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In vitro meat: protein for twelve billion?

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Abstract

This thesis provides the background for the creative component of this MSciComm – entitled 'Meating Expectations' - a 25 minute documentary produced with Rodney August. This documentary covered a novel method of meat production; *in vitro* meat production, meat grown from stem cells, independent of the animal. The documentary investigates how *in vitro* meat is made, why it is necessary, the problems that it could solve and the problems that it could create. The general aim of this thesis was to raise public awareness concerning an *in vitro* meat product.

Conventional meat production is inefficient and unsustainable, severely diminishing freshwater quality and using prime agricultural land. It is the leading cause of loss of biodiversity, causes more greenhouse gases than the entire transportation sector and is undercutting international grain resources and staple food reserves. Today's escalating population, combined with rising affluence and the resultant unparalleled rise in meat consumption, (particularly in developing countries), is causing severe damage to the environment.

In vitro meat production is being researched mainly in the Netherlands and the USA. *In vitro* meat can be grown from embryonic stem cells or adult stem cells without harming an animal. Relative to conventional meat production, *in vitro* meat has the potential to be healthier, more efficient and more environmentally friendly, with less chance of disease and contamination. However, at present, the risk of contamination or error in the production of *in vitro* meat is at the same level as the risk of contamination or error

at companies where conventional meat is processed, such as in the production of sausages, hamburgers, nuggets etc.

However, challenges remain: there are problems with both the embryonic and adult stem cells, the very foundation of *in vitro* meat. Circulation restraints mean the growth of well-structured meats, like steaks, is not yet achievable. The optimal culture medium required to 'feed' the meat is yet to be ascertained. Presently, because of the small scale of production, culturing *in vitro* meat is very expensive. Research and technical advances are required to achieve commercial-scale production, but there is limited funding on offer. It may be a long time before a viable *in vitro* meat product is accessible. Some see social acceptance as the greatest impediment to an *in vitro* meat product.

If an *in vitro* meat product is produced with all the features of meat, which tastes good, is shown to be safe and is cheap, people would most likely consume it. *In vitro* meat is almost here, it may provide a cheap protein source for developed and underdeveloped nations.

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Dedicated to my grandfather Murray Keith May (1930 – 2012)

An unforgettable human being, loved by everyone he met.

Talented surfer, artist, athlete, carver… But most of all a great personality, a kind, witty, clever, lovely person who would give you the shirt off his back.

Glossary

Adipocyte/lipocyte/fat cells: cells that comprise adipose tissue, specializing in the storage of energy as fat.

Adult stem cells (also known as somatic stem cells): undifferentiated cells, found through the body post development, which proliferate via cell division to replenish dying cells and restore damaged tissues. They are present in both juvenile and adult bodies. Adult stem cells are multipotent and can therefore only generate a restricted number of cell types.

Anthropoid: an animal belonging to the great apes, of the family Pongidae, which comprises the gorilla, orangutan and chimpanzee.

Arboreal locomotion: the locomotion of animals in trees.

***Australopithecus*:** an extinct genus of hominins which most likely evolved in Eastern Africa approximately 4 million years ago, then spread throughout the continent. *Australopithecus* became extinct about 2 million years ago.

Basement membrane: a thin sheet of fibres underlying the epithelium, which lines the craters and surfaces of organs including the skin, or endothelium, that lines the inner surface of blood vessels.

Bipedalism: a form of terrestrial movement where an organism travels with its two rear limbs/legs, also known as a biped.

Connective tissue: connective tissue includes extracellular matrix, but can be a tissue in itself, forming sheets of membranes. Connective tissue includes tendons and ligaments for example.

Contemporary human: modern human.

Contemporary nonhuman primate: all living primate species, excluding humans.

Cyanobacteria: also known as 'blue-green bacteria': a phylum of bacteria which gain energy via photosynthesis. Cyanobacteria are no longer categorized as algae.

Dedifferentiation: a cellular process where a terminally or partially differentiated cell reverts to a prior developmental phase. However, there is much debate on whether dedifferentiation occurs at all in normal cells.

Differentiation: the transformation of a cell into a more specialized cell type. Common in adults also. Adult stem cells can divide to produce differentiated daughter cells throughout tissue regeneration and normal cell turnover.

Embryonic stem cells: pluripotent stem cells obtained from the interior cell mass of a blastocyst, an early-phase embryo. Embryonic stem cells are characterized by their pluripotency and by their capacity to replicate indefinitely. They have a far better proliferative capacity than adult stem cells.

Entomophagy: the consumption of insects for food.

Extracellular matrix: extracellular region of cells that offers structural support to the animal cells while also carrying out other important roles.

Fibroblasts: a cell that synthesizes extracellular matrix collagen, the structural basis for animal tissues, vital in healing muscle.

Growth factor: a naturally occurring substance able to stimulate cellular growth, proliferation and differentiation. Growth factors are proteins or peptides involved specifically in growth and cell division. Growth factors can also be described as hormones. Hormone is a more general term that includes proteins that control growth and reproduction. While growth factors can be classified as hormones (molecules that signal between cells), they are more specifically about growth and control of the cell cycle.

Hominin: formerly known as hominid; an animal which is either human or a human ancestor. Hominin contains all species of the human clade after the split from the tribe Panina (chimpanzees). It comprises all of the *Homo* species (*Homo sapiens, Homo erectus etc.*), all of the *Australopithecines* (*Australopithecus africanus* etc.), and other ancient ancestors such as *Paranthropus* and *Ardipithecus*.

Hominoid: any member of the superfamily Hominoidea. Consisting of two groups, the lesser hominoids (gibbons and siamangs), and the great hominoids (orangutans, bonobos, gorillas, chimpanzees, humans). Non-human hominoids are typically called apes.

***Homo*:** the genus of the great apes comprised of modern humans and all closely related species. This genus is presumed to be approximately 2.3 to 2.4 million years old. *Homo* may have evolved from *Australopithecine* ancestors.

Hypertrophy: rise in the volume of an organ or tissue via the enlargement of its constituent cells. For example, training at the gym leads to increased contractile proteins and/or arcoplasmic volume.

In vitro: Latin for *'in glass'*. Research conducted using parts of an organism that have been separated from their usual biological environment, to enable a more detailed investigation than can be done with whole organisms.

In vivo: Latin for *'within the living'*. *In vivo* work is carried out with living organisms in their normal, whole state. Conversely, *ex vivo* research is performed on functioning organs which have been detached from the intact organism.

Induced pluripotent stem cells: a kind of pluripotent stem cell synthetically derived from a non pluripotent cell: typically from an adult somatic cell/adult stem cell. They are comparable to natural pluripotent stem cells, e.g. embryonic stem cells.

Mesoderm: one of the three primary germ cell layers found in the early embryo.

Multipotent cells: a progenitor cell with the ability to generate cells from numerous, but a restricted number of lineages.

Myoblast: in the adult or in muscle regeneration, myosatellite cells, once activated; become myoblasts. Myoblasts are dividing (activated) cells that are making new muscle fibre. Muscle fibres are made when myoblasts fuse together.

Myofibre/muscle fibre: the type of cell found in muscle tissue. Lengthy, tubular cells that occur developmentally from myoblasts to form muscles.

Myofibril: every muscle cell/myofibre contains myofibrils; long chains of sarcomeres, contractile parts of the cell.

Myogenesis: formation of muscle tissue, particularly in embryonic growth.

Myogenic contraction: a contraction instigated by the myofibre/muscle fibre itself, rather than from an exterior stimulus/occurrence e.g. nerve innervation.

Myosatellite cells: small mononuclear progenitor cells located in adult muscle. Situated between the basement membrane and sarcolemma (cell membrane) of individual muscle fibres. They are usually quiescent or dormant, i.e. not actively dividing. They are activated during normal muscle growth and regeneration following injury or disease. They differentiate and fuse to augment existing muscle fibres and to form new muscle fibres.

Myotube: multinucleated fused myoblasts. A group of myotubes form the myofibre that composes the muscle.

Paleo: a prefix meaning *old* and/or *ancient*. Used in specifying early, archaic, and ancient forms or environments.

Paleolithic: a prehistoric period of human history characterized by the advancement of the most primitive stone tools. This period covers about 99% of human technological prehistory. Extending from the most primitive known use of stone tools (most likely by hominins about 2.6 mya), to the completion of the Pleistocene about 10,000 ago.

Pleistocene: the geological epoch that extended from around 2.588 million years ago to about 10,000 years ago.

Pliocene: the period in the geologic timescale extending from 5.332 million to 2.588 million years before present.

Plio-Pleistocene: relating to or linking the Pliocene and Pleistocene epochs together.

Pluripotency: a stem cell with the capacity to differentiate into cells of any of the three germ layers.

Pluripotent stem cells: stem cells that can become any fetal or adult cell type. But are not able to transform into an adult or fetal organism on their own.

Post mitotic: a phase in the cell cycle where cells live in an inactive state: not dividing nor preparing to divide.

Precursor/progenitor cell: a cell that can differentiate into a particular kind of cell, but, is already more specialized than a stem cell (partially differentiated), and is driven to differentiate into its target cell. Progenitor cells can divide only a limited number of times. They tend to be unipotent and have lost most/all of their stem cell multipotency. For example, the term precursor/progenitor cell can be used to describe cells like myosatellite cells that are not yet activated.

Quorn: the prominent brand of imitation meat mycoprotein in the United Kingdom.

Sarcolemma: the cell membrane of a muscle cell. Comprised of a true cell membrane (known as the plasma membrane), and an exterior coat consisting of a thin layer of polysaccharide material made up of multiple thin collagen fibrils.

Somatic cell: any biological cell comprising the body of an organism, with the exception of the germ cells or gametes.

Stem cell: biological cells existing in all multicellular organisms which can proliferate and differentiate into varied specialized cell types, and can self-replenish to create more stem cells. In mammals, there are two main kinds of stem cells: adult stem cells, which are present in numerous tissues, and embryonic stem cells, which are separated from the interior cell mass of blastocysts.

Storage organ: a region of a plant specializing in the storage of energy (typically in the form of carbohydrates), or water. Storage organs tend to grow underground, as this enables better protection from herbivores.

Surimi: a fish-centred food which has been ground to a thick paste, it has rubbery and dense characteristics once cooked. It is usually produced from white-fleshed fish, and often used in the imitation of lobster, crab and other shellfish meats.

Tempeh: a long-established soy product originating in Indonesia. Produced by a natural culturing and regulated fermentation procedure which joins soybeans together into a cake form, similar to a dense vegetarian burger patty.

Tofu: also known as bean curd, a food manufactured via the coagulation of soy juice, followed by pressing the resulting curds into soft white blocks. It is a common part of many East Asian and Southeast Asian cuisines. Tofu has little flavour and is often seasoned or marinated to suit both savoury and sweet dishes.

Totipotency: the capability of a single cell to divide and generate all the differentiated cells in an organism. The fertilised egg or zygote is an example of a totipotent cell.

Transdifferentiation: where a single adult stem cell/somatic cell converts into another mature adult stem cell without going through a transitional pluripotent state/progenitor cell type.

Table of Contents

1 Introduction

1.1 Aims

The overall aim of this thesis was to increase awareness and world knowledge regarding an *in vitro* meat product. More precisely, the objective was to reveal the beneficial potential - concerning human well-being, animal welfare and the environment - of *in vitro* meat. While concurrently explaining the production systems involved and addressing the obstacles confronting a commercially viable *in vitro* meat product.

1.2 Link between film and thesis

This thesis provides the context for the creative component of this MSciComm: a 25 minute documentary produced with Rodney August entitled 'Meating Expectations'. This documentary investigated a new system of meat production, meat grown *in vitro,* also known as 'cultured meat production', a meat grown from stem cells independent of the animal. The documentary covers how *in vitro* meat is made, why it is needed, the problems it could resolve and the problems it could generate.

1.3 Conventional meat production is not sustainable

Meat requires between 5-10 times the agricultural area to obtain the same amount of calories as a vegetarian diet (Schaffnit-Chatterjee et al., 2011).

The contribution of conventional meat production to environmental problems is colossal and thus its potential influence toward their resolution is similarly substantial.

Rearing livestock is unproductive and is persistently diminishing freshwater and agricultural land. The current increasing population, combined with rising affluence and the resultant rise in meat consumption - particularly in developing countries - means that current meat production practices are not sustainable.

1.4 Population growth

It took tens of thousands of years for the human population to get to 1 billion (Steck, Sharma, & Bartelmus, 2008). After 1800 AD; each successive billion required shorter and shorter time periods e.g. only 130, 33, 15, 13 and 12 years for every additional billion (Steck et al., 2008). The human population attained its first billion around the year 1830, the second arrived shortly after in 1930, with the fourth coming around 1974 (Cohen, 1998). The human population is currently at 7 billion (Hodson, 2012).

1.5 Population growth: driving all environmental issues

The increasing human population is driving every environmental issue (Hopfenberg & Pimentel, 2001). It is a major contributor to ecological devastation, jeopardizing the future of the human species (Hopfenberg, 2009). From 1950 – 1990 the number of people on Earth rose from 2.6 – 5.2 billion; during this time; water usage rose by a factor of three, cattle numbers increased from 2.1 to 4.1 billion, grain intake increased by 2.6 times, fish intake rose 4.4 fold and energy consumption increased 5 fold (Corson, 1994). Presently, over 50% of all available freshwater is utilized by humans, meanwhile carbon dioxide levels in the Earth's atmosphere have skyrocketed by almost a third since the industrial revolution (Vitousek et al., 1997). Population growth is damaging biodiversity around the globe; biodiversity which is crucial to a healthy planet and thus to human well-being (McKee, 2005). Especially since a rise in population density tends to lead to even more extensive intensification and manipulation of ecosystems to accommodate this rise (Hern, 1993).

1.6 Population growth is increasing at a declining rate

The population is still increasing, but at a declining rate. From 1965 to 1970 the world's population grew at its fastest at 2.1% annually. By 1995 this figure had dropped to an annual increase of 1.6% (Cohen, 1995). However, even a miniscule population expansion rate can cause significant population rises, if populations are already sizeable (McKee, 2005). Even though population growth rates had dropped by then, 1995 still saw the greatest ever annual increase in population, with an additional 90 million people (Steck et al., 2008). Today the human population is growing at around 1.1% per annum, however, this annual increment is declining (Steck et al., 2008). The majority of the annual global population increase stems from undeveloped countries, where populations are expanding at around 1.9% per year. Conversely, more developed places have lower growth rates of 0.3 – 0.4% per year (Cohen, 1995).

The New Zealand population is also increasing at a declining rate. In fact New Zealand's population growth could stop in the not too distant future (Zodgekar, 2005). In June 2011 New Zealand's population was around 4.41 million; during this year the population increased by approximately 37,400 (0.9%), due to a natural increase of 33,500, combined with a net migration contribution of 3,900 (the lowest population growth in a decade) (Statistic NZ, 2012). New Zealand's population increased by around 1.6% over the past century (Zodgekar, 2005) and 1.3% over the last decade (Bascand, 2011). Estimates predict New Zealand's population will hit 5 million in June 2021, with population growth steadily slowing from there on, due to a closing gap between deaths and births (Statistic NZ, 2012).

1.7 Population growth: future forecasts

Global human population numbers are expected to rise by another 50% before peaking late this century, many researchers believe a decline is likely to follow (Steck et al., 2008). Estimates predict 9.2 billion humans by the year 2050. Present forecasts by the USA Census Bureau indicate population numbers will continue climbing, to at least around 11.4 billion by mid 2060 (Cribb, 2010). The assumption that the human population will ease at around 11-12 billion is reminiscient of past theories this century that the human population would steady at numbers far lower than today's (Hern, 1993). Population estimates remain tentative due to the ambiguity of mortality, migration, future fertility routes, and mistakes in partial or inaccurate empirical data; regarding contemporary population structure, size and expansion rates (Scherbov, Lutz, & Sanderson, 2011).

Theoretically there is the capacity to sustain 2-3 times the number of people predicted by 2050, but economic and social issues mean global food resources could hit a ceiling long before this capability is recognised. As of 2050 worldwide requirements for primary biomass for food are estimated to have doubled; because of population growth and rises in livestock food intake (Koning & Van Ittersum, 2009). As the world population enlarges, arable land, water, energy and biological resources will come under considerable strain to maintain sufficient food sources, while retaining ecosystem integrity (Pimentel et al., 1997). Current intensive agriculture contributes significantly to land degradation, exhausts water resources and spoils the environment (Pfeifer, 2007).

1.8 Agriculture and diminishing water reserves are contributing to climate change

Nearly half of the world's population live in areas competing for fresh water (Pimentel & Pimentel, 1998). Irrigation takes up 70% of the world's freshwater: water is being pumped for irrigation from underground so relentlessly that rainfall cannot replenish it (Brown, 2009). In numerous grain belts, particularly in Asia, freshwater required for irrigation is running dry, while yield capacities for key food crops have idled (Koning & Van Ittersum, 2009). The Middle East is being hit especially hard e.g. from 1950 – 1995 per capita freshwater accessibility dropped by approximately 70%. Reduced water means less food, as agriculture uses the most freshwater of any endeavour (Pimentel et al., 2010). Global agricultural activity, particularly livestock production, is also responsible for approximately 20% of all greenhouse gas emissions; furthering climate change and jeopardizing food yields in numerous areas (McMichael et al., 2007). Increasing temperatures predicted with global warming will shrink crop harvests by a projected 10% for every individual degree celsius increase (Brown, 2009).

1.9 Limited land available

Each year the land available for crops declines. Worldwide over 10 million hectares of quality arable land are damaged and deserted annually (Pimentel et al., 2010). Requirements for new cropland are responsible for over 60% of global deforestation (Pimentel & Pimentel, 1998). Global cropland has reduced to a poor 0.67 acres per capita; half of the (bare minimum) 1.24 acres recommended by food specialists for the growth of a varied and healthy diet. China's average cropland per capita has reduced to a tiny 0.2 acres (Pimentel & Pimentel, 1998). The grain that supports 50% of food energy (when consumed directly), and significantly more when eaten indirectly via livestock, is in jeopardy (Brown, 1997a).

Wide spread cattle grazing still dominates and damages immense regions of land; though there is a snowballing trend toward industrialization and intensification (Steinfeld et al., 2006). With less land and water to work with, farmers are being forced to intensify food output. This intensification is worsening land degradation and water limitations – compromising cropland on a global scale (Pimentel et al., 2010). Erosion has already damaged nearly half of worldwide agricultural land (Paul & Wahlberg, 2008). Today almost all the useful land on the planet is exploited for agriculture. What is left is too sheer, moist, parched or nutrient deficient for agricultural use (Pfeifer, 2007). Conservationists ought to be as apprehensive about future agricultural harvests, as they are about growth of per capita consumption and population expansion (Balmford, Green, & Scharlemann, 2005).

1.10 Future projections

However, in theory global agricultural land could be raised by 80%, but the majority of free land is unsuited to efficient agriculture. Only Latin America and Africa have sizeable and appropriate spare land (Koning & Van Ittersum, 2009). Throughout developing countries, regions designated for the majority of energetically vital food crops must rise significantly (midway estimates are around 23%), to meet estimated food needs for 2050 (Balmford et al., 2005). Worldwide feed and food demands have been estimated to rise twofold in the 21st century, which will add to stresses on water, land, and nutrients (Spiertz & Ewert, 2009). Globally, farmers need to boost food production by over half to feed the additional 2 billion people projected for 2020 (Shah & Strong, 2000).

