Relating beef production at farm level to human health aspects, and the state of art of meat substitution products

HOCQUETTE Jean-François, GRUFFAT Dominique, DURAND Denys
INRA, VetAgro Sup, UMRH, F-63122 Saint-Genès Champanelle

1. Meat substitutes for a better health
2. Is beef really bad for health?
Nowadays, the livestock and meat sectors are facing new and important challenges:

- their environmental impact and role in global climate change;
- balancing the need for increased production of animal products (to satisfy the increasing human population);
- coupled with a lower footprint,
- and addressing societal needs in terms of animal welfare and product quality for the consumer.
More urban people
Some improvements in conventional meat production in terms of GHG emission
Composition in Fatty Acids (FA) of ruminant products

Recommended nutritional supply

MUFA
60% total FA

PUFA
15% total FA

SFA
25% total FA

Too much SFA, not enough PUFA, variable content in *trans-FA*

MILK

MUFA
20-25% tot. FA

PUFA
5% tot. FA

SFA
65-68% tot. FA

MEAT

MUFA
40-45% tot. FA

PUFA
6% tot. FA

SFA
50% tot FA

D. Bauchart *et al.* – 55th Annual Meeting of EAAP – 5th to 9th September 2004 – Bled, Slovenia
Protein consumption in the World

In some countries, much less animal proteins are consumed.

Source: FAOSTAT
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The meat substitutes market is increasing.
Eating proteins from plants

**DID YOU KNOW?**

100 calories of steak

- 8.0 grams of protein
- 7.4 grams of fat

100 calories of broccoli

- 11.1 grams of protein
- 0.4 grams of fat

+ phytochemicals, vitamins and essential nutrients that prevent disease and promote health

Source: *Eat to Live, Dr. Joel Furhman*

https://mamasuorganic.wordpress.com/2014/05/21/animal-vs-plant-protein-how-do-they-stack-up/
Eating proteins from mushrooms?
Principles of cell culture to produce a muscle

- Stem cells
- Fibroblasts
- Connective tissue
- Adipocytes
- Pre-adipocyte
- Pre-myoblaste
- Myoblaste
- Myotube
- Fibre

In the context of cell culture, stem cells differentiate into fibroblasts, which contribute to the formation of connective tissue, and adipocytes, which are involved in the production of fibres.
The first artificial steak was tasted

“Important issues remain to be solved, including technical, social and ethical problems. Consumer acceptance and confidence might be a major issue”.

A special issue of Journal of Integrative Agriculture in 2015
Artificial meat’s strength and weakness

- The environmental impact of artificial meat is difficult to evaluate due to the absence of references on production units.
- However, it may have a moderate interest in reducing greenhouse gas emissions and pollution by nitrates,
- a limited interest for decreasing fossil fuel use or
- a very limited interest concerning water use,
- but it would make more land available.
- It may result in the presence of organic molecule residues in water.
- Furthermore, artificial meat is thought not to be healthy for consumers due to artificial hormones and growth factors, fungicides, and antibiotics required for cell culture.
Consumers’ acceptance?

According to your perception, will *in vitro* meat be well accepted by consumers? Will consumers buy it?

![Bar chart showing the proportions of yes, no, and I don't know responses from different surveys.]

- **Yes**
  - International survey: ~15%
  - French survey: ~45%
  - Paper survey: ~60%

- **No**
  - International survey: ~60%
  - French survey: ~65%
  - Paper survey: ~60%

- **I don't know**
  - International survey: ~20%
  - French survey: ~25%
  - Paper survey: ~15%
“cacaburger” : the protein of the future?

