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RESEARCH ARTICLE

Educated consumers don't believe artificial meat is the solution to the problems with the meat industry

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Abstract

The production of *in vitro* meat by cell culture has been suggested by some scientists as one solution to address the major challenges facing our society. Firstly, consumers would like the meat industry to reduce potential discomfort of animals on modern farms, or even to avoid killing animals to eat them. Secondly, citizens would like meat producers to reduce potential environmental deterioration by livestock and finally, there is a need to reduce world hunger by increasing protein resources while the global population is predicted to grow rapidly. According to its promoters, artificial meat has a potential to make eating animals unnecessary, to reduce carbon footprint of meat production and to satisfy all the nutritional needs and desires of consumers and citizens. To check these assumptions, a total of 817 educated people (mainly scientists and students) were interviewed worldwide by internet in addition to 865 French educated people. We also interviewed 208 persons (mainly scientists) after an oral presentation regarding artificial meat. Results of the three surveys were similar, but differed between males and females. More than half of the respondents believed that “artificial meat” was feasible and realistic. However, there was no majority to think that artificial meat will be healthy and tasty, except respondents who were in favour of artificial meat. A large majority of the respondents believed that the meat industry is facing important problems related to the protection of the environment, animal welfare or inefficient meat production to feed humanity. However, respondents did not believe that artificial meat will be the solution to solve the mentioned problems with the meat industry, especially respondents who were against artificial meat. The vast majority of consumers wished to continue to eat meat even they would accept to consume less meat in a context of increasing food needs. Only a minority of respondents (from 5 to 11%) would recommend or accept to eat *in vitro* meat instead of meat produced from farm animals. Despite these limitations, 38 to 47% of the respondents would continue to support research on artificial meat, but a majority of them believed that artificial meat will not be accepted by consumers in the future, except for respondents who were in favour of artificial meat. We speculated that the apparent contradictory answers to this survey expressed the fact that people trust scientists who

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are supposed to continuously discover new technologies potentially useful in a long term future for the human beings, but people also expressed concern for their health and were not convinced that artificial meat will be tasty, safe and healthy enough to be accepted by consumers.

Keywords: meat production, artificial meat, consumers' responses

1. Introduction

Our society is facing three major new challenges which are summarized below.

Firstly, consumers would like the meat industry to improve the welfare of the animals raised on modern farms and a small subset of consumers are taking this one step further and encouraging modern agriculture to eliminate the need for animals entirely. This shift in the demands of consumers has created two new areas for debate within the meat industry. The first concerns the ability of modern, large scale, agriculture to provide adequate animal welfare standards with the conditions of traditional small family farms considered to be the benchmark. At a deeper theological level, the entire industry of raising and killing animals for human needs has been called into question and is another important moral issue to be solved in our society (Hopkins and Dacey 2008; Tonsor and Olynk 2011; Hocquette *et al.* 2013).

Secondly, coinciding with concerns regarding animal welfare are concerns regarding the environment as a whole. Livestock, particularly ruminants are considered major contributors to global greenhouse gas emissions. The Food and Agriculture Organization of the United Nations claimed that livestock contribute to 18% of greenhouse gas emissions on average (Steinfeld *et al.* 2006). As a result of the recognition of climate change, many agri-businesses have prioritized altering their farming practices and choosing farming systems with the lower carbon footprints. Many scientists agree that research has to focus on how to decrease carbon footprint by livestock while increasing efficiency of production to ensure enough food for the increasing human population. The selection for efficient animals in different systems that reduce environmental impacts is key issue (Scollan *et al.* 2011).

Thirdly, growing global demands for protein necessitate an increase in production. The global population is predicted to grow to 9 billion people in the year 2050 (US Census Bureau 2008), with a huge increase in meat requirements. The Food and Agriculture Organization of the United Nations (FAO 2009) suggests that food production will have to increase by 70% to fulfill the caloric and nutritional needs associated with this population increase. Failing to meet these increases in demand is not an option as it is clear that malnutrition and under nutrition are socially unacceptable.