1.11 Food stocks; apprehension

Recent events surrounding world food stocks and demands have provoked apprehension about future food stores, while distributions of food support to developing countries have plummeted (Bohle, 2001). In the past 10 years; irrigation has declined 12% per capita, fertilizer resources fell 23%, cropland per capita plummeted 20% and grain manufacture per capita dropped significantly (Pimentel et al., 1999). In excess of 30 nations have already suffered from food riots (Paul & Wahlberg, 2008), suggesting a future free of food scarcity may be unavoidable (Koning & Van Ittersum, 2009).

1.12 Malnourished peoples and declining grain stocks

Poverty is intimately linked with changes in agriculture (Von Braun & Pandya-Lorch, 2007), since basic food scarcity is linked to declines in per capita water, cropland, and fossil energy resources, furthering malnutrition (Pimentel et al., 2010). The United Nations Food and Agricultural Organization estimate there are currently nearly a billion malnourished people around the globe (Hodson, 2012). In the world's 70 underdeveloped countries; the total number and percentage of persistently undernourished people is rising, while world food reserves from carry-over stocks diminish (Brown, 2009). For example, cereal stocks consist of 80% of global food supplies, but have been declining for many years (Hopfenberg & Pimentel, 2001). Towards the end of the 1990's, there was sufficient corn stored to satisfy global food necessities for 4 months, today this figure has been cut in half to 6-7 weeks (Schuman, 2011). Presently, the number of countries importing cereal is four times the number of countries that export cereal (Paul & Wahlberg, 2008).

1.13 Some countries are banning food exports

Ninety five percent of the world's countries import more food than they export (Pimentel & Pimentel, 1998). The majority of the 183 nations around the globe are currently, to some degree, reliant on food imports (Pimentel et al., 1997). Once exporting countries are eventually forced to keep excess food supplies at home to feed domestic citizens, many countries in Asia and Africa will be in strife (Pimentel et al., 1997). For example, in sub-Saharan Africa population growth has surpassed food production substantially (Bohle, 2001). Some governments are presently barring food exports and boosting subsidies for bread and basic foods, while offering emergency aid to farmers (Paul & Wahlberg, 2008). For example, in 2007, Vietnam (the second-largest rice exporting nation), banned exports for many months in an attempt to boost locally accessible food resources and thus lower domestic food prices. Such events may uplift those residing in the exporting country, but will cause panic in importing countries (Brown, 2009).

1.14 Rising meat demand

The global cattle system competes with direct human cereal/grain consumption, gratifying affluent consumers worldwide, while destabilizing traditional cattle rearing

(McMichael, 2007). Livestock products currently deliver a third of human civilization's protein intake (Steinfeld et al., 2006). Growing meat consumption has been a key indicator of the universal dietary conversion that has come with economic modernization; meat is presently the leading supply of high-quality animal proteins (Smil, 2002a). In 1900 slightly over 10% of global grain yields were consumed by livestock, by 1950 this figure had risen to 20%, by 1990 it had soared beyond 40%. In 2002 in the USA, over 60% of grain yields were consumed by farm animals (Smil, 2002a). While increases in grain production wane, meat demand is growing faster and faster (Brown, 1997b).

1.15 Rise in meat demand; most prevalent in developing countries

In 1983 developing nations consumed 36% of global meat; by 1993 this figure had climbed to 48% (McMichael, 2007). Developing countries presently consume more than half of the world's meat and this figure is expected to rise (Delgado, 2003). During the last generation, meat consumption levels in developing nations grew three fold (Delgado, 2003). Grain intake in developing nations increased by 80% in the past 3 decades. Contrastingly, developed nations only saw a rise in grain intake of 22% (Schuman, 2011). This increased grain intake is occurring indirectly via increased meat consumption (Schaffnit-Chatterjee et al., 2011). Globally; meat intake has increased fourfold in the past half century (Motavalli, 2002). Humanity is in the initial stages of a demand-driven livestock revolution (McMichael, 2007).

1.16 Rising affluence

Urbanization and globalization are allowing people to evade poverty. As their incomes rise, poor people are eating more animal sourced foods (Fuller, Tuan, & Wailes, 2002). Meanwhile, fast economic growth has boosted incomes within the new urban middle class, generating novel food demands and transforming consumption, mirroring the patterns seen in wealthy countries (Paul & Wahlberg, 2008). People are becoming more meat dependent and the staple diet is becoming protein rich (Mann, 1997). Farmers are struggling to satisfy the requirements of record increases in affluence, which translates to increased consumption of grain and land intensive, animal-derived foods such as milk, meat, and eggs (Brown, 1997a). Many developing nations such as China and India have seen astonishing income expansion over the last 20 years (Von Braun, Gebreyohanes, & Tadesse, 2012). Farmers must now confront the highest ever rises in affluence in Asia (Brown, 1997b), a collection of nations containing over half the world's population (Brown, 1997a). Here meat and dairy consumption is at an all-time high and still rising (Tenenbaum, 2008).

Japanese eating habits have shifted considerably over the past few decades; with the traditional diet of plenty of rice and fish being replaced with the fatty and protein-rich Western diet (Goto, 1992). In China today; there is less focus on basic grains and starches and a higher animal protein intake (Fuller et al., 2002). Traditional Chinese foods such as rice and vegetables are being replaced by processed foods, such as meat and dairy (Gale, 2003). For example, China's meat consumption has grown in excess of 150% since 1985 (Paul & Wahlberg, 2008). Since carnivorous diets require more grain than the more traditional vegetable centred Chinese diet, grain stocks are declining (Khor, 2007).

1.17 Rich get the lion's share

Globalization is catering to a global market tied to a fairly affluent consumer section of the world population (McMichael, 2007). Meat intake around the world remains very unequal (Speedy, 2003). Current consumption patterns reveal that higher income consumers are demanding more animal-derived foods while also receiving a greater portion of worldwide food resources (Paul & Wahlberg, 2008). By the year 2000, the total population of affluent nations made up just 20% of the total world population. Amazingly, these nations manufactured and devoured 60% of total poultry and 40% of total red meat (Smil, 2002a).

Various wild animals in African forests are being hunted as 'bushmeat' (Fa, Currie, & Meeuwig, 2003). In certain parts of Africa, predominately in central Africa, people obtain 80% of their protein from bushmeat (e.g. chimpanzees, gorillas). Bushmeat is an inexpensive and accessible protein supply for the undernourished (Pearce, 2005). Reliance on bushmeat is highlighted by research on five Congo Basin countries. Of these five countries, four fail to produce adequate quantities of non-bushmeat protein to support their human populations. If these trends continue numerous forest mammals may go extinct reasonably soon. Protein malnutrition will likely rise severely if food security in these areas is not quickly resolved (Fa et al., 2003). Suggestions have been made to increase the quality of beef and the accessibility of chicken, especially in rural regions, since this could change consumption patterns and relieve hunting stresses on wildlife (Schenck et al., 2006).

1.18 Trends amongst countries in grain and meat demand

Variation is evident between nations in grain demand. In low-income nations such as in India, grain provides a huge 60% of total calories, people directly consume around one kilogram of grain per day. Conversely, in affluent nations like Canada and the USA, due to the high use of grain in livestock feed, grain intake per person is nearly quadruple that of average consumption levels in India. Since in these nations grain intake mainly occurs indirectly through meat consumption (Brown, 2009). On average, Americans consume just over 120 kilograms of meat each year, conversely; Nigerians typically consume just over 8 kilograms, with Indians eating only a miniscule 5 kilograms annually (Paul & Wahlberg, 2008). In terms of macronutrients, meat provides 10% of total food energy and over 25% of total protein in wealthy countries. In contrast, meat only delivers 6% of total food energy and 13% of all protein in the undeveloped world (Smil, 2002a).

The rise in meat supply is also limited to specific nations and regions. In impoverished African nations and in South Asia; ingestion of meat and animal products is decreasing, from already minimal amounts, while populations rise (Speedy, 2003). Meat-demanding diets relished by many of the industrialized nations are also causing an uneven distribution of environmental effects (White, 2000). To make the situation worse; all oceanic fisheries are at or past capacity, with increases in oceanic fish catches stopping completely in 1989. For the first time in history, fishing cannot supplement farming (Brown, 1997b). Nearly a third of world fisheries are failing or near failure. If fish production cannot be doubled to keep pace with food requirements, the extra 100 million tonnes of (annual) meat needed will have to be sourced via livestock (Cribb, 2010).

1.19 The environmental impact of meat

Livestock's input toward environmental issues is massive and thus its prospective role toward their solution is correspondingly significant (Steinfeld et al., 2006). Meat based diets are having a powerful environmental influence, particularly as livestock become progressively more grain raised (Myers & Kent, 2003). It takes just over 900 kilograms of grain to feed a carnivore for a year. Conversely, less than 200 kilograms of grain are needed to feed someone for a year when eaten directly (Schaffnit-Chatterjee et al., 2011). Meat consumption is pressuring restricted irrigation water and international grain resources (Myers & Kent, 2003). It takes 50,000 – 100,000 litres of water to make just one kilogram of beef (Hodson, 2012), which is roughly 8-10 times more water than required for cereal production (Schaffnit-Chatterjee et al., 2011).

1.20 The environmental impact of biofuels

As fossil fuels start to wane within the upcoming decade, the energy accessible for food production will decline (Pfeifer, 2007). Biofuels have been advocated as a sustainable substitute to fossil fuels. However, biofuels are typically made from ingredients conventionally used as feed grain and food, leading to further price rises in the food sector (Skipper et al., 2009). Research also suggests that expected land-use modifications as biofuel production increases could cause greenhouse gas emissions and other environmental issues (Marshall & Caswell, 2011). Projections show that corn-based ethanol, rather than enabling 20% savings, almost doubles greenhouse gas emissions during a period of 3 decades, while augmenting greenhouse gases for the next 167 years (Searchinger et al., 2008).

1.21 Biofuels; creating global food insecurity

A focus on grain-based fuels in the USA is creating global food insecurity on an unprecedented scale (Brown, 2009). The USA grows 60 – 70% of global corn exports and plays a large role in global corn production for livestock and humans (Tenenbaum, 2008). In the year 2000, 6% of the USA's annual corn yield went to ethanol, today this figure has increased to 40%, enough corn to satisfy 350 million humans (Schuman, 2011). To fill a single tank of a 95 litre SUV automobile with ethanol requires just over 200 kilograms of corn; sufficient calories to sustain a person for a year if eaten directly (Runge & Senauer, 2007). In 2007 the USA made almost half (49.6%) of global ethanol (Banerjee, 2011). The only other substantial ethanol producer is Brazil with 38.3%, the majority stemming from sugarcane (Banerjee, 2011).

Other nations are following suit: in Southeast Asia, huge regions of forest are being felled to grow oil palms to make biofuels (Runge & Senauer, 2007). The recent joining of the energy and food markets suggests that if the fuel value of grain surpasses its food value, economic forces will shift the grain toward the energy/fuel market. This double demand is causing a clash between automobiles and people for grain resources (Brown, 2009). Regardless of rhetorical discursive changes in comprehensions of the environmental and social sustainability of biofuels; biofuel manufacture is still backed today, as the biofuels scheme was and continues to be a chiefly economically-driven undertaking (Leopold, 2010).

1.22 Biofuels causing higher food prices

Demand for biofuels is particularly strong in developing nations. Agricultural resources like labour and land are being diverted to produce biofuel feedstock (Von Braun et al., 2012). Economic growth, rising demand for biofuels and a growing population are driving food prices upward, while increasing global food demand is pressuring global food supplies (Schaffnit-Chatterjee et al., 2011). Biofuels are hastening biomass consumption, undermining crop values and, via increased livestock feed prices, raising the prices for meat and other livestock products (Spiertz & Ewert, 2009). While grain consumption remains higher than production levels, stocks continue to decline, leading to perilously small margins (Paul & Wahlberg, 2008). The bottom line is, grain production is not keeping up with demand, causing higher prices (Brown, 1997b), while allowing only a small buffer for future crop emergencies (Paul & Wahlberg, 2008). By 2020, real prices are expected to rise 20% in cereals and by 50% for meats; when likened with prior decades (Von Braun et al., 2012). As the recent swell in global grain costs is trend propelled, a reverse is doubtful without a turnaround of the trends themselves (Brown, 2009).

Mounting food prices and broadening hunger in many other nations are starting to disrupt the social order. In some regions of Thailand the risk of 'rice rustlers' mean villagers are forced to defend their rice fields with guns (Brown, 2009). "We are witnessing the beginning of one of the great tragedies of history" to quote Lester Brown (Tenenbaum, 2008), an analyst of global resources who started the Worldwatch Institute and now leads the Earth Policy Institute. Facing a global food catastrophe, international relief establishments recently connected with USA grocers, the oil industry, pork, beef, and chicken farmers in pursuing the eradication of government regimes to promote biofuels, especially corn-kernel-based ethanol (Johnson, 2008).

Population growth, rising affluence and increasing meat consumption means conventional meat production methods are not sustainable. Current meat production systems are too inefficient and detrimental to the environment. Furthermore, when conventional meat production is coupled with rising demand for biofuels, global food security is in danger. Chapter 2 will focus on the importance of meat consumption in human evolution, while briefly assessing the nutritious value of meat, the consequences of agriculture and the disadvantages of contemporary meat consumption.

2 Humans as meat eaters

Please refer to the glossary (pages vi - xi) for definitions of key terms in this chapter.

Introduction

The last chapter discussed the contribution of conventional meat production to environmental problems. This chapter will look at the importance of meat consumption in human evolution, while touching on the beginnings of agriculture, the nutritional importance of meat and the disadvantages of contemporary meat consumption.

2.1 Dietary similarities between contemporary nonhuman primates and humans

Modern humans and contemporary nonhuman primates can be traced back to a common herbivorous ancestor (Milton, 1999a), a species assumed to have lived in Africa between 5 and 7 mya (million years ago) (Eaton, Eaton III, & Cordain, 2002). It is probable this primitive hominin ancestor was similar to chimpanzees (*Pan troglodytes*) (Stanford, 1996). With study of the foods eaten by contemporary nonhuman primates, an estimate of the diet of this most recent common ancestor is possible (Eaton et al., 2002). Evidence suggests that the human ancestral lineage was very herbivorous (Milton, 2000). Humans lack the metabolic adaptations to meat eating which are evident in obligate carnivores (Milton, 2000). Most contemporary nonhuman primates have a mixed diet, consisting of a wide spectrum of plant foods and a relatively small spectrum of animal foods (Hohmann, 2009). Though gut proportions vary, the nutritional needs, digestive patterns and intestine form, are very alike in contemporary nonhuman primates and humans (Milton, 1999b). For example, digestion testing on chimpanzees' showed that they react to fibre in a similar way to humans (Milton & Demment, 1988). In fact, a heightened comprehension of the nutritional make up of plant foods in the diet of wild contemporary nonhuman primates could increase our perception of human dietary needs (Milton, 2000).

2.2 Meat eating, distant origins, could chimpanzees provide insight?

How meat became a significant part of the human diet is not well understood. The carnivorous tendencies of our closest relations, contemporary nonhuman primates, could offer insight toward the emergence of this characteristic (Hardus et al., 2012). The finding, chasing, capturing and consumption of vertebrates is seldom seen in contemporary nonhuman primates, excluding baboons and chimpanzees (Butynski, 1982). Only more recent research has revealed habitual, methodical hunting by chimpanzees in numerous environments (Stanford, 1996), although, meat is only a very small part of the chimpanzee diet (Milton & Demment, 1989). However, in high meat consumption phases, adult male chimpanzees at Gombe (located in Western Tanzania), can consume up to 500 grams of meat each week (Milton, 1999a). Chimpanzee hunting may even restrict population expansion in the red-colobus monkey (Stanford, 1996). While typically frugivorous, during some years the amount of carcass biomass consumed by wild chimpanzee groups can go beyond 700 kilograms (Stanford, 2001). These carnivorous inclinations of humans' nearest sibling imply that meat consumption goes back very far (Smil, 2002a).

2.2.1 Problems with using contemporary nonhuman primates to learn about human origins

The study of contemporary nonhuman primates to construct a view of primitive humans is risky. Any implied similar traits between contemporary chimpanzees and the most recent common ancestor are hypothetical, due to the lack of fossil support for extinct nonhuman primates from 5 to 10 mya (Stanford, 2001). Thus, modern chimpanzees should not be presumed similar to the ancestral chimpanzee, just as contemporary humans are not assumed to be similar to the ancestral hominin (Marean, 2002). For example, over 5 million years of independent evolution in the chimpanzee line could have caused a species significantly different from the shared ancestor (Stanford, 1996). The use of the chimpanzee as a gauge of meat eating motifs in human ancestors also disregards other living examples, like the bonobo, which reveal a different view (Marean, 2002). Characteristics of meat allocation by chimpanzees and bonobos vary: in chimpanzees, most of the prey is eaten by adult females and males. Conversely, in bonobos, adult females govern meat accessibility and divide meat among each other and with youngsters (Hohmann, 2009). Thus, chimpanzees only offer a narrow view into the capacity of conceivable behaviours of primitive humans (Stanford, 2001).

2.3 Contemporary nonhuman primates, hunting, meat division and social hierarchy

Hunting, meat allocation and social prominence appear strongly correlated in contemporary nonhuman primates. Similar behaviours may have driven selection for intellect in human ancestors (Stanford, 1999). Studies of baboons, chimpanzees, and modern-day human hunter-gatherers indicate that the hunting element of primitive hominin sustenance was an augmentation of a simple primate pattern and related subsistence behaviours. That is, the earliest hominins were not the first primates to exhibit hunting behaviour (Butynski, 1982). This is supported by the (earlier mentioned) behaviour of contemporary chimpanzees and baboons, who track their prey, hunt co-operatively and divide their meat (Butynski, 1982). Chimpanzees mostly utilize group hunting, a rare behaviour in the majority of other primates. However regularity, co-operation levels and hunting techniques differ among different groups (Hosaka et al., 2002). For example, in the Tai forest of West Africa, chimpanzees hunt with a co-operative method, some are 'drivers', while others play the role of ambush (Stanford, 1999). Contrastingly, chimpanzees at Gombe and Mahale (both located in Western Tanzania) pursue prey in a relatively uncoordinated style (Takahata, Hasegawa, & Nishida, 1984). Similar discrepancies may have existed within primitive *Homo*, perhaps one group was a scavenger of big carcasses in one region and a competent hunter at another region, hundreds of kilometres away (Marean, 2002).

However, hunting is a complicated behaviour, with many variables. Chimpanzee meat consumption levels vary with seasons and in accordance with prey accessibility and varied plant foods (Stanford, 1996). Chimpanzee hunting tends to be more prominent in the dry seasons at Gombe and Mahale (Hosaka et al., 2002). In forest groups, hunting levels increase during times of plant food excess, implying hunting behaviours are spawned via high energy from abundant plant foods (Hohmann, 2009). Interestingly, chimpanzees consume meat at more than twice the speed of orangutans, suggesting that group living could have selected for accelerated meat eating in hominins (Hardus et al., 2012).

Overall, chimpanzees, more than any other contemporary nonhuman primate, engage in an emerging type of labour division. Adult males concentrate on the exploitation of specific resources, particularly vertebrates, for the advantage of other group members, including those of different age and sex (Galdikas et al., 1981). At Tai national park in West Africa, helpful chimpanzee hunters are given meat as compensation for their efforts (Stanford, 1999). Conversely, in the orangutan, mothers tended to reject meat sharing requests, sharing only with their offspring (Hardus et al., 2012). Post-kill at Gombe, chimpanzees are reluctant to divvy meat, ineffective hunters are forced to beg or pick at the leftovers, yet males enthusiastically offer meat to females in barter for sex (Stanford, 1999). However, the meat-for-sex hypothesis is debated, it has been argued that sexually driven meat exchanges in chimpanzees are rare (Gilby et al., 2010).

