

Meat analog as future food: a review

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Abstract

The definition of meat analog refers to the replacement of the main ingredient with other than meat. It also called a meat substitute, meat alternatives, fake or mock meat, and imitation meat. The increased importance of meat analog in the current trend is due to the health awareness among consumers in their diet and for a better future environment. The factors that lead to this shift is due to low fat and calorie foods intake, flexitarians, animal disease, natural resources depletion, and to reduce greenhouse gas emission. Currently, available marketed meat analog products are plant-based meat in which the quality (i.e., texture and taste) are similar to the conventional meat. The ingredients used are mainly soy proteins with novel ingredients added, such as mycoprotein and soy leghemoglobin. However, plant-based meat is sold primarily in Western countries. Asian countries also will become a potential market in the near future due to growing interest in this product. With the current advance technology, lab-grown meat with no livestock raising or known as cultured meat will be expected to boost the food market in the future. Also, insect-based products will be promising to be the next protein resource for human food. Nevertheless, other than acceptability, cost-effective, reliable production, and consistent quality towards those products, product safety is the top priority. Therefore, the regulatory frameworks need to be developed alongside.

Keywords: Meat analog, Future food, Cultured meat, Plant-based meat, Insect

INTRODUCTION

Health awareness in the population and sustainable foods has brought the idea for the innovation of plant protein-based meat in many countries. The semi-vegetarian or known as “flexitarians” who occasionally include the meat in their diet, increasing rapidly. Australia was the most popular country for veganism in 2018, followed by the UK and New Zealand. While the number of vegans in America grew tremendously by 600% from approximately 4 million in 2014 to 19.6 million in 2017 [1]. In terms of sustainability, meat production has driven environmental change and natural resource depletion. The livestock industry requires an estimated 40% arable land, 14.5% greenhouse gas emission, 36% and 29% crop calories produced and agricultural freshwater used, respectively [2,3]. In order to fall drastically unsustainable in the livestock sector, 75% of eating less red meat is needed by the global citizen on average [4].

The consumption of vegetable proteins in food products has been increasing over the years due to animal diseases, healthier foods, strong demand for wholesome and religious food, and economic reasons [5]. As mentioned earlier, the livestock meat-based diet requires more environmental resources than plant protein-based diet. However, development and innovating a new food product that satisfies

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the consumers' demand are very challenging. The quality, nutrition, and sensory characters are the first parameters to be taken into consideration before developing the plant protein-based diet. Some studies have nevertheless demonstrated that the production process and ingredients involved in the meat analogs to be lacking nutritionally (i.e., over-processing, high salt content, and genetically modified organisms) than conventional meat [6–8].

The fact that plant-based protein products present insufficient essential amino acids and trace elements, owing to be more challenging to create a product that imitates the meat nutritional values. The meat analogs available in the market today might be missing the essential fortified elements such as iron due to the main ingredients substituted was either contains eggs and milk proteins or vegetable sources [9]. However, the additional components by chemically synthesized or extracted from natural resources under many processing steps are not the right approach as well and raised a debate among environmentally aware consumers [9]. In this paper, the traditional and current available meat analog is presented. The novel ingredients used, the process, market prospects, future trends, and regulations of the meat analogs are objectively discussed.

FROM TRADITIONAL TO NOVEL MEAT ANALOG

The introduction of meat replacement in food products also known as meat analog (also termed as imitation meat and mock meat) is not new; it was started in the early 1960s [10]. Traditionally, soy protein was used as a popular ingredient in food analogs such as tofu and tempeh (fermented soybean cake). These products have been processed either by simple processing/fermentation techniques, and they have been consumed for centuries [11] as the traditional dishes in many southeast Asian as early as 965CE [12]. In addition to these traditional Asian products, the dry texturized vegetable protein (TVP) was the first launched of meat analogs obtained from the extruded defatted soy meal, soy protein concentrates or wheat gluten [13]. The introduction of this TVP as meat alternatives emerged in the mid to late 20th century [14].

