination of cultured meats. Kolkmann et al. (2020) reported the proliferation of bovine myoblasts in serum-free media as a precondition for scaling up; thus, the cost of meat production per kilogram should decrease.

Apart from increasing the multiplication capacity of stem cells, producing cultured meat on a large scale economically is highly desirable. However, their start-up culture medium was not serum-free as FBS and horse serum were added. This indicates the medium is still being used in cultured meat production which is not allowed in Islam. Benjaminson et al. (2002) has succeeded in using a serum-free medium made from maitake mushroom extract (over 13%) with a high growth rate as compared to that of FBS (14%) in goldfish. Their start-up culture media was also not serum-free.

Myoblasts are attachment-dependent cells that require a sub-stratum or scaffold for proliferation and differentiation of cells. An ideal scaffold must have a large surface area for growth and attachment, allow myoblast contraction, maximise medium diffusion, and easily dissociate from the meat culture (Bhat et al. 2014). Scaffolds should preferably be degradable, palatable, safe, and readily available for large-scale production (Post et al. 2020). Since myoblasts normally undergo spontaneous contraction, a flexible substratum is necessary to prevent the detachment of developing myotubes (Edelman et al. 2005). However, the development of a scaffold that mechanically stretches the attached cells to stimulate differentiation remains a great challenge. Cytoex-3 microcarrier beads have been used as scaffolds in rotary bioreactors; however, these beads have no stretching potential. The approach to mechanically stretch myoblasts involves the use of edible and stimulus-sensitive porous microspheres made from promising materials, such as cellulose, starch (amylose/amylpectin), alginites, chitosan, pullulan, and hyaluronic acid (Cunha & Gandini 2010, Ben-Arye et al. 2020). Manipulation of biologically sourced materials such as collagen should be avoided because collagen is non-replicative and requires substantial production of livestock which this will increase the production cost (Post et al. 2020).

6. The concept of Islamic nutrition

The concept of nutrition in Islam is based on the guidance of Shariah Law, which is sourced from the Qur'an, sunnah, the consensus of Islamic jurists (ijma’) and analogy (qiyas), and the
method of legal consideration (ijtihad) (Sahilah et al. 2016). In Malaysia, Shariah decisions based on ijtihad or ‘fatwa’ on halal matters should be in line with Mazhab Shafie Ahlu-Sunnah wa al-Jamah. Therefore, certain foods are halal and not halal according to the Shariah law, if deemed so by any of these sources. Halal is permissible and not prohibited by the Islamic law. Halal is the opposite of haram, which is impermissible in Islam. Obeying what is halal will be promised a reward while sin is for those who disbelieve in it. Meanwhile, the word toyiban, in terms of language, is a word (masdar) derived from the verb taba, which means good.

Four verses in the Qur’an mention the Halalan toyiban. All these surahs are associated with the word ‘eat’. In simple form, it means “Halal and good”. Among the four, one is in surah al-Baqarah verse 168: “O mankind, eat from whatever is on earth [that is] lawful and good and do not follow the footsteps of Shaitan (the devil). Indeed, he is to you a clear enemy”. The other surahs mentioned in Halalan toyiban are al-Maidah verse 88, al-Anfal verse 69, and an-Nahl verse 114. The meaning of Halalan toyiban encompasses the following; 1. halal foods from halal sources, 2. acceptable by the fitrah method, 3. have a non-shubhah element, and should be 4. hygienic, 5. safe, and 6. nourishing (Amir 2015). Therefore, Muslim consumers should consume food according to the Islamic concept that serves their spiritual and physical well-being.

Halal food from halal sources means halal food permitted by the Shariah law, which is clearly stated in the Qur’an (al-Maidah verse 88, al-Anfal verse 69, an-Nahl verse 114) and MS1500:2019 (third revision). Halal food sources refer to food from self-owned halal resources and not from the acts of stealing, corruption, deceit, and riba (interest).