2.4 Meat evolution, scavenging or co-operative game hunting?

The rise of meat consumption has long been viewed as a central feature of the evolution of primitive hominins, however the timing of this rise and the method of meat attainment are still debated (Stanford, 1996). It has been proposed that meat scavenging comprised part of an intermediary subsistence pattern, denoting a movement from plant-eating to animal-hunting in primitive hominins (Butynski, 1982). However, views have altered from the established opinion that primitive hominins were hunters, to an outlook that assumes them to have been unscrupulous scavengers (Speth, 1989). Scavenging is thought to have ascended during early hominin prehistory to become the principal foraging technique, and was perhaps utilized by the later Pleistocene hominins (Stanford, 1996). Even meat consumption in early *Homo* was most likely scavenger oriented (Ulijaszek, 2002). For example, indications from Bed I, Olduvai (in the Great Rift Valley stretching through Eastern Africa), reinforce the premise that scavenging was the chief meat-obtaining method of hominins, between 2 and 1.7 mya (Shipman, 1986).

Rose and Marshall (1996) contend that escape and evasion were not the most probable tactics for carnivorous hominins confronting opposition and a high danger of predation. They propose these stresses stimulated sociality and collaboration, with hunted and scavenged carcasses being transferred to central areas, which presented spatially stable and defendable reserves such as trees, water, and plant sustenance, leading to recurrent use of specific sites as 'home-bases' (Rose & Marshall, 1996). However, anthropologists have re-inspected numerous classic sites, which were the basis upon which the hunting hypothesis originally emerged. The results were uncertainty regarding the hunting capacities of pre-modern hominins. There is a growing agreement that *Australopithecines*, *Homo erectus*, and possibly even later pre-modern hominins may not have been the avid, co-operative, big-game hunters they were once assumed to be. If hunting did occur, the target may have been small game, and possibly infants and sick adults of bigger mammals (Speth, 1989). Stanford (1996) supports this assertion, claiming that convincing proof is lacking for the theory that primitive man engaged in hunting, that he conjoined with others in risky activities, or that he shared the food accessed via these concocted behaviours (Stanford, 1996).

However, considering the systematic hunting and meat division in chimpanzees, and thus by implication, the high probability of similar behaviours in primitive hominins, why primitive hominins would replace hunting with foraging or scavenging requires further study (Stanford, 1996). This is supported by minimal scavenging evident in contemporary nonhuman primates (Butynski, 1982). Ulijaszek (2002), states that the first solid indication of co-operative hunting of bigger animals came with later *Homo*

(*Homo heidelbergensis* and *Homo neandertalensis,* the social hunter gatherers), and eventually with *Homo sapiens,* the best hunters of all (Ulijaszek, 2002).

2.5 Meat as commodity or social manipulator in our ancestors?

Forest chimpanzees show a more specific prey image, specifically seeking adult prey, hunting in bigger numbers and distributing meat more often, with a more complex co-operation level, when compared to savannah-woodlands chimpanzees (Boesch & Boesch, 1989). In pre-human groups meat might have been a valuable commodity, similar to money, used to obtain dominance or traded for other precious resources. Natural selection may have chosen those hominins most adept at utilizing meat for social manipulation (Stanford, 1999). Meat plays a central and similar role in hunter gatherer societies today (Smil, 2002a).

2.6 Fallback foods during times of scarcity

Humans stem from a rather general line of higher primates, a lineage with the capacity to utilize a diet based on a variety of animals and plants (Milton, 2000). Human ancestors developed in a barren, sporadic and vast environment, where ripe fruits and fresh leaves were possibly not accessible annually (Milton, 1999a). However, with meat providing crucial nutrients, during stretches of scarceness, other less nourishing plants (such as root plants e.g. tubers, turnip) could be consumed solely to provide productive calories (Milton, 1999a). A vital shift in hominin evolution (away from the most recent ancestor shared with chimpanzees) came with the use of underground storage organs as fallback foods to replace herbaceous vegetation (Laden & Wrangham, 2005). Paleo-dental evidence also implies that once the early hominins departed from the hominoid ancestral lineage, a slow rise in the intake of harder and coarser foods ensued, probably in the form of seeds and nuts (Eaton et al., 2002). For example, adjustments in diet-associated adaptations from *Australopithecus anamensis* to *Australopithecus africanus* suggest that solid, coarse foods were imperative in the Pliocene, conceivably as vital foods in the diet (Teaford & Ungar, 2000). This is backed by evidence from studies of tooth shape, size, dental microwear, jaw biomechanics and enamel construction. Signifying a dietary change in the primitive *Australopithecines,* en route for greater dietary flexibility while facing climatic instability (Teaford & Ungar, 2000). Meanwhile, during periods of reduced calorie consumption, from intermittent plant growth or deficiency, animal sourced foods could substitute as the prime calorie supply (Milton, 1999a).

2.7 Human ancestors, dietary adaptations

However, the struggle in digestion evident in primates, with rootstocks, seeds, and carrion, could have implications for the understanding of hominin adaptations. Did this pose problems in early humans? For example, when primates eat seeds, rootstocks, and meat (thought of as vital for hominin survival in savannah-woodlands), the fast bacterial spread in carrion, and the digestion-inhibiting agents in underground storage organs, constrain digestion (Ragir, 2000). It is debated whether hominins would have been capable of digesting raw underground storage organs and animal carrion.

2.8 The adaptations that came with early *Homo*

Human characteristics were largely driven by natural selection functioning to increase dietary quality and foraging effectiveness. Shifts in food accessibility throughout time were a powerful factor in hominin evolution (Leonard, 2003). Investigation of craniodental fossils of *Homo habilis, Homo rudolfensis, and Homo erectus,* reveal no basic dietary adaptation from *Australopith* to *Homo.* Primitive *Homo* was most likely adapted toward versatile sustenance methods, which would have worked well in the varied paleoenvironments during the African Plio-Pleistocene (Ungar, Grine, & Teaford, 2006). Throughout primitive hominin taxa, it is the dietary alterations that set species apart. For example, there seems to have been a slow rise in dietary versatility from *Ardipithecus ramidus* to *Australopithecus africanus* (Teaford, Ungar, & Grine, 2002).

2.9 The beginnings of meat eating, *Homo* arose with routine meat consumption

Australopithecine diets were thought to be mainly vegetarian (Ambrose & DeNiro, 1986). Assessment of carbon isotope ratios from hominin fossils suggest that robust *Australopithecines* and early *Homo* are situated as intermediates between carnivore and herbivore ratios, implying considerable meat intake and an omnivorous diet (Henneberg, Sarafis, & Mathers, 1998). About 2.5 mya, animal sourced foods may have become increasingly prominent in hominin sustenance. Reduced molar size, changes in incisor shape and decreased cranial and mandibular robusticity, imply increased importance on a diet necessitating reduced grinding, and increased tearing, suggestive of meat eating (Eaton et al., 2002). For example, in primitive *Homo,* smaller teeth with finer enamel are evident, which might have boosted effectiveness in cutting chewy foods such as fibrous plants or meats (Ungar et al., 2006). Early *Homo* most likely stemmed from one of the *Australopithecine* species, around 1.8 mya, coinciding with a routine consumption of meat (Ungar et al., 2006).

2.10 Reduced gut size freed energy for brain expansion

When compared against other hominins, humans have a reduced hindgut and gastrointestinal tract. The gut ratios of contemporary humans, when analysed against fossil evidence, suggest that the human line overcame the nutritional limits imposed on body size rises in the great apes (Milton & Demment, 1988). With animal sourced foods satiating daily protein, energy and fat requirements, surplus space in the gut became available for carbohydrate heavy plants, these were used as fuel for the expanding human brain (Milton, 2000). Throughout all primates, bigger brains are associated with richer diets, humans are at the utmost end of this continuum, with the biggest relative brain size and the highest quality diet (Leonard, 2002). Interestingly, primates have powerful jaw muscles that press upon their skull, hampering expansion, making larger brains nearly impossible. About 2 mya, a mutation in the human line reduced this jaw muscle, soon after, brain size started to expand (Forbes, 2011).

Contemporary humans have a diet of far higher quality than would be anticipated for our metabolic needs and body mass. This is probably due to an adaptation to the metabolic expense of our enormous brain (Leonard & Robertson, 2005). Regular consumption of animal sourced foods, allowed sufficient energy for the human lineage to achieve an especially large and complicated brain, while maintaining their evolution as big, energetic, social hominins (Milton, 2003). For example, hominin fossils indicate that significant shifts in diet and relative brain metabolism occurred within the genus *Homo* (Leonard & Robertson, 2005).

The human brain is bigger than expected for a primate of human body size. This suggests a required increase in basal metabolic levels by approximately 8% above levels for a normal primate or mammal of our body mass (Aiello, 2007). A larger brain requires greater energy intake (Gibbons, 1998), yet humans' basal metabolic rate is equal to that of large sheep, whom have far smaller brains. Humans are somehow obtaining sufficient energy to fuel their brains, without the required rise in overall energy consumption. Thus, this energy must be coming from elsewhere (Gibbons, 1998). The large human brain to body size ratio could be due to the decline in the size of the gastrointestinal tract, combined with a decline in its musculoskeletal reinforcements. This change would most likely be linked to higher quality, meat-based diets and additional-oral food maintenance (Henneberg, 1998). This seems to be the case, since the human basal metabolic rate is not higher than expected. The gut has been limited by the perfect amount to counteract the expensive energetic costs of the human brain (Aiello, 2007). This is known as the expensive tissue hypothesis; the energy required for the evolution of large brains in the human line was made possible via a decrease in the size of the gastrointestinal tract (Aiello, 1997).

Within existent Hominoidea, in terms of gut ratio and diet, humans are the outcast taxon. Humans have strayed furthest from their ancestral origins (Milton, 1999a). In humans the gut is the one energy intensive organ which is significantly undersized in comparison to body mass (Aiello & Wheeler, 1995). Interestingly, the African freshwater fish, *Gnathonemus petersii,* has a brain which consumes about 60% of total-body oxygen intake. Given the extraordinary energy needs of the brain of *Gnathonemus petersii*, combined with its carnivorous diet, this fish offers the penultimate test of the expensive-tissue hypothesis. *Gnathonemus petersii* passes the test; its enormous brain is balanced by a smaller mass in the intestines and stomach (Kaufman, 2003). The expensive-tissue hypothesis is also backed by the high quality human diet which only requires minimal detoxification and digestive work (Hill et al., 2000). Additionally, humans are over fat and undermuscled in comparison with contemporary nonhuman primates, this helps to counterbalance the excessive energy requirements of a large brain (Leonard, Snodgrass, & Robertson, 2007).

2.11 Setting the stage for bipedalism – change in environment

Walking upright on two legs (also known as 'bipedalism'), is a vital adaptation of hominins that may have occurred soon after the split of the chimpanzee and human line (Bramble & Lieberman, 2004). It is possible that locomotor flexibility was a critical adaptation of the most primitive hominins, while facing unstable environmental conditions (Teaford & Ungar, 2000). There are many theories regarding what drove selection for bipedalism. Did it free the upper limbs enabling the carrying of infants and foraged goods (Steudel, 1994)? Some believe bipedalism enabled primitive humans to control their body temperature more effectively, by limiting the surface area exposed to the blazing African sun (Steudel, 1994). Bipedalism may have been an adjustment to a water-side role. This claim is backed by observations of contemporary nonhuman primates that enter water bipedally to access food. This water-side notion gains additional support from the theory that wading, (in the most primitive known bipeds), furthered selection pressures toward upright walking (Kuliukas, 2002). There have been arguments supporting heightened visual scope as the driving factor behind upright walking (Steudel, 1994). Other theories claim that bipedalism evolved partly because it is more energy efficient. As the African continent became dry, forests were replaced with grasslands, causing food sources to become more widespread. Within this context, upright walking became advantageous, since it would have considerably lowered the amount of calories expended while foraging for increasingly separated food resources (Leonard, 2002). However, much of these theories are hotly debated e.g. results comparing the energy expenses of bipedalism and quadrupedalism (walking on four legs) in trained capuchin monkeys and chimpanzees, imply that a rise in energetic efficiency would not have occurred in primitive bipeds (Steudel, 1996). Even contemporary human bipedalism does not seem to be especially efficient when compared to quadrupedalism in other primates (Steudel-Numbers, 2003).

The *Australopithecine* hind limb and hip indicate bipedalism, but also imply a less than ideal upright walking movement, in relation to contemporary humans (Hunt, 1994). Inefficient bipedalism supports the hypothesis that upright walking was driven more as a terrestrial feeding stance, rather than specifically for locomotion. An upright stance would have allowed foods once beyond reach to be obtained (Leonard, 2002). For example, the food-collecting role of chimpanzee bipedalism implies that hominin bipedalism may have evolved in-line with 'arm-hanging', as a specific feeding behaviour, that enabled the efficient collection of fruits amongst open-forest or woodland trees. *Australopithecus afarensis* has characters of the hand, torso and shoulder, which have been linked to arm-hanging in chimpanzees. Therefore, an upright postural feeding adaptation could have preceded the completely realized bipedalism that is clear in *Homo erectus* (Hunt, 1994).

Research on the skeletons of Hadar hominins showed features telling of both land-dwelling bipedalism and arboreal suspension or climbing. These very primitive hominins must have dedicated some of their actions to sleeping, eating and evading predators via trees, while simultaneously spending moments on the ground, where they moved bipedally (Susman, Stern Jr, & Jungers, 1984). Within evolutionary history, there may have been more variety in the primitive stages of human bipedalism than has been earlier supposed (Harcourt-Smith & Aiello, 2004). Only with *Homo erectus* may culture, body mass and other characteristics have joined to liberate hominins from their arboreal reliance (Susman et al., 1984).

According to human and chimpanzee reproductive development, daily energy needs throughout gestation and lactation would have been substantially greater for *Homo erectus* females (Aiello & Key, 2002). High value foods like meat would have been critical in the development of young hominins, to aid in brain growth and nutritional requirements (Milton, 2003). For example, a modern human baby requires a diet with 37% of its own body mass in amino acids, adults conversely, only require 15%. Plant parts on their own could not offer the crucial protein and nutrients for infant development (Milton, 1999a). In summary, the genus *Homo* saw a loss of arboreal adaptation, combined with a more upright stance (Ulijaszek, 2002), longer development and maturation rates, and smaller teeth and jaws (Aiello & Wells, 2002), enabling growth of a larger brain (Ulijaszek, 2002).

2.12 Adaptations to a changing environment, increased stature, home range and the beginnings of tool use in *Homo* erectus

Robust *Australopithecines*, stone tool technology, and the genus *Homo,* emerged nearly synchronously around 2.5 mya (Ambrose, 2001). The appearance of *Homo,* and the expansion of *Homo erectus,* can be seen as progressions within the larger setting of environmental transformation, toward enlarged regions of grassland. This resulted in the progression of more grassland-adjusted mammals toward Eastern Africa during the late Pliocene and early Pleistocene (Roche, Blumenschine, & Shea, 2009).

Paleontological evidence specifies that especially swift brain evolution occurred with the rise of *Homo erectus* around 1.8 mya. This was combined with key modifications in diet and foraging behaviours (Leonard et al., 2007), along with a rise in body size and stature between 1.7 and 2 mya, most likely due to increased meat eating (Larsen, 2003). This is supported by the first concentration of tools and tool altered bones, which overlap with the emergence of *Homo erectus* approximately 1.8 mya (Ungar et al., 2006).

Augmented meat intake would have supplied more animal protein. This was associated with the boost in stature evident in the shift from *Australopithecines,* through *Homo habilis,* to *Homo erectus* (Eaton et al., 2002). Energy expenditure increased from 40 to 85% in *Homo erectus,* above *Australopithecine* energy levels. This was caused by a bigger body mass, a more active lifestyle, and an increase in dietary energy, allowing for an expanded home range (Ulijaszek, 2002). A bigger body would have also boosted heat retention and mobility, enabling acclimatization to colder climates (Arjamaa & Vuorisalo, 2010). Increased body size and home range are probable reactions to varying ecological environments at the origin of *Homo erectus*. These may be part of a network of eco-morphological influences, which fuelled the prompt extension of *Homo erectus* from Africa to Asia in the early Pleistocene (Anton & Swisher, 2004).

2.13 Fire

Cooking was an imperative invention in hominin evolution, however, there is very incomplete proof for the orderly use of fire by hominins before 1.5 mya (Leonard et al., 2007). For example, 2 mya the only hint at fire is burnt ground with human skeletons, which most anthropologists regard as coincidence rather than support for deliberate fire (Pennisi, 1999). The oldest indisputable hearths occur only in the middle

Pleistocene of Eurasia, with no finds supporting controlled use of fire back beyond 790,000 years ago (Ungar et al., 2006). The more common opinion is that controlled fire and cooking did not arrive until late in human evolution, around 200,000 to 250,000 years ago (Leonard et al., 2007). When burnt animal bones, hearths and flint materialize throughout the Middle East and Europe (Pennisi, 1999). In theory, the higher the partiality exhibited by a raw-food-consuming hominin for the properties available in cooked food, the more likely cooking would have been embraced following the controlled use of fire. Research revealed that captive apes are inclined to favour cooked food, suggesting that Paleolithic hominins would also have chosen cooked food over raw. This negates the hypothesis that the control of fire preceded cooking by a sizeable interval (Wrangham & Carmody, 2010). Interestingly, feeding tests indicate no substantial discrepancies in the speed of digestion of meals, excluding or including cooked chicken, by wild chimpanzees (Milton & Demment, 1989).

2.14 Cooking meant easier chewing, digestion and increased energy gained from meals

Although greater meat intake during human evolution surely promoted dietary quality, meat-eating on its own may have been inadequate in supporting human evolution, since modern humans struggle on raw diets that comprise meat (Carmody & Wrangham, 2009). There is persuasive support for humans being biologically adapted to diets comprised of cooked food (Wrangham & Carmody, 2010). For example, human foragers have never been documented as subsisting without cooking, and people who select a 'raw-food' life-style, suffer lack of energy and compromised reproductive functions. Calculations imply that a raw food diet could not provide enough calories for a typical hunter–gatherer (Wrangham & Conklin-Brittain, 2003).

Raw food may not have been digested fast enough to maintain the excessive energy needs of the human hunter–gatherer (Hunter, 2008). Cooking meant food became easier to chew and digest, while bettering the overall energy value of plant and animal foods (Carmody & Wrangham, 2009). For example, great apes and chimpanzees spend over 6 hours per day chewing. On a chimpanzee diet a person would eat for nearly half (42%) of their day (Wrangham et al., 1999). Cooking compromises the structure of meat, it gelatinizes the collagen. Thus, cooked meat should require reduced effort in digestion when compared with raw meat (Boback et al., 2007). As mentioned earlier, around 1.9 mya (Plio-Pleistocene), *Homo erectus* developed a bigger body and brain size, with a decline in tooth size. This was feasible due to a shift toward a high energy diet, requiring less chewing (Pasquet & Hladik, 2005). These adaptations are possibly indicative of routinely cooked meat (Wrangham et al., 1999).