The additional demands being placed on the current agricultural system is serving to increase the already existing competition for energy, land and water supplies between livestock, crops and human beings. Food producers, therefore, face the challenge of producing ever increasing quantities of safe, affordable animal proteins, using a finite resource base and while increasing animal welfare and using less and less animals to avoid killing them and less and less lands or biological resources to protect the environment in order to meet consumer demand.

However, according to some experts, the capacity of meat production by conventional means is close to its maximum (FAO 2011) and further production, even if possible, would come at high costs of greenhouse gas emission, land usage, energy use and water use (Post 2014). Given the appropriate technology is developed, meat alternatives have the potential for three major advantages over traditional meat production which make them attractive in this climate of increasing demand coupled with diminishing resources. These advantages are: (i) less and less usage of animals (Dawkins and Bonney 2008), even need of almost no animals which may solve welfare and moral issues; (ii) less environmental impact of meat alternatives than production of meat from alive livestock (Tuomisto *et al.* 2011); and (iii) the ability for mass production to take advantage of economies of scale (Post 2012). Among meat alternatives, *in vitro* meat produced from stem cells is presented as an interesting process because it mimics natural meat, not only in shape and aspect, but also in biological composition because *in vitro* producers are supposed to artificially synthesize real muscle cells.

Some researchers are convinced that it is the logical progression of the meat industry, while others criticize either the technical possibility to produce artificial meat or the potential advantages of such a process. The debate has been quite extensive and thus far failed to reach a consensus between experts in the field. Therefore, we believe that the continuation of this debate and the decision to continue research into *in vitro* meat or devote those resources to other avenues is now best placed neither in the scientific nor the technical arenas, but should be debated with consumers and citizens. However societal debate is often biased by media coverage of the issues, particularly with the presentation of partial arguments. We thus hypothesized that as a result of positive media coverage (Goodwin and Shoulders 2013),

consumers opinion would be largely positive. Therefore we developed a questionnaire evaluating opinions on artificial meat and distributed it to different groups of educated people around the world.

2. Methods

2.1. Principles of the survey

A survey with the same questions was asked either orally or over the internet to different groups of people. For all but two questions there were three possible responses: (i) yes, I agree; (ii) no, I disagree and (iii) I do not know. At the end of the questionnaire, some demographic information was gathered about gender, country, occupation and age.

The questionnaire was supplied to respondents in one of two different ways. Before answering the questionnaire, the first method involved respondents viewing a short power point presentation covering (i) the principles of artificial meat production; and (ii) its ability to solve the potential problems faced by the meat industry in terms of welfare, environmental and food security issues. This method was time consuming but ensured a better understanding of the issues by the respondents. People were invited to answer the questions on a sheet of paper. Therefore, this method is referred as the paper survey in this manuscript.

The second method was based on a questionnaire freely available on internet and sent to different mailing lists or groups of people known by researchers. The survey was preceded by a small text to explain the problem, followed by the internet questionnaire with the same questions as in the first method. The small text has been built from abstracts from scientific papers which explained the challenges facing the meat industry (FAO 2006; Scollan *et al.* 2011) and the principles of artificial meat production with its potential ability to solve the mentioned challenges (Post 2012). The internet survey was mainly distributed in English, except in France where it was distributed in French.

2.2. Details of the questions

The questionnaire was built with 10 questions always asked in the same order (Table 1).

The questionnaire began with a question asking the respondent to indicate if they thought *in vitro* meat was a feasible and realistic technology. Both the presentation and the written information provided to respondents gave the indication that *in vitro* meat was indeed a feasible and realistic technology. Respondents who answered 'yes' to this question were better able to give more balanced opinions to the questions in the remainder of the questionnaire.

The next two questions asked "Do you think meat pro-

duced *in vitro* will be healthy?" and "Do you think meat produced *in vitro* will be tasty?". These questions aimed to evaluate the respondents trust in *in vitro* technology and the likelihood of their acceptance of the product.

