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Food Engineering as a Potential Solution for Mitigating of the Detrimental Effects of Livestock Production

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Abstract

Global demand for meat is on the rise. Increase in livestock production is the first but not the best solution to supply this demand. Livestock production leads to an increase in the greenhouse gasses, causing global warming and climate change, which also has a negative impact on the livestock breeding. Thus, scientists have concentrated on the production of *in vitro*-engineered meat which could be tasty, healthy and environmental friendly to substitute livestock meat. In this article, the environmental impacts of livestock production system on the climate change, water quality and public health are discussed, and then the artificial meat production technology, its benefits, challenges and consumer's reactions are reviewed.

Keywords: GHG reduction, Global warming, Food engineering, Laboratory meat production

1 Introduction

Global demand for livestock products is estimated to double by 2050 due to increase in human population from 7.2 to 9.6 billion by 2050 (1).Global change in lifestyle has led to increase in demands for agricultural products by about 70%. Moreover, meat production is expected to increase from 258 to 455 million tons (2). Livestock production requires facilities and natural resources for animal feed production, manure and animal product processing, transportation and marketing. All of these contribute to climate change, water and air pollution, land use change, and other environmental impacts (3). Around 28% of the land in the European Union equals to 65% of the agricultural land, occupied by livestock production system. Air, water and soil quality, global climate and biodiversity, biogeochemical cycles of carbon, phosphorus and nitrogen are affected by livestock production (4). Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons are the main greenhouse gases (GHG) involved in the regulation of global temperature (5-9). The normal temperature on earth should be -6°C.GHGs absorb a part of the heat waves from the sun and also its reflection and then trap them in the atmosphere. GHG concentration flow in the atmosphere leads to global warming (3).The livestock sector is responsible for 14.5% of global GHG emissions (10), which may lead to increase in air and water pollution, land degradation and decrease in biodiversity (3, 11-13). Generally, livestock sector contribution in anthropogenic GHG emissions is 53% of N_2O, 44% of CH_4 and 5% of CO_2 emission (10). Rise in the world population and livestock products demand (2) has led to ideas about other ways of protein production such as new technologies in producing *in vitro* engineered meat. It is also known as a cultured, 'lab-based', or artificial meat (14). The engineered meat is made of animal stem cells cultured in a specific medium containing the necessary nutrients and energy sources for proliferation and differentiation into muscle cells and adipocytes to produce a commercial large scale natural tasty meat in the near future (15-17). Therefore, water, land, nutrients and energy requirement might be relatively less than livestock production, because artificial meat is the only muscle tissue which will be developed without using biological structures such as respiratory and digestive system. Rapid growth rate of engineered meat means that preparing it requires shorter time and also smaller input requirement than that of animal rearing (18). The engineered meat production has a less global warming potential and environmental threat than livestock production (19). Although food preferences, changes in social habit over time and encouraging the consumers to use artificial meat instead of the traditional one is difficult, the engineered meat may become more

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common as a part of the diet in future. Since current knowledge of mass production is in its early stages due to technical, ethical and social issues, it might be assumed that the production of highly valued meat will face great technical challenges. Thus, a great range of research will be required to establish an *in vitro* engineered meat production system on a large scale. Current review article discusses the direct and indirect impacts of livestock production system on air, water quality and climate change. Here, we will discuss the necessity to find a proper meat alternative to reduce livestock products demand; and then we will review all important aspects of the engineered meat production, environmental impacts, advantages of engineered meat, and finally technical and social challenges in the engineered meat production and market acceptance as a novel food.

