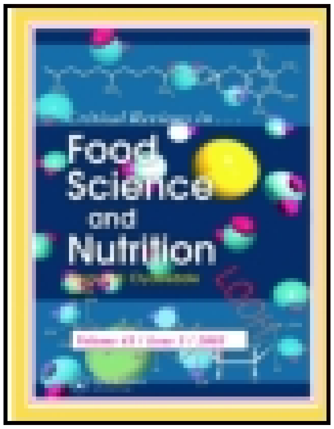

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In Vitro Meat: A Future Animal-Free Harvest

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Abstract

In vitro meat production is a novel idea of producing meat without involving animals with the help of tissue engineering techniques. This biofabrication of complex living products by using various bioengineering techniques is a potential solution to reduce the ill effects of current meat production systems and can dramatically transform traditional animal-based agriculture by inventing ́animal-freeô meat and meat products. Nutrition-related diseases, food borne illnesses, resource use and pollution, and use of farm animals are some serious consequences associated with conventional meat production methods. This new way of animal-free meat production may offer health and environmental advantages by reducing environmental pollution and resource use associated with current meat production systems and will also ensure sustainable production of designer, chemically safe and disease free meat as the conditions in an in vitro meat production system are controllable and manipulatable. Theoretically, this system is believed to be efficient enough to supply the global demand for meat, however, establishment of a sustainable in vitro meat production would face considerably greater technical challenges and a great deal of research is still needed to establish this animal-free meat culturing system on an industrial scale.

Keywords: In vitro meat, history, techniques, benefits, objections

1. Introduction

In vitro meat production is the manufacturing of meat and meat products through tissue-engineering technologies without involving the animal rearing and killing. In vitro meat production could have financial, health, animal welfare and environmental advantages over traditional meat production (Haagsman et al. 2009). The techniques for in vitro meat production are not beyond imagination and the basic methodology involves culturing muscle tissue in a medium in a large bioreactor (Bhat and Bhat 2011a). Starting cells for meat production could be taken from live animals biopsy or animal embryos and then put into a culture media where they start to proliferate and grow, independently from the animal. Production of in vitro meat for comminuted and processed meat products, such as sausages, burgers and nuggets will be easier to develop (Datar and Betti 2010, Bhat and Bhat 2011a, 2011c), however, for the commercial production of highly-structured unprocessed meat, a great body of research is still needed to be done (Bhat and Bhat 2011c). In the long term, tissue-engineered meat is the inescapable future of humanity; however, in the short term the extremely high cost of the biofabrication of tissue-engineered meat is the main potential obstacle, although large-scale production and market penetration are usually associated with a dramatic price reduction (Bhat and Bhat 2011a).

2. History

Aiming for the production of cultured animal muscle protein for long term space flights or habituation of space stations, the first significant investment into cultured meat research was made by NASA scientists who cultured muscle tissue from the common goldfish (*Carassius auratus*) in Petri dishes (Benjaminson et al. 2002). The cultured muscle explants obtained in the study were washed, dipped in olive oil with spices, covered in breadcrumbs, fried and judged by a test-panel who agreed that the product was acceptable as food (Benjaminson et al. 2002). Itôs been in 2013 only that scientists crossed one big stride in the area of in vitro meat production by producing the worldôs first in vitro meat based burger. The burger contained five-ounce in-vitro meat patty and was cooked and tasted by a sensory panel in Riverside Studios in London. It took only three months to grow the beef, worth more than $330,000, in the laboratory using stem cells harvested from a cowôs shoulder. The panellists said that the burger tasted, ñalmostò like a conventional one. This event aroused the expectations of the people to see the cultured meat and meat products on the shelves of the supermarkets within few years of time. These products may take the form of luxury items in the beginning and maybe available at first in the form of such exotic treats as snow leopard burgers or rhino sausages (Zaraska 2013).