The responses to the following question, "Do you think the meat industry is really facing important problems (environment degradation, animal welfare, inefficient production to feed humanity)?" were also likely to be influenced in a positive manner by either the presentation or the written information provided to respondents prior to the questionnaire.

From this question, it was logical to then ask the respondents if they thought that *in vitro* meat could help resolve some of these problems. Different possibilities exist to potentially reduce animal welfare and carbon footprint of livestock while sparing meat to feed the whole human population. One of the most commonly presented solutions is a reduction in the overall consumption of meat or even to eat no meat (Vinnari and Tapio 2009). Therefore we decided to compare the potential ability of artificial meat to solve the problems by comparison to these solutions only (eating less meat, or eating no meat). To provide a more comprehensive response, we designed two questions, one asking what respondents would recommend to others, and the other asking what they would do themselves.

The next questions concerned the ability of artificial meat to environment degradation and animal welfare problems. This issue has been assessed by the two following questions: "Do you think that *in vitro* meat will significantly contribute to reduce the environmental impact of livestock?" and "Do you think that *in vitro* meat will significantly contribute to reduce the animal welfare problem?"

Assuming that respondents had been convinced by artificial meat so far through the different questions, the last challenges are on one hand to convince public authorities to financial support research on this technology, and on the other hand to convince consumers to buy and to eat it. The two last questions were to assess the point of view of respondents about the feasibility of these two points.

2.3. Statistical analysis

Distributions of respondents according to their age and sex as well as standardized residuals (which are standardized differences between observed and theoretical effectives) were calculated using the R Software version 3.1.0 (R Core Team 2014) and two packages specialized in data analysis: the ade4 package (Dray *et al.* 2007) and the FactoMineR package (Husson *et al.* 2014). Multiple correspondence analyses (MCA) were performed with questions 1 to 10 except questions 5 and 6. In this type of analysis, associations between variables are uncovered by calculating the chi-square distance between different categories of the

Table 1 Questions of the survey

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 (Scollan *et al.*, *Animal Production Science*, 2011, 51, 1–5).

In recent years the notion has been growing that alternatives may be needed for conventional meat production through livestock. This is generally based on concerns about sustainability, environmental burden and animal welfare. These concerns have grown due to further intensification of livestock herding and slaughtering, and on the other hand a predicted rapid increase in global meat consumption (Steinfeld *et al.* FAO, 2006).

As one of the alternatives for livestock meat production, *in vitro* culturing of meat is currently studied. The generation of bio-artificial muscles from satellite cells has been ongoing for about 15 years, but has never been used for generation of meat, while it already is a great source of animal protein. In order to serve as a credible alternative to livestock meat, lab or factory grown meat should be efficiently produced and should mimic meat in all of its physical sensations, such as visual appearance, smell, texture and of course, taste. This is a formidable challenge even though all the technologies to create skeletal muscle and fat tissue have been developed and tested. The efficient culture of meat will primarily depend on culture conditions such as the source of medium and its composition. Protein synthesis by cultured skeletal muscle cells should further be maximized by finding the optimal combination of biochemical and physical conditions for the cells. Many of these variables are known, but their interactions are numerous and need to be mapped. This involves a systematic, if not systems, approach. Given the urgency of the problems that the meat industry is facing, this endeavour is worth undertaking. As an additional benefit, culturing meat may provide opportunities for production of novel and healthier products (Post, *Meat Science*, 2012, 92, 297–301).