2.15 Cooking broadened dietary scope

Cooking may have extended the dietary scope of *Homo erectus*, later *Homo* and early humans, making once inedible plants become edible e.g. raw underground storage organs such as potatoes (Arjamaa & Vuorisalo, 2010). In a survey of underground storage organs consumed by African foragers, 21 out of 48 of the palatable underground storage organs needed cooking to become edible. The cooking of underground storage organs would have boosted the available energy of a hominin diet, without enlarging comparative foraging costs (Wrangham et al., 1999). When cooked, the nutritional value of tubers rises, as more of the carbohydrate energy becomes obtainable for biological processes (Arjamaa & Vuorisalo, 2010). However, this is debated: nutritional studies of wild tubers used in modern foraging groups imply that the energy they contain is strikingly less than that of animal foods, even post-cooking (Leonard et al., 2007). Reservations endure regarding the use of cooking, and the dependence on roots and tubers in stimulating rapid brain evolution with the rise of early *Homo* (Leonard et al., 2007).

2.16 Meat adaptive genes?

The increased meat eating of longer-lived humans, when compared against nonhuman primate ancestors, poses a paradox. In numerous animal models concerning human lifespan and disease, heightened fat and caloric intake is linked with increased pathogenesis and reduced longevity. A shift toward increased meat consumption would have augmented contact with toxins and pathogens e.g. raw meat, especially from scavenging of decaying carcasses, would have amplified risk of infectious pathogens (Finch, 2010). It has been implied that mutations toward meat-adaptive genes in primitive hominins allowed the change from a herbivorous ape diet to the omnivorous human diet, while simultaneously bringing about a significant rise in longevity, as the new genes also granted disease resistance (Lund & Olsson, 2006). For example, the reduced mortality evident in human youngsters and adolescents under pre-industrial circumstances, when compared against wild chimpanzees, implies a superior resistance to infections. In comparison to contemporary nonhuman primates, humans have experienced high exposure to inflammatory elements (such as a diet high in fat and calories, non-infectious inflammagens' from cooked food and aerosols, and infections via pathogens from consuming scavenged carcasses). These highly inflammatory conditions would be presumed to boost mortality and reduce longevity, yet in humans the exact opposite has occurred (Finch, 2012).

A genome-wide, inter-species assessment, to locate specific genes under directional selection pressures, via human, chimpanzee, and rhesus macaque samples, revealed data which implied an early evolutionary change to a diet involving considerable levels of meat. The study also exposed genetic adaptations to offset the dangers of high cholesterol, pathogens and recurrent diseases, correlated with a meat-intensive diet (Luca, Perry, & Di Rienzo, 2010). One example is apolipoprotein E (apoE), with the E3 allele existing in *Homo,* which lowers the chances of developing vascular disease, permitting the transformation to a more omnivorous hominin diet (Finch & Stanford, 2004). In addition, a meat intensive diet most likely required advancement in the capacity to digest bacteria. This is supported by lysozyme, a protein that helps with the degradation of gut bacteria which is under positive selection in numerous primate taxa, including humans (Vallender & Lahn, 2004).

2.17 Agriculture and its consequences

Domestication of animals and plants was one of the essential advances in the history of the human species (Larsen, 2006). It is assumed that around 35% of the pre-agricultural human diet stemmed from animal sourced foods. With a diet comprised of over 30% meat and animal products, it is probable that pre-agriculture, humans had significantly greater amounts of dietary protein, and fewer carbohydrates (Luca et al., 2010). Agriculture led to a limited diet, involving substantial reliance on crops, less meat intake and a high intake of low nutrient plants. This caused a rise in mortality from nutrition related disease (Larsen, 2003). Human skeletal remnants from archaeological sites reveal a move from foraging to farming, with a consequential decline in diet and food procurement. This caused a reduction in well-being for the majority of human populations during the past 10,000 years (Larsen, 2006). For example, there was a substantial drop in nutrient ingestion, with 50 – 70% of the calories in an average agricultural diet being derived solely from starch (Luca et al., 2010). Agriculture encompassed a drop in oral and overall health, shown via higher incidences of dental and skeletal pathological illnesses (Larsen, 1995). Agriculture also enabled the population to control the food, resulting in a food excess, leading to a substantial increase in the human population (Luca et al., 2010).

2.18 Proteins and amino acids; why meat is complete

Amino acids are the foundation of protein, and protein is vital to the body and brain (Braverman et al., 2003). The body is unable to produce the essential amino acids, they must be obtained from food. Eight out of the twenty amino acids are absolutely vital for a healthy body. Any amino acid can become crucial, if any of the eight critical amino acids are absent or deficient (Pensel, 1997). Meat is an especially good source of protein as it contains amino acids at just the right levels to sustain a healthy body (Pensel, 1997).

2.19 Meat disadvantages

At present, the excessive amount of meat and saturated fat intake in the USA and other Western countries exceeds nutritional requirements, boosting chronic diseases like diabetes mellitus and cardiovascular disease (Walker et al., 2005). Meat production has other disadvantages too, including unprecedented negative environmental effects and diseases such as foot and mouth; a lethal viral infection that can spread from livestock to humans. The outburst of foot and mouth disease in Britain in 2001 lead to the culling of 8.65 million sheep, cattle, pigs, and lambs, while simultaneously deterring tens of millions of consumers (Smil, 2002b). As mentioned in the previous chapter, rearing livestock is inefficient, requiring enormous amounts of water and crops to feed the animals (Smil, 2002b). For example, 89 – 97% of the total energy within livestock feed, and 80 – 96% of the protein in the grains consumed by livestock, is lost in the farming process (Smil, 2002b). Meat can also contain dangerous hormones and antibiotics (Galbraith, 2002).

Meat consumption played a vital role in human evolution, especially in the development of a large and complex brain. However, the advent of agriculture, and the consequential shift away from hunting and gathering, has led to a significant rise in the human population, and consequentially, a rise in meat consumption. Current meat production methods appear unsustainable. The next chapter will evaluate a potential solution to the current problems involved with conventional meat production.

3 *In vitro* meat production

Please refer to the glossary (pages vi - xi) for definitions of key terms in this chapter.

Introduction

The previous chapter covered the importance of meat consumption in human evolution. As well as touching on the nutritious value of meat, the consequences of agriculture, and the disadvantages of contemporary meat consumption. This chapter will look at a potential solution to the current problems involved with conventional meat production. Around the world, but especially in the Netherlands, there is considerable interest in methods of producing cultured or *in vitro* meat (Bartholet, 2011), as a more sustainable alternative to farmed meat (Bhat & Bhat, 2011).

I think that indeed in vitro meat could supplement traditional meat to take strain off the environment (Roelen, 2012).
Professor Bernard Roelen (*in vitro* meat researcher and stem cell biologist).

3.1 The history of *in vitro* meat

In vitro meat is a novel idea which was brought about via funding from NASA, in an attempt to develop more practical foods for long term space missions (Bartholet, 2011). In the year 2000, Benjaminson, Lorenz and Gilchriest grew skeletal muscle explants *in vitro* from the muscle tissue of a goldfish (Benjaminson, Gilchriest, & Lorenz, 2002). In 1999, Wiete Westerhof, Willem van Eelen and Willem van Kooten obtained a Dutch patent for a scaffold-based method of *in vitro* meat production (Edelman et al., 2005a). The team went on to obtain other European patents and, ultimately, two American patents (Bartholet, 2011). Ever since his food obsession developed during hard and hungry times as a prisoner of war in Japan (Bartholet, 2011), Van Eelen had dreamed of growing meat *in vitro* (Bhat & Bhat, 2011). However, Catts and Zurr were the first to grow *in vitro* meat using tissue engineering. Their ambition was to grow, and maintain for long durations, tissue structures of varied geometrical size and intricacy, in an effort to generate a novel artistic palette, to draw attention to, and test perceptions concerning the use of new biological knowledge (Catts & Zurr, 2002). In 2004, Jon F. Vein of the USA also obtained a patent over the manufacture of tissue-engineered meat (Vein, 2004). However, the underlying idea goes back further, to the 1930's:

> *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* (Edelman et al., 2005a).

Sir Winston Churchill

There is a team of researchers and supporters who are trying to shift the methods of tissue engineering toward food manufacture, creating meat in laboratories independent of the animal. They are called The *In Vitro* Meat Consortium and they had their first meeting in 2008 (Stephens, 2010). Presently, the research groups of this consortium are situated at various universities in Sweden, the Netherlands, and Norway, with the Dutch group leading the way, attempting to develop a pig derived cell lineage; a group of cells that can be maintained forever under regulated settings (Stephens, 2010).
The University of Utrecht is concentrating on muscle cell proliferation, while the Eindhoven University of Technology is studying bioreactors and scientists in Amsterdam are investigating culture media (Bartholet, 2011).

3.2 Muscle development *in vivo*

How could *in vitro* meat progress further? The available information stresses two dissimilar methods, roughly named 'scaffold-based' and 'self-organising' tissue culturing systems. Each technique has its own unique technological challenges and is tailored to alternate outcomes (Stephens, 2010). Before going into *in vitro* meat production, it is important to understand how meat develops *in vivo* or *'within the living'*. Skeletal muscle growth in vertebrates starts in the early phases of the embryo and remains throughout adulthood. Multipotent cells from the mesoderm within the embryo are devoted to muscle tissue formation. In other words, these cells are seemingly committed to muscle cell differentiation, however not all of them differentiate toward muscle tissue right away. Various extrinsic and intrinsic signals momentarily curtail muscle tissue formation (also known as myogenesis), enabling the proliferation of a population of myosatellite cells (also known as skeletal muscle progenitor cells), which remain accessible in adult muscle tissue (Bailey, Holowacz, & Lassar, 2001). The myosatellite cell is an inactive precursor cell situated between the basal lamina (also known as the basement membrane), and sarcolemma of each muscle fibre (Anderson, 1998). The systems that produce myosatellite cells have been well studied, but the components directing the development and differentiation of the myosatellite cell population remains undetermined (Bailey et al., 2001).

Once healthy skeletal muscle has matured, its myosatellite cells become dormant (Zammit, Partridge, & Yablonka-Reuveni, 2006). It is thought that a system of self-renewal replenishes and sustains this myosatellite cell population (Partridge, 2002). Myosatellite cells are muscle-specific dedicated precursors, that play a crucial part in postnatal muscle growth, muscle hypertrophy and muscle repair. In response to injury, exercise, stretching or electrical stimulation, myosatellite cells are activated, producing a population of cells known as myoblasts. Myoblasts differentiate and fuse (Bailey et al., 2001), to form new myofibres (muscle fibres), and to enlarge and/or regenerate existing myofibres (Anderson, 1998). Myosatellite cells are thought to be strong contenders for the treatment of muscular diseases. There is much to discover as regenerative medicine necessitates the control of myosatellite cell behaviours both *in vitro* and *in vivo* (Kuang & Rudnicki, 2008).

3.3 A limited proliferative capacity *in vitro*

Once isolated, the myosatellite cells proliferative capacity drops significantly. Conversely, *in vivo*, even low numbers of myosatellite cells can repair substantial sections of skeletal muscle tissue. This reduction in proliferative ability *in vitro* is most likely caused by the change in environment surrounding the cells (Boonen & Post, 2008). The greatest obstacle within stem cell research may be revealing the external and internal mechanisms of the cells, which control self-renewal and differentiation pathways (Raff, 2003). Since myosatellite cells are destined to become skeletal muscle, they are a likely candidate for an *in vitro* meat product (Bhat & Bhat, 2011).

3.4 Another source for tissue restoration?

New research suggests that myosatellite cells may not be made up of a solitary, uniform population; there could be other supplies of cells supporting myogenesis in mature muscle (Partridge, 2002). Concerning maintenance and repair, organ-specific stem cells might not be entirely dependent upon their own sources. In specific situations, usually associated with muscle damage, stem cell populations located within other cell lines and within tissues from different germ layers, have participated toward tissue regeneration (Filip et al., 2005). Research has revealed that myogenic cells (muscle forming cells) can be obtained from bone marrow. However, the mechanisms and characteristics of the kinds of cells involved remain unspecified, and the legitimacy of the research has been questioned (Camargo et al., 2003). Also, numerous other intramuscular cell groups have shown the ability to provide myonuclei and fill the role of the myosatellite cell (Zammit et al., 2006). Thus, testing the concept that myosatellite cells independently carry out the renewal of damaged adult muscle (Bailey et al., 2001). However, the support of these non-satellite cells toward muscle/myofibre formation is limited and perhaps unwarranted. Even though these cells display myogenic potential, they are unable to participate considerably toward muscle formation and function. It is questionable whether non-satellite cells make up part of a physiologically significant muscle repair system, or just indicate some ambiguity in the systems that regulate the destiny of muscle progenitor cells/myosatellite cells (Zammit et al., 2006).

3.5 Skeletal muscle regeneration and tissue engineering

The engineering of skeletal muscle is a biological substitute for the restoration of lost muscle tissue post injury or disease. It is centred round a mixture of adult or embryonic stem cells, biomaterials and agents or stimuli. Although more research is needed to identify the processes included in muscle regeneration and to pinpoint the mechanisms involved in the survival, replication and differentiation of stem cells (Longo et al., 2012). However, progress is being made. Danoviz and Yablonka-Reuveni (2012) developed a basic protocol for the separation and growth of myosatellite cells from the adult skeletal muscle of the hind limb of a mouse. Their research was also applicable to different kinds of muscle and the muscle of other animal species (Danoviz & Yablonka-

Reuveni, 2012). Royer et al. (2002) established that murine skeletal muscle contains two groups of muscle progenitor cells (myosatellite cells). Both populations are able to be directly isolated and both have the capacity to differentiate *in vitro* toward skeletal muscle cells (Royer et al., 2002). Biophysical stimuli are also imperative in attaining the preferred function and texture of engineered muscle cells (Boonen et al., 2010). For example, mechanical provocation is one necessary component in myogenesis. Stretching muscle cells *in vitro* has been shown to be effective in modelling hypertrophy (muscle growth/expansion) *in vivo*. Skeletal muscle is also an attractive area for tissue engineering, due to its possible use for an *in vitro* meat product (Liao & Zhou, 2009).

3.6 Embryonic stem cells and *in vitro* meat production

Within muscle tissue, the vasculature system, combined with connective tissue (including extracellular matrix), myofibres and muscle-residence cells, generates the niche for myosatellite cells. This niche is imperative in regulating proliferation and driving differentiation of myosatellite cells to maintain muscle tissue (Wilschut, Haagsman, & Roelen, 2010). For successful *in vitro* meat production, *in vivo* processes must be emulated as closely as possible. Stem cells obtained from embryos are called embryonic stem cells (Haagsman, Hellingwerf, & Roelen, 2009). Embryonic stem cells are a desirable choice for an *in vitro* meat product, due to their limitless proliferative abilities and there capability to differentiate toward nearly any cell type (Bhat & Bhat, 2011). Theoretically, once an embryonic stem cell line is ascertained, its infinite renewal ability will eradicate the demand to gather more embryonic stem cells. Thus, it is possible that a single cell line could be adequate to feed the world (Bhat & Fayaz, 2010). For embryonic stem cells to develop into myofibres (muscle fibres), they initially need to differentiate into myoblasts (Langelaan et al., 2010). A substantial challenge with embryonic stem cells is to shift their differentiation toward myoblasts, while simultaneously avoiding the development of other cell lines (Bartholet, 2011). It appears to be harder to provoke myogenesis (muscle/myofibre formation) in embryonic stem cells *in vitro* than *in vivo*. For example, myoblasts from human embryonic stem cells easily fuse into myofibres when transferred to damaged muscle in mice *in vivo*. Conversely, when this process is carried out *in vitro*, it is problematic. It seems some vital *in vivo* niche elements are absent in the *in vitro* arrangement (Langelaan et al., 2010).

Embryonic stem cell lineages with limitless proliferative promise have yet to be achieved in farm animals (Fox, 2009). However, embryonic stem cells have a far better proliferative capacity than adult stem cells (myosatellite cells), and would therefore be more suitable for the generation of *in vitro* meat (Roelen, 2012). What is required is a stem cell line from a farm animal that can be cultured almost indefinitely and can efficiently differentiate to skeletal muscle (Roelen, 2012). Thus far, true embryonic stem cell lineages have only been established from rhesus monkeys, humans, rats and mice (Bhat & Bhat, 2011). However, the gradual amassing of genetic mutations could limit the proliferation phase for effective long-term embryonic stem cell proliferation (Bhat & Fayaz, 2010). An *in vitro* meat production system needs much cell proliferation to culture large amounts of muscle tissue, but the majority of cells have a limited number of culture replications before they will suffer a natural cell death; this is known as the Hayflick limit. There are three methods used to combat this restriction in an *in vitro* meat production system: routinely refilling the culture, use of an immortal cell lineage or the immortalization of a cell lineage. Generally cells will fall under the first method, although embryonic stem cells come within the second classification (Datar &

Betti, 2010). As for the third option, the immortalization of a cell lineage is contentious, since cell line immortalization requires genetic manipulation (Datar & Betti, 2010).

3.7 Myosatellite cells and *in vitro* meat production

Myosatellite cells have been separated and differentiated from the skeletal muscle of chicken, lamb, cattle, turkey, pig and fish (Datar & Betti, 2010). However, myosatellite cells are disadvantaged, as they are a rare muscle cell with restricted proliferative capacity (Datar & Betti, 2010). To become suitable for producing meat *in vitro,* their proliferative ability must be enhanced to equal those seen *in vivo* and/or in embryonic stem cells. It is predicted this will be achieved by improving culture environments, via better imitation of the *in vivo* roles of cells (Langelaan et al., 2010). Myosatellite cells are also susceptible to cancerous alterations in long-term culture, this is a strong issue of debate (Bhat & Bhat, 2011). Thus, in an *in vitro* meat production procedure, re-gathering of myosatellite cells to lower the chance of unprompted alteration may be required (Datar & Betti, 2010).

3.8 Dedifferentiation

Differentiated cells can be dedifferentiated to revert toward an embryonic like condition. These are known as induced pluripotent stem cells. They act just like embryonic stem cells, proliferating under ideal culture conditions (Haagsman et al., 2009). Interestingly, stem cells obtained via dedifferentiation of a person's own cells, may become a novel source for the regeneration of muscle. A greater comprehension of the systems implicated in dedifferentiation, could allow scientists to manipulate and perhaps even control the plasticity of the differentiated state, this could help to further the progress of regenerative medicine (Cai, Fu, & Sheng, 2007). The cells of humans and mice have already been dedifferentiated. In recent times, induced pluripotent stem cells dedifferentiated from farm animals have been defined. This method could be applicable to *in vitro* meat, because post dedifferentiation, cells could re-differentiate toward myofibres. However, obstacles exist in this method (Haagsman et al., 2009). Therefore, currently the most concrete cell foundation for *in vitro* meat is myosatellite cells or embryonic stem cells (Edelman et al., 2005a).

Matured adipocytes (fat cells) are able to be dedifferentiated *in vitro*, reverting to a prior multi-potent precursor cell lineage, also known as a dedifferentiated fat cell (DFAT cell) (Datar & Betti, 2010). Subsequently, DFAT cells can be transdifferentiated into myofibres, making them an alluring surrogate to stem cells (Bhat & Bhat, 2011). However, Rizzino (2007) argued against these claims, asserting that the multipotency, transdifferentiation and dedifferention of once differentiated cells, could be caused by unusual processes producing cellular look-alikes (Rizzino, 2007).