TVP comprised of wheat gluten and other vegetable proteins have an elastic and somewhat spongy in texture or in other words, provide an endless array of textured which is favorable to be utilized as meat analog products [15]. TVP is made most commonly from soybeans. Texturized soy protein (TSP) for example is extremely versatile for food ingredients due to its meat-like texture attributes and it also provides similar protein quality to that of animal proteins [11]. Besides, the ingredient from vegetable proteins is an inexpensive source and they can be modified into wonderful meat substitutes such as canned meat [16], meat extender in beef patties [17], and pet foods [18].

However, the adoption of plant-based diets could be difficult for some people. Various barriers can be linked, for instance, the strong off-flavor or beany flavor of soy-derived products. This flavor was due to the activity of lipoxygenases, saponins, and isoflavones which in turn limits the use of soy-based protein as a meat analog [5]. The other major concern of food proteins in legume crops such as soybeans, lentil, common beans, and peas is the allergenic effect [19], that has also led to the constraint of meat analog development from these sources. In addition, protein from cereal (wheat, rye, and barley) is also harmful to some individuals due to gluten intolerance [10].

Early 21st century, meat alternatives entered the mainstream due to demand toward healthy food and sustainability implications of consumer's diet continued to increase alongside, as alternatives to conventional meat [14]. In the last decade, the modern advances technology in food science and manufacturing has been introduced in meat analog products which can mimic the taste, texture, look, and functionality of conventional meat-based products [14]. The current interest has focussed more on the direct development of non-traditional protein sources in meat analogs such as plant-based 'meat' and cultured meat. This technology can overcome the limitation of the use of

conventional protein-based, especially from legumes and cereals. In recent years, the edible insect will be expected to be the prospects for human foods due to its rich in protein and good fat. A supermarket chain in Switzerland and Germany for instance, have already started selling insect burger patty and mealworm balls. Meanwhile, in Europe and North America, a growing number of insect protein-based products for human consumption and in animal feed have also been reported [20]. The history of meat alternatives can be seen in Fig. 1.

Plant-based meat

Advanced plant-based meat is defined as products use plant-derived ingredients which has attribute exactly to animal-derived meat, and it is indistinguishable from their animal-based equivalents [21]. The development of acceptable quality attributes for meat analog in terms of taste and texture often to be linked with the biggest challenge for food producers because their characteristics depending on the ingredients used [22]. Plant-based meat proteins must be unfolded, cross-linked and aligned themselves to form microscopic and macroscopic fibers. In order to texturize plant-based meat, techniques such as extrusion, spinning, and simple shear flow have been applied [23]. Following this treatment, heating, cooling, drying, or coagulation is applied to solidify the structure [9]. High protein levels in the recipe are always associated with the good water binding capacity and their rheological properties. However, the intervention of non-proteinaceous ingredients also somehow plays an important role in solidification which is not based on protein gelation, because hydrocolloids solidified through coagulation [14]. Currently, the plant-based meat industry has primarily focussed on the development of burger patties, mince, and sausages. The primary meat cuts such as steak are not main research and development due to the complexity in the structure composition [14].

Several companies in Western countries have successfully developed plant-based meat analogs such as Beyond Burger (BB) and Impossible Burger (IB). The ingredients used for these products might vary, but almost all of them contain soy protein, wheat gluten, egg protein, or milk proteins [22]. The overviews for both products are available in the book chapter of plant-based meat analogs written by Kyriakopoulou and Dekkers [9]. In this review paper, we intend to elaborate on the novel ingredients used in BB and IB. Non-genetically engineered ingredients such as beetroot incorporated in BB is to give color to meat analog products, which resembles the feeling of a 'bleeding' when cooking applied [24,25]. Pea proteins such as vicilin used in BB have been reported to form heat-induced gels [26] and pea protein isolate exhibited similar emulsification properties to soybean protein isolate [27]. Meanwhile, soy leghemoglobin (SLH) used in IB which is not the only function to give red-tinted liquid mimicking the 'bleed' from minced beef but can also impart a meat-like flavor profile onto plant-based meat products [28].