Food acceptable by fitrah means that fitrah and human nature are not inclined towards something disgusting. Disgusting animals such as lice, fleas, lizards, and caterpillars are prohibited from being eaten by syarik (Syariah law and fatwa). Human nature in the aspect of food is regarded in the term “toyiban”, described by al-Razi (2000) “...toyiban means something which is found to be compelling that captivates the soul”. Meanwhile, al-Qurtubi (1964) describes the food that is acceptable by fitrah in this way, “…toyiban is something that is found to be compelling, that is why it is forbidden to eat dirty animals such as lizards.” Subhah or masbooh foods are foods that come from dubious or uncertain sources, in which Muslims do not know the halal or haram of any kind of food and drink. Therefore, every Muslim must refrain from eating food of unknown halal status. Rasulullah SAW said, “Surely, what is Halal is clear and what is Haram is clear, between those two is syuhah (a dubious area) that many people do not know about. So, whoever distanced himself from it, he has saved his religion and his honour and those who fall into it, he has fallen in the state of Haram’ (Hadith riwayah Muslim w.y.).

Acceptable food is deemed Halalan toyiban and must be hygienic and safe. Hygiene is a dietary practice free of najs (impure things) and filth. Ibn ’Ashur (1984) in his interpretation of Halalan toyiban emphasises on the aspect of hygiene. Safe foods emphasise aspects that do not pose harm to humans. Ibn Kathir (1999) states “Halalan is what is permissible to eat”. Toyiban is good for the soul and does not affect the body or mind. Hygienic food in terms of preparation and storage can prevent humans from being affected by foodborne diseases caused by pathogenic bacterial contamination, such as Salmonella Typhi, S. Paratyphi, Escherichia coli O157: H7, Bacillus cereus, Listeria monocytogenes, Vibrio cholerae, and V. parahaemolyticus. Individuals affected by these bacteria may experience diarrhoea, vomiting, and dizziness. Hygiene should be prioritised among food operators to ensure food cleanliness and safety. The presence of heavy metals and pesticides should also be avoided in foods, beverages, cosmetics, and pharmaceutical products.

Halalan toyiban food also means nutritious food that benefits the physical and spiritual aspects. Al-Zuhaili (2002) states “Toyiban is something . . . that benefits the wellbeing of the body, spiritual and faith”. The best food helps prevent disease and improve health to an optimal level. Six categories of nutrients, protein, carbohydrate, fat, fibre, vitamins, and minerals, are important for the body. The intake of grains, fruits, and vegetables also helps reduce the risk of obesity or being overweight. Grains, fruits, and vegetables are crucial components for maintaining health. The Halalan toyiban diet is also associated with physical and spiritual activities that can improve the level of health in accordance with the Prophet Muhammad SAW’s practices in life, such as fardhu (obligatory) and sunnah (voluntary) prayers, as well as fasting for three days a month. Thus, the six elements (halal foods from halal sources, acceptable by fitrah, non-shubhah elements, hygienic, safe, and nourishing) in the Halalan toyiban diet concept will be taken into account in relation to Halalan toyiban and the darurat (exigency) of cultured meat.

Halal food in Malaysia is based on MS1500:2019 (third revision), which is generally described as halal food guidelines (Malaysian Standard 2019). Among the items 3.4 in MS1500:2019, halal food includes food and beverages and/or ingredients that are permitted based on Shariah law and fatwa, and among the conditions that need to be met are food that 3.4 a) does not consist or contain parts of animals prohibited by Shariah law and fatwa; b) does not contain anything that is unclean according to Shariah law and fatwa; c) is not intoxicated in accordance with Shariah law and fatwas; d) is not human part or its proceeds are not permitted by Shariah law and fatwa; e) is not toxic or harmful to health; f) is not used during the preparation, processing, or made using instruments contaminated with najs in accordance with Shariah law and fatwa; and g) is not included in the process of preparation, processing, or storage in contact with the mixture, or in close proximity to food that fails to meet items 3.4 (a) and (b).

Meanwhile, according to MS1500:2019, najs are defined as impurities according to Shariah law and fatwa. According to Shariah law, Najs are: a) dogs, pigs, and their offspring or descendants; b) Halal food contaminated with non-halal items; c) Halal food direct contact with non-halal items; d) Any liquids and objects removed from human or animal holes such as urine, blood, vomit, pus, faeces, and placenta; e) carcasses or halal animals that are not slaughtered in accordance with Shariah law and fatwa except aquatic animals and certain insects; and f) Khamr (liquor) and food, drink, or goods containing or mixed with khamr. Khamr is an intoxicating liquor or liquid prohibited according to the Shariah law and fatwa. Therefore, based on item 3.4 a) halal food intake should not consist or contain parts of animals prohibited by the Shariah law and fatwa. Cultured meat can only be eaten if its production complies with the conditions outlined by the Shariah law and fatwa.