1.1 Effect of livestock production system on carbon dioxide emission(CO_2)

Livestock sector is responsible for 9% of carbon dioxide anthropogenic emissions, when pasture degradation and deforestation for feedcrop land are taken into consideration (3). Direct impacts of livestock system in carbon emission to the atmosphere is lesser than indirect emissions (3). One of the most important ways of indirect CO_2 emission by livestock is fossil fuel for mineral fertilizer production, which is used in feed production. The most important routes of GHG emissions from livestock production system are manure and artificial fertilizers. Nitrogenous fertilizers, which are used in crop productions, contribute significantly to GHG emissions. Fossil fuel, manufacturing process of fertilizer production, packaging, transport, and application of the fertilizer contribute to emit more than 40 million tons of CO_2 per year (3). In the modern livestock production systems a large amount of energy is used for diesel machinery involved in seeding, herbicides/pesticides production, land preparation, harvesting, transport, and also a part of energy is used for electrical devices involved in irrigation, drying, heating, cooling, ventilation and etc. (3, 20, 21). Although livestock's respiration process emits3 billion tons of CO_2, they are recycled by biological system (3, 22). Transport of livestock products as well as the livestock products processing, storage and refrigerated transport require fossil fuels which are responsible for the CO_2 emission. Part of the CO_2 emission is produced from shipping the products in long distances such as, feed delivery to the livestock production sites, animal products delivery to markets and raw ingredients delivery around the world (20, 21).

1.2 Effect of livestock production system on Methane (CH_4) emission

Livestock contributes 35–40% of global anthropogenic CH_4 emissions. Enteric fermentation may contribute to emission of 86 million tons of CH_4 per year. Ruminant animals like cattle, buffaloes, sheep, goats and camels produce significant amounts of CH_4during normal digestive processes (3). Rumen microbial content of animal digestion system converts the consumed food to digestible feed during enteric fermentation, which releases a CH_4 by-product (23). Methane emissions related to livestock will increase to 60% by 2030, if the livestock production expansion continued in the same rate (24). Methane is emitted from manure by anaerobic decomposition of organic substance. Globally, anaerobic decomposition of manure is responsible for4% of the global anthropogenic methane emissions (3).

1.3 Effect of livestock production system on nitrogen emission

Livestock contributes to 65% of global anthropogenic emissions of N_2O, the most effective of the three major GHG. Livestock produces virtually two thirds of the total anthropogenic N_2O emissions (3). Fertilized croplands and manure are responsible for global increase in N_2O emissions (25). Current styles confirms that this level will significantly increase in future (24). Animal wastes, faecal and urine excretion (26) and manure-induced soil (27) are responsible for a major amount of the nitrogen emission to the atmosphere. Conversion of nitrogen oxides (NO_x) to nitric acids is taking place in the presence of moisture. Besides harmful effects of nitric acids to the respiratory system as well as some materials, it forms acid rain that return the pollutions to the soil, which can be harmful for biological ecosystem (3, 4).

1.4 Ammonia

Livestock contributes to 64% of global anthropogenic emissions of NH_3, which is mostly from manure (3). Global anthropogenic ammonia emission was estimated to be about 58million tons per year in 1993 and it will reached 118million tons per year by 2050 (28). Ammonia and nitrogen oxides emissions contribute to the formation of tropospheric ozone (O_3), the third most important GHG, which is a direct driver of global warming. The tropospheric ozone induces oxidative stress; hence as a result, reduces ecosystem productivity, decreases the sink strength of ecosystems for atmospheric CO_2, indirectly leading to global warming (29-31).

1.5 Land use change to feed production for livestock

Since the 1850s,forests and natural fields have been converted to croplands and pastures for livestock production (32). Land degradation happens because crop producers drain the soil resources from nutrient, which leads to change in physical, chemical, and biological properties of soil (3). Land use change influences the natural carbon cycle, because in comparison to the croplands and pastures the majority of the carbon in soil and vegetation is sequestered by natural fields such as forest (33). In addition, land use change can produce other type of gas emissions like CH_4 and N_2O by soil microorganisms that result in global warming (34).

1.6 Effect of livestock production on water pollution and depletion

Water has a critical role in the functioning of the ecosystem, and human activities are the most important factor in mobilizing this vital natural resource. Freshwater sources are essential for global sustainability, food development and maintenance, industrial growth and ultimately human life (3, 35). However, only 2.5% of total water resources are fresh water, which has been distributed unequally. More than 2.3 billion people in 21 countries live in water stressed situation (1000 and 1700 m^3/person/year) like Iran, Yemen, Egypt, Mexico, North China and India (3, 36, 37). Water consumption by livestock is considerable, and with respect to increase in livestock meat production, livestock water demand has projected to 71% from 1995 to 2025 (35) .Around 60% of total water withdrawals by livestock was from ground water sources in the United States in 2010 (38). Currently, Iran's agriculture consumes about 92% of the freshwater to supply 90% of the food demands (39). Total water use to produce around 60 million tons of beef every year is higher than the total freshwater reserves on the planet. For instance, water use ranges from 11,000 L/kg body weight of beef in Japan to 37,800 L/kg in Mexico. This variation in water use is probably due to differences in local evaporation, transpiration, livestock production systems, and animal productivity (40). World population is expected to grow by around 2.3 billion people between 2009 and 2050, thusabout two-thirds of the world population would experience water shortage in the next coming decades (41).

