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Food Security and Protein Supply -Cultured meat a solution?

H L TUOMISTO

Wildlife Conservation Research Unit, University of Oxford, Tubney, Oxon OX13 5QL, UK

Summary

Feeding the world's growing human population with increased consumption of livestock products would require huge expansion in agricultural production by 2050. This study compared environmental impacts of producing different protein sources for human nutrition, including crops, livestock products, *Spirulina*, mycoprotein based Quorn^{TM} and cultured meat. The results showed that *Spirulina* and cultured meat have the lowest land use per unit of protein and unit of human digestible energy. Crops have the lowest energy use and greenhouse gas (GHG) emissions per unit of energy and protein. The energy use in cultured meat production is at the same level with other livestock products, whereas GHG emissions are lower. It is concluded that the overall impacts of replacing livestock products with crops, *Spirulina*, Quorn and cultured meat would be beneficial for the environment and would potentially improve food security as less land is needed for producing the same amount of protein and energy.

Key words: *in vitro* meat, Quorn, land use, energy use, greenhouse gas emissions

Introduction

The world human population has been estimated to grow from current 6.9 billion to 9.2 billion by 2050 (UN, 2010). The consumption of livestock products has been predicted to double between 1999 and 2050 (FAO, 2006). Currently, livestock production occupies directly and indirectly about 30 % of the ice-free terrestrial surface on the planet and amounts to about 18 % of the global warming effect (FAO, 2006). Sustainable food production in 2050 would require enormous changes in the current food production technologies and consumption habits.

The main function of livestock products in human nutrition is to provide a source of protein and energy. The total average protein consumption globally is 75.3 g/person/day of which 24.3 g is animal protein (FAO, 2006). In the industrialized countries the average protein consumption is 106.4 g/person/day of which 56.1 g comes from animal products. Biologically it is not necessary to circulate plant protein through animals before human consumption. All essential amino acids for human nutrition could be retrieved directly from plants by combining cereals and pulses. Some legumes, e.g. soybeans, include all the essential amino acids.

New technologies are also developing novel alternatives to meat, for example mycoprotein based products (Wiebe, 2004) and cultured meat (Edelman et al., 2005).

Mycoprotein (the trade name Quorn™) is a filamentous fungus *Fusarium venenatum* that is grown in continuous flow culture process (Wiebe, 2004). The mycoprotein contains all the essential amino acids for human nutrition, and therefore is an adequate substitute to meat. However the Quorn products also include some egg albumin that is essential for binding.

Cultured meat (also called *in vitro* meat) is produced by growing animal muscle cells in a laboratory (Edelman et al., 2005). Stem cells are taken from an animal embryo. Engineered *Escherichia coli* bacteria are used for the production of specific growth factors that induce the stem cells to differentiate into muscle cells. The muscle cells are grown in a bioreactor on a medium composed of the cyanobacterial hydrolysate supplemented with the growth factors and vitamins. The technology is still at the research stage and commercial cultured meat is not yet available.

Cyanobacteria itself is used for food. *Spirulina* (*Arthrospira*) is the most commonly used species in commercial open pond cultivation. The protein content of *Spirulina* varies between 50-70% of dry matter (DM) and the biomass yields between 30-90 tDM/ha/year (Richmond, 1988). United Nations' organisation called the Intergovernmental Institution for the use of Micro-algae Spirulina Against Malnutrition (IIMSAM) promotes production of *Spirulina* in developing countries for improving protein and micronutrient supply.

Many studies have compared the environmental impacts of different agricultural products by allocating the impacts per mass unit (Williams *et al.*, 2006; Blonk *et al.*, 2008). However, the mass allocation does not provide sufficient information about the comparable impacts of different alternatives because of different nutritional values of livestock and plant products. This paper compares the land use, energy use and GHG emissions of different crops, livestock products, cultured meat and Quorn by allocating the impacts per unit of protein and energy. Finally, it is estimated how much land would be saved by retrieving all protein for human nutrition from crops or by replacing conventional meat with cultured meat.

Material and methods

In this study, the land requirements, energy use and GHG emissions were allocated per unit of protein and per unit of human digestible energy. Transformation factors were created in order to calculate the protein and energy contents of the original Functional Units used in the data. The data for the environmental impacts of the production of the foods compared are presented in Table 1. The production of crops and livestock represent the average production systems in the UK, except soybeans and maize are imported in the UK (Williams et al., 2006). The system boundaries included the processes from input production up to the farm or factory gate. The conversion factors used for converting a ton of carcass dead weight to a ton of edible meat were 0.3856, 0.4555, 0.4455 and 0.5147 for beef, lamb, pork and poultry, respectively. It was assumed that a weight of an egg is 60 g. The energy and protein contents of the products are presented in Table 2.

