In vitro meat production system: why and how?

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Abstract Due to the nutritional importance and the sustained popularity of meat as a foodstuff, the livestock production sector has been expanding incessantly. This exponential growth of livestock meat sector poses a gigantic challenge to the sustainability of food production system. A new technological breakthrough is being contemplated to develop a substitute for livestock meat. The idea is to grow meat in a culture in the lab and manipulate its composition selectively. This paper aims to discuss the concept of In Vitro Meat production system, articulate the underlying technology and analyse the context of its implications, as proposed by several scientists and stakeholders. The challenges facing this emerging technology have also been discussed.

Keywords Cultured meat · IMPS · Stem cells · GHG emissions · Consumer acceptance

Introduction

With scientific innovations and technological advancements, the field of food has witnessed some revolutionary changes which have been primarily consumer directed as food

production and processing is a highly consumer sensitive domain. A new technological breakthrough is being contemplated to develop a substitute for livestock meat since there are several incentives to implement this technology, called In Vitro production of meat or lab culturing of meat. Embracing the technology would allow us to combat the problems posed by conventional production of meat. The idea is to grow meat in a culture in the lab and manipulate its composition selectively. This is proposed to yield several outcomes in the interest of consumers, environment as well as animals raised for meat. This technology is being critically evaluated for meat production as it is considered globally that meat must continue to be a part of our diet. It provides several essential nutrients chiefly, high quality protein, highly bioavailable iron and zinc, omega - 3 fatty acids, vitamin B₁₂ and all the B-vitamins except folic acid (Bender 1992; Voedingscentrum 2003). Besides, it is a major source of several other readily available minerals such as potassium, phosphorus, magnesium and calcium. Liver and to a lesser extent kidney, are also rich in vitamin A (Speedy 2003).

Concerns arising from expansion of meat sector and alternative to livestock meat

Due to the nutritional importance and the sustained popularity of meat as a foodstuff, the livestock production sector has been expanding incessantly. With present average meat consumption of 42 kg per year globally (UNEP GEAS 2012), the sector has expanded rapidly in recent decades. The data underline that since 1960, global meat production has become threefold and is suggested to continue to rise, from 233 million metric tons (Mt) in the year 2000 to 300 million Mt. in 2020 (Speedy 2003; Alexandratos and Bruinsma 2012; Rosegrant et al. 1999). This growth is precisely attributed to growing population, rising affluence and urbanization across the world

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(Tuomisto and Teixeira de Mattos 2011; Delgado 2003). This exponential growth of livestock meat sector poses a gigantic challenge to the sustainability of food production system. According to the latest revision of UN population prospects, the global demand for food is expected to increase by 70 % as a result of population growth. Globally, some 670 million tons of cereals are used as livestock feed annually, representing over one-third of total world cereal use (Speedy 2003). This leaves little portion to feed the large and growing population of the world. According to UNEP, if the feed grown worldwide for livestock is released for human use, it would be sufficient to feed 3.5 billion people (Garnet 2010). A decisive action is required if the sector is to satisfy this growth in consonance with the society's goals for food security, environmental sustainability and improved human health. Socially and morally, several efforts dedicated to combat this problem reduce the burden of only conventional methods of meat production but do not provide a concrete substitute.

Researchers have proposed an innovative solution for altogether replacing the livestock meat with the lab cultured meat (Edelman 2003). Also called In vitro meat/lab meat/synthetic meat/artificial meat, its fabrication involves a method of producing meat for human consumption wherein the protein cells are grown from a culture of animal stem cells or the whole muscle is synthesised *de novo* in a laboratory. It works on the principles of tissue engineering and involves an advanced approach of creating meat from muscle where animal slaughter is eliminated; the only step of involvement of the animal is the donation of suitable cell.

