The contribution of artificial meat in reducing carbon emission and mitigating climate change

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Abstract. The consumption of conventional livestock meat contributes significantly to greenhouse gas emissions, exacerbating climate change. As an alternative, artificial meat, or cultured meat, has emerged as a potential solution to reduce the environmental impact of meat production. In this paper, contribution of artificial meat in reducing carbon emission and mitigating climate change is analyzed. Comparison of the impact on carbon emission between artificial meat and conventional lifestock production system is conducted. The results indicated that artificial meat has advantage over natural meat. In terms of life cycle assessment in cultured meat, current LCA lack some practical data in commercial-scale, and the factor about transportation, usage, retail, and waste disposal should be included in the future assessment, which will give a more comprehensive and accurate assessment in whole life cycle of artificial meat production. In conclusion, while artificial meat holds promise for reducing carbon emissions and mitigating climate change, more research and development are needed to realize its full potential and address the associated challenges.

1 Introduction

Recently, with the raise of environmental awareness and continuous development in food industry, meat production gradually becomes a popular topic in reduction of carbon emission. According to the statistical report on Per Capita Major Food Consumption of National Residents in 2023 published by National Bureau of statistics of the People's Republic of China (NBSPRC), the consumption of meat production had been oscillating upward from 2016 to 2022, increasing from 26.1kg to 34.6 kg, demonstrating the rising demand in meat consuming [1]. On the other hand, the process of production require plenty of land use, which causes the loss of habitats for wildlife and irreversible damage of ecosystem, indirectly leading to extinction of some threatened species and imposing overwhelming pressure on environment. Recent research shows that the process of raising livestock contributes to 14.5% greenhouse gas emission, and the production of beef emit 44% anthropogenic methane emission and 53% of anthropogenic nitrogen dioxide emissions [2]. In order to follow the trend of sustainable development and carbon emission reduction, artificial meat is gradually emerging and become hotspot in food industry in recent decades. Cultured meat cultivated by stem cell of animals and plant-based meat shares indistinguishable flavor and appearance

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may become proper substitute of conventional meat. Some researches revealed that artificial meat, especially cultured meat includes "approximately 7-45% lower energy use (only poultry has lower energy use), 78-96% lower GHG emissions, 99% lower land use, and 82–96% lower water use depending on the product compared", which effectively relieve the pressure imposing on the environment [3]. This paper aims to holistically review the process of producing different categorization of artificial meat and evaluate whether artificial meat plays an important role in reducing carbon emission and slowing down the process of climate change. In the end, this paper will focus on challenges in future developing and give some practical advices towards these potential problems.

2 Manufacture of artificial meat

Artificial flesh can be primarily categorized into three varieties: those being meat substitutes derived from vegetal extracts and mycota, vitro-cultivated (or lab-generated or synthetic flesh) produced via tissue biotechnology or originating from genetically altered organisms and cloned fauna through genetic manipulation, as illustrated in fig. 1 [4].

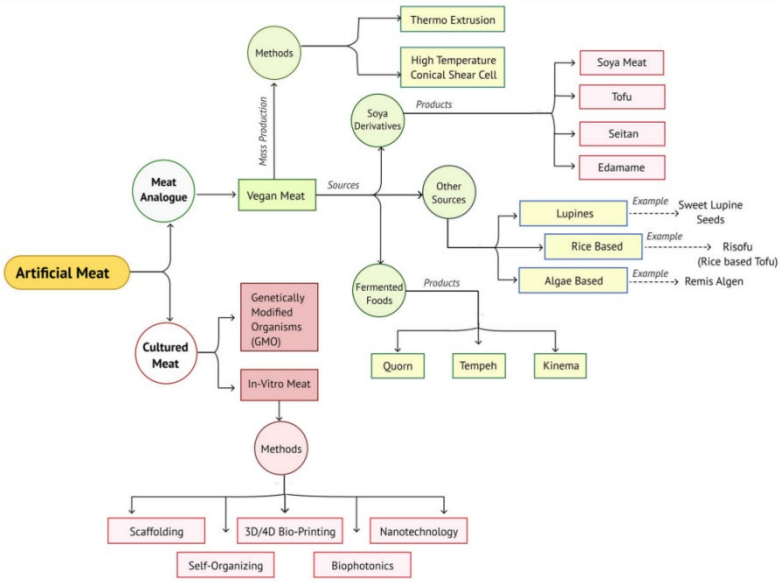

Fig. 1. Classification of Artificial meat [4]