6.1. Permissibility of cultured meat to be consumed

Understanding the manufacturing process of cultured meat can explain its halal status. There are three factors that need to be considered to allow cultured meat to be eaten by Muslim consumers. 1. The type and source of animal cells used must comply with the Islamic laws. 2. The medium used for culturing stem cells in mature meat. 3. The biomaterial used in proliferation (using microspheres, spread sheets, or porous edible scaffolds) or the structure and morphology of meat. Islamic perspectives on cultured meat will be discussed based on the use of ESCs, MCs, serum, and biomaterials as the source of meat construction. There are six principles used as a guideline for cultured meat rulings that can be consumed. They are; 1. Halal and haram animals; 2. Animal slaughter; 3. Not derived from a source of najs (impurity); 4. Istihalah tammah (perfect substance change); 5. Maslahah (public interest
or benefit) and mafsadah (damage); and Darurat (exigency) of cultured meat.

Principle 1: Halal and Haram animals.
All products produced from halal animals are deemed halal as long as the slaughtering is Syariah compliant (Kashim et al. 2018). Thus, the use of cattle for cultured meat is halal or permissible as long as Syariah compliant. According to MS1500:2019, there are two types of animals, land and aquatic animals.

All land animals are halal as food except the following: a) Halal animals that are not slaughtered according to the Shariah law and fatwa; b) Najs al-mughallazah animals, i.e., pigs and dogs as well as their descendants and derivatives; c) Animals with long pointed teeth or tusks that are used to kill prey such as tigers, bears, elephants, cats, and monkeys; d) Predatory birds such as eagles and owls; e) Pests and/or poisonous animals such as rats, cockroaches, centipedes, scorpions, snakes, wasps, and other animals; f) Animals that are forbidden to be killed in Islam such as bees (al nahalah) and woodpeckers (hud-hud); g) Creatures that are considered repulsive such as lice and flies; h) Farmed halal animals that are intentionally and continually fed with najs; and i) Other animals forbidden to be eaten in accordance with Shariah law and fatwa.

All aquatic animals are halal except a) aquatic animals that are poisonous, intoxicating, or hazardous to health; b) animals that live on land and water, such as crocodiles, turtles, and frogs; c) aquatic animals that live in najs or intentionally and/or continually fed najs; and d) other aquatic animals forbidden to be eaten in accordance with Shariah law and fatwa (MS1500:2019). Najs is further explained in Principle 3.

Principle 2: The Islamic process of animal slaughtering.
Every animal that is halal in Islam is in accordance with MS1500:2019, and it is slaughtered according to Shariah law. Guidelines for halal slaughter animals have been set up by MS1500:2009 (second revision) (MS1500:2019 third revision, item 3.5.2, was issued to form a new manual; thus, MS1500:2009 is still applicable for the process of halal animal slaughter). Item 3.5.2: The slaughtering process must consider the welfare of animals in accordance with Shariah law, and the conditions of slaughter must also be complied with. Qur’an has stated in chapter an-Nahl verse 5 “And He creates farm animals [Cattle, goat, sheep, camel and etc.], you derived warmth from them and [various other] uses; and from them you obtain”. Additionally, from the hadith narrated by Shaddid bin Aus, Verily Allah has enjoined goodness to everything; so when you kill, kill in a good way and when you slaughter, slaughter in a good way. So every-one of you should sharpen his knife, and let the slaughtered animal die comfortably (Muslim, hadith 1555). Shariah Law and fatwa do not allow the charity of animals to be neglected. The slaughter act shall sever the trachea (halqum), oesophagus (marikh), and both the carotid arteries and jugular veins (wadajain) to hasten the bleeding and death of animals. Bleeding was spontaneous and complete. The slaughter knife or blade is sharp and free from blood and other impurities. Bones, nails, and teeth should not be slaughtered.