Methods of production (technology)

The idea to create meat artificially can be traced back to as many as 80 years when Frederick Edwin Smith had predicted: "It will no longer be necessary to go to the extravagant length of rearing a bullock in order to eat its steak. From one 'parent' steak of choice tenderness it will be possible to grow as large and as juicy a steak as can be desired" (Birkenhead and Smith 1930). A couple of years later, Winston Churchill also commented on the idea "Fifty years hence we shall escape the absurdity of growing a whole chicken in order to eat the breast or wing by growing these parts separately under a suitable medium" (Churchill 1932). Since then, two major technologies have been developed for the actualization of the idea. The heart of the scheme is the biotechnological approach that broadly involves cell culture and tissue culture/tissue engineering techniques and based on their design, they are also popularly known in the jargon of biotechnology as 'Scaffold-based' and 'Self-organizing techniques', respectively (Edelman et al. 2005).

Self-organizing technique

The first technique involves the use of an explant from the muscle of a donor animal which is then proliferated in a nutrient medium. In 1912, Alexis Carrel managed to keep a piece of chick heart muscle alive and beating in a petri dish, demonstrating that it was possible to keep muscle tissue alive outside the body, provided that it was nourished with suitable nutrients (Bhat and Bhat 2011). But in the real time context, the genesis of the idea roots back to the beginning of 21st century when Benjaminson, Gilchrist and Lorenz used tissue-engineering techniques for the production of meat (Benjaminson et al. 2002). They placed skeletal muscle explants from goldfish (*Carassius auratus*) in diverse culture media and observed a varied pattern of growth, with regard to increase in surface area over 7 days. The results based on the medium were as - fetal bovine serum: 13.8 %, fishmeal extract: 7.1 %, shiitake extract: 4.8 %, maitake extract: 15.6 %. The explants were also placed in a culture containing dissociated *Carassius* skeletal muscle cells and an increase of 79 % in the explant surface area was recorded. In other research initiatives, Benjaminson has also made possible to keep muscle tissue alive in a fungal medium (with risk of infection associated with serum-based media); the chicken muscles could be sustained for a maximum of two months in a petri plate (Wolfson 2002). Though the results of the experiment were rewarding, the problem of lack of blood circulation still holds back the long term success of the idea (Dennis and Kosnik 2000). However, Benjaminson has expressed the hope to overcome this hurdle, together with his team. The explant method can be applied for In Vitro Meat Production System (IMPS) because the researchers propose that the tissue formed will most closely resemble meat, containing muscle cells, fat and other cells in familiar proportions, as present naturally and this composition would best mimic the *in vivo* environment. In spite of this, the problem remains i.e. proliferation potential is limited; new biopsies would be required from donor animals on a regular basis.

The Self organising technique helps to create structured meat i.e. meat produced will have a well defined 3-D structure, just as the natural conformation of meat. The same can be achieved using the principles of tissue engineering for *de novo* synthesis of muscle tissue (Edelman 2003).

Scaffold-based technique

The second method of culturing meat involves suitable stem cells which can be obtained from variety of tissues (Hamburger junction 2012). This method is the scaffold-based technique, where, embryonic myoblasts or adult skeletal muscle satellite cells are proliferated, attached to a scaffold or a carrier and then perfused with a culture medium in a suitable bioreactor (Kosnik et al. 2003).

The principle of scaffold-based technique is that suitable muscle cells are proliferated on a carrier called scaffold in the presence of a culture medium in a bioreactor. Such culturing results in myofibers which may then be harvested, processed and consumed as meat or its products (Bhat and Fayaz 2011). There are currently two elaborate propositions for using cell culture to create meat in lab (Boland et al. 2003). One has been written by Vladimir Mironov for the NASA (Wolfson 2002), while the other by Willem van Eelen who holds a worldwide patent for a similar system (Van Eelen et al. 1999). Vladimir Mironov proposed that cells be grown on collagen spheres where they would attach and differentiate in a bioreactor. On the other hand, Willem van Eelen's proposal suggested use of a collagen meshwork in place of spheres and refreshing of culture medium from time to time. Alternatively, the culture medium can be percolated through the meshwork and collagen can be replaced by other edible proteins or artificial substrates. It may also use two-dimensional monolayers of muscle cells sandwiched onto each other after harvesting (Bhat and Fayaz 2011). Such a technique is expected to be appropriate for producing processed ground meat products, but not for producing highly structured meats, such as steaks. A more refined approach such as Self Organising Technique is required to produce a structured muscle tissue (Edelman et al. 2005).