3.9 Culture media

Perhaps the most pressing issue in the production of *in vitro* meat is finding the optimal culture medium. This medium must boost and encourage growth while consisting of edible ingredients. Media constituents will be a considerable cost element, due to the large amounts that will be needed (Datar & Betti, 2010). *In vitro* meat demands a cost effective culture media, comprised of all essential nutritional elements (Bhat & Fayaz, 2010). Culture media must be given in a manner easily accessible to myoblasts and nearby cells, since a digestive system is not included (Edelman et al., 2005a). This culture medium must make the culturing of cells affordable, while being free of animal products (Bhat & Fayaz, 2010). Presently, myoblast culturing generally occurs in animal sera, an expensive medium, which does not sit well with consumer approval or industrial scale application (Datar & Betti, 2010). For example, the current US$1.10 per gram price of the fetal bovine serum in which the meat is cultured (this adds up to an excess of US$1,100 per kilogram), is a major obstruction to a commercially viable *in vitro* meat product (Yanke, 2011). Fetal calf serum encompasses growth factors essential to mammalian cell proliferation (Haagsman et al., 2009). However, complex protein blends could, rather than being derived from animals, be harvested from plants. This would substantially lower the cost of culture media (Haagsman et al., 2009). Serum-free culture media and industrial serum substitutes present a more practical alternative to mammalian cell culture. Lowering operation expenses and procedure unpredictability, while reducing the risk of infectious agents (Datar & Betti, 2010).

Amazingly, a serum-free medium produced via mushroom extract has attained a greater muscle growth level *in vitro,* than fetal bovine serum (Edelman et al., 2005a). It is also plausible to create growth media via blends of restricted amounts of purified chemical compounds. This medium can be made completely free of any animal products, however, the cost of these media is currently very high (Haagsman et al., 2009). Serum-free media have been established to sustain myosatellite cells *in vitro,* from the sheep, pig and turkey (Datar & Betti, 2010). Cyanobacteria are an obvious option for a serum-free culture media, however alternate research has revolved around the growth of algal proteins (Tandy, 2009). Although, one setback is that myosatellite cells from different animals have varied needs and react differently to specific media factors (Datar & Betti, 2010). It is assumed that the use of complicated blends of elements, like plant cell extracts, combined with partially purified growth factors, is the most logical system (Haagsman et al., 2009).

3.10 Growth factors

As well as providing appropriate nutrition to proliferating muscle cells in culture, it is essential to supply sufficient growth factors (Bhat & Bhat, 2011). Growth factors are created and discharged by muscle cells, and in tissues, they are also supplied by different cell types (Edelman et al., 2005b). Producing an ideal concoction of growth factors and hormones is a difficult task (Datar & Betti, 2010). Myosatellite cells from distinct species have unique needs, and react differently to specific additives and/or regulatory aspects. Thus, extrinsic regulatory influences must be specialized to the selected species and cell type (Bhat & Bhat, 2011). Furthermore, growth factor mixture may need to be altered throughout the development of the culturing process. The proliferation stage could require a specific mixture of hormones and growth factors, while the differentiation phase might require a different blend (Datar & Betti, 2010). The successful method will require the capacity for changes in the growth factor composition of the culture medium (Edelman et al., 2005b). Purified hormones or growth factors could be added to media from an outside agent, like transgenic bacterial, animal or plant species. Alternately, a kind of artificial cell signalling mechanism could be produced, to enable co-cultured cells to discharge growth factors, as a catalyst for cell development and proliferation in nearby cells (Datar & Betti, 2010). For example, a co-culture system could be developed which enables liver cells (hepatocytes), to provide the growth factors necessary for cultured muscle production (Edelman et al., 2005b). Growth factors have already been recognized which significantly alter myoblast behaviours (Langelaan et al., 2010).

3.11 Co-culturing

Typically, cells are proliferated and differentiated using a monoculture, this enables an easily regulated environment with no interference of other cell types (Haagsman et al., 2009). Myoblasts are dedicated to the production of skeletal muscle, however they generate very small levels of extracellular matrix (Langelaan et al., 2010). Some data suggest that the extracellular matrix is important for guiding regeneration and ordered growth within skeletal muscle and other *in vivo* tissues (Haagsman et al., 2009). Therefore, additional cells may be required to obtain the desired muscle (Langelaan et al., 2010). Fibroblasts existing in muscle are chiefly accountable for the growth of extracellular matrix, and thus could be an advantageous addition to the culture procedure (Bhat & Bhat, 2011), since the extracellular matrix is responsible for meat texture (Haagsman et al., 2009). Meaning the co-culturing of myotubes amongst fibroblasts, to produce extracellular matrix, could be a useful method to enhance myofibre maturation, while simultaneously creating a more meat-like texture (Langelaan et al., 2010). Especially because *in vitro,* fibroblasts have been proven to increase the speed of myotube formation (Haagsman et al., 2009). Although, co-cultures of myoblasts grown alongside fibroblasts include the danger of fibroblasts outgrowing myoblasts, due to discrepancies in growth speeds (Bhat & Bhat, 2011).

Co-culturing has proven effective for the engineering of *in vitro* skeletal muscle, when fibroblasts are sown as a small proportion of the total cell population (Haagsman et al., 2009). However, co-culturing may not be necessary. Instead, it is likely that the texture of *in vitro* meat will mainly be obtained after processing. Just as the texture of sausages and hamburgers (due to processing), is different from the texture of a steak, the texture of *in vitro* meat will be largely dependent on processing (Roelen, 2012).

3.12 Bioreactors

Even though biochemical stimuli are crucial during differentiation (as mentioned earlier), biophysical stimuli are also vital in the development toward myofibres with *in vivo* like structure and properties. A crucial obstacle that must be surmounted is the failure of muscle cells to completely mature within muscle engineered structures (Langelaan et al., 2010). One prospective issue linked with *in vitro* meat is muscle wasting or atrophy, via a decrease of cell size due to denervation, lack of use or various diseases. Consistent contraction is a requirement for skeletal muscle, and encourages differentiation and healthy myofibre formation, while averting atrophy. Muscle in the body is stimulated via nerves, enabling routine, ordered contraction, whereas an *in vitro* method would essentially culture denervated muscle tissue, hence the need for muscle contraction roused by alternative methods (Bhat & Bhat, 2011).

Myoblasts rely on attachment, therefore a substratum or scaffold is necessary for proliferation and differentiation to take place (Edelman et al., 2005b). There are multiple methods to get skeletal muscle precursor cells/myosatellite cells, to differentiate and fuse into skeletal muscle tissue (Edelman et al., 2005b). For example, mechanical stimulation spurs myoblast alignment and myotube maturation, influencing both proliferation and differentiation of muscle cells (Langelaan et al., 2010). During contraction, myotubes generate a growth factor that boosts their protein production. Mechanical stimulation can have a comparable influence on undeveloped myotubes (Haagsman et al., 2009). Alternatively, neuronal action can be simulated via the application of suitable electrical stimuli to *in vitro* cultures, this has been demonstrated as being fundamental to the growth of established myofibres, as the initiation of contraction encourages myotubes to differentiate into myofibres (Bhat & Bhat, 2011).

Therefore exercise via electrical prompts may be a practical answer to atrophy during *in vitro* meat production (Bhat & Bhat, 2011).

Also, the cells can be occasionally stretched (Edelman et al., 2005b). Repeated stretch and release has been proven to increase myoblast differentiation into myotubes. For example, implanting magnetic micro-particles within myoblasts can provoke differentiation when placed in a magnetic field (Edelman et al., 2005a). A stretchy scaffold is also required, to avoid maturing myotubes detaching during impulsive contractions, since newly developed myotubes contract spontaneously in culture (Bhat & Bhat, 2011). Flexible scaffold beads have also been suggested to meet the need for scaffold contraction (Bhat & Bhat, 2011). These stimulations are a similar concept to exercising at the gym, over a few weeks the tissue develops into adult muscle (Edelman et al., 2005b). For the effective tissue engineering of myofibres, a bioreactor must include the capacity to implement biophysical stimulation procedures, which mimic *in vivo* conditions during muscle regeneration (Langelaan et al., 2010).

3.13 Scaffold-based techniques to create ground and processed meats

In scaffold based methods, myosatellite cells or embryonic myoblasts are multiplied, fastened to a carrier or scaffold (e.g. microcarrier beads or collagen meshwork), and immersed with culture media within a bioreactor (Bhat & Bhat, 2011). Environmental prompts drive cell fusion toward myotubes, these myotubes then differentiate to become myofibres. The myofibres can then be detached from the scaffold and are ready to be cooked (Edelman et al., 2005b). Different types of scaffolding could be utilized in the *in vitro* meat production process, e.g. myofibres can be cultured on mesh or miniature beads suspended in growth media, these can stretch to rouse motion and solidify the meat. Alternately, myofibres can be developed on big sheets of digestible or straightforwardly detachable material (Hopkins & Dacey, 2008). However, due to circulation restraints, these methods currently only allow production of thin sheets of meat, applicable to ground meats (Edelman et al., 2005b). The resultant two-dimensional monolayers of myofibres can be piled on top of one another post-harvest (Bhat & Fayaz, 2010). By stacking multiple converging sheets of myofibre culture, a three-dimensional meat product can be constructed (Datar & Betti, 2010). Although scaffold techniques might be suited to processed meat production, like mince or sausage, they are not sufficient for growing well-structured meats, like steaks (Edelman et al., 2005a).

The ideal scaffold would consist of a sizeable surface region for development and connection, be supple to enable contraction, augment medium dispersion and be conveniently separated from the meat culture. Myotubes differentiate best on scaffolds with tissue like rigidity (Bhat & Bhat, 2011). While indigestible materials should not be ruled out (Datar & Betti, 2010), optimal scaffold ingredients would be organic, edible and obtained via animal free resources (Edelman et al., 2005b). However, scaffold-based methods encounter a practical obstacle in the separation of the meat from the scaffold. Current meat removal methods involve adjoined muscle cell layers being removed either mechanically or with enzymes, these techniques can harm the extracellular matrix and the muscle cells which they are there to generate. Although, thermo responsive veneers that convert from hydrophobic to hydrophilic at reduced temperatures, can free muscle cells and their extracellular matrix in one piece when cooled (Datar & Betti, 2010).

3.14 Self-organizing techniques to produce structured meat

To manufacture well-structured meats, self-organizing procedures are needed (Bhat & Bhat, 2011). Cells can be cultivated in substrates that permit the progression of ''self-organizing constructs'', to manufacture more solid constructions of tissue (Hopkins & Dacey, 2008). In a model of mammalian muscle cells within a three dimensional template, cells are sustained and supplied within bioreactors, so the three dimensional self-arrangement of the natural tissue enables the delivery of the nutrient supply, establishment of aeration and waste removal (Haagsman et al., 2009). However, the prospect of producing structured cuts of meat is still limited, due to the absence of blood flow within *in vitro* muscle tissue (Pluhar, 2009). *In vivo* blood flow is vital; delivering nutrients and oxygen to cells, while simultaneously eradicating metabolic waste (Bhat & Fayaz, 2010).

Structured meats require a perfusion system akin to a blood supply, to deliver nutrients and oxygen close to growing cells, and to remove waste products. Currently the inner cells of the meat tend to die, as they do not receive sufficient nutrients (Bartholet, 2011). Researchers are working on tissue engineering methods, such as a branching network of edible, porous, flexible material to 'vascularize' the meat, raise nutrient dissemination and increase medium flow (Bhat & Fayaz, 2010). Myoblasts and various other cells can then fasten to this network (Edelman et al., 2005b). This should eventually enable the delivery of vital nutrients to all cells (Bartholet, 2011), allowing the creation of wholly artificial muscle (Bhat & Bhat, 2011). However, a repeatable and regular integration of vascular systems, within a co-culture structure, will present a demanding challenge (Langelaan et al., 2010). For now the construction of these synthetic vascular networks does not brood well with industrial scale production (Datar & Betti, 2010). Other areas requiring additional development using this system are the apparatus for harvesting, the requirement for pharmaceutical quality sanitation, sterility and equipment and process regulation (Haagsman et al., 2009).

Alternately, living muscle tissue can be proliferated *in vitro,* this technique enables production of well-structured meats, like steaks (Bhat & Bhat, 2011). This method was used by Benjaminson, Gilchriest and Lorenz, who grew goldfish muscle explants while researching techniques to produce muscle protein for astronauts (Benjaminson et al., 2002). The result was similar to fish fillets, it was cooked and rated highly by food panellists (Bhat & Bhat, 2011). Explants have the benefit of already including all the cells the muscle consists of, therefore closely imitating an *in vivo* assembly. Although, insufficient blood dispersal within explants means significant growth is not currently possible (Edelman et al., 2005a).

3.15 Relative to conventional meat, *in vitro* meat could offer a number of benefits

3.15.1 Composition

In vitro meat would enable unparalleled control concerning meat composition and quality, via managements of flavour, fat constituents, proportions and content. This would be achieved through culture media ingredients and/or through co-culturing with various cell types (Bhat & Bhat, 2011). Fat ratios could also be managed through the addition of fats in post-production (Bhat & Fayaz, 2010). Most conventional meats contain high levels of saturated fatty acids, with lower amounts of poly-unsaturated fatty acids. Saturated fatty acids are linked with heart disease, while poly-unsaturated fatty acids have a favourable influence on blood cholesterol. With *in vitro* meat fat proportions could be altered to become healthier (Edelman et al., 2005b). For example, healthier omega 3 fatty acids could replace the (heart disease associated) omega 6 fatty acids, which are found in high amounts in the majority of livestock (Pluhar, 2009). The health characteristics of *in vitro* meat could also be heightened by inserting specific kinds of vitamins to the culture media (Bhat & Bhat, 2011).

3.15.2 Disease control

The possibility of bacterial contamination could be reduced by stringent quality management rules, unachievable in current farming systems (more information on contamination will be provided in later paragraphs) (Edelman et al., 2005b), as the manufacture of *in vitro* meat would be supervised within a laboratory, possibly enabling the eventual eradication of food borne sicknesses, like mad cow disease (Langelaan et al., 2010). Within an *in vitro* meat processing factory, the procedures to guarantee a disease free environment would be of a similar expense (financially) to any conventional meat processing factory. However, currently the possibility of error or contamination during the production of *in vitro* meat is equivalent to the risk of error or contamination at conventional meat processing companies, such as in the processing of sausages, nuggets, and hamburgers (Roelen, 2013). Furthermore, by lowering the levels of human to animal contact, the frequency of pervasive inter-species disease could drop substantially (Datar & Betti, 2010). Moreover, the threats of contact with dioxins, hormones and pesticides connected with regular meat, could be considerably diminished (Edelman et al., 2005b).

3.15.3 Efficiency

As a system with minimal waste products, low land and resource requirements, *in vitro* meat might relieve the environmental affliction shown by current meat production methods (Datar & Betti, 2010). A large amount of protein consumed by livestock (75–95%), is squandered on metabolism and indigestible parts (Pluhar, 2009), conversely, with *in vitro* meat, no energy or matter is wasted on producing uneatable body parts or bones (Edwards, 2010). *In vitro* meat would also lower stress on fresh water resources and agricultural land (Fox, 2009). Beef farming requires 2.7 times more energy input and 250 times more land in comparison to *in vitro* meat production (Yanke, 2011). In a laboratory, manufacture can be organized vertically, and situated anywhere, as there is no requirement for large land areas to contain animals (Lincicum, 2010). Rather than clearing more forest for livestock and crops, these regions could be reforested or used to capture and store carbon to mitigate climate change (Tuomisto & de Mattos, 2011). When compared to conventional meat farming, *in vitro* meat could slash energy input by nearly 45%, with 99% lower land utilization and approximately 96% lower water usage (Ford, 2012).

3.15.4 Reduced greenhouse gas emissions

Reduced livestock numbers could pave the way toward reduced greenhouse gas emissions and land use (Langelaan et al., 2010). *In vitro* meat would be a crucial system for moderating the carbon footprint of livestock (Fox, 2009). Most of the greenhouse gases released from livestock stem from the removal of forest and feed crops and from methane emanated directly from the animals (Lincicum, 2010). Research proposes that greenhouse gas emissions may be cut by up to 96%, when contrasted against beef farming using conventional techniques (Ford, 2012). Beef farming is predicted to include around 48 times more greenhouse gas emissions, when compared to *in vitro* meat production (Yanke, 2011).

3.15.5 Less production time and no need to ship meat round the globe

In vitro meat could be manufactured within a time range of weeks, contrasting starkly with the months to years taken for the growth of conventional livestock (Edelman et al., 2005b). Meaning feed levels and human labour for *in vitro* meat would be significantly curtailed. The marginal land involved in the growth of *in vitro* meat, could enable meat to be produced domestically, in nations that would usually depend upon imported meats (Bhat & Bhat, 2011). Therefore, meat would not need to be transported around the world, since production locations could be positioned near consumers' (Tandy, 2009). Some advocates envisage small town meat labs, selling *in vitro* meat at street shops catering to 'locavores' (Bartholet, 2011). Also, the transport demands for *in vitro* meat should be decreased, as entire animals are no longer needed (Tuomisto & de Mattos, 2011).

3.15.6 Cheap protein for a growing population

Meat demand is on the rise, *in vitro* meat production will be imperative to satisfy consumer demand (Bhat & Fayaz, 2010). *In vitro* meat offers significant prospect for the circumvention of food shortages, which can be anticipated with the growing population (Haagsman et al., 2009). The requirement for alternate protein supplies mandates *in vitro* meat production (Bhat & Fayaz, 2010).

3.15.7 Wildlife conservation

In vitro meat production may hold advantages for wildlife conservation, since it diminishes pressure for transforming natural environments into agricultural land (Tuomisto & de Mattos, 2011). The worldwide market for rare animal meat has destroyed natural populations of countless threatened animal species. In theory, *in vitro* meat offers a new method for obtaining meat from endangered animals, which are presently overexploited and/or hunted (Bhat & Bhat, 2011). *In vitro* meat could effectively wipe out animal suffering, as it would only require a small amount of animal biopsy material to supply the required cells for meat production (Yanke, 2011).

3.15.8 Food for space

In vitro meat could play a vital role in supplying food for future long term space missions. There are also alternative scenarios where it is difficult to supply food, such as scientific work places in polar areas or war encampments in remote regions etc. Under these circumstances it would be more practical and feasible to grow food *in situ.* *In vitro* meat could provide this (Bhat & Fayaz, 2010).

3.15.9 Less animal waste

In vitro meat production would generate significantly lower levels of animal waste than conventional farming (Yanke, 2011). *In vitro* meat production involves markedly reduced nutrient losses to waterways when assessed against standard meats. For example, waste from cyanobacteria (as the culture medium), could be easily regulated (Tuomisto & de Mattos, 2011). *In vitro* meat may need antibiotics to guarantee sterility during production. Although, since the meat would be grown in a closed structure, instead of in an exposed farm environment, any bioreactor pollution or escape of antibiotics beyond the bioreactor, could most probably be confined to the laboratory (Yanke, 2011). *In vitro* meat is also proposed to be potentially grown without any hormones or growth factors (in non-physiological amounts) (Van Eelen, 2007).