Japanese scientist Mitsuyuki Ikeda has developed a “burger” made from soya, steak sauce essence, and protein extracted from human feces present in sewage sludge of Tokyo.
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Nutritional quality of beef

- **Proteins**
  - 100 g of beef provide:
    - 30 to 50% of proteins Recommended Dietary Allowances (RDA)
    - 48 à 75% of 9 essential amino acids

- **Lipides**

- **Micronutrients: minerals and vitamins**

- **Water**

- **Beef is a preferred source of proteins for human body**

  High DIAAS Index (Digestibility Indispensable Amino Acid Score), higher than the one for vegetable products (Rémond *et al.*, 2014)
Nutritional quality of beef

Proteins

Water

Micronutrients: minerals and vitamins

Lipides

Beef is an important, and sometimes exclusive, source of micronutrients

<table>
<thead>
<tr>
<th></th>
<th>Quantity</th>
<th>RDA</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>3 mg / 100 g</td>
<td>20 to 30%</td>
<td>More absorbable than in plants</td>
</tr>
<tr>
<td>Zn</td>
<td>3 to 7 mg / 100 g</td>
<td>20 to 30%</td>
<td>Very good availability</td>
</tr>
<tr>
<td>Se</td>
<td>10 µg / 100 g</td>
<td>20 to 30%</td>
<td>Very rich</td>
</tr>
<tr>
<td>Vitamin B12</td>
<td>2.2 µg / 100 g</td>
<td>50 to 100%</td>
<td>Only in animal products</td>
</tr>
</tbody>
</table>
# The nutritional value of meat

<table>
<thead>
<tr>
<th>Nutrient per 100g</th>
<th>Beef</th>
<th>Lamb</th>
<th>Pork</th>
<th>Calf liver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin A</td>
<td></td>
<td></td>
<td></td>
<td>Rich source</td>
</tr>
<tr>
<td>Vitamin B&lt;sub&gt;1&lt;/sub&gt;</td>
<td></td>
<td></td>
<td>Rich source</td>
<td>Rich source</td>
</tr>
<tr>
<td>Vitamin B&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Source</td>
<td></td>
<td>Source</td>
<td>Rich source</td>
</tr>
<tr>
<td>Vitamin B&lt;sub&gt;6&lt;/sub&gt;</td>
<td>Rich source</td>
<td></td>
<td>Source</td>
<td>Rich source</td>
</tr>
<tr>
<td>Iron</td>
<td></td>
<td></td>
<td>Source</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>Rich source</td>
<td>Rich source</td>
<td>Source</td>
<td>Rich source</td>
</tr>
<tr>
<td>Selenium</td>
<td></td>
<td></td>
<td>Source</td>
<td>Rich source</td>
</tr>
<tr>
<td>Potassium</td>
<td>Source</td>
<td>Source</td>
<td>Source</td>
<td>Source</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Source</td>
<td>Source</td>
<td>Source</td>
<td>Rich source</td>
</tr>
</tbody>
</table>

≥ 15% of the RDA per 100g = Source; ≥ 30% of the RDA per 100g = Rich source
Nutritional quality of beef

- **Poor in lipids**: 1 to 10% (Basarab et al., 2007; Cuvelier et al., 2005)
- **Poor in cholesterol**: < 0.8% (Geay et al, 2002)

The same amount of lipids is obtained with 100 g of beef steak, 53 g of farmed salmon, and 58 g of egg.

**Lipid composition**: (Afssa, INCA2, 2007)
- MUFA: 44%
- SFA: 49%
- PUFA: 7%

- **Micronutrients**: minerals and vitamins

- **Proteins**
- **Water**
- **Lipides**

**FA composition of beef must be improved but...**
Beef contains interesting FA

- **Conjugated Linoleic Acids (CLA)**
  - primarily synthesized by ruminants
  - 24 identified isomers whose majority is rumenic acid (9\textit{cis},11\textit{trans} CLA)
  - Many potentially beneficial properties for humans against cancers, cardiovascular disease, diabetes, immunity, body composition

- **Trans MUFA**
  - The major isomer is 11\textit{trans} 18:1 (Vaccenic acid) \(\Rightarrow\) Many potentially beneficial properties for humans
  - But some diets can increase the content of another isomer (9\textit{trans} 18:1) \(\Rightarrow\) harmful to human health