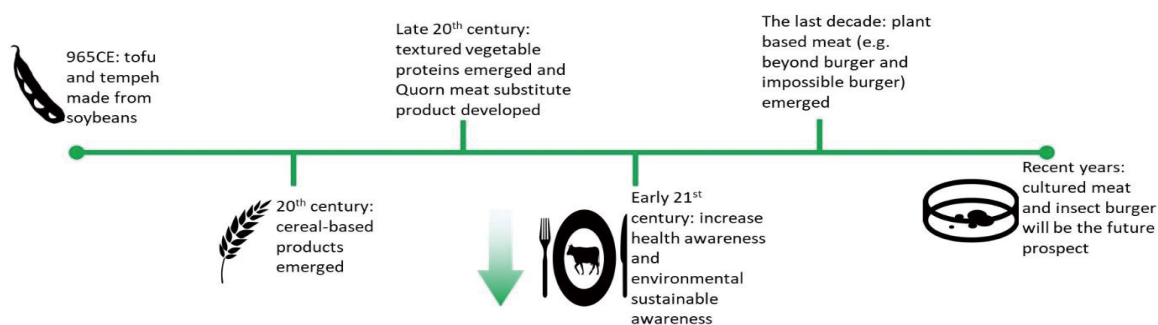


Fig. 1. History of meat analogs.

Another novel plant-based meat product is Quorn meat, which is launched in the UK in 1985. This food product used fermentation technology from the soil fungus *Fusarium* to create mycoprotein [29]. The production process for novel ingredients obtained for both burger patties mentioned above was not similar to mycoprotein plant-based meat that innovated in the Quorn product. A filamentous mycoprotein produced from fungus was chosen for the production of plant-based meat because it can give fibrous texture like a meat to the final product [29]. Mycoprotein produced is naturally low in fat and contains high fiber content as well as high-quality protein. The high protein content is due to the mycoprotein itself poses an excellent pattern of amino acids [11]. The filamentous fungus is produced strictly under controlled conditions in bioreactors and the further process steps are needed to mold unordered filamentous fungus such as forming, steaming and, texturizing [30]. Currently, several minced-type products from mycoprotein are commercially available such as chunks, sausages, and burgers [29].

Cultured meat

In vitro meat refers to the edible meat obtained by collecting cells from living animals and then proliferating them with cell engineering. This process is a part of the cellular agriculture that obtains meat without going through the process of raising livestock [31]. The name varies, sometimes called cultured meat, clean meat, *in vitro* meat, and lab-grown meat [32]. The invention of this novel meat without livestock was started in 2013 by Mark Post, who the first pioneer in the production of burgers in the lab. However, the idea of bioartificial muscles (BAMs) is not new, as this information can be found in 1932 in the “Thoughts and adventures” book written by Churchill [33]. Even, BAMs produced from the skeletal muscle resident satellite cell have been found for the last two decades through biotechnology approaches [34]. Although the development of BAMs from satellite cells are not well known, these BAMs can become a valuable source of animal proteins for future food prospect. A summary of the content and conclusions of recent reviews about the production of cultured meat from stem cells is presented in Table 1.

Table 1. A summary of the content and conclusions of recent reviews about the production of cultured meat from stem cells (Derived from Kadim et al. [38])

Reference	Topic covered and conclusions
Langelaan et al. [39]	A review on the requirements to increase the feasibility of meat production <i>in vitro</i> . The challenges highlighted are to find an appropriate stem cell source, to grow them in a three-dimensional environment inside a bioreactor, and to provide essential cues for proliferation and differentiation.
Stephens [40]	The discussion on the development of meat in laboratories without living animal and the impact towards emergent social, ethical, and regulatory issues.
Bhat and Fayaz [41]	The authors noted that <i>in vitro</i> meat offer health and environmental advantages. The great challenges of this technology to deal with the production of highly-structured and to establish a sustainable <i>in vitro</i> meat on an industrial scale.
Tuomisto and de Mattos [42]	Cultured meat is effectively conserve environment by reducing energy use (7%–45%), greenhouse gas (78%–96%), land use (99%), and water use (82%–96%) than conventional meat.
Dodson et al. [43]	The authors focussed on the potential of adipose tissues as a source of stem cell for future clinical applications. The adipose tissue might contribute good palatability of cultured meat.
Post [34]	<i>In vitro</i> culturing as one alternative for livestock meat production. This bio-artificial muscle is a great source of animal protein. The challenges are to make sure <i>in vitro</i> meat mimics the conventional meat in term of physical sensation such as appearance, smell, texture, and taste.
Welin et al. [44]	A review on the ethical issues of cultured meat. The authors concluded “It will need a bit of time to obtain there, it will take people a long time to adapt”.
Young et al. [45]	The authors concerned the health promoting compounds in novel meat. They highlighted the availability and high quality of essential amino acids, phytanic acid, conjugated linoleic acids and antioxidants which are importance for human diet.
Goodwin and Shoulders [46]	A study in some countries about stories of news article in relation to cultured meat. From this discussion can assist scientists to understand the consumers’ perceptions and strategise for the development of cultured meat.
Post [37]	Author presented the “proof of concept” of cultured meat can be grown in laboratory. This novel studies have opened the new door for future research on the production of meat without rearing the animal so that benefit the environment.