Cells

The meat is majorly composed of skeletal muscle which consists of several cell types. These skeletal muscle fibers are a result of proliferation, differentiation and fusion of embryonic myoblasts or the satellite cells (Langelaan et al. 2010). A number of cell types have been proposed for the IMPS by several authors; these are Myosatellite cells, Embryonic stem cells and Adult stem cells. The satellite cells or the myoblasts have been found responsible for muscle regeneration and differentiate easily to form myofibrils eventually. On the other hand, stem cells can differentiate into different cell types and are primarily found in the development stages of organisms (Post 2012; Williams 2012).

a) Embryonic Stem Cells

Theoretically, they are an obvious option for IMPS due to their virtue of unlimited regenerative potential. However practically, genetic mutations over the time are likely to limit the production potential of an embryonic stem cell. Also, these cells would have to be stimulated to differentiate into myoblasts (Mattick and Allenby 2010; Datar and Betti 2010). Further, such stimulation of embryonic stem cells does not promise the retention of the same proliferative characteristics. Despite the long term culturing of embryonic stem cells now, it has not been possible to culture cells lines with infinite self-renewal capacity (Bhat and Bhat 2011).

b) Myosatellite Cells

These cells are considered as the most suitable source of cells for culturing of meat. They are a rare muscle tissue possessing limited regenerative potential and recapitulate the process of myogenesis with high efficacy, unlike the embryonic stem cells. Myosatellite cells from different sources have been isolated and characterised and they differ greatly in their proliferation and differentiation capabilities (Edelman et al. 2005; Datar and Betti 2010; Post 2012; Bhat and Bhat 2011).

c) Adult Stem Cells

Distinct from the embryonic stem cells in many ways, adult stem cells differentiate into a certain type of cell only or into a similar type of cell. For the purpose of culturing cells in IMPS, the epithelial stem cells are supposed to be a viable option as they form the primary component of meat i.e. muscle (Williams 2012). The adipose tissue-derived adult stem cells are the multi-potent cells which are envisaged for use in IMPS. The biggest shortcoming of using adult stem cells is that they are prone to malignant transformation. But Datar and Betti (2010) have concluded that collection of adipose tissue-derived adult stem cells is much less invasive than that of myosatellite cells.

Besides the culturing, proliferation and subsequent harvesting of isolated individual cell types, Edelman et al. (2005) have suggested the idea of co-culturing myoblasts with fat cells.

Culture media and growth factors

What fundamentally supports and promotes the culturing of the cells is the culture medium, together with the appropriate growth factors as it provides the requisite nutrition for the growth of the tissue. Traditionally, the medium employed for culturing the skeletal cells comes from an animal source; serum-based medium from adult, newborn or foetus (Coecke 2005). The growth factors are produced by the muscle cells themselves as well as provided by other cell types such as hepatocytes (Edelman et al. 2005). Moreover, as the process enters the differentiation and maturation phase from the proliferation phase, the changing demands of the cells (muscle) may require a change in the formulation of culture media. The external growth regulators and promoters can be added from transgenic organisms producing recombinant proteins (Houdebine 2009). The shortcomings of the medium include the high expenditure required for it as it covers a big fraction of the overall cost of culturing the cells (Mattick and Allenby 2010) and requires regular replenishing, the ethical concerns attached to the source of media (Fetal Calf Serum) and the potential infection that it may incorporate into the system (Datar and Betti 2010). However, alternatives like lipids such

as sphingosine 1-phosphate and amino-acid rich mushroom extracts have been suggested for the serum based media (Edelman et al. 2005; Datar and Betti 2010).