A discussion on cultured meat based on the use of ESCs and MCs as a source of stem cells has been reported by Hamdan et al. (2017). Two types of cells can produce cultured meat, ESCs and MCs. ESCs contain embryonic cells resulting from fused male and female gametes. However, used embryonic stem cells that have not yet become a body and have not differentiated into other limbs (mudghah, a piece of flesh) are said to be in a state of ‘alaqah (a piece of blood) in the uterus of the female animal (Ibn ‘Atiyah 2001; Al Qurtubi 2006). It is impossible to slaughter an embryo in the form of ‘alaqah; thus, the slaughter status is on the mother of the foetus. From the hadith of the Prophet SAW: “The slaughter of the foetus follows the slaughter of the mother (slaughtering the foetus in the womb, it is enough to slaughter the mother)” Narrated by al-Tirmizi (al-Tirmizi 1996). In Islamic blood, ‘alaqah is considered unclean/pure; however, in the production of cultured meat, ‘alaqah are separated from the mother’s uterus that has been slaughtered according to the Shariah law, which gives it the status of clean or edible cultured meat because its status changes from ‘alaqah to mudghah (clean/pure meat) (Hamdan et al. 2017). However, it depends on Islamic scholars who consider mudghah to be clean/pure.

Cultured meat derived from MCs is obtained from biopsy (tissue removed from a living body). If the animal is not slaughtered as prescribed by the Islamic law, it becomes a carcass, and it is impossible for us to eat it. Similarly, any severed part of a surviving (land) livestock animal can become a carcass. The Prophet SAW said, “Anything that is cut from livestock while it is still alive then it is a carcass.” Riwayah of al-Tirmizi (Al-Tirmizi 1996). Therefore, the intake of MC-type stem cells is halal if the animal is slaughtered according to the Shariah law. However, if the meat of aquatic animals is cultured, it is legally halal because the carcass is halal. Allah SWT says, “It is lawful to you all water-game.” al-Maidah: 96. Both ESCs and MC-type stem cells are halal in producing cultured meat as long as the ESCs and MCs cells are obtained from halal animals slaughtered in accordance with Shariah law.

Principle 3: Not derived from a source of najs (impurity).
Under this, materials for cultured meat should not be derived from a source of najs/najis. According to MS1500:2019, Najs are defined as impurities according to Shariah law and fatwa. There are three categories of najs. 1. Al-mughallazah, which is considered as severe najs, including dogs, pork, and any liquid and objects discharged from their orifices, descendants, and derivatives; 2. Al-mutawasitas, which is considered as medium najs and does not fall under severe or light najs such as vomit, pus, blood, khamar (liquor), carrion, liquid, and objects discharged from orifices; 3. Al-najiss, which is considered as the light source. The only najs in this category were urine from a baby boy aged two years and below who had not consumed any other food except his mother’s milk.

Based on MS1500:2019, the serum and biomaterials for scaffolds should be considered. Serum is derived from the blood. The use of blood in Islam is forbidden, as Allah SWT says “Indeed, Allah only for bids you to eat carcasses, and blood, and pork, and animals that are slaughtered not because of Allah. But whoever is compelled (to eat it) not for want of it nor (also) to exceed the limit, then there is no sin for him. Indeed, Allah is Most-Forgiving, Most Merciful” al-Baqarah Verse 173. Scaffolding is used to shape the structure and morphology of meat as desired or to proliferate cells. Any biomaterial derived from animals must be halal, and biomaterials derived from animals include gelatine/collagen (halal and non-halal), chitin/chitosan (aquatic animal is halal), and hyaluronic acid (halal and non-halal). All materials of plant origin, such as cellulose, amylose/amylopectin, pullulan, and alginate. The polymer options for scaffolds for cultured meat via non-animal sourcing have been summarised by Post et al. (2020). Scaffolding made from cattle gelatine must comply with the Shariah law and fatwa. Gelatine derived from animals such as pigs is not halal, and it cannot be used at all (Laila Liyana et al. 2018). Meanwhile, marine animal gelatine is halal. However, the use of collagen/gelatine should be minimised due to the substantial production of livestock. Thus, promising materials for halal scaffolds must originate from plant sources or synthetic biopolymers. Many synthetic biopolymers must be considered, including polymers (Post et al. 2020). The use of microorganisms such as bacteria and fungi are halal as long as the bacteria and fungi are grown in a pure medium. For instance, the nitrogen source from yeast extract is halal; however, peptone from porcine or bovine is not slaughtered as Shariah law is not recommended. The growth of bacteria in najs medium is considered as al-jatallah (animal lives in najs), where they are purified after three days of cleansing in pure and clean water.
If the scaffold source comes from recombinant technology, the animal genes will come from the synthesised DNA sequences. The expression of protein from animal sources is not allowed, as MS 1500:2019 stated that halal food covers foods and beverages and/or their ingredients permitted under Shariah law and fatwa, and it fulfils the following conditions: a. does not consist of or contain any part of the matter of an animal that is prohibited by Shariah law and fatwa.