The effect of the livestock sector on water resources are not well recognized by the decision makers. The total direct or indirect water usage by the livestock sector is often overlooked. Livestock production needs service water, particularly in industrialized farms, to clean the animals and their units, and also for cooling facilities used for the animals and their products (milk, meat) (38). Water use in feed cropland, is much higher than that of the other water usage described above (3, 42). Similarly, the influence of livestock in water depletion is ignored and mainly focused on water contamination by animal manure and waste.

1.7 Effect of livestock production system on water pollution

Most of the used water for drinking and servicing in livestock sector returns to the nature in the form of manure and wastewater form. Livestock sector contains a significant amount of drug residues, heavy metals, pathogens and nutrients like nitrogen, phosphorous, potassium. These substances can cause serious health hazards in the environment, if they entered into the water sources or stored in the soil (3, 26).

1.8 The main water pollutants related to livestock sector

High concentration of nutrient in the ecosystem leads to eutrophication, which might be a health threat. Nutrient ingestion by animals can be high. Most of the ingested nutrients return to the nature and may become a threat to water resources (3). Excessive amount of the nutrients in water resources and eutrophication can lead to the over-growth of aquatic plants and toxic algae blooms leading to death of fishes due to oxygen insufficiency, loss of biodiversity, loss of coral reefs, bad water flavor and odor, and excessive microbial growth. Livestock-related activities can significantly accelerate eutrophication, a usual process in the ageing of lakes, trough high rate of nutrients and organic substances penetration into the aquatic ecosystems (43-46).

1.9 Biological contamination is a health threat-related to livestock.

Livestock generates many zoonotic micro-organisms and parasites that threaten human health. Many biological contaminants, including Escherichia Coli (3, 47) and Salmonella (3, 48) can survive for a long time in the animal faeces applied as fertilizers on land, leading to water resources contamination (3). Importantly, many of the viruses, including Ebola, influenza, Hendra and Nipah are aresome of the important livestock pathogensthat threat human health (49). Giardia, Cryptosporidia, Fasciola hepatica and Fasciola gigantica are also important parasite infections transmitted through ingestion of contaminated water or food (3, 50).

1.10 Effect of livestock production system on terrestrial biodiversity

Intense land usage for livestock production and rangeland conversion into cropland leads to decrease in biodiversity. Habitat degradation and change, and land fragmentation leads to eradication of native species with invasive non-native plants (51, 52). It is expected that livestock grazing will lead to a global decrease in main species abundance in rangeland until 2050 (53). Reduced species richness via eutrophication, and acidification are the consequences of nitrogen deposition in soil (54).The livestock sector has a significant effect on agriculture system and is responsible for 78% of the biodiversity losses (55, 56).

1.10 How can we reduce livestock impacts onclimate and water?

Scientists have concentrated on diminishing the GHG emissions from the livestock sector. A key solution to reduce GHG emissions could be decrease in meat consumption. Another way is to shift human dietary style toward a vegetarian diet or other meat protein alternatives such as mycoproteins. Most of the people do not like using vegetable derived meat due to taste, allergic irritation and psychological issues. Hence, an engineered meat can be an alternative. Tissue engineering is a new medical technology to construct a tissue from patient-derived cells seeded onto scaffolds. Specific biochemical and physical conditions are provided for cultured cells to produce tissues with maximum similarity to the original one for transplantation. We can use the tissue engineering technology to differentiate muscle cells and adipocytes from farm animal-derived stem cells by mass production in food industry (14, 18). Summary of the state of the techniques to make tissue engineered meat, meat production procedure, technical challenges, benefits, ethical issues and social attitudes are discussed in the following sections.