	Yes (code 1)	No (code 2)	I don't know (code 0)	
Q1. Do you think this <i>in vitro</i> meat technology is feasible and realistic?				
Q2. Do you think meat produced <i>in vitro</i> will be healthy?				
Q3. Do you think meat produced <i>in vitro</i> will be tasty?				
Q4. Do you think the meat industry is really facing important problems (environment degradation, animal welfare, inefficient production to feed humanity)?				
	Change nothing in consumption (code a)	Eat less meat (code b)	Eat no meat (code c)	Eat <i>in vitro</i> meat (code d)
Q5. To solve the potential problems that the meat industry is facing, do you think that human beings should				
Q6. Would you prefer yourself as an individual:				
	Yes (code 1)	No (code 2)	I don't know (code 0)	
Q7. Do you think that <i>in vitro</i> meat will significantly contribute to reduce the environmental impact of livestock?				
Q8. Do you think that <i>in vitro</i> meat will significantly contribute to reduce the animal welfare problem?				
Q9. As prime minister or chief of your government, will you support financially research on <i>in vitro</i> meat?				
Q10. According to your perception, will <i>in vitro</i> meat be well accepted by consumers? Will consumers buy it?				
Are you?	A male		A female	
With an age	<30 years (young group)	30–50 years old (medium group)	Older than 50 (old group)	
Someone who does not know the meat sector	Scientist working on meat	Other scientist	Not scientist but working in the meat sector	

variables and between the individuals (or respondents). Data are represented as points in a Euclidean space to visualize associations between variables.

3. Results

3.1. Characteristics of the respondents

A total of 817 people responded to the internet based survey in English (a subset of 604 answers including 103 from North America, 146 from China, 168 from other Asian countries, and 83 from Africa was analyzed in details). A further 865

responded to the internet survey in France, and another 208 people responded with a paper based French and English survey (Table 2).

A majority of the respondents of the paper survey were female scientists, but not aware of the difficulties of the meat sector (Table 2).

3.2. Answers to the perceived characteristics of artificial meat

More than half of the respondents (at least 53%) claimed that the “artificial meat” technology was feasible and realistic

(Table 3). A non-negligible proportion of the respondents (between 10 and 20%) had no opinion. However, within the paper survey, the proportion of people saying that the “artificial meat” technology was feasible and realistic was higher (75.4%) and the proportion of hesitating people lower (10.6%) (Table 3). A high proportion of young females and of old males answered that the “artificial meat” technology was feasible and realistic whereas medium and old females answered the opposite (Fig. 1-A).

Regarding the two questions related to the healthiness and taste of artificial meat, all surveys showed that many

respondents had no strong opinion (from 29.6 to 37.7%, Fig. 2). However, while the rest of respondents answered in majority No to the these two questions in the internet surveys, respondents answered in majority Yes to these two questions in the paper survey (Table 3).

A large majority of the respondents claimed that the meat industry is facing important problems related to the protection of the environment, animal welfare or inefficient meat production to feed humanity. This proportion was however the lowest in the case of the paper survey (47.4%), than by internet (66.2% for the international survey and 81.6%

Table 2 Social characteristics of the different groups of respondents¹⁾

	International survey (%)	French survey (%)	Paper survey (%)
<30 years	48.8	65.2	31.3
30<years<50	40.2	23.3	53.7
>50 years	10.9	11.6	15.0
Male	54.1	36.8	41.4
Female	45.9	63.2	58.6
Someone who doesn't know the meat sector	21.5	59.5	22.2
Not scientist but working in the meat sector	8.3	11.2	5.1
Scientist	53.1	26.9	47.0
Scientist working on meat	17.1	2.3	25.8

¹⁾ The international and French surveys were based on a questionnaire-freely available on internet and sent to different mailing lists or groups of people known by researchers, either people from different countries (international survey) or French people (in the case of the French survey). The surveys were preceded by a small text to explain the problem, followed by the internet questionnaire (Table 1). The paper survey involved respondents viewing a short power point presentation covering (i) the principles of artificial meat production; and (ii) its ability to solve the potential problems faced by the meat industry in terms of welfare, environmental and food security issues. This method was time-consuming but ensured a better understanding of the issues by the respondents. People were invited to answer the questions on a sheet of paper.