Although, the concept of in vitro meat production appears to be of recent times, however, the idea of *in vitro* meat for human consumption was predicted long back by a writer and Conservative politician Frederick Edwin Smith, 1st Earl of Birkenhead, who predicted that ñIt will no longer be necessary to go to the extravagant length of rearing a bullock in order to eat its steak. From one ôparentô steak of choice tenderness it will be possible to grow as large and as juicy a steak as can be desiredò (Ford 2009). The concept was also written after few years by Winston Churchill in essay ôFifty Years Henceô later published in book ôThoughts and adventuresô in 1932. A French science fiction author Rene Barjavel also made the mention of cultured meat in his novel ôRavageô in 1943 later translated as ôAshes, Ashesô in 1967. Alexis Carrel in 1912 managed to keep a piece of embryonic chick heart muscle alive and beating in a Petri dish. Many people have already filed patents on the production and other aspects of in vitro meat (Vein 2004, Van Eelen 2007). In the early 1950s Willem Van Eelen of Netherlands independently had the idea of using tissue culture for the generation of meat products. Since at that time the concept of stem cells and the in vitro culture of cells still had to emerge, it took until 1999 before Van Eelenõs theoretical idea was patented (Bhat and Bhat 2011a). SymbioticA harvested muscle biopsies from frogs and kept the tissues alive and growing in culture dishes (Catts and Zurr 2002).

3. Problems associated with current meat production

3.1. Animal suffering and cruelty

Meat demand is expected to increase highly in developing countries and slightly in developed counties until 2020 (Rosegrant et al. 1999, Delgado 2003). The consumption of meat has grown from 234 pounds per person in 1980 to 273 pounds in 2007 in the USA alone (Pluhar 2010) and to meet this production 10 billion terrestrial food animals were slaughtered in 2007 in the USA which accounted for nearly 25 percent of the worldõs total of non-aquatic animals killed for food (Alexander 2011). Conventional meat production systems are involved with desensitizing and excessively brutal slaughter of millions of food animals to meet the ever increasing demand and addiction to meat. Although, moral views on killing animals are divided (Welin 2013, McMahan 2002, Cavalieri and Singer 1994), but there is general consensus that animal suffering is an evil (Welin 2013, DeGrazia 1996). Present indoor intensive meat production, in particular, is not good from the point of the welfare of the animals (Welin 2013) and there are also huge problems in present-day slaughter house practices (Welin 2013, Eisnitz 2006).

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Animals are intensively kept in the current meat production systems in order to increase the production, disregarding the well-being of the animals. An estimated 27 billion animals were being kept as livestock globally at the beginning of 2010 with 66 billions slaughtered each year around the globe (Schlatzer 2010). Herding of animals in confined spaces in unfavourable conditions is practiced and cattle in feedlots often stand knee-high in manure and arrive at slaughterhouses covered in faeces (Pollan 2002). Many of the world's 17 billion hens and meat chickens each live in an area that is less than the size of a sheet of paper (FAO 2006). High stress levels are observed in the animals, resulting in disease, abnormal behaviour and death due to the non-adaptability to these unnatural conditions (Crok 2003).

3.2. Resource use

30 percent of the land surface is used globally for the livestock production with 33 percent of arable land being used for growing livestock feed crops and 26 percent being used for grazing (Steinfeld et al. 2006). This area usage is accompanied by a share of only 17 percent of calories that animal products contributed in 2003 to global food supply (FAOSTAT 2008, Ramankutty et al. 2008). About 70 percent of the fresh water use and 20 percent of the energy consumption of mankind is directly or indirectly used for food production, of which a considerable proportion is used for the production of meat (Bhat and Bhat 2011b). At these rates, the world cannot sustain an increased burden on its natural resources due to heightened demand for meat (Fox 2009).