**Principle 4: Istihalah tammah (perfect substance change).**

*Istihalah* (transformed) is a process used to purify najs-contaminated substances, which can occur either naturally or through human intervention. Substances that were previously deemed haram could become halal, and they can then be used in various food industries. For example, the consumption of wine/liquor in food is harmful (impermissible). However, through the process of *istihalah* or extension of the fermentation process, the wine turned into vinegar/acetate owing to the presence of acetic acid bacteria. Vinegar is halal to be consumed and used in food. Characteristics associated with wine, such as smell, taste, and colour, were no longer detected.

In line with this concept, cultured meat derived from serum-grown cells may be categorised as halal as it undergoes the process of *istihalah tammah*; however, this depends on the opinions of different Islamic scholars (Kashim et al. 2020). *Istihalah tammah* (completely transformed) refers to the conversion of najs into a new purity substance. In the process of cultured meat, cultivation of ESCs or MCs in the serum is not seen as al-jallalah (co-propagations) or faecal-eating animals due to ESCs or MCs are not as a whole animal. Therefore, our findings are in contrast with the findings of Hamdan et al. (2017) who mentioned the mature cultured meat needs to be completely cleaned from the serum and rinsed with pure water to obtain clean meat (Hamdan et al. 2017). In accordance with MS1500:2019, blood, plasma, and serum are forbidden to be consumed unless they are used as medicine where there are no other options.

The Islamic rule on the use of blood is divided into two categories: flowing and non-flowing blood. According to the consensus of Muslim jurists (*ijma*), the use of flowing blood as food is not allowed or haram. However, there are differences in the opinion (*khilaq*) among scholars in determining blood rules that do not flow. Blood exists in the liver, heart, lung, meat, and bone of halal animals, and it can be eaten according to Shafee’s mazhab, but not in fishes which are considered forbidden najs. According to Shafee’s mazhab, blood in meat and bone have two opinions and is forgiven najs based on *taccsur ihtiraz minhu* (difficulty to avoid) or najs. MS1500 is based on the opinion of Shafee’s Mazhab; thus, the use of serum as a growth medium for ESCs or MCs should be avoided.

**Principle 5: Maslahah (public interest or benefit) and mafsadah (damage).**

Islamic jurisprudence (*fiqh*) scholars have defined the *maslahah* (public interest or benefit) concept as a method of permissibility based on serving the public interest of Muslim community, whether useful or harmful (al-Ghazali 1992, Ibn Abd al-Salam 2000). *Maslahah* is also defined as an attribute of act that realises the benefits and necessity of Shariah law to preserve one’s faith/religion, life/soul, intellect, family/lineage, and wealth/property (Kashim et al. 2021). *Mafsadah* (adverse, damage, or harmful) is contrary to *maslahah*, and it is defined as something that causes adverse or harmful effects to society in terms of faith/religion, life/soul, intellect, family/lineage, and wealth/property (Ibn Ashur 2007).

If we look at the perspective of *maslahah* in terms of life/soul, an increase in world population and wealth will increase food demand for meat and other food sources. Therefore, cultured meat is an alternative to conventional animal husbandry. The tissue samples used in cultured meat need lesser number of animals as compared to conventional meat production, which might indicate a promising approach to relieve animal suffering. Zhang et al. (2020) have suggested that the benefits of cultured meat are also considered in the health and safety of human beings, where it provides food safety guarantee technology with a low risk of bacterial contamination during the production process. Additionally, cultured meat production systems may be under strict quality control, and the risk of exposure to pesticides, arsenic, dioxins, and hormone-associated conventional meat can be significantly reduced (Bhat et al. 2014). Cultured meat is a sustainable and eco-friendly means of producing meat (Zhang et al. 2020). Although cultured meat is not yet being produced in high mass volume and faces technical challenges, it is speculated that the overall energy balance will favour cultured meat when indirect costs and environmental benefits are taken into account (Bhat et al. 2015).