3.16 Obstacles to *in vitro* meat

3.16.1 Contamination/pollutants

In vitro meat could have a distinct risk profile when compared to conventional meat. Attention must be given to the care of additional substrates and other culture media ingredients, since *in vitro* meat production may involve a heightened risk of substrate contamination (Bhat & Fayaz, 2010). However, in relation to conventional meats, *in vitro* meat should have a lower risk of microbial contamination (Edwards, 2010). At the moment, contamination of conventional meat occurs at or just after slaughter, when there is contact of the intestines, or the content of the intestines, with the meat. The intestines contain many bacteria that normally do not get in contact with the meat; however, if they do make contact, the bacteria can proliferate and cause contamination (Roelen, 2013). Because *in vitro* meat production will occur in a sterile environment (Haagsman et al., 2009), and since *in vitro* meat is never in contact with bacteria, by definition it should not be contaminated (Roelen, 2013). Of course contamination with any bacteria or fungus can occur during processing, but this risk is exactly the same as with conventional processed meat today. If meat is being processed to make hamburgers or sausages this has to be done in such a way that bacteria cannot grow, for example, by working at cold temperatures (Roelen, 2013). *In vitro* meat will also have a reduced risk of pathogen contamination, as this can be more easily controlled (Welin & Van der Weele, 2012). However, there is the chance that the systems employed to manufacture the culture media will cause an entirely novel set of problematic pollutants, which must be altered or quarantined. For example, the culture media will require bioprotein and an ingredient to mimic blood serum (Edwards, 2010).

3.16.2 Commercial scale production

A commercial-scale *in vitro* meat production system, with the capacity to grow meat at levels equivalent to conventional slaughterhouses, is significantly impeded by insufficient research toward large-scale *in vitro* meat growth (Datar & Betti, 2010). *In vitro* meat based commodities will entail substantial culturing in sizeable bioreactors, as a large and rigid culture surface is required to produce abundant muscle cells (Bhat & Bhat, 2011). It is assumed that approximately $160 million is required toward research for *in vitro* meat commercialization (Tuomisto & de Mattos, 2011). To produce *in vitro* meat with current technology would require about $5 million per kilogram (Edelman et al., 2005b). This excessive cost is because tissue culture equipment for *in vitro* meat production within the laboratory setting is expensive, due to the small scale of production. Presumably, once *in vitro* meat has reached commercial-scale, and is being produced in large bioreactors, costs will be drastically reduced (Roelen, 2013). Improvements in the technical facets of *in vitro* meat production will increase efficiency significantly and reduce costs substantially. Still, it is improbable that *in vitro* meat will rival conventional meat in supermarkets in the near future. Although household technologies which were initially too expensive for mass acceptance (e.g. internet, computer, microwave), eventually became affordable and common; the same may occur with *in vitro* meat (Edelman et al., 2005b).

3.16.3 Social acceptance

The greatest challenge to *in vitro* meat could be an in-built repulsion to unusual foods (Tuomisto & de Mattos, 2011). Some view social approval as the greatest hurdle to commercial-scale *in vitro* meat production (Bartholet, 2011). The assertion that something is immoral because it is artificial is commonplace with debates concerning novel biotechnologies. For some people, the mere fact that *in vitro* meat is man-made is their chief concern (Hopkins & Dacey, 2008). However, the general approval of meat substitutes like tofu and Quorn (a leading type of synthetic meat in England. The mycoprotein utilized in the production of Quorn is derived and grown from a fungus: *Fusarium venenatum*), authenticate the outlook that the public are unlikely to completely decline an *in vitro* meat product (Tandy, 2009).

3.16.4 Meat; more than just edible cells/tissue

The structure of skeletal muscle and its biochemical elements effect the muscles conversion to meat and its sensory properties such as flavour, juiciness, colour, and tenderness. Muscle features at slaughter are determined by animal type (male/female, age, breed) and breeding circumstances. For example, in ruminants, nutrition often affects metabolism, muscle composition and muscle structure, therefore influencing meat quality (Geay et al., 2001). Even travel time to slaughter can be an influence. Forty-eight slaughter bulls were taken to slaughter by road transport with travel times ranging from around 30 minutes to 6 hours. An expert sensory panel favoured meat from animals which travelled for 3 hours, in preference to the 30 minute or 6 hour travelled animals. They evaluated this meat as more tender and rated it higher in terms of 'overall liking' (Villarroel et al., 2003). A significant challenge to a commercial *in vitro* meat product will be matching the complex features of muscles and varied meat cuts that are so crucial to the approval and appreciation of meat.

It is also imperative to take into account that meat and muscle tissue are biochemically different. The metabolic responses that occur post-slaughter, such as protein denaturation and enzymatic proteolysis, influence the taste, look and texture of the meat. One ambiguity regarding metabolism is if these post-slaughter reactions will happen with *in vitro* meat post-harvest, to transform *in vitro* muscle tissue into conventional meat as it is defined today (Datar & Betti, 2010).

In vitro meat offers numerous benefits over conventional meat production. *In vitro* meat could complement conventional meat, to reduce pressure on the environment. However, many obstacles remain regarding both embryonic stem cells and myosatellite cells, obtaining the optimal culture medium, growing structured meats, achieving commercialization, and gaining public acceptance. Chapter 4 will expand on the latter point, looking at public responses to a commercially viable *in vitro* meat product.

4 Communicating the prospect of *in vitro* meat

Please refer to the glossary (pages vi - xi) for definitions of key terms in this chapter.

Introduction

The previous chapter covered *in vitro* meat production, advantages and obstacles. This chapter discusses how the public could respond to a commercially viable *in vitro* meat product.

I have encountered many different reactions [to in vitro meat], from disapproval to people that consider cultured meat as the solution of the century (Roelen, 2012).
Professor Bernard Roelen (*in vitro* meat researcher and stem cell biologist).

4.1 Diet – a tricky topic

People's behaviour can seem counter intuitive when it comes to diet. Knowledge of nutrition is often insufficient to motivate the right food choice. This is because food is not just used to meet energy needs, but also for general satisfaction and enjoyment (Parnell, 2012). Eating favoured foods is pleasurable, and fear of giving up these foods is a significant hurdle to healthier diets (Birch, 1999). With an *in vitro* meat product, people will desire familiar flavour, look and texture. These attributes will take priority over evidence, statistics and science, since most people do not choose foods according to facts (Parnell, 2012). However, if a product with all the features of meat is affordable and accessible, and is produced without harming animals, people would most likely purchase it for reasons ranging from concern for the environment, to animal welfare, to anxiety regarding zoonotic diseases (Haagsman et al., 2009). To change what people eat, they must be shown that their current diet is not satisfactory (Parnell, 2012).

4.2 The consumer and conventional meat quality cues

It is apparent that the extrinsic features of meat can be used as quality prompts, while simultaneously affecting hedonistic and sensory perceptions (Issanchou, 1996). Consumers often utilize rather unexpected cues as quality indicators e.g. meat colour, as a way of judging tenderness. However, in the majority of cases, the consumer is conscious that these prompts are not very predictive of the qualities being sought. This may be due to the inaccessibility of more reliable quality cues and/or available quality cues which consumers are not comfortable with interpreting e.g. complex ingredient lists (Grunert, 2002). Increasing consumer directed information might not resolve this issue. Research suggests that providing consumers with more information might not just be ineffective, but could occasionally cause increased confusion and consumer anxiety (Grunert, 2005). Brands are helpful here, as reliable quality indicators; they help consumers to associate good or bad eating experiences with distinct brands. However, brand-free products make it hard for consumers to develop quality expectations, like with meat for example (Grunert, 2002). The above mentioned aspects could also (in theory) be applicable to a commercial *in vitro* meat product.

4.3 Different meat, different consumer?

It is clear the meat business is transforming from a traditional production guided industry toward a consumer propelled industry (Issanchou, 1996). Research indicates that opinions and knowledge toward health and nutrition vary amongst chicken, pork and beef consumers. Thus, information and outlook toward diet and meat products affect decisions, in particular, the probability of eating different kinds of meat. In fact, socio-demographic factors can help predict meat product choice and meat consumption amounts (Guenther et al., 2005).

4.4 Consumer attitudes often differ from consumer actions

Research shows that consumer attitudes are weakly correlated with purchase behaviours, as indicated by a lack of demand for free range and organic meat (Grunert, 2006). Consumers tend to turn a blind eye to animal husbandry. People are disturbed by the thought of animal slaughter, yet excited about their fresh eye fillet steak at dinner (Tandy, 2009). Many of the public have strong opinions about meat production, however for the majority of consumers, opinion will most likely not affect purchase behaviour (Grunert, 2006). Not a great deal of research has been carried out on the social and ethical issues surrounding *in vitro* meat (Bhat & Fayaz, 2010). Probably because it is still not available for public consumption.

4.5 An existing market for *in vitro* meat?

However, Regmi and Gehlhar (2001) state that knowledge and opinions toward health matters influence consumer consumption choices. Accordingly, food demand in the USA has shifted in recent times; with a drop in total red meat consumption from 79% in 1970 down to 62% by the turn of the century. Meanwhile there has been an increase in the amount of chicken consumed; from 21 - 38% (these figures are assumed to be at least partly driven by health related reasons) (Regmi & Gehlhar, 2001). Although food safety and health apprehensions drive motivation for organic food purchases, ethical anxieties, especially in accordance with levels of animal welfare, play a considerable part in the choice to buy organic food. This implies that the organic market could benefit from studies on consumer motivation to purchase organic foods, by utilizing ethical concerns as a gauge of product quality (Harper & Makatouni, 2002). Consumer concerns about animal welfare could therefore be a useful ploy in the marketing of an *in vitro* meat product.

Consumer apprehension about animal welfare and sustainability has led to adjustments in food production and advertising in some nations. Numerous developed nations have enforced new systems, some that directly influence animal farming (Regmi & Gehlhar, 2001). In these developed nations, a group of consumers is growing who have greater awareness and regard for standard industrialized food production methods, their negative influence on animal welfare and the environment (Weatherell, Tregear, & Allinson, 2003). For example, with chicken and pork, satisfactory production systems and adequate animal welfare appear to be vital factors for the future (Verbeke & Viaene, 1999).

4.6 Traditional consumer meat preferences could provide marketing insight for an *in vitro* meat product

From a sensory perspective, consumer meat choices are swayed by tenderness, juiciness (Resurreccion, 2004), texture, appearance/colour, and to a smaller degree by differences in flavour (Risvik, 1994). Appearance therefore influences perceived consumer quality and thus has a considerable effect on purchasing actions. Colour and fat content are the most powerful appearance features (Risvik, 1994). Higher fat content in meat is negatively correlated with consumer quality expectations when viewing raw meat, even though higher fat content enhances the quality of the consumer's eating experience (Grunert, 2002). This makes consumer expectations paradoxical for the producer, with intramuscular fat negatively linked to healthiness, despite its positive effect on flavour and juiciness (Issanchou, 1996). Interestingly, research has shown that meat packaging and beef colour effect appearance perceptions and likeliness to purchase, while having no effect on taste perceptions or eating pleasure (Carpenter, Cornforth, & Whittier, 2001). It is clear, therefore, that knowledge of the sensory preferences of traditional meat consumption could be invaluable to the effective marketing of a successful *in vitro* meat product.

Enhanced communication could contribute toward a decrease in the ambiguity often surrounding meat and meat products. Various solutions have been suggested, such as quality indicators, like brand and label, or better communication from butcher to consumer (Issanchou, 1996). Various other attributes also affect consumer meat preference, including alterations in convenience, price, shifts in distribution, and health issues (Resurreccion, 2004). A survey involving 320 meat eaters in Belgium found that safety associated meat factors were imperative in influencing pork and beef purchases after the BSE (also known as 'mad cow disease') catastrophe (Verbeke & Viaene, 1999). Other overall patterns are present in meat demand, such as the rising concern for reduced-fat products and the ever increasing allure of convenience products (Issanchou, 1996). Consumer preference appears driven by available time and ingredients to hand. Meat tends to be used as a fast and convenient food to suit busy consumer lifestyles. Thus, processed beef is likely to grow in popularity in future within beef markets (Issanchou, 1996). This could be good news for *in vitro* meat, as the scaffold-based techniques required to grow meat similar to ground/processed meats are currently more feasible than the self-organizing methods required to grow structured meats such as steaks (Edelman et al., 2005a).

4.7 'Restructured beef' and consumer reactions

The value of red meat can be improved by the restructuring of less tender meat cuts. Restructured beef steaks were analysed by 300 meat eaters, where increasing levels of connective tissue were added to measure the tolerance of connective tissue in product texture. Restructured beef steaks with 10 – 20% additional connective tissue were tolerated. However, steaks with 30% additional connective tissue resulted in negative observations; such as lower levels of acceptance and reduced juiciness (Resurreccion, 2004). These results could offer valuable insight toward consumer reactions to texture in an *in vitro* meat product.

4.8 Meat substitutes

4.8.1 Entomophagy; insects for protein

The greatest initial challenge to *in vitro* meat may be an intuitive aversion to unusual foods (Tuomisto & de Mattos, 2011). However, people are already consuming unusual foods (Illgner & Nel, 2000). In less developed nations insects provide a profuse supply of vitamins, minerals, fats and critical proteins (Durst et al., 2010), as well as high levels of zinc and iron (DeFoliart, 1992). Globally, almost 1,700 different types of insects are said to be consumed for human food (Durst et al., 2010). It is ironic that numerous non-governmental and international establishments attempt to protect crops comprised of less than 14% protein, by destroying an alternate food source (insects), which could include up to 75% protein (a higher quality protein) (Ramos-Elorduy, 1997). In their most popular dried form prominent in village marketplaces of the underdeveloped world, some insect species contain levels of crude protein in excess of 60% (DeFoliart, 1992). Since insects are especially rich in amino acids, they can provide a valuable nutrient supply for humans (Durst et al., 2010).

Cultivated insects would be many times more efficient than conventional meat production with a much smaller environmental effect (Roelen, 2012). A Western acknowledgment of the significance of insects as a food source could generate enormous ecological advantages (DeFoliart, 1999). In many regions insects are plentiful and can be bred with little effort and in limited/small spaces. Also, in contrast to livestock, where offal, bones and other organs are nearly inedible, the whole insect can be utilized for food (Meyer-Rochow, 2010). Cultivated insects would only release approximately 1% of the greenhouse gases of an average cow per kilogram of bodyweight acquired. The production of one kilogram of farmed crickets emits around 1.5 grams of greenhouse gases, whereas cows produce almost 3 kilograms of greenhouse gases per kilogram of bodyweight obtained (Hodson, 2012). However, a disadvantage of insects is that up scaling is difficult (Roelen, 2012).

Insects are very efficient protein converters, a crucial feature for the commercial manufacture of animal proteins. Crickets are far smaller than cows, but are five times faster at transforming plant matter into biomass (Ramos-Elorduy, 1997). Remarkably, insects can subsist on organic waste; enhancing their sustainability attributes, while opening up numerous advantages. For example, insects could transform organic waste into high-protein feed for livestock, especially chicken (DeFoliart, 1999). Insects also have a high reproductive capability, can be bred in varied environments, have brief life cycles, are available year round and are cost effective to source (Illgner & Nel, 2000). It has also been implied that some plants which are prevalent and typical of arid areas, but of low food value, could be employed for the farming of their accompanying insects. This would result in the production of high quality protein, since insects far exceed the protein and fat levels of the plants they consume (DeFoliart, 1992).

A positive aspect concerning insects is that the ick factor is only in the mind (people eat shrimps and lobsters so why not other crustacea like insects?) (Roelen, 2012). However, the greatest obstacle is still public perception. Entomophagy has all but been ignored in Western texts, in spite of the vital role it plays as a protein source in various regions of the globe (Illgner & Nel, 2000). The majority of people in developed nations avoid insects and/or are reluctant to eat them. This is most likely due to their appearance, more than their taste, although, insects might be consumed in future by processing and combining them with other foods (Mitsuhashi, 2010). In theory, a similar method could be effective in the gradual introduction of commercially viable *in vitro* meat. Could *in vitro* meat be combined with traditional meats? This 'insect ick factor' may offer valuable insight to the upcoming hurdles which will be confronted by *in vitro* meat advocates.

4.8.2 Vegetarian meat

Many doubts are based on the man-made, unnatural production techniques required for *in vitro* meat (Lincicum, 2010). However, *in vitro* meat is made up of muscle tissue very similar to traditionally reared meat, differences exist only in methods of production (of course, it can also be debated that traditionally produced meats are not natural) (Tuomisto & de Mattos, 2011). Currently, there exists a strong demand for meat substitutes (Bhat & Fayaz, 2010). Man-made, unnatural meat substitutes are common amongst vegans and vegetarians. Produced from vegetable protein extracts or cultured fungus hyphae, they are processed and given a meat-like texture. Future protein scarcity was estimated as far back as 1955, it was around this period that research was initiated toward the processing by microorganisms of waste starch from cereal production; to create edible protein. *Fusarium venenatum* was the mould with the greatest potential (Tandy, 2009). A product called Quorn was the end result. Even though it was considerably unnatural and technology dependent, it has become prevalent with followers of health foods (Ford, 2012). After the fungus has been removed from its fermentation tank, it is altered to provide a consistency similar to meat and synthetically flavoured to taste like meat (Tandy, 2009).

There are a few ancient examples of this system of artificial food manufacture (Tandy, 2009). Tempeh is a long established meat substitute made in Indonesia via the fermentation of cooked soya beans with the pin-mould known as *Rhizopus* (Ford, 2012). A similar protein based food is tofu, derived from soya bean curd. Interestingly, tofu does not bear a resemblance to conventional meats: in fact, it was never supposed to. Over time it has possibly been misconstrued by the public, especially as it has occasionally been incorrectly perceived and consumed as a meat analog that tastes different to meat (McIlveen, Abraham, & Armstrong, 1999). Meat substitutes have been easily accessible for around 2000 years; it is likely some will gain significance as per capita meat stocks decline (Ford, 2012). The acceptance of such man-made, technology dependent and unnatural meat substitutes is encouraging for the development of a commercial *in vitro* meat product.

4.9 Surimi; a well-accepted, cheap and technologically altered form of meat

Surimi is an intermediary food derived from minced fish flesh that has been washed, purified, and combined with cryoprotectants to protect it from frozen storage (Kelsky, 1990). Walleye pollock is the most widely used fish species in the surimi industry, due to its abundance, gel-forming capacity, annual accessibility, good taste and white colour (Kelsky, 1990). Fish paste/gel seafood's go back far within the history of traditional Asian food (Pangsorn, Laong-manee, & Siriraksophon, 2007). In 1975, Japanese corporations began manufacturing imitation crabmeat and other shellfish analogs, causing increased interest in surimi overseas (Kelsky, 1990). Today surimi has developed into one of the more powerful options within Asian seafood, due to modern advances in manufacture and utilization systems (Pangsorn et al., 2007). Surimi based imitation seafood's are very popular in Europe and the USA (Mansfield, 2003). In fact, the extraordinary growth in the intake of imitation shellfish from Alaskan pollock surimi has instigated an exploration for alternate kinds of fish, which could offer other sources for surimi (Fiddler et al., 1993). For example, Japanese jack mackerel (*Trachurus japonicus*), hoki (*Macruronus novaezelandiae*), blue whiting (*Micromesistius poutassou*), and sardine are currently being used for surimi production. New Zealand hoki has shown promise as an alternative surimi source because of its abundance and the high quality of hoki surimi (Kelsky, 1990). Surimi is another example of a technologically altered, yet still well accepted food, once again providing hope for an industrial scale *in vitro* meat product.

In vitro meat could eventually become the favoured choice amongst meat substitutes, as it is distinct from other products in being animal-derived, and in terms of constitution it is not a meat substitute at all (Bhat & Fayaz, 2010). *In vitro* meat can definitely be used in processed or ground meats - such as hamburgers - as either a central element or as an additive. This would enable the current textural limitations of the *in vitro* meat product not to compromise the final processed product. Here one could envisage greater consumer approval (Datar & Betti, 2010).

4.10 How will *in vitro* meat be marketed?

A successful *in vitro* meat product requires effective product marketing (Langelaan et al., 2010). Social approval may be the greatest threat to a commercial-scale *in vitro* meat product (Bartholet, 2011).