2.1 Vegan meat

Vegan meat, which is also extracted from plant and fungi, use thermo-extrusion technology to texturize protein extracted from plant into fiber under relative high temperature as 140-180 Celsius. Formatting author names and author affiliations

2.2 Cultured meat in vitro environment

For cultured meat, there are typically 2 main technologies to cultivate the meat in vitro environment as scaffolding technique and self-organizing technique. Scaffolding technique is to use embryonic myoblast (skeletal stem cells) extracted from tissue of agricultural animals, and allow the stem cell to develop on scaffold within bioreactor, which is indispensable circulatory system that offers moderate conditions (temperature, pH, pressure,

nutrient feeding) for cells to growth and differentiate while eliminating metabolic waste. Combined forces in bioreactor help improve diffusion and achieve a high mass transfer rate with a low shear stress level. In terms of scaffold, this technique uses a plant-derived growth medium or animal derived growth medium such as collagen in vitro meat production system to provide nutrient for cell growth and help them change into fiber when the cells are placed on scaffold. Another method to cultivate cultured meat is to explant tissue from animals to Petri plates with nutrient mixture, growth medium of fetal bovine serum to support cell proliferation. After it finishes growing and achieve meat size, it was marinated in olive oil, garlic and deep-fried, and then the meats are submitted to the sensory panel reporting that the explants and newly grown tissue looked and smell end edible [4].

3 Comparison of the impact on carbon emission between artificial meat and conventional lifestock production system

3.1 Cultured meat

Some earlier literatures use life cyle assessment conclude that cultured meat is generally environmentally friendly comparing to conventional meat, as demonstrated by Tuomisto and de Mattos in 2011[3]. They found that the cultured meat involves lower energy use, lower greenhouse gas emissions, lower land use, and lower water use depending on the product compared. However, this result is not definitive and certainty since it lacks data from practical production in commercial-scale and fail to consider the complex reaction between society and technology, such as consumer acceptance and economic factor [5]. Additionally, the feedstock used in the system evaluated by previous literature does not match current situation of cultured meat production, requiring further evaluation in energy usage.

In terms of carbon emission, although the prediction significantly varies from each other due to different system and different media cultivating cultured meat [6], the overall Global Warming Potential carbon dioxide equivalent is lower than conventionally produced meat, such as beef. Considering the long -term impact in mitigating climate change brought by cultured meat, however, the effect is not explicit. According to previous analysis, although carbon emission is far less than emission of other greenhouse gas (GHG) that has larger global warming potential (GWP), carbon dioxide causes more propounded effect since it stays longer than any other GHG. As a result, the impact brought by carbon dioxide is irreversible while other GHG is reversible. Unfortunately, the main gas emitted by production of cultured meat is carbon dioxide, because it needs fossil fuel to warm cultured cells, meaning the long-term effect is not obvious. According to the prediction from John Lynch and Raymond Pierrehumbert in 2019 shown in fig. 2 [6], in next 1000 year all the 4 cultured meat has relative advantages over conventional meat at first, but as the time proceed cultured-d even exceed the worst cattle system, suggesting the role cultured meat played in mitigating climate change is not absolute and conclusive [6, 7] (fig. 3). Moreover, recent study about cradle-to-gate life cycle assessment conveyed an opposed opinion in carbon emission, arguing that when adding energy usage in providing necessary growth medium for cell growth and energy required for constructing facility, they found that global warming potential (GWP) for all scenarios was greater than the minimum reported GWP for retail beef [8]. It states that cultured meat may have more severe impact in carbon emission than conventional meat, contradicting to previous assumption that cultured meat is environmental-friendly product.