3.3. Global warming and pollution

The livestock sector contributes 18 percent of the anthropogenic greenhouse gas emissions and 37 percent of the anthropogenic methane emissions to the atmosphere worldwide

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(Steinfeld et al. 2006). Williams et al. (2006) calculated 4.58 kg CO2-eqivalents per kg for poultry meat (assuming 70% dressing yield) whereas Hirschfeld et al. (2008) summarised a range of 1.66 to 4.6 kg CO2-eqivalents per kg live weight in the light of the existing literature. The biggest share of energy usage and GHG-emissions occur at the farm level, nevertheless the retail market is responsible for 20 percent of energy usage and 9 percent of GHG-emissions in poultry production (Katajajuuri 2008). In a Japanese analysis Ogino et al. (2007) reported that the life cycle of 1 kg of beef leads to GHG emissions of 36.4 kg CO2-equivalents, equivalent to the use of nearly 14 litres of diesel or nearly 16 litres of fuel or driving an average European car 250 kilometres.

By the year 2050 a rise in annual greenhouse gas emissions will be observed from 11.2 (in 2000) to 19.7 gigatonne of carbondioxide, carbon equivalent and in the same period annual global meat production will rise from 228 (in 2000) to 465 million tonnes (Steinfeld et al. 2006). Current meat production system is responsible for the emissions of nitrogen and phosphorus, pesticide contamination of water, heavy metal contamination of soil, acid rain from ammonia emissions, erosion and subsequent habitat and biodiversity loss (Asner et al. 2004, Savadogo et al. 2007, de Haan 1997).

3.4. Inefficient nutrient conversion

Current meat production systems are not efficient in nutrient conversion as 1 kg poultry, pork and beef requires 2 kg, 4 kg and 7 kg of grain, respectively (Rosegrant et al. 1999). Approximately 85 percent of the global soy production (Pachauri 2008, WWF 2008) or a third of the global cereal production (FAO 2008) is consumed by livestock animals and due to the natural conversion losses within the metabolism of each animal, a big share of calories is lost for human

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nutrition when cereals, soy or other plant products are fed to animals and not to humans directly. The total expenses for feed, including cereals, pulses, bran, fish meal and oils, made up around 1300 million tons by 2008 (FAO 2009). With the population of nine billion people over the course of the next few decades (Specter 2011), and great proportion of which facing starvation, it no longer makes sense to contribute staple crops toward inefficient meat production (Bhat and Bhat 2011b).

3.5. Diseases and health concern

The conventional meat production systems have a deleterious effect on human health through animal disease epidemics and nutrition related diseases. More serious threat is posed by the chicken flu having the potential to kill millions of people through epidemics or even pandemics (Webster 2002). With a six fold increase in gastro-enteritis and food poisoning in industrialized countries in the last 20 years, food-borne illnesses have become increasingly problematic (Nicholson et al. 2000, Bhat and Bhat 2011a, b). Everyone, even non meat-eaters, at an international scale is put at risk by the pathogens released from stressed, immune-compromised, contaminant-filled livestock, which are administered routine non-therapeutic doses of antibiotics in their feed (Alexandar 2011). Approximately 70 million are sickened annually by infected food in the United States alone (Pluhar 2010, Alexandar 2011). Contaminated meats and animal products are the most common causes of food borne diseases in EU, USA and Canada (Barnard 1995, Mead et al. 1999, Nataro and Kaper 1998, European Food Safety Authority 2006, Fisher and Meakens 2006).

Nutrition related diseases, such as cardiovascular disease and diabetes, associated with the over-consumption of animal fats are now responsible for a third of global mortality (WHO 2001, Bhat and Bhat 2011a, b).

3.6. Religious restrictions and social taboos

The conventional meat is associated with certain serious religious issues like *Halal, Jatka, Jewish,* etc depending on the ritual method of slaughter opted during the slaughtering of the food animals. As *in vitro* meat is not associated with the killing of the animals, it is most probable to get free from these religious restrictions (Bhat et al. 2014). Further *in vitro* meat is an option for those people who are vegetarians and do not eat meat because of the ethical reasons associated with the conventional meat.