2 An overview of the techniques involved in the *in vitro* engineered meat

At first, NASA made small quantities of healthy and safe fish tissues. A testers group smelt the engineered tissue, but did not eat it to judge how appetizing it was (57). Then, Dutch researchers showed that the isolated muscle-derived progenitor cells have long-term expansion and differentiation capacity (58). In another attempt, electrical stimulation in skeletal stem cells accelerated sarcomere assembly in both 2D and 3D conditions. The expanded stem cells were then differentiated into muscle cells using chemical/biological clues in the appropriate cell culture media (59). Finally, Professor Mark from Maastricht

University launched the world's first cultured beef burger from cow muscle cells and on fifth of August 2013 in a London press conference, the burger was cooked and eaten (60).

2.1 Cell sources and engineered meat production procedure

The myosatellite cell, a muscle tissue specific stem cell, and embryonic stem cell which are responsible for muscle regeneration are used for engineered meat production (15, 17). Adult stem cells have self-renew capacity, with an unlimited number of cell doublings for tissue regeneration. Stem cell proliferation and differentiation should be tightly regulated to avoid uncontrolled cell growth (61). Proliferation and then differentiation of satellite cells are the challenging steps to produce meat. The goal of the cell proliferation phase is to expand the number of cells to be sufficient for mass production. Current methods in satellite cells isolation and culturing support about 30 population-doubling number and 50-70 doubling can probably be achieved, using proper conditions (62). Collins et al. showed a major improvement in harvesting satellite cells using a combination of mild enzymatic digestion and trituration by keeping them in the replication phase (63).When stem cell niche environment is maintained in the harvested cells, they can grow more appropriately. Basement membrane is one of the most important parts of niche with a regulatory role in proliferation of the stem cells via signal transduction applied by extracellular matrix reorganization (61). For example coating the culture dish with laminin, main basement membrane protein, or matrigel, could increase the satellite cell proliferation rate and also myogenic differentiation capacity via Wnt signaling activation (64). In addition, satellite cell self-renewal are influence by regulatory circuits such as TGFb1, Pax7, Notch and Wnt (65). These regulatory mechanisms can be targeted with specific agonists to induce proliferation and delay differentiation. Also there are other non-invasive cell sources for stem cells. The breastmilk stem cells also have the potential to be differentiated into different cells derived from mesenchyme (66), including adipocyte and muscle cells or other cells that can be potentially used as food such as hepatocytes (67).

2.2 Mechanical cues

To mimic the natural and 3D structure, a scaffold is needed with appropriate qualities to allow cell adhesion and proliferation and tissue recapitulation. Myocytes, as an anchorage-dependent cell, need enough substrate stiffness to be functional and contractile. Thus, scaffolds should provide a large and flexible surface area to allow contraction, best medium diffusion and easily detachment from the culture (68).The best material for scaffold would be natural and edible like collagen that provides porosity and flexibility to the structure (69). Protein content and quality of skeletal muscle tissue is compromised by expressing contractile proteins in differentiated satellite cell. The cells are usually seeded in a collagen gel and it is critical to provide anchoring sites in the culture dish. Tissue-like matrix is responsible for cell adhesion balance, contractility, and finally differentiation. Differentiated satellite cells will organize the collagen gel to the structure, which is a thin tissue strip among the anchors, and will form bioartificial muscle (68, 70, 71). Differentiation leads to satellite cell conversion into primitive muscle cells containing myotube, which start to express skeletal muscle proteins like myogenin and muscle myosin heavy chain (71-73). After differentiation, the muscle will develop increasing tension between the anchor points. This tension is the major trigger for protein production. Biochemical material like growth factors and mechanical nature of the scaffold are involved in subsequent newly formed myocyte hypertrophy (70). Passive stretch and tension, and electrical stimulation induce protein production and force generation. Electrical stimulation, which has a critical role in muscle cell differentiation, myoblast maturation and sarcomere formation, is dependent on coating and matrix stiffness (74). In addition to contractile proteins, other proteins are also critical for texture, color and taste of the artificial muscle tissue. For instance, myoglobin, a heme-carrying protein, is responsible for the meat pink color, and determines meat taste as well. It was shown that myoglobin expression is regulated collectively by activation of transcription factors including MEF2, NFAT and Sp1, difference in intracellular calcium current and low intracellular oxygen pressure (75). Scaffold removal from the cell sheet is the main challenge in tissue engineering. Cell sheets detachment is performed mechanically, enzymatically and low-temperature liftoff from smart thermoresponsive coatings (76, 77). Generally, 3D-printing collagen-based meshwork is used as a biocompatible and biodegradable scaffold. The cells seeded on the scaffolds are held into a stationary or rotating bioreactor filled with nutrient. The cells start to fuse and form myotubes, which is subsequently differentiated into myofibers with the aid of differentiation media. Soft texture or boneless meat is produced by using this technique which can be used to make hamburger and sausages (71, 78, 79). In summary, with the aid of current technology in skeletal muscle cultivation, making the engineered meat is possible.