Scaffold

A scaffold acts as a substratum for cell attachment, proliferation and differentiation because they are anchorage-dependent (Bhat and Bhat 2011). According to Edelman et al. (2005) the scaffold for cultured meat must be edible and derived from a non-animal source. Besides, the scaffold should be flexible enough to facilitate mechanical stretching and contraction that would help in stimulation of cell differentiation but this continues to be a challenge of IMPS for example, Cytodex-3 microcarrier beads used as scaffolds in rotary bioreactors are devoid of stretching potential. Ideally, a scaffold should imitate the *in vivo* condition because the cells differentiate best on a scaffold with tissue-like flexibility/stiffness. The scaffold mechanisms are variable depending upon the shape, composition and other characteristics. Datar and Betti (2010) have asserted that large surface of the scaffold is a desirable aspect of its construction. In regard of the shape of scaffold, they have discussed the proposals of Edelman and Van eelen. They have also discussed that the texturised surfaces of scaffold would cater well to the requirements of the muscle cells such as alignment. Different edible and inedible polymers such as collagen, cellulose etc have been suggested as the base material for scaffold development, which would render it porous (Williams 2012). The detachment of the differentiated cells from the scaffold after its removal from the bioreactor is also a challenging task.

Bioreactor

The basic objective of employing a bioreactor in IMPS is medium perfusion. For large-scale commercial production of cultured meat, bioreactor stands as a giant requirement of IMPS because the cells need an enclosed and large surface area for culturing and proliferation into sufficient numbers (Bhat and Bhat 2011; Martin et al. 2004). Besides, it would fulfil the role of promoting tissue growth by creating a favourable environment. According to Datar and Betti (2010), adequate levels of perfusion form the basis for production of large culture quantities. They also state the couple of ways in which this can be achieved i.e. by using bioreactors and oxygen carriers. The key advantages of a bioreactor are that cells are in near-continuous suspension, fluid shear is low and tissue assemblies can be easily suspended. As far as the bioreactor of industrial scale is concerned, at least theoretically, scaling-up the lab-type designed bioreactors to industrial sizes should not affect the physics of the system (Edelman et al. 2005). A more critical analysis of bioreactor type and

design can be found elsewhere (Datar and Betti 2010; Bhat and Bhat 2011).

Contraction and atrophy

The growing skeletal muscle requires regular contraction because it promotes differentiation and averts the chances of atrophy. Atrophy is a condition of muscle wasting where loss of muscle occurs due to either lack of use or denervation or cell size reduction (Charge et al. 2002; Fox 1996; Ohira et al. 2002). Though the muscle *in vivo* is innervated, it has not been established whether the absence of innervation is a problem. Repeated stretching and relaxation equal to 10 % of length for six times an hour enhance differentiation into myotubes (Powell et al. 2002). Electrical stimulation has also been shown to contribute to differentiation in some organisms (Kosnik et al. 2003). Hence, exercise by electrical stimulation can expectedly prevent atrophy in IMPS (Datar and Betti 2010; Edelman 2003).

Tissue engineering of muscle fibers

Another approach, as suggested by Vladimir Mironov, proposes the creation of an artificial muscle completely, using tissue engineering techniques. He has mentioned about the polymer for nutrient perfusion and cell attachment and also about the idea of co-culturing the myoblasts with other types of cells to mimic the actual structure of muscle. However, the method to create the artificial capillaries is not much talked about.

As a matter of fact, this proposal has certain inherent limitations and challenges viz. the absence of blood flow which discourages the possibility of formation of a 3-dimensional structure of cells and makes removal of metabolic end products difficult (Fox 1996), limitations in nutrient diffusion etc. A couple of solutions have been suggested to overcome these problems which have not been discussed here as they are out of the scope of the central idea but can be located in details in Bhat and Bhat (2011).

Proposed implications and advantages of the technology

For technology of IMPS is a promising undertaking, its effects must be well understood and carefully framed. There are several critical consequences that IMPS is hypothesised to have and these will influence different domains of the society (Ford 2009; New Harvest 2014).

Health

To understand the possible effects of IVM on consumers' health, we must first look into the areas where livestock meat

creates problems. Livestock meat is a threat to public health by the virtue of its production system and consumption pattern. Where the production of meat places an indirect health burden on society, meat consumption is predominantly linked to multitude of health related problems.