3.7. Extinction and endangered species

Because of the legal or illegal encroachment of the forest land for livestock rearing and farming, many of the animal species are losing their natural habitats and are becoming extinct. Livestock rearing for the production of conventional meat has been one of the predominant causes for many threatened or entirely exterminated species (Myers et al. 2005). More than a quarter of all rain-forest land in Central America has been converted to cattle rearing since 1960 (Catherine 1985) and 70 percent of former tropical rainforest in Costa Rica and in Panama has been stripped and converted to cattle-raising pasture. According to a leading article in 2004 ñThe Rise of Vegetarianismò in Nutrition and Dietetics, the Journal of the Dieticiansô Association of Australia, almost 40 percent of the land of Brazil has been cleared for raising beef.

3.8. Deforestation

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Animal derived foods require much more land to produce a certain amount of food energy than plant based foods (Peters et al. 2007). In Brazil, the cattle sector is the key driver of deforestation in the Brazilian Amazon, responsible for an estimated 80 percent of all deforestation in the Amazon region (Chomitz and Thomas 2001, Grieg-Gran 2006). The cattle sector in the Brazilian Amazon alone is responsible for 14 percent of the worldôs annual deforestation (Greenpeace-International 2009).

3.9. Non-availability of exotic meat

Meat from various wild animals is not available for human consumption in most parts of the world. As *in vitro* meat does not involve the killing of animals and as it would be equally difficult to grow meat of farm animals and those of exotic wild animals, *in vitro* meat may come up in future in the form of different luxurious exotic meat varieties to tap its full market potential.

4. Techniques of production

Committed muscle tissue formation during embryological development begins with mononucleated myoblasts of limited proliferation capacity (Benjaminson et al. 2002) which fuse with each other and form multinucleated myotubes. These multinucleated myotubes upon maturation result into non-proliferative myofibers (Campion 1984). Increase in number of myofibers and number of nuclei per myofiber are kept minimal postnatally. However, in instances requiring repair or regeneration the myosatellite cells, located between the basal lamina and sarcolemma of an associated myofiber, are responsible for generating new myofibers or contributing additional myonuclei to existing ones (Le Grand and Rudnicki 2007). These mononucleated myosatellite cells are normally in a quiescent and non-dividing state (Hill et al. 2003) and are activated in vivo by weight-bearing stress or injury and divide asymmetrically into self-renewing myoblasts and committed myofibers (Benjaminson et al. 2002, Le Grand and Rudnicki 2007).

In vitro meat has already been produced on small scales but obviously, small biopsies will not be of practical importance and thus the use of tissue engineering to produce in vitro cultured meat for large-scale commercial production has been proposed. It is a powerful technique that is mainly being designated for regenerative medicine in a wide variety of tissues and organs (Bach 2003, Mol et al. 2005) and is attempted to mimic neo-organogenesis ex vivo for the treatment of various diseases and surgical reconstruction. In vitro production of edible skeletal muscle tissue from farm animals (Edelman 2005) is one of the range of the applications of tissue engineering of skeletal muscle besides in vitro model systems for drug-screening (Vandenburgh et al. 2008), pressure sores (Gawlitta 2007) and in vivo transplantation to treat muscular dystrophy and muscular defects (Boldrin et al. 2008).

The different techniques or design approaches for an in vitro meat production system range from those currently in use, like cell culture and tissue culture, to the more speculative possibilities like organ printing, biophotonics and nanotechnology (Bhat and Bhat 2011a, Bhat 2011).