3 Benefits of the engineered meat

In vitro engineered meat is expected to deliver lowered water usage, GHG emissions, eutrophication, and land use in comparison to conventional meat production. Engineered meat is being developed as a healthier and more efficient alternative to livestock meat. There are several studies that have investigated the environmental impact of *in vitro* engineered meat. Tuom is to et al. used life cycle assessment to evaluate the environmental impacts of large-scale engineered meat production. Comparing to conventional European meat production, the engineered meat emits nearly 78-96% lesser GHG, 99% lesser land use, 82-96% lesser water , and 7-45% lesser energy use; however, the energy consumption depends on the source of meat; for instance, poultry meat uses lesser energy in comparison to the engineered meat production (19). On the contrary, the other comparative study focused on the energy consumption in supportive industry for engineered meat production such as culture media production and cleaning steps. The results indicated that *in vitro* engineered meat consumes more industrial energy than livestock meat. Comparative evaluations of the adverse effect of fabricating engineered meat on global warming depend on the natural meat sources as well; for instance, the engineered meat seemed to have a larger global warming potential than pork or poultry, but less than beef. *In vitro* meat requires less land and lower amount of feedstock than livestock (80).

Smetana et al. used different assessment (cradle-to-plate) to compare engineered meat to a series of meat alternatives like plant, mycoprotein, and dairy-based, and chicken, as a conventional meat with the least environmental impacts. The results revealed that *in vitro* engineered meat and mycoprotein-based substitute had the highest environmental impact, which was due to high industrial energy requirements for medium cultivation. Chicken and dairy-based substitute has moderate and soy meal-based, and insect-based substitute have lowest environmental impact. The engineered meat just has beneficial impact on land use and freshwater toxicity. The overall consequence is that engineered meat production seems to have lesser environmental impact than some conventional meat like beef, and probably pork, but more than chicken and plant-based substitutes (81).

Another benefit is that engineered meat could have less biological risk and diseases, due to standardized methods in production. In addition, the composition of engineered meat could be altered to make the meat healthier or make it for specialized diet, for example by using higher level of poly-unsaturated fatty acids in the culture medium. Protein synthesis by engineered skeletal muscle cells could be increased by using the optimal biochemical and physical culture condition (82). One of the main goals of engineered meat is to slaughter significantly lesser number of animals. From the perspective of animal activist, this could attract vegans, vegetarians and others who are interested in decreasing meat intake due to ethical issues (83). The engineered meat product could be made in large scale, and also there is no need for functional integration (84).