I've mentioned cultured meat to scientists, and they all think, 'great idea.' When I talk to non-scientists, they are more afraid of it. It sounds scary. Yet it's basically the same stuff: muscle cells. It's just produced differently (Bartholet, 2011).
Hanna Tuomisto; Ph.D. candidate at the University of Oxford and co-author of Environmental Impacts of Cultured Meat Production.

The launch of an *in vitro* meat product is challenging, although possible harmful connotations could be counterbalanced by the positive influence of *in vitro* meat on the environment, animal welfare and world food resources. Thus, the thought that people would consume a meat grown in a laboratory does not appear so improbable (Langelaan et al., 2010).

4.11 The 'ick factor': public acceptability and attitudes

From a viewpoint of societal acceptance, the technological nature of *in vitro* meat is a negative attribute. Links with cloning, Frankenstein, and the unknown can all too easily arise (Bhat & Fayaz, 2010). In fact, even mentioning *in vitro* meat conjures up gusto at one end of the continuum and reproach at the other.

I wonder if you can get people to eat that stuff. There are safety questions, technical problems and a very huge 'yuck' factor to deal with (Fox, 2009).
Michael Hansen from Consumers Union in Yonkers, New York.

In vitro meat needs to be as natural as possible; it can be tweaked (by changing the cells, or via additional ingredients), but this would necessitate customization. Firstly, the priority is to produce a viable *in vitro* meat product and to have people accept it. Further down the track, tweaks or additional ingredients can be supplemented, but this will require another step for the consumer (Roelen, 2012).

Some people reject *in vitro* meat purely on the basis that it generates an emotional response of disgust. Many examples of disgust, however, are culturally learned, not biologically entrenched (Lincicum, 2010). Disgust derives from a negative reaction to bad-tasting food and extends, in humans, toward a system for excluding from the mind items which one's culture deems offensive. In the latter, disgust is founded on the thought of what the food is and on its temperament, rather than on its sensory attributes (Hopkins & Dacey, 2008). Concerning the people who feel disgust toward *in vitro* meat; are these reactions centred on something recognizably immoral or are they a form of neophobia? (Hopkins & Dacey, 2008). Interestingly, retorts in Europe to genetically modified crops imply that there could be an extensive rejection of new or unusual foods (Tandy, 2009). This is precarious, as *in vitro* meat is inclined to be mistakenly connected with genetically modified foods (Bartholet, 2011). However, the general acceptance of foods such as Quorn and tofu validate the opinion that the public is unlikely, as a whole, to reject *in vitro* meat (Tandy, 2009). An initial response of disgust to *in vitro* meat should be replaced by a more logical understanding. Feelings toward novel technologies gradually change, this is already starting to happen with *in vitro* meat (Lincicum, 2010). People have stated that though they felt repulsion when initially hearing of *in vitro* meat, they subsequently altered their stances (Hopkins & Dacey, 2008).

4.12 Insight from genetically modified foods and consumer reactions

Research suggests that the higher the amount of apparent consumer risk, the more difficult it becomes for consumers to see the advantages of the food. This implies that merely providing more positive information could be an ineffective method for altering consumer attitudes (Grunert, 2002). It is also intriguing that consumers interpret familiar risks as less scary than unfamiliar risks. This is a trend applicable to attitudes toward genetic modification and other new foods (Grunert, 2005), such as *in vitro* meat.

Alleged risks are associated with underlying overall consumer attitudes, such as the 'attitude to nature' – concerning the basic premise that humans ought to live in accord with nature. This outlook is strongly correlated with the supposed risks in genetically modified foods. This is called the attitude activation effect, where additional knowledge about a technology triggers underlying negative attitudes (Grunert, 2002). This implies the genetically modified food issue is governed chiefly by consumer concern regarding the use of technology in food manufacture. Much of this concern is dependent upon credence characteristics, where the typical consumer cannot determine the food quality alone, but instead must rely on the reports of others (e.g. is this orange really free from genetic modification?). As there tends to be no possible method to confirm the claims made regarding such food products, credibility can become particularly low. However, research on organic food purchasing behaviours in Europe, has revealed that once consumers believe information to be trustworthy, that information will be in greater demand and become more effective (Grunert, 2002). Even seemingly insignificant things, such as including contact details on food products (such as telephone numbers), seem to aid consumer confidence levels and trust (Costa-Font, Gil, & Traill, 2008). To explore how credence quality characteristics form, both psychological and sociological methods are required (Issanchou, 1996). This knowledge would be vital for the efficient marketing of a commercial *in vitro* meat product.

4.13 It's not 'real' meat, it's not natural

A common assertion exists that non-natural things are intrinsically bad, and man-made meat is thus morally questionable. This is an articulation of the common 'naturalistic fallacy' – the propensity to mistakenly connect the natural with the good. However, most essential life-saving medicines are unnatural and humans are as natural as any animal or tree (Lincicum, 2010). This view insists that consuming *in vitro* meat will isolate us from nature in some vague and undetectable way (Lincicum, 2010). However, *in vitro* meat is authentic meat. It would enable people to 'have their cake and eat it too', allowing meat consumption, while simultaneously sparing animal lives, with a reduced toll on the environment (Hopkins & Dacey, 2008). If *in vitro* meat is to be a success, its advocates will have to persuade consumers that little risk exists in its production (Pluhar, 2009).

4.14 People are far from what they eat

We are far from what we eat. When we're eating a hamburger, we don't think, 'I'm eating a dead cow.' And when people are already so far from what they eat, it's not too hard to see them accepting cultured meat (Bartholet, 2011).
Professor Bernard Roelen (*in vitro* meat researcher and stem cell biologist).

If people can eat the unhealthy and overly-processed meat of factory raised animals, then surely they can eat a healthy and safe *in vitro* meat (Bartholet, 2011). One of the major problems with *in vitro* meat is that initially, people wonder if it is safe or even edible. This is an issue that will solve itself, as there are numerous foods that people consume today, that are also cultured in a factory. Cheese, for instance, is a rubbery and smelly substance produced in a factory, which people happily consume. It should be the same with *in vitro* meat. When it is in the supermarket and cheap, people will buy it (Roelen, 2012).

4.15 Consumer reactions thus far

An optimistic attitude was acknowledged from audiences in international and national discussions. Internet-debates and web-surveys showed that most people support the manufacture of 'victimless' meat. Others however, have exhibited dispositions of disgust as they view *in vitro* meat as unnatural (Haagsman et al., 2009).

Which attributes govern the success or failure of *in vitro* meat?

- Sustainability: participants stressed sustainability as imperative to success.
- Product name was interpreted as a significant risk factor. For some, this was correlated with Frankenstein like links.
- *In vitro* meat is overtly presented as an alternative to traditional meat; some participants supposed *in vitro* meat should be completely different from traditional meat. As a novel product requires its own identity to enable it to be competitive.
- The system of food production ought to be transparent, particularly with technologically manufactured food. Transparency is also useful to reveal the advantages of *in vitro* meat, like sustainability. Conversely, complex technology, bioreactors and embryonic stem cells can instigate links with cloning.
- *In vitro* meat is not limited by land, or location, opening up opportunities for new regions of manufacture and for different land uses.
- *In vitro* meat could benefit from other environmentally friendly innovations. For example, algae cultures could produce the culture media.
- Animal flesh can be unreliable, because of sickness, variable growth and stress. *In vitro* meat could offer a far more dependable option (Haagsman et al., 2009).

The instinctive and primary response of many meat eaters to the *in vitro* meat concept is repulsion. An unscientific poll revealed comments like ''that's disgusting!'' and ''who knows what they would put in that stuff?'' (Pluhar, 2009). *In vitro* meat can be considered as a new product. Thus, it is probable that it will not be accepted by consumers immediately. Due to the newness of *in vitro* meat, no papers currently exist concerning consumer tolerance. However, there have been general reactions on internet debates. Here are some excerpts from two online discussions. The first is an American/global forum popular with people into technology and science (http://science.slashdot.org/article.pl?sid=02/12/31/1425214&mode=thread&tid=134) (Edelman, 2003). The second forum is a Dutch list, mainly visited by people concerned with advancements in sustainability (http://www.ddh.nl/pipermail/duurzaamlijst/2001/thread.html#40) (Edelman, 2003). The responses are mainly negative. There were multiple arguments that stated:

1 - *The technique is unnatural.*

2 - *It alters the intrinsic value of the animal.*

3 - *Genetically engineered, Frankenstein food.*

The challengers can mainly be categorized in one of two brackets: people who believe it is natural to slaughter animals for eating and the 'green people' - those anxious about animal well-being and the fair dissemination of resources around the globe. Interestingly, genetic engineering is brought up numerous times by the 'green people' and also by those who do not fall into either of the two categories, but are worried about their safety. However, in the articles discussed in these forums, no reference was ever made to genetic engineering. Therefore, it is possible that the third argument (genetic engineering) is linked with fear of the unknown. Argument 1 was evident in both groups 1 and 2, whereas argument 2 only arose with the 'green people' (Edelman, 2003).

The Dutch government in recent times promised around €800,000 for a new four-year assignment that would maintain the stem cell research at Utrecht, while instigating research regarding the moral and social issues linked with *in vitro* meat. Cor van der Weele of Wageningen University is writing up the philosophical facets of the new Dutch research. She has been fascinated by the emotional responses that some people have regarding *in vitro* meat. "We call it the 'yuck response,' " she says. "People initially think that it might be something contaminated or disgusting" (Bartholet, 2011). The study will evaluate common reactions to *in vitro* meat; assessing responses across varied locations and cultures. To help develop methods to frame *in vitro* meat that could increase consumer interest (Bartholet, 2011).

4.16 Misleading media representations

Numerous YouTube videos and online articles were studied to get an idea of the terms and phrases the media are using in their framing of *in vitro* meat, since the way in which *in vitro* meat is represented by the media could influence public perception. A few common trends were obvious. With YouTube videos (mainly news related), *in vitro* meat came under many different names, some of which were misleading and/or easily linked with science fiction or scientific stereotypes. For example, test tube meat (Uygur, 27/02/2012), lab burger (CNN, 06/12/2010), biomeat (Arizona, 31/01/2011), mystery meat (Arizona, 20/02/2012), Frankenfood (Sand, Kachur, & Trogen, 22/03/2011, and artificial meat (CNN, 06/12/2010). Occasionally the sampled videos included entire phrases, analogies or jokes concerning science fiction, with some videos including repulsive and often misinformed statements.

Examples included:

A technology that's met with universal optimism from the scientific community and universal repulsion from the general public (Sand et al., 22/03/2011).

A Dutch scientist is working on a food that gives a whole new meaning to mystery meat (Arizona, 20/02/2012).

I just get very uneasy about anything that's in a lab or genetically enhanced (Arizona, 31/01/2011).

Is your mouth watering? I don't know if mine is (Arizona, 05/01/2012).

Even if it looks the same, tastes the same and is just as safe, would people really eat beef made in a lab (CNN, 20/02/2012)?

That's eventually how you will get the Star Trek, ah, food dispenser (Uygur, 27/02/2012).

The yuck factor is pretty high, so how do you convince people out there; including me, to give it a shot (CNN, 06/12/2010)?

In vitro meat media releases, online articles and some blogs revealed a similar trend, with misleading or science fiction names such as:

Bio-sausages (Coghlan, 31/08/2011), synthetic meat (Coghlan, 31/08/2011), synthetic burger (Ghosh, 19/02/2012), artificial burger (Collins, 19/02/2012), test tube meat (Winter, 20/02/2012), Schmeat (Hanlon, 22/06/2012), future flesh (Hyena, November 17, 2009), test tube beef (Reporter, 29/06/2011), test tube hamburger (Reporter, 29/06/2011), fabricated burgers (Grumble, 29/06/2011), test tube tucker (Grumble, 29/06/2011), Frankenburgers (Wills, 25/02/2012), artificial meat (Levitt, 03/11/2012), lab-grown hamburger (Ghosh, 19/02/2012) petri-dish meat (Herald, 09/09/2011) and lab-grown sausage (Herald, 09/09/2011).

Many misrepresentative, science fiction style phrases were also evident:

Tanks of grow your own T-bone steak (Hodson, 2012).

A burger grown in a laboratory. Sounds like science-fiction (Levitt, 13/08/2012)?

Fake meat: is science fiction on the verge of becoming fact (Hanlon, 22/06/2012)?

Yet to cross the threshold between fantasy and reality (Hanlon, 22/06/2012).

It remains to be seen, however, whether it will find favour with a public that likes to think of its chops, steaks and sausages as having their roots in nature, rather than in test tubes (Gayle, 17/01/2012).

Lab-raised snarlers and steaks may not yet taste like the real thing, and their appearance suggests they would not be winners in the supermarket (Stone, 31/12/2011).

The test tube tossers have been at this sort of thing for a while (Grumble, 29/06/2011).

Concerning sending a suitable potential volunteer to be the first to consume *in vitro* meat; *She has a thing about the perils of cell phone towers, and we can imagine she would be similarly suspicious of stem-cell steaks. She also is a fanatical opponent of GE crops, and presumably would see scientifically engineered food in the same unfavourable light* (Grumble, 29/06/2011).

It's the Jetsons' like vision of something called in-vitro, or test tube meat (Wills, 25/02/2012).

Thus the media could be a powerful contributor toward shaping public perception and appear likely to augment the 'ick factor'. Common trends within the media regarding *in vitro* meat should be studied further. This was not possible with the time restraints of a master's degree.

4.17 The likelihood of New Zealanders' accepting this product

People eat what is accessible in the environment in which they live e.g. a person from New Zealand (where traditionally, dairy products and meat have been inexpensive), is likely to consume large amounts of meat and dairy. New Zealand contains a predominately carnivorous population, with less than 10% of the population omitting some or all meats from their diet (Parnell, 2012). After Argentina, Uruguay and Paraguay, New Zealand and Australia have the highest per capita red meat consumption (Norat et al., 2001). In New Zealand meat eating families spend about 20 - 25% of their food budget on meat; a considerable amount. If meat expenses could be reduced, this would enable a significant reduction in food expenditure (Parnell, 2012).

If *in vitro* meat tasted as good as traditional meats and was available in the supermarket at a lower price, people might purchase it (Parnell, 2012). This is supported by studies in Europe and the USA which have revealed that aspects such as taste and cost are more relevant to people making food decisions, than are weight control or nutritional eating (Mhurchu & Ogra, 2007). With *in vitro* meat people will demand familiar appearance, texture and taste, as food is not only used to meet nutrient requirements, but for pleasure and enjoyment too (Parnell, 2012). Many alternate protein sources are currently available, such as plants and fungi, used to produce varied meat analogues that are reasonably priced (Haagsman et al., 2009). Meat analog products have progressed with advances in texture, appearance, mouth feel, colour and flavour; they are a nutritional meat substitute which can occasionally come close to equalling real meat products (Riaz, 2001). However, the drawback of these foods is the absence of texture and taste; meat analogues are no competition for real meat (Haagsman et al., 2009). Conversely, in theory *in vitro* meat has the potential to satisfy both the nutritional and hedonic needs of meat eaters (Bhat & Fayaz, 2010).

4.18 When will *in vitro* meat reach the supermarkets?

Professor Julie Gold, a biological physicist at Chalmers University of Technology in Gothenburg, Sweden says "It could take years before commercialisation… There's very little funding. What it needs is a crazy rich person" (Vidal, 21/01/2012). There are few scientists researching *in vitro* meat, this research is expensive and there is very limited funding on offer. If this does not change it will be a long time before a viable *in vitro* meat product is available. It is impossible to predict when *in vitro* meat will reach the supermarket; it will not be within several years at least. Perhaps in several years it can be produced reliably in a culture dish. For a commercial-scale product, bioreactors are required, that will be technologically demanding. Then there is issues of consumer acceptance, interest from companies to gain financial support, there is numerous variables involved (Roelen, 2012).

Not a great deal of research has been carried out on the social and ethical issues surrounding *in vitro* meat. Existing research concerning consumer behaviour and conventional meats could provide marketing insight for a successful *in vitro* meat product. The greatest initial challenge to *in vitro* meat may be social approval. The acceptance of man-made, technology dependent foods, such as meat substitutes, cheese, and surimi, is encouraging for the prospect of a commercial *in vitro* meat product. When it is in the supermarket and cheap, people will buy it. However, the media could be a powerful contributor toward shaping public perception, common trends within the media regarding *in vitro* meat should be studied further. Chapter 5 will evaluate the link between the academic component and the film, 'Meating Expectations', made with Rodney August. The main points of the thesis will be summarized and concluded with informed discussion and personal insight regarding an *in vitro* meat product.

5 Discussion and conclusions

Please refer to the glossary (pages vi - xi) for definitions of key terms in this chapter.

The previous chapter assessed potential public reactions to a commercially viable *in vitro* meat product. This chapter will include the link between the academic component and the film, 'Meating Expectations', made with Rodney August. The main points of the thesis will be summarized and concluded with informed discussion and personal insight concerning an *in vitro* meat product.

In my opinion all alternatives to farmed meat are welcome, whether they are plant-based, in vitro meat or insects and the like (Roelen, 2012).
Professor Bernard Roelen (*in vitro* meat researcher and stem cell biologist).

5.1 Link between film (creative component) and thesis (academic component)

This thesis provides the context and background for the creative component of this MSciComm – entitled 'Meating Expectations' - a 25 minute documentary made with Rodney August. This documentary covered a new way to produce meat, with *in vitro* meat production; meat grown independent of the animal, via cell culture. The film explores what *in vitro* meat is, how it is made, why it is necessary, the problems that it could solve and the problems that it could create. *In vitro* meat is explored in a New Zealand setting while hinting at global implications. Numerous characters are followed in the film, revealing varied reactions to the idea of an *in vitro* meat product.

5.2 Why is there a need for this research?

In vitro meat is a novel concept, still in its infancy. The objective of this thesis was to raise public awareness and contribute to world knowledge regarding an *in vitro* meat product. More specifically, my aim was to show the beneficial potential - regarding human well-being, animal welfare and the environment - of *in vitro* meat, while simultaneously explaining the production processes involved and addressing the challenges confronting a commercially viable *in vitro* meat product. The written thesis (or academic component) of this MSciComm is especially important, because it will provide detailed insight into a controversial scientific topic, still in the experimental stages. This final chapter will provide an overall summary of the entire thesis, combined with informed discussion about the possible consequences of a commercially viable *in vitro* meat product.

5.3 The response to the film

The responses to the film thus far have been diverse. The majority of viewers with whom I have discussed the film were pleased that the film covered such a controversial topic in such an impartial, balanced and user-friendly manner:

You tackled an issue that was multi-layered and unravelled it smoothly. And you did so in an accessible way. In vitro meat is a subject, we've discovered, few people have heard of. You introduced a concept new to many and presented it so the main aspects were covered in a way all could understand.

Carolyn Guytonbeck, viewer, 17/11/12.

The film was always intended to be neutral, neither for nor against *in vitro* meat, the facts were what were important. Viewer feedback also revealed that people were pleased with the structure/layout of the film:

I liked how you started with questions and ended up giving different perspectives re: each question. It was really well done.
Himang Mujoo – viewer, 17/11/12.

Viewers seemed particularly impressed that the film addressed the big questions such as: could human meat be produced? Could *in vitro* meat spell the end of farming in New Zealand and destroy the economy? And if so, what would happen to the empty farms, would they become eco-sanctuaries or cities? Could *in vitro* meat help the population to grow even larger?