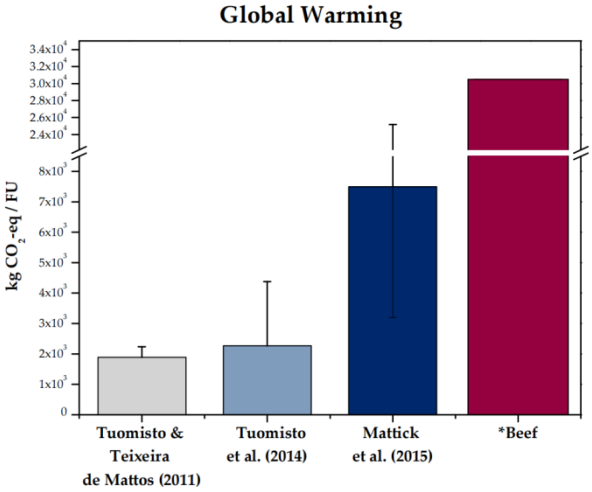

Fig. 2. CO_2 and GHG emission predicted by previous researches [7, 9]

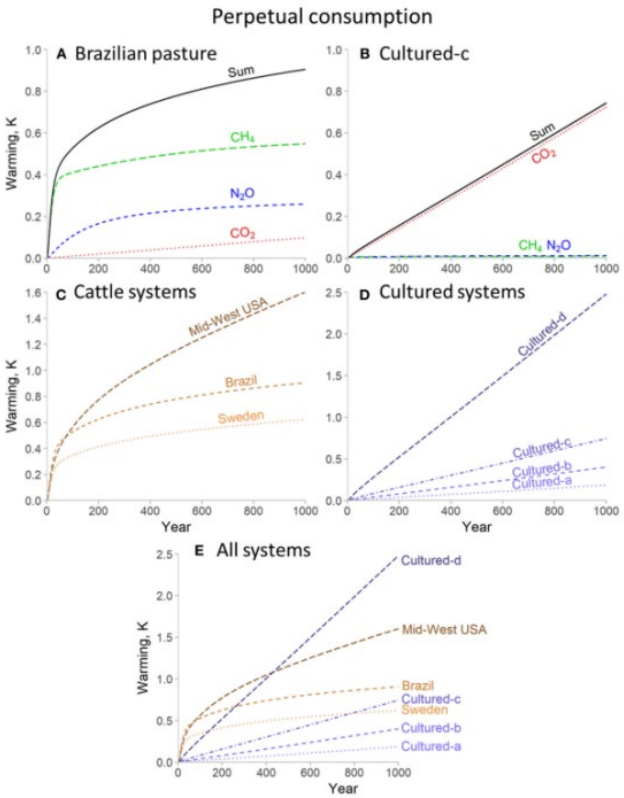

Fig. 3. Prediction of effect in climate change from 3 conventional meat production system and 4 cultured meat system in 1000 years [7]

3.2 Vegan meat

Life-cycle assessments show that products like the Beyond Burger and Impossible Burger, burgurs that are composed of plant-based meat, result in lower greenhouse gas emissions, approximately 3.2 to 3.5 kg CO_2-eq per kilogram of product, compared to the range of 10.2 to 48.5 kg CO_2-eq per kilogram for beef raised in feedlots [10]. However, this situation is not absolute as well since when considering amino acid and nutrient density, the differences between vegan meat and real meat is not clear because of high efficiency of animal meat to meat nutrient need. Furthermore, using some advanced land management, such as pastured beef system, involving rotating grazing and crop grazing, can counteract greenhouse gas emission (GHGE) and result in net negative carbon footprint that is less than carbon emission of vegan meat. Moreover, just like situation in cultured meat, plant-based meat mainly emits significant carbon dioxide when animal meat dominantly produces methane, suggesting long-lasting impact in climate change [10].

4 Conclusion

Based on previous literature, artificial meat, especially the vegan meat that has wide range of application, generally play an important role in reducing carbon emission and alleviating global warming in recent decades. Nevertheless, more detailed examination and evaluation should consider since the long-term effect of artificial meat is not significantly advantageous than conventional meat if we put situation in a larger time scale. In terms of life cycle assessment in cultured meat, current LCA lack some practical data in commercial-scale, and the factor about transportation, usage, retail, and waste disposal should be included in the future assessment, which will give a more comprehensive and accurate assessment in whole life cycle of artificial meat production. Although the specific effect in reducing carbon emission and softening global warming remains uncertain, the overall contribution, such as reducing land use and water use, reveals that artificial meat is more sustainable than conventional meat. Artificial meat is full of potential due to its environmental impact; however, it still needs some time to achieve commercialization and wide range of application, and social and economic factors such as different level of acceptance among different kinds of consumers need to further evaluate in the future.

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