Williams (2012) has described the ill effects of livestock meat on health under two major categories:

- a) Meat composition
- b) Meat food based infection

Meat composition Where on one hand meat provides several essential vitamins and minerals, on the other hand, its lipid components like saturated fat and dietary cholesterol increase the risk of diseases like atherosclerosis etc. Studies have correlated high meat consumption with elevated rates of chronic diseases particularly, diabetes, Cardio Vascular Diseases (CVD) and cancer which, eventually lead to morbidity and mortality (Armstrong and Doll 1975; Dwyer and Hetzel 1980; WHO 2009). These health risks are variable, depending on the animal (source) of meat and the handling conditions it is subjected to (Bender 1992). A lot of such cases are reported and recorded in the USA and other westernised countries which, represent a growing concern for the developed nations (Thorogood et al. 1994).

Cultured meat is expected not to pose such a problem; Williams (2012) has suggested that modifying the ratio of omega 6 and omega 3 fatty acids could help create a healthier meat since in the western world, the ratio of these two is in favour of omega 6, rather than omega-3. This can be done by altering the DNA of the progenitor cells, a step that can be taken care of in IMPS.

Meat food based infection Gold (2004) has elaborated on the various aspects of meat food based infection. According to him, the infection in meat originates from poultry farm itself as they are disease ridden. He also highlights that the industry has created an environment favourable to highly contagious agents. As per the World Health Organisation ‘Campylobacter species are now the commonest cause of bacterial gastroenteritis in developed countries, and cases are predominantly associated with consumption of poultry’. Some 90 % chickens in US and 50–75 % in the UK are infected with Campylobacter. Also, trichinosis has been a constant concern relating to meat food. The outbreak of diseases like Bovine Spongiform Encephalopathy (BSE), Swine flu and Foot and Mouth Disease (FMD) have raised health concerns time and again (Fox news 2009; Johnson and Gibbs 1998).

Another facet of livestock meat production is the uncontrolled use of antibiotics and other drugs to promote growth. This results in human health hazards, particularly of antibiotic resistance (Gold 2004; Sanders 1999). Even in India,

unconstrained use of antibiotics like oxytetracycline, chlorotetracycline, doxycycline, enrofloxacin, ciprofloxacin, neomycin etc. has been reported (CSE India 2014; NDTV 2014). This has woven a vicious circle of challenges that has led not to only increased antibiotic resistance but also the need for more effective antibiotics in the world for treating several formidable health problems. Most important of all, industrial animal production involves public health concerns surrounding feed formulations including animal tissues, arsenic and antibiotics plus the occupational health risks and risks for nearby communities (Bhat and Fayaz 2011; Walker et al. 2005).

Precisely, IMPS will reasonably counter these issues as there is no involvement of factory farming and drug feeding in culturing of meat in the lab (Bhat and Fayaz 2011; Mattick and Allenby 2010; Edelman et al. 2005; Ford 2009). Datar and Betti (2010) have asserted that myocyte culturing is a solution to this set of health related concerns posed by livestock meat.

Animal Welfare and ethical concern

When meat itself implies murder, animal welfare concern is inevitable. The development of IMPS appears to be a matter of moral pull more than technology push (Weele and Driessen 2013). This is because to cater to the increased meat demands of modern society, animals are intensively reared at industrial farms and only meat production is targeted, irrespective of the well-being of animals. Thus, animal welfare becomes a serious human concern (Edelman 2003). Practices like herding of animals in confined spaces in hostile conditions, rough handling, long distance transportation without proper food and water, injuries due to poorly designed ramps and pens, overcrowding and exposure to extreme weather conditions inflict extreme brutality on animals. The total number of broilers (for chicken meat) killed in the UK in 2002 exceeded 800 million and 99 % of them were factory farmed. Besides, hens are also kept in battery cages for laying and several other birds are kept in narrow wire cages. This causes deprivation and creates endemic welfare difficulties. Multiple forms of injury appear due to the wire mesh cage floor and as a matter of fact, beef cattle, sheep and pigs suffer atrocities in similar manner (Williams 2012; Gold 2004).

The ethical concerns attached to conventional meat production system still surface in the media and a huge western population opposes the way in which meat is traditionally produced (Edelman 2003). But for a long time now, there is a unanimous opinion of the people on animal suffering being an evil (DeGrazia 1996). Thus, some of them are looking forward to more animal-friendly alternatives which makes cultured meat, if commercialised effectively, a suitable option for consumers in the future.