- **n-6/n-3**
  - Good balance between PUFA n-6 and PUFA n-3 \(\Rightarrow\) n-6/n-3 < 5

- **PUFA LC n-3**
  - Significant amounts of EPA (20:5 n-3) and DPA (22:5 n-3) \(\Rightarrow\) Many beneficial properties for human
  - Low amount of DHA (22:6 n-3) \(\Rightarrow\) Many beneficial properties for humans
## Animal feed: a mean to modulate beef FA

<table>
<thead>
<tr>
<th></th>
<th>Concentrate</th>
<th>Concentrate + linseed</th>
<th>Pasture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total lipids (g/100 g)</td>
<td>3.8</td>
<td>1.7</td>
<td>2.9</td>
</tr>
<tr>
<td>% of total FA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SFA</td>
<td>48.5</td>
<td>39.0</td>
<td>38.4</td>
</tr>
<tr>
<td>Trans MUFA</td>
<td>1.9</td>
<td>6.5</td>
<td>3.2</td>
</tr>
<tr>
<td>CLA</td>
<td>0.3</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>PUFA n-3</td>
<td>1.0</td>
<td>4.4</td>
<td>2.9</td>
</tr>
<tr>
<td>PUFA n-6</td>
<td>4.3</td>
<td>9.8</td>
<td>5.0</td>
</tr>
<tr>
<td>LC PUFA n-3</td>
<td>0.5</td>
<td>1.5</td>
<td>1.1</td>
</tr>
<tr>
<td>n-6/n-3</td>
<td>5.1</td>
<td>2.7</td>
<td>1.7</td>
</tr>
</tbody>
</table>

(Bauchart et al., 2009, Garcia et al., 2008)

- Linseed supplementation or pasture improve nutritional quality of beef (n-6/n-3 < 5)
- But be careful to increased *trans* MUFA (beneficial or harmful isomers?)
Why and how limit peroxidation of PUFA in meat?

Prooxidant conditions

Animal stress (transport, slaughtering...)
Deleterious processing (O₂ rich atmospheres, long cooking, ...)
Type of meat (rich in iron, rich in lipids...)

Modification of the nutritional value
- Loss of PUFA
- Appearance of toxic products
- Decrease of proteins digestibility
- ...

Peroxidation of PUFA in meat

Modifications of sensory qualities
- Appearance of negative flavors
- Loss of color
- ...

Antioxidant supplementation during:
- the finishing diet
- meat processing

With:
- lipophile antioxidants (vitE...)
- vegetable extracts
- oligoelements (Se, Mn...)

INRA SCIENCE & IMPACT
Lipid peroxidation in steaks after 9-month-frozen storage: effect of antioxidant diet supplementation

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Ageing methods</th>
<th>MDA concentration (µg/g tissue)</th>
<th>Control</th>
<th>Control + Vitamin E (155 IU/kg DM)</th>
<th>Control + Vitamin E + Plant extracts (rich in polyphenols)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longissimus thoracis</td>
<td>carcass</td>
<td>0,265 &lt;sup&gt;a&lt;/sup&gt;</td>
<td>0,236 &lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0,130 &lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>vacuum</td>
<td>0,176 &lt;sup&gt;a&lt;/sup&gt;</td>
<td>0,136 &lt;sup&gt;a&lt;/sup&gt;</td>
<td>0,124 &lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Semi-tendinosus</td>
<td>carcass</td>
<td>0,210 &lt;sup&gt;a&lt;/sup&gt;</td>
<td>0,162 &lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0,136 &lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>vacuum</td>
<td>0,174 &lt;sup&gt;a&lt;/sup&gt;</td>
<td>0,127 &lt;sup&gt;a&lt;/sup&gt;</td>
<td>0,105 &lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
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(©Gobert et al., 2011)