Table 1. The environmental impacts of crop and livestock products (Williams et al., 2006), Quorn (Blonk et al., 2008) and cultured meat and *Spirulina* (Tuomisto & Teixeira de Mattos, Submitted)

	FU	Land use ha	Energy use MJ	GWP kg CO2-eq
wheat	t DM	0.14	2460	804
potatoes	t DM	0.02	1260	215
soybean	t DM	0.42	3010	1300
maize	t DM	0.14	2380	650
field bean	t DM	0.30	1970	1010
Spirulina	t DM	0.03	10111	839
beef	t carcass DW	2.30	27800	15800
pork	t carcass DW	0.74	16700	6360
sheep	t carcass DW	1.38	23100	17500
poultry	t carcass DW	0.64	12000	4570
eggs	20 000 eggs	0.66	14100	5530
milk	10 000 litres	1.19	25200	10600
quorn	t WW	0.17	38000	2300
Cultured meat	t WW	0.02	31700	1896

FU=Functional Unit, GWP=Global Warming Potential, EP=Eutrophication Potential, AP=Acidification Potential, DW=Dead Weight

Table 2. Nutritional values of the products (Food Standards Agency, 2002).

	Nutritional value	
	energy kcal/100g	protein g/100g
Maize	342	12.7
Rice	357	6.7
Wheat	310	12.7
Potatoes	76	2
Soybean	370	35.9
Field bean	328	22.1
Spirulina	369	64
Beef	129	22.5
Pork	123	21.8
Sheep	148	20
Poultry	108	22.3
Eggs	151	12.5
Milk	66	3.2
Quorn	107	16.3
Cultured meat	108	19.1

The global impacts of replacing livestock products by in vitro animal protein technology were estimated by using the FAO data for global livestock protein consumption (FAO, 2008) and the global GHG emissions and land use related to livestock production (FAO, 2006). The data for the annual demand of meat in the UK was also based on the FAO database (FAO, 2008). The global average land requirements for production of soybean were compared with the Highest Yielding Countries by using the global average crop yields and the average crop yields in the top five highest yielding countries as an average in 2003-2007.

Results

The results show that plant protein production requires significantly less land, energy and has lower GHG emissions compared to production of animal protein (Figure 1 and 2). However, cultured meat and *Spirulina* have the lowest land use requirements per unit of protein (Figure 3). When impacts were allocated per unit of energy, potatoes and *Spirulina* had the lowest land requirements followed by cultured meat. Cultured meat had higher energy use both per unit of energy and per unit of protein than poultry and pork, but lower than beef and sheep. Also milk and eggs had lower energy use than cultured meat per unit of protein and per unit of energy. However, cultured meat had the lowest GHG emissions compared to any other livestock based protein.