Table 3 Answers to questions related to the perceived characteristics of artificial meat¹⁾

	International survey			French survey			Paper survey		
	Yes (%)	No (%)	I don't know (%)	Yes (%)	No (%)	I don't know (%)	Yes (%)	No (%)	I don't know (%)
Q1. Do you think this <i>in vitro</i> meat technology is feasible and realistic?	53.6	28.7	17.7	53.6	26.5	19.9	75.40	14.00	10.60
Q2. Do you think meat produced <i>in vitro</i> will be healthy?	32.4	37.5	30.1	21.8	41.2	37.00	42.00	26.1	31.9
Q3. Do you think meat produced <i>in vitro</i> will be tasty?	24.3	38.00	37.7	19.6	41.3	39.2	37.40	33.00	29.60
Q4. Do you think the meat industry is really facing important problems (environment degradation, animal welfare, inefficient production to feed humanity)?	66.2	25.2	8.6	81.6	12.6	5.8	47.40	38.60	14.00
Q7. Do you think that <i>in vitro</i> meat will significantly contribute to reduce the environmental impact of livestock	39.9	37.1	23.00	32.9	42.00	25.1	33.00	41.70	25.30
Q8. Do you think that <i>in vitro</i> meat will significantly contribute to reduce the animal welfare problem?	45.00	37.8	17.2	35.6	46.7	17.7	30.60	47.60	21.80
Q9. As prime minister or chief of your government, will you support financially research on <i>in vitro</i> meat?	46.7	37.2	16.1	37.9	42.8	19.3	40.5	35.1	24.4
Q10. According to your perception, will <i>in vitro</i> meat be well accepted by consumers? Will consume buy it?	19.2	48.7	32.1	9.2	64.5	26.2	15.5	51	33.5

¹⁾ Respondents had an oral presentation (paper survey) or a written summary regarding artificial meat (international and French internet surveys) before they answered the questionnaire.