4 Technical challenges in the engineered meat production

Meat tissue engineering has at least three main challenges including scale, efficiency and taste. To generate acceptable volume of meat for a large population, cell culture scale and condition has to be several times higher than that of used for medical application. Bioreactor design, selection and production of biomaterial, optimization of culture medium, tissue conditioning optimization and quality control of engineered meat such as the genetic stability of the cells are major problems in scaling up the engineered meat. The global meat production is around 293 million tons/year (84). There is approximately 5-10^6 cell/gr of skeletal muscle tissue and, the number of all skeletal muscle progenitor cells that differentiate into mature muscle cells and get integrated into skeletal muscle are around 1.5_10^{21}cells/year (84, 85). This estimation can provide an assessment for the crude scale of the number of cells required for industrialization. Currently, capacity of the large bioreactors for cell suspension culture is approximately 25,000 liters with maximum cell load of 7-10^6 cell/ml (84, 86). Providing the surface attachment for cells in bioreactors is also critical to sustain proliferation and survival of satellite cells. Different microcarriers are available to support the large scale of adherent cells in huge bioreactors (87). Waste washout, oxygen and nutrient delivery are some of the obstacles with large volumes of cell culture in big bioreactors. Stirring the cell suspension can be a solution for most of the problems, but the membrane of the most mammalian cells is not able to tolerate sheer stress caused by agitation. As a result, the cells in high scale might suffer from insufficient and inhomogeneous transfer of oxygen and nutrients due to limitation in stirring speed (88). Another important problem in large scale cell culture in big bioreactors is CO_2 removal. The CO_2accumulation affects cell growth which is usually removed from the culture medium via a combination of both agitation and air sparging. Due to low rates of used agitation and sparging, CO_2accumulation is a limiting stage in large scale cell culture and growth (89). Even if all the technical problems of the large scale culture could be resolved, producing adequate amount of meat for increasing world population by 2050, would require a huge number of bioreactors. It was estimated that around one reactor for every 10 humans is required to supply the meat demand (84, 85). Huge amount of culture medium also is needed for this scale of cell culture. Hence, medium production and storage in large scale will be another challenge (85). The discarded of the culture medium in a safe way is also another problem which remains to be solved. Besides, some of the stem or progenitor cells might differentiate to undesirable phenotypes. They may modify epigenetically or undergo karyotypic abnormalities during culturing. These kinds of undesirable results must be detected and controlled for human health safety (90, 91). Several techniques based on physical parameters like electric conductivity could be used for cell culture process monitoring, which will be sufficiently strong to guarantee cell culture quality. For instance Dielectric spectroscopy is one of the safety control tools, which has been used in the medical field which might be helpful to monitor the biological parameters of cell culture (92). In addition, the nature of commercial cell culture media like the source of components, extraction method and processing should be controlled through a life cycle assessment. Considering the large scale of cell culture for meat production, a range of innovation through chemical and mechanical engineering will be required for quality control of cell based products. Optimization of the cell culture variables, like specific components of medium and serum, is essential to improve the efficiency of the culture and consistency of the products. Feed composition of medium, biochemical and biophysical condition of culture, and the possible interactions between medium components should be defined to produce healthy engineered meat (18).

The Good manufacture Practice (GMP) guidance has been developed to create an awareness of ranging from important issues in cell and tissue culture. Based on the GMP guideline, the quality of all used materials, methods and their application should be confirmed (93). Optimization of the cell culture condition including both medium synthesis and serum supplementation is also important. Serum might be considered as a potential source of contamination which needs breeding livestock and slaughtering the animals as well.

Ultimately, synthetic culture media without using serum products is the ultimate goal in the cell culture. Since fetal bovine serum is a supplement in cell culture with unknown composition, which could contain a wide range of undesirable factors; hence, omitting fetal bovine serum from cell culture medium seems to be critical. Several types of culture media have been produced with minimal or no animal derived components. However, different type of cells are able to grow in serum-free media, each cell type needs special medium composition and there is no standard serum-free media for all cell types (94). Also, several serum-free media have been developed for myoblast cell differentiation with the capability of active tension generation (95). More studies must be performed to omit serum from the whole cell culture process to decrease the dependency on livestock products.

Taste, texture and juiciness of engineered meat are also a challenge in its production. Meat taste is related to amino acid and peptide concentration and also the intramuscular fat content of meat (96, 97). Special taste of cooked-meat is related to the reaction between specific sugars, amino acids and fatty acids, particularly during heating (98-100). Since that feed and nutritional conditions of animal as well as postmortem conditions can affect the taste of the meat due to protein, sugar and fatty acid oxidation (101, 102), suggesting the feed conditions of the skeletal muscle culture could be effective on taste development in engineered meat. Thus, taste of meat is an important quality to be investigated in engineered meat production system.