4.1. Cell culture/ Scaffolding techniques

In these techniques, embryonic myoblasts isolated from a farm animal embryo or skeletal muscle satellite cells isolated from a farm animal muscle biopsy are proliferated and attached to a scaffold or some type of carrier like a collagen meshwork or microcarrier beads and then introduced into a bioreactor which may be rotating or stationary and filled with a culture medium rich in nutrients and growth factors. With the help of various environmental cues, these cells fuse to form myotubes. The myotubes differentiate into myofibers with the help of differentiation media (Kosnik et al. 2003). The resulting large number of myofibers may then be harvested from the scaffold, minced and used in the preparation of comminuted and emulsion based meat products.

There are two detailed proposals regarding the production of in vitro meat by using cell culture or scaffolding techniques and both the proposals are similar in nature (Boland et al. 2003, Zandonella 2003). One of the two proposals, based on emerging field of tissue engineering, was written by Vladimir Mironov for the NASA (Wolfson 2002) whereas the other one is available as a worldwide patent in the name of Willem Van Eelen (Van Eelen et al. 1999). Both of these proposals are yet to be tested and Catts and Zurr (2002) seems to be the first who has actually produced meat by this method. Both of these proposals work by growing myoblasts in suspension in a culture medium within a bioreactor. According to the Mironov̂s proposal the myoblasts are made to grow on collagen spheres as a substrate within a bioreactor whereas Van Eelen proposed the use of a collagen meshwork in place of collagen spheres with the culture medium refreshed from time to time or percolated through the meshwork. By using various differentiation factors and media, the myoblasts fuse together to form the myotubes which differentiate into myofibers. Once differentiated, these myofibers could be harvested and used in the preparation of meat products. Thus, these cell culture based techniques produce ground boneless meats with soft consistency and do not produce highly structured meats like steaks. However, cells can also be grown in substrates that allow for the development of óśselforganizing constructsôô that produce more rigid structures. Scaffolds developed by using natural and edible biomaterials like collagen that allow for 3-D tissue culture and complex structuring of meat have been proposed and attempted (Hopkins and Dacey 2008).

4.2. Self-organizing /Tissue culture techniques

A more ambitious approach is required to produce the highly structured meat in the form of self-organizing constructs (Dennis and Kosnik 2000). Benjaminson et al. (2002) cultured Gold fish (Carassius auratus) muscle explants in vitro. They took slices of goldfish tissue, minced and centrifuged them to form pellets, placed them in Petri dishes in a nutrient medium and grew them for 7 days. While using fetal bovine serum as the nutrient medium, the explants grew nearly 14% and with Maitake mushroom extract, the explants grew over 13%. When culture containing dissociated *Carassius* skeletal muscle cells was used, it showed a surprising 79% growth in surface area in a weekôs time and the explants and their newly grown tissue looked like fresh fish fillets. The newly grown meat was marinated in olive oil and garlic and cooked by deep fat frying method and presented to a panel for observation. Although, the panel did not eat the product, however, they reported that the fish looked and smelled good enough to eat (Benjaminson et al. 2002, Britt 2002, Sample 2002, Hukill 2006). The benefit of the tissue culture techniques is that the explants closely mimic in vivo situation and the resulting explants contain all the tissues which make up meat in the right proportions. However, the cells become necrotic in absence of blood supply when separated for long periods by more than 0.5 mm from a nutrient supply (Dennis and Kosnik 2000). For the production of entirely artificial muscle, Vladimir Mironov gave a concept of a branching network of edible porous polymer through which nutrients could be perfused and myoblasts and other cell types can attach (Wolfson 2002).

Such a design using the artificial capillaries for the purpose of tissue-engineering has been proposed (Zandonella 2003). By co-culture the myoblasts with other cell types, like the myooids, it is possible to create a more realistic muscle structure which can be organized in much the same way as real muscles (Dennis and Kosnik 2000, Dennis et al. 2001, Kosnik et al. 2001).

Future efforts in culturing meat will have to address the limitations of current techniques through advances that make cultured cells, scaffolds, culture media, and growth factors edible and affordable.