The process of producing cultured meat starts with an excised a small piece of tissue from living animals, which is done with a small biopsy under anesthesia. Culturing of skeletal muscle cell from satellite cells can be done through the proliferation and the differentiation phase [34]. Briefly, in the proliferation stage, the stem cells are first separated from the tissues and the cells are then developed into other new muscle tissue. Generally, the stem cells itself have the self-renewing ability so that it can create new muscle tissue on its own as long as there are growth factors available [35,36]. Cells are cultured within specific liquid media contains some specific nutrients (depend on the cell species and tissue type), which provide the conditions needed for tissue growth [21]. The proliferation process doubles the 50 population over 7–8 weeks and this process is continuing in the bioreactors until trillions of cells are produced [37].

The differentiation stage took place when a sufficient number of cells have been produced. Satellite cells are differentiated when there are no growth factors supplied in the medium [34]. Then, the cells merged and formed myotubes naturally. Subsequently, they submerged in a collagen gel with a central hub located in the middle of the culture dish to form a donut-shaped muscle fiber of 1 mm diameter. The muscle cells' innate tendency to contract which is a potent stimulus for muscle maturation and protein production. The production of this muscle fiber took only three weeks to be harvested, and it required 10,000 muscle fibers for preparing 85 g of hamburger [37]. This cultured meat is believed to be safer than other types of meat analog products because it did not contain allergenic substances such as presented in plant-based meat. Also, healthier meat can be produced by replacing saturated fatty with beneficial polyunsaturated fatty acids. However, eliminating fetal bovine serum and antibiotic from the cultured medium is necessary to make the cultured beef become sustainable and accepted [37].

MARKET PROSPECTS

Without a doubt, the popularity of meat analogs is booming as increasing numbers of consumers seek protein alternatives and sustainable food. Notably, in Germany, France, the Netherlands, the United Kingdom, Italy, and Sweden are among the top countries in research and development of alternative meat proteins [9], with Europe dominates the global meat substitutes market. Although today we believe that replicating the meat alternative so-called “meatless” is going to break the market in coming years ahead due to big companies eager to expand their market share as demand soars for meat alternatives. The prediction of plant-based alternatives could grow at a compound annual growth rate (CAGR) of 10% by 2029 and it is equal to \$1.4 trillion, based on the estimation of meat substitute sales in the USA, the United Kingdom, Germany, Italy, France, the Netherlands, Sweden, and Belgium in 2018 [47]. Currently, the meat substitutes market is in the competitive landscape due to the presence of numerous small players.

Most of the plant-based meat products industry predominantly concentrated in western countries. A lower acceptance of meat alternative foods in some Asian countries is due to the food neophobia. However, this seems to be the case across cultures, and the acceptance towards new foods will increase over time, as consumers become more familiar with the products [48]. In order to see the consumers' acceptance of meat alternatives, a survey has been conducted in three popular countries which are the USA, China, and India. Surprisingly, China (95.6%) and India (94.5%) were recorded the highest acceptance as compared to the USA (74.7%) [48]. The shift toward the consumption of meat alternative is driven by not only of healthy diets, but also the growing millennial, information of food source is reached, animal welfare issues, and impact on the environment [49]. Therefore, Asian countries could also be the relevant market in the future in exporting meat analog products. As well, according to FAO [50], the consumption of plant-based meat in developing

countries continues to rise and will be expected to increase up to 73% by 2050.