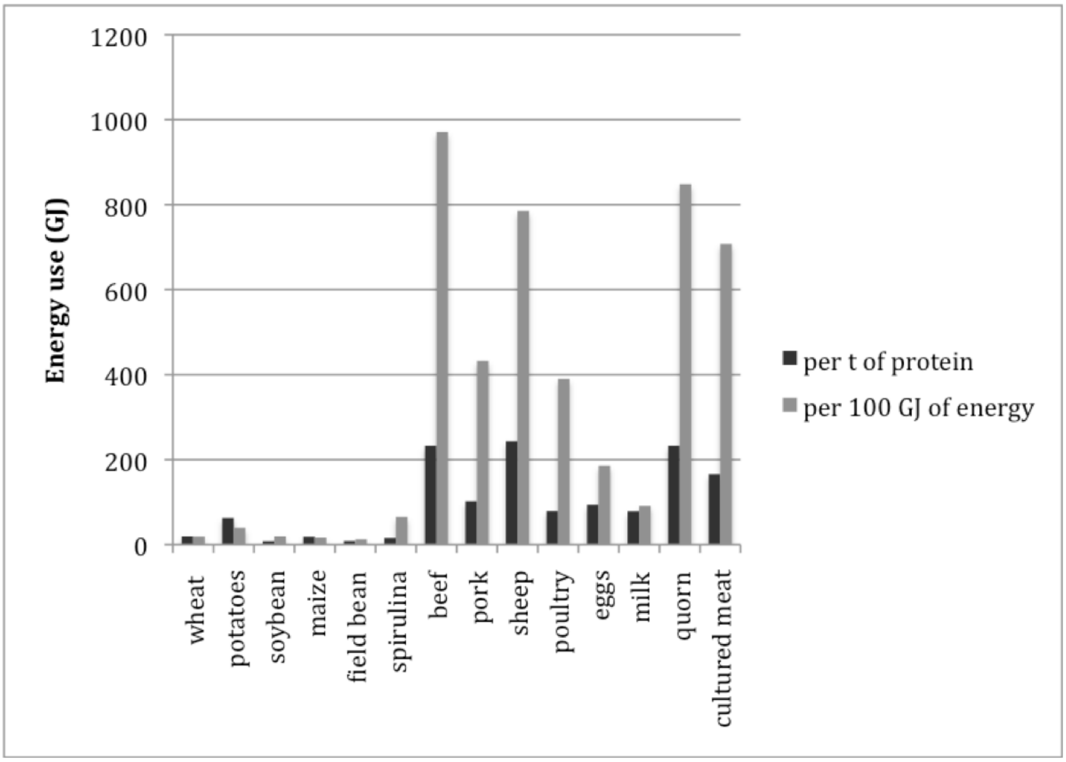

Figure 1. Comparison of energy use of producing different food products allocated per ton of protein and 100 GJ of food energy.

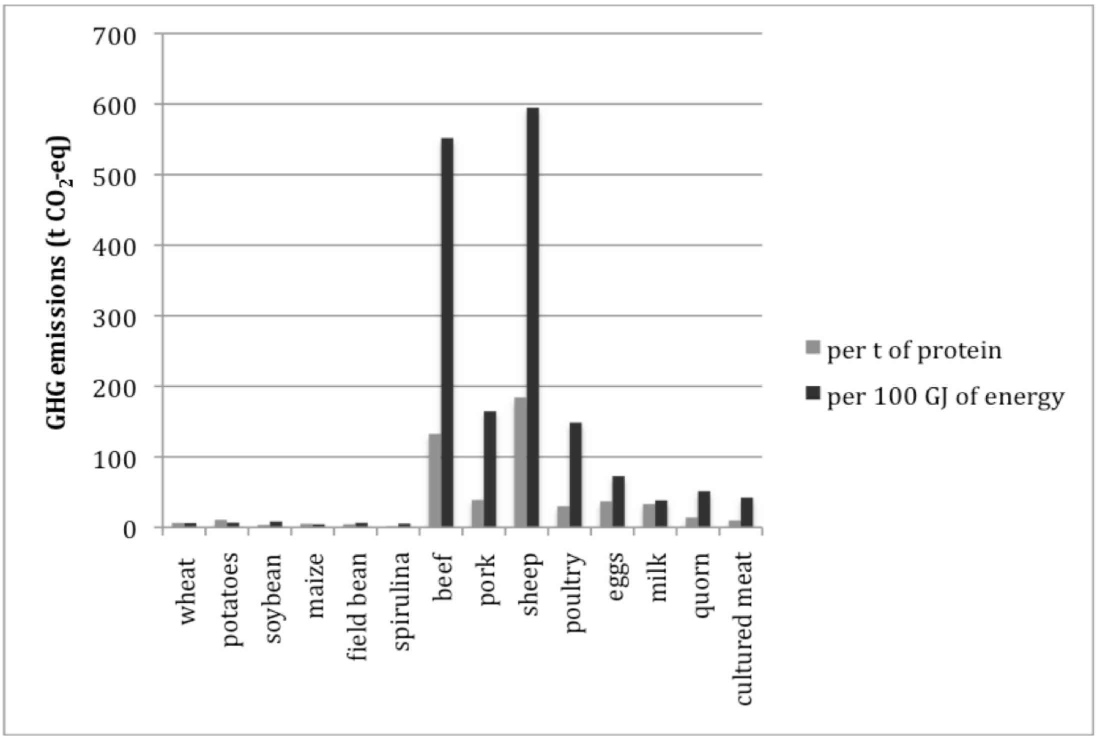

Figure 2. Comparison of GHG emissions of producing different food products allocated per ton of protein and 100 GJ of food energy.