4.3. Organ Printing

Although, cell culture and tissue culture techniques can produce meat, however, the problems associated with these techniques is that they simply produce the versions of ground soft meat and they fail to provide consistency, vascularization, fat marbling or other elements of workable and suitably-tasting meat. Organ printing, a new technique of producing organs for transplantation procedures, provides solution to these problems by using the principles of ordinary printing technology-the technology used by inkjet printers to produce documents. By using the solutions of single cells or balls of cells and spraying the mixtures onto the gels that act as printing paper, it is probably feasible to produce meat for edible purposes by removing the paper by a simple heating technique or by using automatically degradable stuff.

The technique essentially involves spraying of live cells in layers which fuse to create three dimensional structures of any shape, such as rings and tubes or sheets. Thus the feasibility of producing entire organs through printing is possible which would not only have the basic cellular structure of the organ but would also include, built layer-by-layer, appropriate vascularization providing a blood supply to the entire product. Furthermore, from the view point of the production of meat for consumption purposes, marbling could be added as well, providing taste and structure. Essentially, sheets and tubes of appropriate cellular components could create any sort of organ or tissue for transplantation or for consumption (Mironov et al. 2003, Aldhous 2006, Hopkins and Dacey 2008).

4.4. Biophotonics

A new probable technique for the production of in vitro meat that relies on the effects of lasers to move particles of matter into certain organizational structures, biophotonics, is a new process of using light to bind together particles of matter. Although, the mechanisms of this field are still poorly understood, this phenomenon produces so called óoptical matterô in the form of certain organizational structures such as three-dimensional chessboard, or hexagonal arrays, in which the crystalline form of materials, such as polystyrene beads, can be held together by nets of infrared light. The matter will fall apart when the light is removed.

This has a binding effect among a group of particles that can lead them not only to be moved one by one to specific locations but that can coax them to form structures. Although, the phenomenon would be of prime interest to the medical sciences and technologies such as drug delivery or microencapsulized substances to individual cells, however, there is intriguing possibility of the usage of the technology in the development of tissues including meat (Hopkins and Dacey 2008). Arrays of red blood cells and hamster ovaries have already been created using this technology (Mullins 2006). Given the success of creating two-dimensional arrays, there is the possibility of producing tissue formations that use only light to hold the cells together, thus eliminating the need for scaffoldings (Hopkins and Dacey 2008).

4.5. Nanotechnology

One more prospective technique of production of synthetic meat, nanotechnology is the production and alteration of materials at the level of the atom and molecule. This highly emerging field holds out enormous possibilities keeping in view a concept of a speculative technology i.e. some version of an ―assembler‖, a robot the size of a molecule that would allow moving matter at the atomic and molecular level. The nanotechnologists are exploring all the possibilities and beneficial technological interventions that they would like to do with the help of these molecular scale sized robots. Knowing the basic concept that everything is made of the same basic atoms but simply arranged in different ways means that we would be able to construct virtually any substance we wanted from scratch by putting together exactly the molecules we wanted. Interestingly, one of the first examples given of the speculative technology of nanotechnology was that of synthesized meat (Bhat and Bhat 2011a).

Thus, technologies ranging from the actual to the speculative promise a variety of ways to create real meat without killing animals. Though still commercially infeasible at the moment or in some cases technologically infeasible for several years to come, the point here is not to be distracted by the fact that we cannot yet make use of these technologies but rather to decide whether we should support the development of these technologies (Hopkins and Dacey 2008).

5. Benefits of In vitro Meat Production

In vitro meat has the potential to greatly reduce animal suffering and make eating animals unnecessary, even while satisfying all the nutritional and hedonic requirements of meat eaters (Holmes and Dacey 2008). The first important advantage of producing cultured meat is better control over meat composition and quality by manipulating the flavor, fatty acid composition, fat content and ratio of saturated to polyunsaturated fatty acids through composition of the culture medium or co-culturing with other cell types (Bhat and Bhat 2011b). Furthermore, by adding factors to the culture medium which might have an advantageous effect on the health, like certain types of vitamins, health aspects of the in vitro meat could be enhanced (Van Eelen et al. 1999). Thus by culturing meat under the controlled and manipulatable conditions we can obtain designer meat with a suitable nutritional profile.