For majority of people, the most appealing feature of cultured meat is its moral promise for animals. Hence, animal

organizations also welcome the idea of cultured meat. Interestingly, PETA was so moved by the idea of cultured meat that it announced a prize of US \$1 million to promote IMPS. Hence, IMPS is proposed to bring an end to the animal suffering associated with traditional method of livestock rearing and slaughter. Weele and Driessen (2013) have highlighted the persistent opinion of Peter Singer who describes cultured meat as the main source of hope to curb animal suffering. Further, it has been discussed by several authors that in vitro meat has the potential to eliminate animal suffering and environmental damage (Stephens 2013).

In the panorama of discussions on IMPS, some other apprehensions have also found acknowledgement. Some authors have raised ethical concerns against the idea of IMPS. According to Mattick and Allenby (2010), the biotechnological feasibility of culturing animal muscle in the lab leads to the likelihood of culture of human cells in the lab too. Though the author does not consider it to be a grave issue at the moment but, it may lead to some catastrophic repercussions in the far-fetched future; a form of cannibalism is expected come into practice. Fearing such impacts, cultured meat may be ethically less acceptable to certain social groups.

On the other hand, Welin and Weele (2012) suggest that in course of production of ‘victimless meat’, we may deteriorate our traditional relationship with animals. This is viewed as an apparent threat to the connect of humans with the nature. As the IMPS would eliminate the rearing of animals for meat, the process is alleged to break the existing harmony between humans and nature. Infact, this is supposed to help us embrace the nature as we would be able to give a better fate to the animals. Rearing of animals could then be replaced by adoption of animals for their better existence. Yet another aspect of ethical concern addressing the humans is based on the artificiality of cultured meat. The social and moral acceptance of cultured meat is speculated to be low because it is not derived by a natural process. Such a perception hampers the idea of relieving the animal suffering. Questions have been raised over the ‘unnaturalness’ of cultured meat when, there exists no universal definition of ‘naturalness of meat’. It is protested that artificially grown meat will be inferior to the naturally obtained meat and will introduce a detestation in the minds of consumers. Contrary to the ideas proposed, cultured meat can be made or designed to be superior to the natural meat (Hopkins and Dacey 2008).

Environment

a) Pollution

Perhaps the most worrisome impact of industrial meat production, analyzed and discussed in many scientific publications in recent years, is the role of livestock in climate change. The raising of livestock has a direct role in emission of

methane (CH₄) and nitrous oxide (N₂O), described as one of the most aggressive greenhouse gases by the World Bank (Lesschen et al. 2011; Williams 2012; UNEP GEAS 2012). Globally, about 9 % of emissions from agricultural sector consist of Carbon dioxide, 35–45 % of methane and 45–55 % of nitrous oxide (McMichael et al. 2007; Navigating the numbers 2014). There is ongoing debate about the magnitude of these emissions, with a discrepancy to the estimated values of FAO (18 % of total global anthropomorphic GHG emissions) (Tuomisto and Teixeira de Mattos 2011). The acknowledgement for this situation comes from the factory farming industry itself as: ‘Livestock buildings are a major anthropogenic source of atmospheric pollutants, such as ammonia, nitrous oxide, methane and carbon dioxide, which contribute to soil acidification and global warming’ (Gold 2004). As per the scientific logical, the levels of nitrogen and phosphorous are so high in the farm animals because they can absorb only a limited fraction of the amount contained in their feed. About 70–80 % of dietary nitrogen fed to cattle, pigs and laying hens is excreted by these animals as faeces and urine. As mentioned before, contrary to the general trends of GHG emissions, Carbon dioxide (CO₂) is only a small proportion of the emissions from livestock cultivation. The biggest share of GHG emissions is from two other gases: methane (CH₄) and nitrous oxide (N₂O). These are not only emitted in large quantities, but are also potentially harmful as they carry a global warming potential (GWP) of 25 (using a 100-year timeframe) and 296 respectively (UNEP GEAS 2012). This is a clear indication of the magnitude of environmental damage caused by these gases. Besides, the emissions vary in nature; direct ones are produced directly due to enteric fermentation and urination by the animal and the indirect ones are from the crops from animal feed, emissions from fertiliser production and manure application etc. (Tuomisto and Teixeira de Mattos 2011).