- Carcass ageing is the most deleterious conditions for lipid peroxidation
- Animal diet supplementation with vitamin E combined with plant extracts rich in PP exert an effective antioxidant action preserving frozen meats towards peroxidation
Lipid peroxidation during processing: effect of antioxidant diet supplementation

Experimental design

Animals
Twenty five 4-5 year old Normand cull cows

Feeding conditions

<table>
<thead>
<tr>
<th>Diet</th>
<th>Basal diet</th>
<th>Lipid supplement</th>
<th>Antioxidant supplement</th>
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<tbody>
<tr>
<td>L</td>
<td>Straw (30) Concentrate (70)</td>
<td>Extruded linseeds</td>
<td></td>
</tr>
<tr>
<td>LE</td>
<td>Straw (30) Concentrate (70)</td>
<td>Extruded linseeds</td>
<td></td>
</tr>
<tr>
<td>LEP</td>
<td>Straw (30) Concentrate (70)</td>
<td>Extruded linseeds</td>
<td></td>
</tr>
</tbody>
</table>

40 g oil/kg diet DM  155 IU/kg diet DM  7 g/kg diet DM

100 d. finishing period

Meat processings
Semitendinosus (ST) muscle

Ageing
12d in entire carcass

Packaging
ST steaks
4d. under air  14d. Under vacuum
(UAP)  (UVP)

7d. under modified atmosphere
(MAP)

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4d. under air  14d. Under vacuum
(UAP)  (UVP)

7d. under modified atmosphere
(MAP)
Lipid peroxidation during processing: effect of antioxidant diet supplementation

- higher lipoperoxidation in meats under air or modified atmosphere packaging
- The association of vit E and plant extract rich in polyphenols protected all packaging conditions even in meats enriched in n-3 PUFA against lipoperoxidation

(Gobert et al., 2011)
Cohort studies & meta-analysis

Among multiple meat components, heme iron has been shown to play a pivotal role in the promotion of colorectal carcinogenesis.

(Bastide et al. 2015, Cancer Research, Bastide et al. 2016, Cancer Epidemiol Biomarkers Prev)
Central role of heme in carcinogenesis

Red meat

Diet

Heme

Processed meats

Heme nitrosiled

catalysis

Lipoperoxides → Alcenals

4-HNE (4-hydroxy-2-nonenal) from ω6 PUFA

Cytotoxic and genotoxic

Aldehydes

ADN adducts

Mutagenic Genotoxic

Initiation

Promotion

Normal crypt

Aberrant crypt

Adenoma

Adenocarcinoma

gastro-intestinal tractus

Central role of heme in carcinogenesis
How to limit (prevent) this risk?

First strategy
Formulation of meat products which **limit** the formation of peroxides, N-nitroso compounds or cytotoxic compounds in intestine:

- addition of antioxidant during processing

Experimentation: animal model which received a control diet or a diet with **marinated** meat or not

Another strategy:
**Animal dietary strategy** during finishing period with vitamins, trace elements and vegetable extracts rich in polyphenols are developed on live animals to prevent peroxidation processes

- the grap-olive marinade limits the effect of red meat consumption on peroxidation in the colonic lumen
- numerous studies show that animal diet supplementation with vitamin E combined with plant extract rich in PP increases antioxidant capacity of meat

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Conclusions
Points of view in favour of meat

We eat meat because it is necessary, natural, normal and nice (4Ns)

More and more people are defending meat (or beef)

Appetite 91 (2015) 114–128
Biodiversity

Carbon sequestration

Happy cows

Natural feeding

PUFA-rich meat

Beautiful landscape

Photo credit ©: JF Hocquette
Meat traditions: the co-evolutions of humans and meats

Leroy et al., Appetite 90 (2015) 200–211

Holistic level
Cultural and religious implications, symbolism, and ethics

Value level
Societal differentiation and hierarchical positioning

Community level
Linguistic developments, societal consolidation, and meat rituals

Security level
Hunting strategies, resource management, social cooperation, and meat sharing systems

Physiological level
Nutritional and evolutionary impact of meat

+ Proximal processes
Personal inclinations, cognitive decision-making, perceptual developments, …

Heuristic model
Culture
Nature
The meat market today

Future of the meat market

Conventional Meat

Meat Substitutes
- Plants
- Mycoproteins

Agroecology

Meat from agroecology

Conventional Meat

GMO Cloning

In vitro Meat??