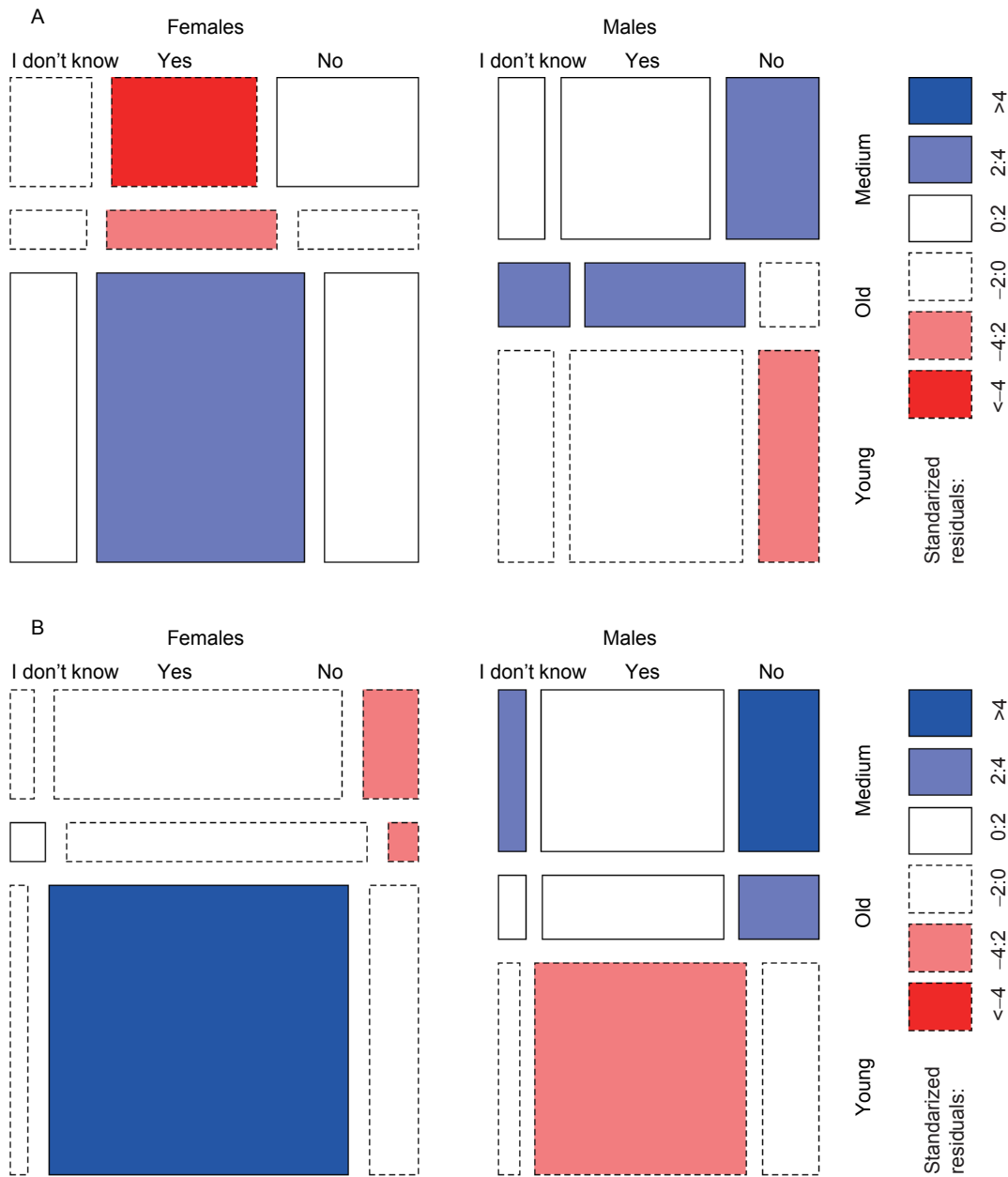


Fig. 1 Distribution of responses by gender and age for: A, survey question 1 “Do you think *in vitro* meat technology is feasible and realistic?” and B, survey question 4 “Do you think the meat industry is really facing important problems such as environment degradation, animal welfare, inefficient production to feed humanity?” Age ranges were classed as follows: Young<30, Medium≥30 and ≤50, Old>50 years. Standardized residuals are standardized differences between observed and theoretical effectives. Over-representations and under-representations of the numbers of respondents in each cell are indicated in blue and in red respectively.

for the French survey) (Table 3). Among respondents, a high proportion of young females, in contrast to the young males, claimed that the meat industry is facing important problems (Fig. 1-B).

Regarding the two questions related to the potential advantages of artificial meat concerning environmental and welfare issues, all surveys showed that some respondents had no strong opinion (from 17.2 to 25.3%). However, while the rest of respondents answered that artificial meat

could have some advantages in the international survey, the majority of French respondents and scientific respondents answered the opposite (Table 3).

When compared to other options such as changing nothing in meat consumption, eating no meat or eating less meat, a majority of respondents (59.4% for French people to 64.5% for the other surveys) would recommend eating less meat. However, less were keen to follow this recommendation themselves (41.3% for French people to 58.7% for the

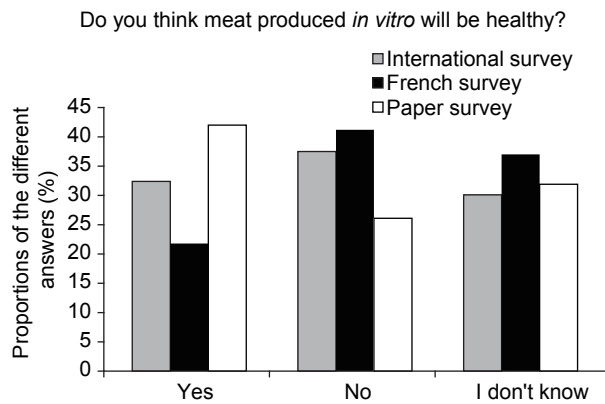


Fig. 2 Answers to question Q2 “Do you think meat produced *in vitro* will be healthy?” Respondents had an oral presentation (paper survey) or a written summary regarding artificial meat (international and French internet surveys) before they answered the questionnaire. The proportions of the different answers.

other surveys). A non-negligible proportion of respondents would recommend changing nothing in meat consumption (from 6.8 to 25.9%), especially for themselves (from 19.3 to 35.8%). The proportion of respondents who would prefer eating no meat or artificial meat was low and did not vary much between groups except for French nationals (Table 4, Fig. 3). This may be due to the fact that a large proportion of the French Nationals were vegetarians.