Many viewers discussed the presenter, stating how vital she was to the film. The presenter's 'chatty, laidback' demeanour provided balance, producing a nice contrast with the serious topic and stern character opinions:

The chatty manner was fun and took the serious edge off it.
Carolyn Guytonbeck, viewer, 17/11/12.

The presenter provided witty, yet informative segues between the various sections of the film. However, more importantly, the presenter gave the viewer someone to relate to:

The presenter was excellent, the highlight of the film.
Patricia Wardell, viewer, 17/11/12.

Like the majority of viewers, the presenter knew nothing of *in vitro* meat; she took the viewer with her on a 'personal journey of discovery'.

Overall there have been very positive reactions to the film talent. Especially Professor Bernard Roelen (*in vitro* meat researcher and stem cell biologist) and Doug Nestor (*in vitro* meat opposed commercial fisherman). Bernard provided a logical, factual perspective, his view being that *in vitro* meat offers a method of meat production with reduced environmental impact, imperative in decreasing environmental destruction from conventional meat production methods. Conversely, Doug Nestor's reaction to *in vitro* meat was indicative of how I believe many people will respond. Doug was against *in vitro* meat from the second he heard about it and no amount of statistics or information would change his mind. Doug could not see the benefits of *in vitro* meat; he was blinded by the ick factor. As far as Doug was concerned, meat grown from stem cells in a laboratory was just too off putting.

5.4 Problems encountered

During film production the main problems encountered were in the development of the storyline, with the story changing numerous times. This meant time wasted filming sequences which would ultimately be cut from the film. Also, as *in vitro* meat is still in the experimental stage, and produced overseas, we were unable to film any real *in vitro* meat. Thus we had to create re-enactments and insert sequences of farm animals and people consuming conventional meats. Consequentially, some of these shots looked like 'filler' and perhaps seemed repetitive.

5.5 Why is the film important?

The film is especially important because it should reach a wider and different audience than the academic thesis. The film will educate 'Joe Public' about the potential and perhaps even necessary food revolution that is *in vitro* meat. The film places *in vitro* meat in context, as a partial solution to rising populations, food shortages and unsustainable farming, helping the public to understand the technology and develop an opinion. In the film we experience brief insight toward opinions from interviewees from a wide array of backgrounds. I am sure viewers would be intrigued that one of the people in the film who would consume *in vitro* meat (Marika Tait), is a vegan. Conversely, the commercial fisherman (Doug Nestor) and farmer (John Ransley): both carnivores, viewed *in vitro* meat with disgust.

5.6 Attitudes, opinions and future research

However, this revulsion at the idea of *in vitro* meat can be expected from farmers and fishermen, as their livelihood depends on conventional meat production. Likewise, we should expect the views of Professor Bernard Roelen (*in vitro* meat researcher and stem cell biologist) would be in support of an *in vitro* meat product. Clearly these people are inherently biased and an unbiased audience should have been consulted, but this was not possible with the time restraints of a 25 minute documentary. Interestingly, Wageningen University in the Netherlands is currently researching the effect of life style, environment and mood on people's attitude toward *in vitro* meat (Roelen, 2013). This will provide insight on the opinions of those for whom a large-scale change in the population's diet will not endanger their career or livelihood (Datar, 2013). For now, online observations from social media sites like Twitter indicate that *in vitro* meat supporters tend to be future oriented and well educated (Datar, 2013).

5.7 Thesis highlights

While writing this thesis, intense debates and discussions arose, due to the controversial nature of *in vitro* meat. I would be asked about my thesis topic at dinners or social events as people were very interested. Some would react with disgust, seemingly closed to the idea. Conversely, others would react with intrigue, wanting to know more about the advantages *in vitro* meat offered over conventional meats. There was also a smaller group of people who already knew of *in vitro* meat. These people tended to be pro-*in vitro* meat, with more knowledge concerning its advantages over conventional meat production methods.

Before drawing conclusions: I will summarise the main points of the thesis.

5.8 Conventional meat production methods are not sustainable

The input of conventional meat production toward environmental issues is enormous. Raising livestock is inefficient and is relentlessly reducing freshwater and agricultural land, contributing to basic food scarcity. Conventional meat production necessitates large amounts of grain, undercutting global grain resources and staple food supplies, furthering malnutrition and contending with direct human grain consumption. Farming is also the leading cause of reduced biodiversity, while contributing more greenhouse gases to the atmosphere than the entire transportation sector. Globally, livestock feed and human food demands have been predicted to increase twofold in the 21st century, this will amplify environmental pressures. Meanwhile demand for biofuels is especially intense in developing nations, agricultural resources are being diverted to grow biofuel feedstock. This double up in demand is creating tension between people and automobiles over grain resources (Chapter 1).

5.9 Rising population, growing affluence and increasing meat demand

Urbanization and globalization are enabling people to avoid poverty. As their incomes increase, poor people are consuming more animal sourced foods. The current rising population, linked with escalating affluence and the consequential unparalleled rise in meat consumption, especially in developing countries, means that current meat production systems are untenable. Present consumption patterns also show that higher income consumers are demanding more animal derived foods while obtaining a larger share of global food resources. However, meat consumption around the globe remains imbalanced. There are parts of the world where meat consumption is already low, and continues to decline (Chapter 1).

5.10 Carnivorous evolution

The carnivorous tendencies of human's nearest sibling (the chimpanzee) suggest that meat eating originated very early in human evolution. Across all primates large brains are linked with better diets. Humans are at the extreme end of this scale, with the largest relative brain size and the best quality diet. Around 2.5 mya animal sourced foods became progressively more important for human ancestors'. Consistent consumption of animal sourced foods allowed sufficient energy for the human lineage to attain an especially large and complex brain, while sustaining their evolution as large, energetic, social hominids. However, around 10,000 years ago, the advent of agriculture resulted in a rise in the human population. Hunter-gathering was replaced with animal husbandry. Today, the large population combined with rising meat demand, mean current meat production methods are not sustainable. However, there could be a solution with *in vitro* meat (Chapter 2).

5.11 *In vitro* meat production

In vitro meat can be cultured from embryonic stem cells, or adult stem cells, however obstacles remain with both cell types. Embryonic stem cells are an attractive option for an *in vitro* meat product, due to their unlimited proliferative capacity and their ability to differentiate toward almost any cell type. However, one sizeable challenge with embryonic stem cells is how to push their differentiation toward muscle tissue, while simultaneously evading the growth of other cell lines. Embryonic stem cell lineages with unlimited proliferative potential have yet to be realized in farm animals (Chapter 3).

Adult stem cells obtained from adult muscle tissue are known as myosatellite cells or muscle precursor/muscle progenitor cells. Since myosatellite cells are fated to become skeletal muscle, they are a prospective candidate for an *in vitro* meat product. Myosatellite cells have been isolated and differentiated from the skeletal muscle of cattle, lamb, chicken, pig, turkey, and fish. However, to become appropriate for growing *in vitro* meat the myosatellite cells' proliferative ability must be improved (Chapter 3).

Perhaps the most demanding issue in the production of *in vitro* meat is discovering the ideal culture medium. This medium must foster cell growth, be economical, be comprised of edible ingredients and preferably be free of animal products. Thus far, animal serum-free media have been developed which maintain myosatellite cells *in vitro* from the sheep, turkey and pig (Chapter 3).

For effective *in vitro* meat production a bioreactor is required with the capability to apply biophysical stimulation procedures (a similar notion to training at the gym) that imitate the *in vivo* environment during muscle regeneration. Biophysical stimuli (e.g. the mechanical stretching of tissue) are crucial in the progression toward a muscle tissue with *in vivo* arrangement and properties (Chapter 3).

There are two dissimilar methods of *in vitro* meat production, roughly named 'scaffold-based' and 'self-organising' tissue culturing systems. Each method has its own unique technological challenges and is tailored to alternate outcomes. Scaffold techniques are appropriate for processed meat production, allowing growth of thin sheets of meat suitable for ground meats like sausage or mince. Due to circulation limits this technique is not capable of growing complex, structured meats, like steaks. To produce structured meat self-organizing methods are required. Structured meats' require a perfusion system akin to a blood supply to deliver nutrients and oxygen close to growing cells, and to remove waste products. Researchers are working on tissue engineering methods, such as a branching network of edible, porous, flexible material to 'vascularize' the meat, raise nutrient dissemination and increase medium flow (Chapter 3).

5.12 *In vitro* meat advantages

Comparative to conventional meat, *in vitro* meat could provide numerous advantages.

In vitro meat would permit adjustable fat ratios, with healthier fats than those in conventional meats, as well as additional vitamin options. Also, eventually the potential for meat contamination could be considerably lessened, with the possibility of eradication of food-borne sicknesses like mad cow disease. The protocols to ensure a disease free environment would cost the same (financially) as any conventional meat processing factory. Currently the danger of contamination or error in the production of *in vitro* meat is on par with the danger of contamination or error at conventional meat processing companies e.g. in the production of sausages, hamburgers, nuggets etc. However, contamination of conventional meat is usually caused by the intestines, or the content of the intestines, coming into contact with the meat. As the intestines contain many bacteria that can cause contamination. Clearly this threat does not apply to an *in vitro* meat product. Overall, when compared against conventional meats, *in vitro* meat will have a lower risk concerning microbial contamination. Furthermore, by reducing the levels of human to animal contact, the incidence of persistent inter-species disease could be substantially lowered. With an *in vitro* meat product, the risks of contact with hormones, dioxins, and pesticides linked with conventional meat could be greatly reduced (Chapter 3).

An *in vitro* meat production system would have minimal waste products (when compared to conventional meat production), while reducing pressure to convert natural environments into agricultural land. It could alleviate the environmental burden evident in current meat production methods and offer advantages for wildlife and biodiversity conservation. When compared against conventional meat farming, *in vitro* meat could lower energy input by almost 45%, with 99% less land required and around 96% less water usage. Greenhouse gas emissions could drop by up to 96%, when weighed against beef farming using conventional methods. An *in vitro* meat production system would not squander energy on the growth of inedible body parts, like bones for example. *In vitro* meat factories could be positioned near consumers, reducing food transportation costs, while also enabling food production *in situ* in remote regions. *In vitro* meat could effectively (in theory) eliminate animal slaughter, as it would only need a small number of animal biopsies to source the required cells for meat growth (Chapter 3).

5.13 *In vitro* meat challenges

Challenges remain however; some view social acceptance as the greatest hurdle to a commercially viable *in vitro* meat product. There is inadequate research toward commercial-scale *in vitro* meat production, research is costly and there is little funding on offer. To produce *in vitro* meat with existing technology is extremely costly due to the small, laboratory scale of production. Although, when *in vitro* meat reaches commercial-scale, these expenses should be substantially reduced. It is estimated that $160 million is needed toward research for *in vitro* meat commercialization. However, producing an *in vitro* meat product that resembles the appearance and texture of structured meat cuts, such as steak, will be a considerable challenge. Even if this is achieved, the financial expenses will most likely be enormous, and the required technology, especially for large scale production, will require even further development. There are other potential issues: it is vital that *in vitro* meat is produced under sterile circumstances to prevent microbial contaminations. Needless to say, contamination by fungus or bacteria can happen during processing, with *in vitro* meat this risk will be equal to the risk of contamination during conventional meat processing. However, one downside is that *in vitro* meat will have a greater risk of substrate contamination (chapter 3).

5.14 Perceptions and reactions to *in vitro* meat

Many people have qualms about the technological and artificial production procedures required for *in vitro* meat. Associations with Frankenstein, cloning, and the unknown easily arise. Overall responses to *in vitro* meat on internet debates, show mostly negative reactions. Plans have been made in the Netherlands to start research about common reactions to *in vitro* meat across diverse cultures and locations. Another factor in moulding public opinion will be the way in which *in vitro* meat is framed by the media. I sampled numerous *in vitro* meat videos and articles online and noticed a few familiar trends. *In vitro* meat came under multiple different names, many of which were deceptive or associated with scientific stereotypes and science fiction. I came across whole analogies, phrases and jokes regarding science fiction, some of which included repulsive and misinformed statements. Thus the media, in my opinion, will most likely supplement the ‘ick factor’. I think the framing of *in vitro* meat requires better communication between scientists and the media, between the media and the public and between scientists and the public (Chapter 4).

5.15 Existing research on consumers and conventional meats

Existing research regarding conventional meats and consumer purchasing behaviours could also (in theory) be applicable to the successful marketing of a commercial *in vitro* meat product. Research suggests that presenting consumers with more product data might not just be ineffectual, but could occasionally increase consumer apprehension and misunderstanding. Although health and safety anxieties push motivation for organic food purchases, ethical concerns, particularly about animal welfare, play a substantial part in the decision to buy organic food. Thus an *in vitro* meat product would likely benefit from a marketing campaign concentrating on food safety, ethical attributes and healthiness (Chapter 4).

Current consumer meat inclinations could offer marketing insight for an *in vitro* meat product. From a sensory viewpoint, consumer conventional meat choices are persuaded via texture, appearance/colour, tenderness, juiciness, and by a lesser amount, via flavour differences. For example, higher fat levels in meat are negatively linked with consumer quality anticipations when viewing raw meat, even though higher fat content increases the quality of the consumers eating encounter. Other general motifs are evident in meat demand, such as the increasing desire for reduced-fat products and the ever rising appeal of convenience products. This could be good news for *in vitro* meat, as the scaffold-centred methods needed to produce meat similar to ground or processed meats are closer to becoming reality, than the self-organizing methods needed to grow structured meats, such as steaks (Chapter 4).

5.16 Entomophagy

A Western acknowledgment of the significance of insects as a food source could generate enormous ecological advantages. Cultivated insects would be many times more efficient than conventional meat production, with a much smaller environmental effect. Perhaps insects might initially be introduced to the Western world by processing and combining them with other foods or employing them as feed for livestock. In theory a similar weaning method could be useful for the gradual introduction of a commercially viable *in vitro* meat product (Chapter 4).

5.17 Insight from genetically modified (GM) foods

One kind of artificial food that has been enthusiastically disparaged by Europeans, though supported by Americans, is genetically modified (GM) crops. People seem to interpret 'non-GM' as an optimistic feature in itself, while associating the use of genetic modification with a collection of disadvantages and risks. For the most part, people associate genetic modification with uncertainty, unhealthiness and anxiety toward the possible effects gene technology could have on nature. Research implies that the higher the level of apparent consumer danger, the harder it becomes for consumers to see the advantages. It is also intriguing that consumers interpret familiar risks as less severe than unfamiliar risks. This is relevant to attitudes toward genetic modification and other novel foods, such as *in vitro* meat. Consumer responses to genetic modification could offer useful information regarding possible reactions to an *in vitro* meat product (Chapter 4).

5.18 Conclusions

5.18.1 What do I think?

I personally think that meat eaters should consider eating *in vitro* meat, or at least supplementing some of their conventional meat diet with *in vitro* meat, both for the benefit of the environment and for animal welfare. I can envisage future conservation-style advertising campaigns from *in vitro* meat advocates or corporations, with statements such as; '*In vitro* meat Mondays – do your part for the planet and your fellow animals.' The introduction of an *in vitro* meat product will be difficult, although potential harmful associations could be counterbalanced by the constructive influence of *in vitro* meat on animal welfare, food security and the environment. Thus, the idea that people would purchase meat grown in a laboratory does not seem overly implausible.

5.18.2 Vegetarianism

I am predominantly vegetarian and I would have no problem consuming an *in vitro* meat product, as no animals would be harmed in its production. However, I also understand that many vegetarians have no need for *in vitro* meat, as they receive all their dietary needs from vegetables (e.g. much of India is vegetarian or vegan). Why change a diet that already works? However, I disagree strongly with those vegetarians and vegans who are against *in vitro* meat entirely, especially those who do not want it to become commercially viable. I have met people who hold this view, reasons tend to fall under the following categories:

- We don't need to consume any animals. The world should be completely vegetarian and/or vegan.
- It is immoral to use an animal for human benefit.
- There is no way to get the animals 'permission' to take its cells for *in vitro* meat production.

I assume a significant number of vegetarians/vegans dietary stances are motivated by animal welfare and/or environmental conservation. Of course, in an ideal all vegetarian world, *in vitro* meat would not be required. However, a vegetarian world is unrealistic and conventional meat production is not going to disappear anytime soon. My argument is that every 100 *in vitro* meat burgers consumed, would in theory be 100 conventional meat burgers that were not consumed, and thus by implication, animal lives spared and environmental damage avoided. Opposing a commercial *in vitro* meat product indirectly (and unintentionally) causes more environmental destruction and the slaughter of more animals. Thus, I personally feel that vegetarians/vegans who are vegetarian/vegan for environmental or animal welfare purposes (and non-vegetarians/vegans of similar conviction) ought to feel obliged to support an *in vitro* meat product. The $1 million prize on offer from PETA (People for the Ethical Treatment of Animals) for the first commercially viable method of producing *in vitro* meat by June 2012 is testament to this perspective (Yanke, 2011). Despite this incentive, nobody managed to produce *in vitro* meat before the deadline to receive PETA's prize. However, due to the promising research thus far, PETA has extended the deadline to 2013 (Mackey, 2012).

5.18.3 The target market

The majority of the world's population consume meat, if *in vitro* meat is going to make a difference to the environment and to animal welfare, then the primary goal is to have meat eaters supplement or replace conventional meat with *in vitro* meat. This would reduce strain on the environment by lowering overall conventional meat consumption. Because vegetarians/vegans are a minority who do not consume meat, it makes little sense to target this demographic. Having vegetarians and/or vegans consuming *in vitro* meat would not reduce conventional meat consumption, and therefore would not help the current environmental situation. However, it would have been interesting to conduct a survey to see what percentage of meat eaters and vegetarians would support *in vitro* meat, and what percentage would be against it (Datar, 2013). This was not possible with the time restraints of a master's thesis.

5.18.4 Will people eat it? What about other sources of sustainable protein?

As mentioned earlier; I would imagine that the public could be weaned onto *in vitro* meat via conventional meats that are partly composed of *in vitro* meat. Or perhaps *in vitro* meat could start initially as a cheap protein additive to meals. I also think that entomophagy, which is just beginning to penetrate the Western world, provides an interesting parallel to an *in vitro* meat product. Like *in vitro* meat; insects have a similar ick factor, and will struggle with acceptance among Westerners. This may offer valuable insight to the upcoming hurdles which will be confronted by *in vitro* meat advocates.

In an ideal world, people would think logically about a commercial *in vitro* meat product, putting their initial averse reactions aside to consider the environment and animal welfare. However, food choice is governed by pleasure, impulse and satisfaction. Interestingly, yoghurt, cheese and numerous meat substitutes are made via quite technology dependent and unnatural methods. Yet over time, the public 'acclimatized' and accepted these foods. I believe the same will occur with *in vitro* meat. When it tastes good, is cheap and shown to be safe, people will buy it. *In vitro* meat will become 'normal' just like cheese, yoghurt, Quorn, tofu, surimi, bread and other man-made foods. *In vitro* meat is almost here, it may provide a cheap protein source for both developed and underdeveloped nations. The public needs to know about this.

In vitro meat was originally scheduled to be eaten for the first time in October 2012. Mark Post was going to have an *in vitro* meat patty cooked by Heston Blumenthal, and consumed by a celebrity (Russel, 2012). However, the first official eating of *in vitro* meat has been delayed, until an as yet unknown time (Roelen, 2012). With the extension of the $1 million prize from PETA for the first commercially viable *in vitro* meat (Mackey, 2012), Mark Post is still in with a chance. For now, the future of conventional meat is both unsustainable and uncertain. Conversely, the future of *in vitro* meat holds hope and promise.

6 References

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