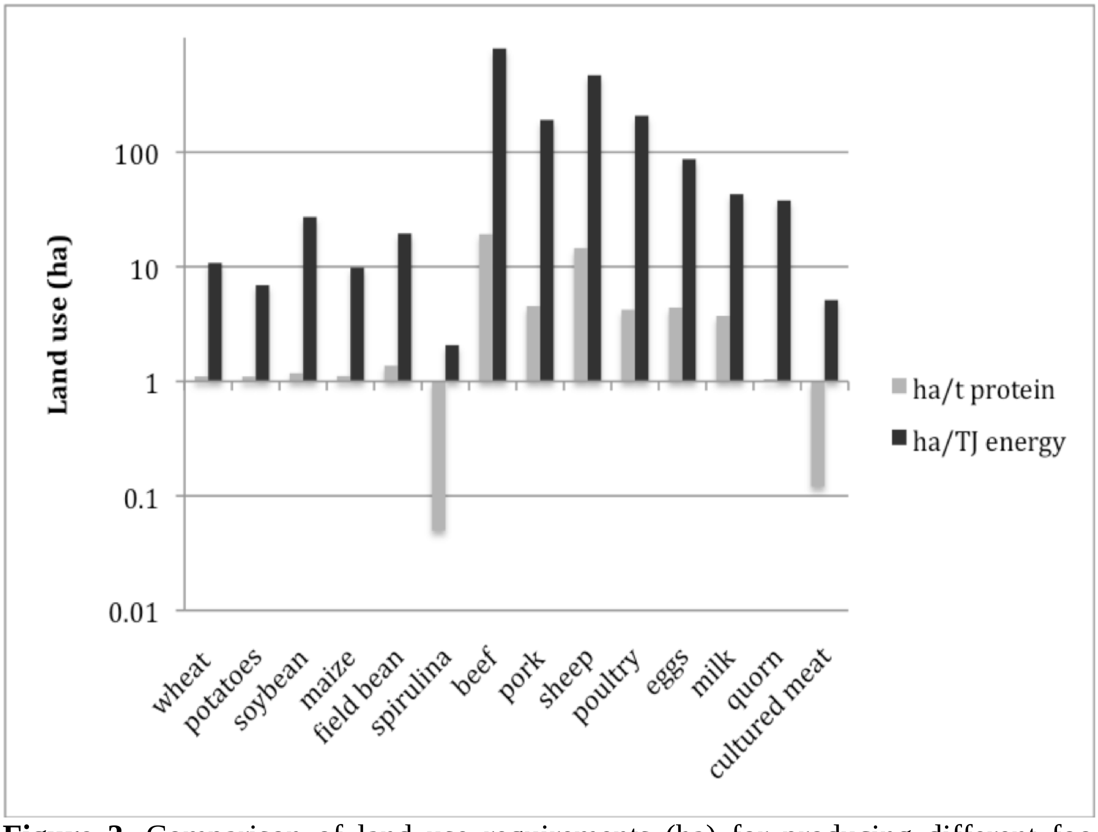

Figure 3. Comparison of land use requirements (ha) for producing different food products allocated per ton of protein and TJ of food energy.

Currently the global livestock protein consumption is about 59.3 million tones/year. The production of that amount of soybean protein requires between 1.8 to 2.6 million km^2 of land area ranging from the highest yielding countries to the world average soybean yields. This equates to 6.7% or 4.6% of the total land area that is currently used for livestock production and 55% or 38% of the arable land that is currently used for livestock feed production. Replacing livestock protein with *in vitro* technology would require only 0.07 million km^2 land which is about 0.2% of the current land area that is used for livestock production.

In the UK replacement of conventionally produced meat by cultured meat would require only 1.2% of the land area that is currently used for production of meat. Energy requirement would be about 7% higher and GHG emissions 88% lower compared to the current GHG emissions related to the meat production in the UK.

Discussion

The study showed that widespread conversion to vegetarian diet or replacing meat with cultured meat or Quorn would substantially reduce the GHG emissions and demand of agricultural land. Even though the energy requirements for cultured meat scenario are slightly higher compared to the current meat production in the UK, the overall energy balance would be more beneficial if the opportunity costs of land use are taken into account (Tuomisto et al., 2009). The land that is released form livestock production could be used for production of bioenergy. Furthermore, the land released from agriculture could be utilised for wildlife conservation.

If all livestock production were replaced by alternative production technologies, grassland habitats might suffer. However, utilising some cattle for landscape maintenance purposes could conserve these habitats. This study did not take into account the additional impacts that may occur when the side products of meat production, such as leather and wool, would need to be produced separately.

A change in food consumption habits towards vegetarian diets and replacing livestock products with alternatives would also provide health benefits as the consumption of saturated fat would be reduced. In cultured meat technology the quality of fatty acids can be controlled and only beneficial fatty acids could be used (Edelman et al., 2005).

More research efforts are needed for developing cultured meat technologies and other alternatives for meat. Resources are also required for educating public to accept new science based technologies for solving problems that the humanity faces.

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