Regarding the question related to any public financial support to “*in vitro* meat” research, all surveys showed that some respondents had no strong opinion (from 16.1 to 24.4%). However, while the majority of international scientists responding with the internet and paper surveys answered that this type of research could be useful, the majority of French young respondents answered the opposite, and thus do not support any public research on artificial meat (Table 3, Fig. 4).

Regarding the question related to public acceptance of “*in vitro* meat”, all surveys showed that some respondents had no strong opinion (from 26.2 to 33.5%), but a majority of respondents (especially young French people) answered that artificial meat will not be accepted by consumers (Table 3, Fig. 5).

3.3. Relationships between answers

Multiple correspondence analyses (MCA) allowed discriminating three groups of respondents based on their answers “Yes” [:1], “No” [:2] or “I don’t know” [:0] to questions 1 to 4 and 7 to 10 (Fig. 6): (i) respondents with no strong opinion who responded “I don’t know” to most of the questions; (ii) respondents who mainly answered “No” to most of the questions suggesting they are against artificial meat and (iii) respondents who mainly answered “Yes” to most of the questions suggesting they are in favour of artificial meat.

The sole answer which was not associated with any of these groups (Fig. 5) was answer “Yes” to question 4 [Q4:1]: “Do you think the meat industry is really facing important problems (environment degradation, animal welfare, inefficient production to feed humanity)?”

Respondents with no strong opinion were characterised by answers “I don’t know” to question 1 [Q1:0] (is artificial meat feasible?), questions 7 and 8 [Q7:0 and Q8:0] (ability of artificial meat to reduce the environmental and the animal welfare problems) and question 9 [Q9:0] (public support in favour of research on artificial meat) (Fig. 6).

Respondents against artificial meat mostly answered “No” to question 1 [Q1:2] (is artificial meat feasible?), question 7 [Q7:2] (ability of artificial meat to reduce the environmental problem) and question 9 [Q9:2] (public support in favour of research on artificial meat) (Fig. 6).

Respondents in favour of artificial meat mostly answered

Table 4 Answers to questions Q5 and Q6 related to the solutions to reduce the potential problems raised by the meat industry¹⁾

	Eat no meat (%)	Eat less meat (%)	Eat <i>in vitro</i> meat (%)	Change nothing in meat consumption (%)
			International survey	
Q5. To solve the potential problems that the meat industry is facing, do you think that human beings should:	3.1	64.5	11.1	21.3
Q6. Would you prefer yourselves as an individual:	8.9	58.7	7.8	24.7
			French survey	
Q5. To solve the potential problems that the meat industry is facing, do you think that human beings should:	25.4	59.4	8.3	6.8
Q6. Would you prefer yourselves as an individual:	34.0	41.3	5.3	19.3
			Paper survey	
Q5. To solve the potential problems that the meat industry is facing, do you think that human beings should:	0	62.9	10.7	25.9
Q6. Would you prefer yourselves as an individual:	1.4	53.6	9.2	35.8

¹⁾ Respondents had an oral presentation (paper survey) or a written summary regarding artificial meat (international and French internet surveys) before they answered the questionnaire.

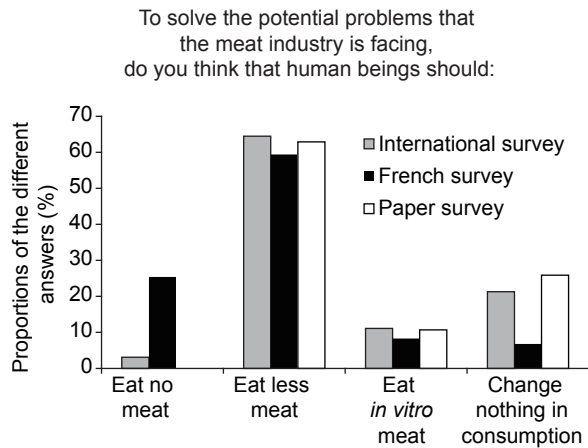


Fig. 3 Answers to question Q5 related to the recommendations to reduce the potential problems raised by the meat industry. Respondents had an oral presentation (paper survey) or a written summary regarding artificial meat (international and French internet surveys) before they answered the questionnaire.