Insects

Mycoproteins

Conclusions

The success of meat substitutes are partly due to the new social drivers of meat consumption (the necessity to improve human health, animal welfare and environmental protection).

The urbanisation of human beings further and further away from rural culture has brought about a decrease in knowledge and acceptance of conventional meat production, making people also less able to express a critical and informed view about artificial meat.

Meat has a high health value.
Beef is a preferred source of proteins for human body
Beef is an important, and sometimes exclusive, source of micronutrients
Beef contains good and bad fatty acids
Linseed supplementation or pasture improve nutritional quality of beef
Attention should be taken to prevent peroxidation of fatty acids and hence the carcinogenicity of meat

Meat does bring with it positive health, social and historical values.

The future market of meat is likely to be more complex.
Final thoughts of Prof De Smet

- “Meat is a delicious, high quality nutrient dense-food, but the importance of meat in the diet should not be overestimated
- The content of some micronutrients in meat can be increased mainly by feeding strategies, but the impact of these approaches is at best modest
- High consumption of red and/or processed meat is associated with a small increase in risk for colorectal cancer
- There are mitigation options for the adverse effects of high red and processed meat consumption
- Meat consumed in moderate amount fits very well into balanced diets”
Enhancing the nutrient profile of meat by primary production strategies

“Pro:
- Natural
- No shift in eating pattern required
- Population-wide impact
- Good bioavailability
- No risk for overdosing
- Potential added value for meat producers”

“Contra:
- Less versatile compared to processing
- Variable out outcomes, hard to make nutrition claims
- Milk and eggs more responsive than meat
- Possible sensory defects
- Allocation of added value questionable”

De Smet et al., 2016. ICoMST August 2016.
Driving forces in favour or against artificial meat

- Environmental issues
- Animal welfare concerns
- Human health concerns
- Pleasure to eat meat
- Good for health
- Symbol of force
- Urbanization
- Less knowledge in agriculture
- Less contact with farm animals
- Development of the hamburger

Decrease in meat consumption

High value of meat

Decrease in meat knowledge

Trust in science

- Unnaturalness of the product
- Expensive price
- Concerns about human health
- Concerns about sensory traits
- Uncertain ability to solve environmental issues
- Researchers = apprentice sorcerers

Acceptance of artificial meat
Maybe one day?

Cultured meat will almost certainly be accompanied by unintended and unanticipated consequences.
The choice in 2050, or later on?

Challenges:
- Creating large chunks of meat
- More proteine
- Ecotax +25%
- Taste and texture
- Consumer acceptance
- Industrialization

Post, 2012
The success of artificial meat is partly due to the new social drivers (human health, animal welfare and environmental protection).
Consumers’ reactions and attitude formation

Most of the consumers hesitate when asked the question whether they would be willing to try cultured meat in the future (Verbeke et al., J Integr Agric 2015, 14(2): 285–294)
Drivers of meat consumption

In the past

- Availability
- Nutritional needs
- Cultural factors

Meat Consumption

Now

- Sensory factors
  - Color
  - Flavor
  - Tenderness
- Cultural and psychological factors
  - Lifestyle
  - Moral
  - Habits
- Marketing factors
  - Price
  - Brand
  - Label

Meat Consumption

Drivers of meat consumption
Meat: a social issue?

The invention of artificial meat can save our planet.

What is meat?
Meat: a social issue?

Do not be afraid to say « I love meat »