Texture and integrity of meat is determined by the intramuscular connective tissues, composed of extracellular molecules like collagens and glycoproteins, and also the amount and distribution of the adipose tissues. Adipose tissues development leads to disorganization of the intramuscular connective tissue structure which causes the meat tenderness (103). In addition to tenderness, Juiciness of meat is also related to percentage of fat which varies in different types of skeletal muscles (104). Medium composition and feed condition and of cell culture must be optimized to produce a highly quality engineered meat with the best taste, texture and juiciness to attract consumers.

5 Challenges and outlooks for consumer's acceptance of *in vitro* engineered meat

How will consumers react to engineered meat production technology? Under which conditions will customers accept and adapt to eat engineered meat? Will engineered meat be compatible with highly valued conventional meat? Customer's acceptance or rejection depends on two sets of determinants. The first one is the personal and societal advantages and health- threatening risks of the engineered meat. Technology-related issues are the second set of determinants such as quality control and safety assurance of cell culture and perceived naturalness of the engineered meat. Customer cognizant about the engineered meat production technology is so effective in acceptance or rejection of the engineered meat by market (105). Since, one of the advantages of this technology is decrease livestock production, animal activists and vegetarians, who hate the idea of slaughtering animal, might be conceived to use engineered meat (83). Most potential objections to the engineered meat were overviewed by Hopkins et al. including concern about unknown hazards of the engineered meat technology, doubt about realness and naturalness of the artificial meat, repelling the idea of eating engineered meat and moral issues related to the engineered meat technology and its application (83). Costumer reactions toward engineered meat were investigated in three EU countries, Belgium, Portugal and the United Kingdom. Initial costumer reactions after learning about engineered meat were feelings of disgust, fear of the unknown, uncertainly about safety, health and naturalness. Consumers imagined few direct personal advantage of engineered meat, but they accepted possible societal benefits related to environment and food security (106). A media coverage in 2015 about artificial meat overemphasized the important role of the vegetarians in artificial meat acceptance (107). A survey conducted in the Netherlands showed that only 14% had heard of artificial meat and claimed to know a little about that. After explaining the artificial meat technology and its advantages and disadvantages, about 63% of the people supported the idea of engineered meat production and 52% were interested to try it (108). In another study, after giving customers basic information about engineered meat, only 9% of people rejected, two thirds hesitated and about quarter supported the idea of trying engineered meat. Generally, consumers were doubtful about trying the engineered meat even if it becomes available, those how are vegetarian will be doubtful about its safety and health (105). Recently, a study investigated the effect of information provision on the attitude toward engineered meat. Results showed that it can be affected by positive information about sustainable product (109). Also, it is important to give the simple and apprehensible information about final product, but not about production method, to increase public acceptance (110).

Cost and sensory expectations has appeared as major obstacles. In 2015, the *in vitro*-grown burger producer announced that the burger price from *in vitro* engineered meat decreased so that the price will be compatible with a conventional meat (111). The price drop was astonishing in just 2 years, which could be a good sign for the engineered meat commercialization. Taken together, people need scientific assurance to trust the engineered meat. It can be claimed that *in vitro* engineered meat can reduce our stress on the environment, through reduction in livestock production, agricultural land and water usage. However, the possibility of other improvements, like price, quality, safety, similarity to conventional meat, is difficult to predict. Consequently, it is crucial to be more transparent about all aspects of the engineered meat production. A tasty meat is a basic requirement for societal acceptance, but beyond that, the societal perception depends on too many factors. If the detrimental effects of conventional meat production on environment continually increases and if tasty engineered meat lead to mitigating the damage to the nature by preventing animal and plant extinction, this novel meat may finally become a highly valued food and also as a regular part of food program (84).

6 Conclusions

Raising world population needs more livestock products such as meat to supply their food demands. GHG emissions, water pollution, land use change and degradation are some of the well-known impacts of livestock production system. Therefore, finding a proper meat alternative seems to be essential. Engineered meat could be a good meat substitute with less environmental impacts. Using the engineered meat could be economically efficient; if it considers that the consuming budgets for the prevention of global warming will be decreased remarkably.

Although the *in vitro* engineered meat was produced, cooked and tasted successfully, its production in a large scale has some technical challenges such as, cell source selection and providing a biochemical and physical cell culture condition. Even if the engineered meat becomes available in the market, it was shown that social acceptance will be an obstacle which needs more effort to satisfy consumer to accept and eat the artificial meat.

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