As the production of in vitro meat does not involve animal killing, it does not come with all the vicissitudes of animals. The in vitro meat production is likely to reduce the suffering of animals and the number of animals involved in the meat production. Theoretically, a single farm animal may be used to produce the worldôs meat supply (Bhat and Bhat 2011a, b). If ten stem cells divide and differentiate continually for two months, they could yield 50,000 metric tons of meat (Bartholet 2011). Furthermore, the chances of meat contamination and incidence of food borne diseases could be significantly reduced by the strict quality control rules, such as Good Manufacturing Practices, that are impossible to introduce in modern animal farms, slaughterhouses, or meat packing plants in most of the countries. In addition, the risks of exposure to pesticides, arsenic, dioxins, and hormones associated with conventional meat could also be significantly reduced (Bhat and Bhat 2011a, b, c).

The in vitro meat production system produces meat rather quickly by using very low energy as the nutrients are utilized in the development of muscular tissues only and other supporting tissues and biological structures required for successful living, locomotion and reproduction like bones, respiratory system, digestive system, skin, and the nervous system are not developed. Almost 75 to 95 percent of the feed given to an animal in the traditional meat production systems is lost because of metabolism and inedible structures like skeleton or neurological tissue (Madrigal 2008, Alexander 2011, Bhat and Bhat 2011a, b). Thus, in vitro meat production system is energy efficient as well as time efficient and will take several weeks instead of months (for chickens) or years (for pigs and cows) before the meat can be harvested. As projected by the first *In vitro* Meat Symposium in 2008 held in Norway, the first commercial *in vitro* meat products will be available in the next 5 to 10 years at prices competitive with European beef (~$5,200-$5,500 per ton or 3,300 to 3,500) (Alexander 2011).

The in vitro meat production system has many other benefits like reduction in resource use and a favourable ecological foot print. In vitro meat production will substantially reduce the use of land because the facilities could be built vertically, taking up less ground space and thus producers could place production centres in or near cities which will additionally reduce the transportation costs involved (Kuang 2008, Datar and Betti 2010). In vitro production will reduce the carbon footprint of meat products and can reduce greenhouse gas emissions from raising livestock for meat by as much as 90 percent and land and water resources for raising meat by up to 80 percent (Fox 2009, Schneider 2013). This significant reduction in the land use opens the prospects for other uses of this land including reforestation which may help in restoration of many endangered species.

In vitro meat production is a humane way of producing meat with comparatively low effects on environment and thus it will have a strong support in the scientific, environmental, and animal rights communities (Hopkins and Dacey 2008, Schneider 2013). It will also supply new meats and meat products in the future market by culturing cells from captive rare or endangered animals or even cells from samples of extinct animals could be used to produce exotic meats.

Thus meat from rare and endangered animals would be available without affecting the population of these animals. Further, it may offer humane meat of lab origin for people who are vegetarians due to the ethical reasons.

There are many situations like space missions, stations in Polar Regions, troop encampments in isolated theaters of war and bunkers designed for long-term survival of personnel following a nuclear or biological attack in which it is more economical to produce food in situ and in vitro meat production is one of the prospective options. For space missions for longer periods and permanent bases, bioregeneration becomes a more attractive option (Drysdale et al. 2003). A controlled ecological life support system (celss) would not only provide fresh food, but also deal with waste, and provide oxygen and water (Saha and Trumbo 1996, Benjaminson et al. 1998, Drysdale et al. 2003).

The in vitro meat would render itself free from social taboos like *Halal, Jatka, Jewish*, etc as the production of meat does not involve slaughtering of animals. Other benefits associated with in vitro meat production are potential impact on reducing cardiovascular diseases, liberation of land for nature (including wild animals) and food scarcity that can be expected with an increasing world population.