The interesting points of plant-based meat products, there is no laboratory-manufactured meat slaughtering process. Thus, it is not applied as a restricted religious food such as halal. However, one greater concern of cultured meat is in regards to halal status because the meat is derived from live animal tissue and grown *ex vivo* on a petri dish in the lab. Since this novel product is a new discovery and has never been discussed by classical jurists, the halal status is unknown. Nevertheless, the halal status of cultured meat can be resolved if the culture medium or stem cell obtained from an only halal slaughtered animal [51]. Also, it is permissible if the blood or serum is not incorporated in the culturing stage [51]. Besides, in terms of the market forecast, the demand and supply of halal food are increasing throughout the world and will be expected to be the most profitable and influential market arena for the food business. The halal food is registered at a 6.1% CAGR in terms of revenue, from US\$1.14 billion in 2017 to reach up to US\$1.63 billion by 2023 [52].

FUTURE TRENDS

As well as cultured meat, meat analog from insects will promise a new source of protein for human food in the future. Insects do contain not only high protein but also sufficient in vitamins, unsaturated fatty acids, and minerals, which can be considered nutritious [53]. Insect consumption can also help to sustain the environment as insect rearing requires very less space and create less pollution than livestock production [54]. The easy source of protein can be obtained at a lower environmental cost, contribute positively to the livelihoods and nature ecosystems [55]. Insects are reported to produce fewer greenhouse gases and less ammonia than livestock had [56]. In the next century, insects will become a relevant source of food due to factors such as rising the cost of animal protein, animal diseases, environmental pressures, population growth, and increasing demand for protein, especially among the middle classes. Currently, more than 1900 species have been reported to be used as food and around 2 billion people in more than 100 countries relied on the insect as their traditional diets [55].

In most Western countries, they tend to trigger disgust perception towards insects and associate eating insects with primitive behavior [55]. Contrarily, edible insects are common in some developing countries and marketed as street foods. Also, a variety of insects offered in stalls and local restaurants in southern African and Southeast Asian countries mainly. It has been eaten daily due to inexpensive cost and convenience. The economic contribution from insect markets is considerable in developing countries but sometimes is not reported and underestimated [55]. Even though insect proteins, already in the mainstream in some Asian markets, but now a growing number of companies in Europe and North America started using insects for human food and in animal feed [20]. For instance, the Swiss food retailer (Coop) launched insect-based burgers and insect energy bars in their shop in 2017 and obtained positive feedback from the customers. In Germany in 2018, Bugfoundation started selling its insect fortified burger made from buffalo worms and soy protein [57].

In terms of safety issues, eating insects also are associated with the risk of disease and illness because of low food safety standards available [58,59]. Since many scientists and food producers have the interest to develop alternative meat products beyond the current nature of the processing, the new regulation has been set by the European Union (EU) to all the novel food products, including insect food products to be listed under the Novel Food Regulation. All the new food products must be tested and approved first by the European Food Safety Authority to ensure their health safety before being marketed [57].

LAW AND REGULATIONS

Implementation of food laws and regulations is essential in order to protect human life, health, and consumer interest as well as to ensure fair practices in food trade. For example, the EU has put newly developed foods under the Novel Food Regulation which defined as food that had not been consumed or do not exist in the EU before 15 May 1997, which the first regulation applied to novel food [21]. There are three principles of regulation on novel food set by EU: i) safe for consumers; ii) novel products must be appropriately labeled, to avoid misleading the consumers; and iii) novel food should not be nutritionally disadvantageous when intended to replace by any means [21]. Other countries that have implemented novel foods legislation include Australia, New Zealand, and Canada [55].

CONCLUSION

It can be concluded that there is a high demand for meat analog in the current and future markets. The most significant interest in this product is not due to vegan consumer's number increase, but it was driven by the consumers concerned about healthy foods and a sustainable environment. Nevertheless, there is still limited meat analog in the current market and predominantly available only plant-based meat. Cultured meat for instance, still not marketed, due to the development itself is not an easy task. It took several years for the research and development to ensure the quality equivalent to conventional meat. Besides, the insect-based products at any time can be produced by alternative meat producers, due to available resources. But, other than safety issues, the acceptance towards insect-based meat is the foremost hurdle that must be overcome.

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