b) Water use

In the times when the world is facing increasing water shortage, the livestock sector forms over 8 % of global human water use (Goffman 2012). In Brazil, the production of beef devours up 15,500 m³/t of water and chicken 3918 m³/t. Gold (2004) has mentioned some startling figures of water consumption. While the intolerable strain put by the large population of farm animals on the dwindling water resources is evident, the problem is exacerbated by the polluting of water supplies by these animals. The farmed animals in the United States produce 130 times the waste as the human population. Conventional meat production system recycles huge amount of freshwater, potable water into polluted, wastewater. According to a report, ‘slaughterhouses in developing countries release large amounts of waste into the environment, polluting land and surface waters... In some slaughterhouses

there is not even running water for cleaning'. Moreover, it is not only effluent and blood which are polluting the water supplies (Gold 2004).

c) *Burden on Land resources*

The globalisation of food trade has turned the contemporary industrial meat production system into a lucrative business with different processing set ups in different countries. It is reported that the manure of industrially farmed pigs includes gases like ammonia, methane, hydrogen sulphide, carbon monoxide, cyanide, phosphorus, nitrates and heavy metals along with over 100 microbial pathogens like salmonella, cryptosporidium, streptococci and girardia (Goffman 2012). The vast areas of agricultural land covered by the fodder produced for animals require extensive use of fertilisers, pesticides, herbicides, insecticides and fungicides. This leads to elevated nitrate levels and eventually pollution.

As per the literature described by Datar and Betti (2010), IMPS would have a lessened demand for water, energy and land. They have enumerated several reasons for this such as absence of by-products, faster growth of cultivated tissue and vertically directed growth of the IMPS. Also, losses from diseased animals is excluded. According to a Life Cycle Analysis conducted by Tuomisto and Teixeira de Mattos (2011) IMPS was concluded to reduce the environmental burden posed by conventional livestock cultivation by many-fold. Compared to the conventionally produced European meat, cultured meat involves approximately 7–45 % lower energy use (where poultry sector has shown lower energy use), 78–96 % lower GHG emissions, 99 % lower land use and 82–96 % lower water use. Tuomisto and Roy (2012) have compared the environmental impacts of hypothetical large-scale production of cultured meat to the impacts of livestock production in the European Union-27 and concluded that on replacing all of the meat produced in the EU-27 by cultured meat, the GHG emissions, land use and water use would be reduced by two orders of magnitude versus the current livestock meat production practices. Besides suggesting changes in human diet as a significant tool to reduce GHG emissions (UNEP GEAS 2012), he/they also mention the idea of opting for less “climate-harmful” meat. This literature indicates that if implemented, IMPS can be expected to provide a near solution to these environmental problems.

Challenges

Merely equating the histology of cultured meat with that of conventional meat does not assure the consumer acceptance. It is a well known fact that any technology introduced in the public domain creates turbulence. Right from the time of its inception, the proposed idea of IMPS is face-to-face with some inherent challenges. Among these, the most significant

and formidable challenge is to achieve the consumer acceptance for cultured meat. This covers the different aspects of food appeal like appearance, taste, flavour, texture, mouthfeel etc. (Post 2012). Due to the novelty of the food, there is no significant literature about the consumer studies but the little documented data suggest an amalgamated response. One of the food experts said it was “close to meat, but not that juicy” and another said it tasted like a real burger (BBC News 2013). A recent survey revealed that 80 % of Americans would not eat lab grown meat (though the younger population is more willing to try it) (CNN 2014). However, in a poll in the UK, 68 % of the participants voted in favour of cultured meat by saying that they would eat in vitro meat (Guardian 2012). The Dutch government has funded a programme (currently in progress) studying the potential consumer acceptance of cultured meat. It is felt that cultured meat may sound unnatural and unappealing to some consumers. Already, there are numerous arguments made like, the IMPS changes the intrinsic value of the muscle (animal), resistance in the name of genetic engineering of the food, Frankensteinfood etc. (Edelman 2003). In his article about the problems with in vitro meat, Welin (2013) has discussed the opinion of Hopkins and Dacey, i.e. cultured meat is ‘unnatural’ even when they state that there is no universal definition of ‘unnatural’ or ‘artificial’. In such a situation, it is difficult to frame an opinion because it is a matter of subjectivity but a solution must be derived for putting down every potential barrier to consumer acceptance (FST Journal 2013).