6. Objections to In vitro Meat

There are many advocates of in vitro meat production due to its environmental advantages and animal welfare issues; however, it has also simultaneously generated doubts and criticism (Welin 2013). One of the serious objections associated with the public acceptance of the in vitro meat is its unnaturalness which seems to play a large part in much resistance at least in Europe to new food technologies (Welin 2013). Moreover, some people may depreciate the value of the in vitro meat by thinking it as artificial meat and not the real thing whereas others worry about the concept saying it could result in victimless cannibalism by its ability to culture human muscle tissues (Hopkins and Dacey 2008, Peterson 2006, Mcilroy 2006). Further, people always worry about the danger of consuming untested novel materials. People pay attention to the reaction of disgust in trying to judge whether a new, and especially biotechnological, process is morally permissible and whether it should be legally permissible (Hopkins and Dacey 2008, Kass 1997).

Another objection that is already familiar from critiques of ethical vegetarianism is that animalsô lives will go better, paradoxically, in a world with something like the present meat industry, than in a world with universal or widespread vegetarianism (Hopkins and Dacey 2008)**.** Another argument is that in vitro meat production systems will use original cells gathered from some animal in a morally suspect way and that the use of such cells will morally taint all future generations of tissue (Hawthorne 2005).

Although, considered to have a good ecological foot print and sustainable means of disease free meat, in vitro meat may have a completely different risk profile and much attention would require to be paid to the safety of added substrates and other compounds of the culture medium (Bhat and Bhat 2011a, b, c). Another problem with the *in vitro* meat production system is the absence of livestock based farming that may alienate us from nature and animals. Further, it will certainly affect the economies of those nations which are involved in the large scale production of conventional meat and are dependent on the meat export.

There are also some other problems or objections with in vitro meat which are technological in nature. The first problem is pertaining to the cost of production as presently the extremely high cost of the meat culturing is perceived as the main potential obstacle. Although large-scale production and market penetration are usually associated with a dramatic price reduction (Bhat and Bhat 2011b), *in vitro* meat production on an industrial scale is feasible only when a relatively cost effective process creating a product qualitatively competitive with existing meat products is established (Bhat and Bhat 2011b). Further, at present no new technologies are available regarding the processing of in vitro meat. New processing technologies have to be developed for making the in vitro meat competitive with the conventional meat. The sensorial characteristics of in vitro meat like colour and appearance may have some difficulties as the cultured meat produced and tasted by a sensory panel in Riverside Studios in London in 2013 was reported to be colourless. There are two different ideas regarding the sensorial characteristics of the cultured meat. Because cultured meat is explicitly introduced as an alternative to the problems of normal meat, cultured meat should be as meat-like as possible in order to be a real alternative for 'traditional' meat from animals. On the other hand, a new product needs a profile of its own; otherwise it will not be able to compete. From this perspective, it is not essential for the product to resemble and should in fact be clearly distinctive from traditional meat (Bhat and Bhat 2011c).

7. Conclusions

Current meat production methods are associated with many problems like animal welfare issues, high risk of infectious animal diseases, nutrition-related diseases, resource use, erosion, habitat and biodiversity loss, and environmental pollution. In the light of this sizable negative impact of conventional meat production on the health and environment, in vitro meat holds great promises as an alternative to slaughtered animal flesh provided consumer resistance can be overcome. Ever growing demand for meat and the shrinking resources available to produce it by current methods also demand a new sustainable and environmentally beneficial production system. In vitro production of meat has many health and environmental benefits and is expected to be a sustainable source of humane, chemically and microbiologically safe meat. Since crucial knowledge is still lacking on the biology and technology, further research and financial impetus is required in the area for the establishment of a commercially feasible system with a relatively cost-effective process creating a product qualitatively competitive with existing meat products.

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