In terms of the intellect view, the technologies involved in cultured meat production were derived from tissue and bioprocess engineering, which encompassed various stages, including the isolation and proliferation of stem cells, identification and choice of biomaterials, and design of co-culture systems with various cell types such as muscle and fat (Post et al. 2020). Thus, cultured meat is an innovative technology that is not readily available for application in small or large volumes for meat production. From the property perspective, cultured meat will overcome the issues of land, energy, and water consumption, greenhouse gas emissions, and waste management in meat production (Zhang et al. 2020). Avoiding these issues may reduce the cost of production and the release of gaseous methane and animal waste into the environment.

From the perspective of *masfadah*, cultured meat has technical challenges in its production, thus, lacking cost-effective and resource-efficient methods for scaling up. Cell resources, proliferation and differentiation, serum-free media, bioreactors, scaffolding with direct perfusion, suspension culture, microcarriers, promising nutrient additives with synthetic biology, and customised production of artificial meat with 3D printing are some of the technical challenges in producing cultured meat. All these technical challenges were fully reviewed by Zhang et al. (2020). Post et al. (2020) reported the regulatory challenges of cultured meat across countries and continents. A comparison of US- and EU-cultured meat regulatory systems has been discussed in detail by Post et al. (2020). Finally, there is consumer acceptance towards cultured meat. Consumer acceptance is a necessary component for commercial success in the short- and long-term of cultured meat for societal benefits. Survey data indicated that the responded inconsistent questions were dependent on a number of factors, including the phrasing of question and nationality of sample (Post et al. 2020) summarised key outcomes from consumer surveys on cultured meat by several researchers with different response value questions on consumer acceptance.

**Principle 6: Darurat (exigency) of cultured meat.**

*Darurat* (exigency) refers to a situation required for immediate action, in which people often act irrationally and perform prohibited acts to protect their religion, soul, mind, family, and wealth (al-Suyuti n.d., Kashim et al. 2021). However, the determination of *darurat* should be in line with Shariah law to avoid the liberal use of this rule (Rahman et al. 2019). For instance, the use of non-halal substances in medicine is permissible under *darurat* circumstances to save lives or prevent disease from worsening.

Cultured meat is not yet categorised as an exigent food because Malaysia imports beef meat from several countries. Malaysian imported halal-certified beef meat in 2019 from India (73%), Australia (16%), New Zealand (5%), and Brazil (4%), with a net import value of USD 485 million (USDA Foreign Agricultural Service Malaysia, 2020). In the Islamic view, meat is halal and toyyib (Halalan toyyiban) as long as the slaughtering of animals is according to the Shariah law and fatwa.
The Food Safety and Quality Division of the Malaysian Ministry of Health and several other government agencies are charged/responsible for implementing and enforcing the law under Malaysia's Food Act 1983, and the Food Regulations of 1985 governs food import and export regulations/procedures, including routine compliance, sampling, inspection, import control, and regulation. Malaysia's halal certification and dairy facility registration requirements are among the many regulations and procedures related to shipping food and agricultural products to the country.

7. Conclusion

Cultured meat is an innovative meat product that can reduce the negative impact on environment, and it is a safe and long-term alternative to meat production. Cultured meat seems to have a significant impact on the livestock and food industries. In our view, for cultured meat to be consumed by the Muslim community, it must fulfill several conditions as specified here. Stem cells of cultured meat must come from halal animals and animals should be slaughtered according to the Shariah law and fatwa. Additionally, the medium and biomaterials for scaffolds used in the production process of cultured meat must be Halalan toyyiban (Halal foods (pure) from halal source, acceptable by fitrah, have no-shubhah elements, hygienic, safe, and nourishing) and not derived from animal sources. Cultured meat production has to be in line with six principles as discussed in this study. It is hoped that this preliminary study will provide a reference to authorities, industry, society, and countries that have the same value as Malaysia.

Funding

This work was supported by the Universiti Kebangsaan Malaysia, Malaysia under Grant [DIP-2021-015].

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Appreciation has been extended to Universiti Kebangsaan Malaysia (DIP-2021-015) and the Department of Islamic Development Malaysia (JAKIM) to enable the publication of this paper. We thank Prof. Dr. Mark Johannes Post, Department of Physiology, Maastricht University, CARIM, Maastricht, Netherlands for his assistance with this study.

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