Apparently, the in vitro meat will have to struggle for a while before it can actually be embraced by the consumers because it presently suffers some serious flaws. Due to the absence of the natural pigment myoglobin, the cultured meat looks devoid of its pleasant red colour. And as a matter of fact, it is even devoid of the mineral otherwise abundantly present in meat i.e. iron. According to (Datar and Betti 2010), the nutrients present naturally in meat that are not synthesised by the muscle must be provided for example, vitamin B₁₂. Post (2012) has commented that creating or mimicking the natural flavour in the in vitro meat is a gigantic challenge because more than a thousand water soluble and fat derived components bring about the flavour of meat. Besides, the flavour of meat is intricately balanced by a multitude of peptides and aromatics modified during several biochemical processes and produced at processing stage such as maillard reaction. Also, another important factor contributing to the flavour of meat is fat. (FST Journal 2013; Mottram 1999). However, the scientists at Modern Meadow (A US based company) flavour the steak chips using sauces, like teriyaki or barbecue, before placing them in a food dehydrator. This takes up to a week (CNN 2014).

Lastly, the most important factor in deciding the consumer acceptance is the ‘yuck factor’. It is described as a spontaneous feeling towards the idea of eating so-called unnatural meat

cultured in a lab. A logically convincing argument against the anticipated resistance of consumers for cultured meat is presented in an article emphasising the fact that (In Vitro Meat News 2014) making people aware of the production process of the livestock meat or the conventional meat would generate an aversion in their minds for it and perhaps usher them to opt in vitro meat over real meat. But in the case of food, the overall sensory appeal overrules the logics. A commodity like food has a psychological and emotional value attached to it implying that the discussions about cultured meat are not always only rational (FST Journal 2013).

In addition to the possible opposition by the consumers, there is an array of other technical challenges posed. To set up the suitable stem cell lines is the first major challenge, followed by efficient isolation of stem cells. And if the stem cell line is contaminated, it would be advisable to have more than a single stem cell line (Welin 2013). The chances of contamination can be introduced by the substrate as well. Next is the increasing complexity of the problems associated with the culture media like developing its sufficient quantities for market demand, more importantly, the unethically obtained Fetal Calf Serum (FCS), essential for growth (Williams 2012) etc. Though a practical answer to this has been provided by Tuomisto and Teixeira de Mattos (2011) where the use of Cyanobacteria Hydrosylate is recommended but this has not received much acceptance. Where the removal of scaffold is in itself a problem (due to a possible collapse of the meat structure after its detachment from the scaffold) (Datar and Betti 2010) creating a scaffold for the structured and unprocessed meat also poses a challenge. The biggest of all, the tissue engineering of muscle fibers remains to be a difficult task for in vitro production of meat (FST Journal 2013).

Legislation

Since the IMPS still belongs to the laboratory and not the commercial domain, there has been no mention of the legislation that would look into the affairs of cultured meat. This is expected to be a crucial decision because a number of considerable factors are associated with the large-scale massive and commercial production of in vitro meat.

Conclusion

The development of IMPS technology has its due promises and credits. Once the technical challenges are met with, it shall become easier to introduce the technology in the commercial arena. Though a cent percent replacement of livestock meat by IVM will remain a mere thought but, a lot of potential stability can be brought about by IMPS. Meat being a sensitive muscle food, all regulations pertaining to IVM will have

to be stringently framed and followed. IVM shall soon bring a revolution of human, animal and environment friendly meat. A new product of human ingenuity shall change the way meat is produced, consumed and studied.

Conflict of interest It is declared that there is no conflict of interest between both the others.

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