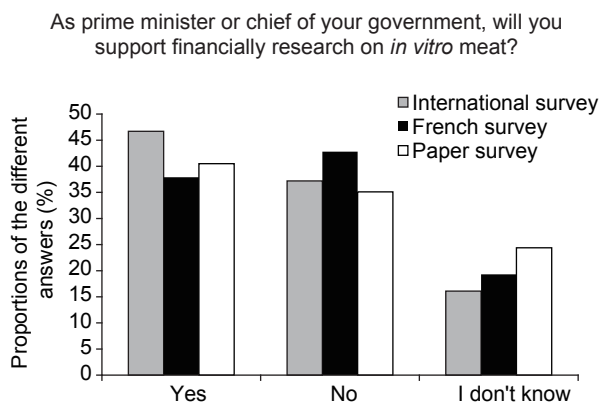


Fig. 4 Answers to question Q9 related to any public financial support to *in vitro* meat research. Respondents had an oral presentation (paper survey) or a written summary regarding artificial meat (international and French internet surveys) before they answered the questionnaire.

“Yes” to question 10 [Q10:1] (acceptance by consumers), and also questions 2 and 3 [Q2:1 and Q3:1] (taste and healthiness of artificial meat) (Fig. 6). Projections of answers to questions 5 and 6 indicated that the answers d (a preference to eat artificial meat) to both questions [Q5:d and Q6:d] were associated to this group of respondents (Fig. 6). Projections of gender, sex, main background and professional activity showed no association of these factors with any of the three groups of respondents (data not shown).

4. Discussion

A majority of the respondents of the international survey

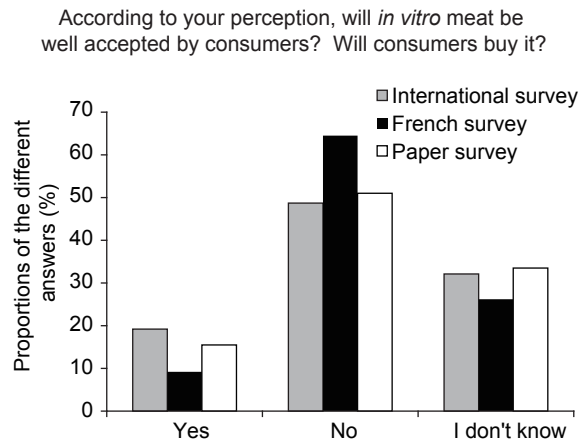


Fig. 5 Answers to question Q10 related to consumer acceptance of *in vitro* meat. Respondents had an oral presentation (paper survey) or a written summary regarding artificial meat (international and French internet surveys) before they answered the questionnaire.

made by internet were scientists. This can be explained by the fact that the French scientists in charge of the survey contacted their colleagues working in different countries. However, most of these scientists did not work in the meat sector. A majority of the respondents of the French survey made by internet were young female who were not scientists. This can be explained by the fact that the French students in charge of the survey contacted their friends who were of a similar demographic, young, not scientists and unaware of the difficulties of the meat sector. In the case of the French survey, a subset of the respondents identified as vegetarians.

Since results were similar between the two surveys made either orally or on internet, results were interpreted for both approaches together. In fact, the surveys were not built so as to give the most faithful possible image of all the meat consumers or the human beings of a gender, a country or a continent. In other words, the investigated population was not representative of all the sectors of society. It was more representative of a fairly uniform population rather than of different social types, since the people belonged mainly to educated environment (scientists and students). Because of this potential bias of the study, we focused our analysis and interpretation on relationships between answers to the different questions for the same respondents.

The fact that, most of the respondents thought that the “*in vitro* meat” technology was feasible and realistic, confirmed our hypothesis. This can be interpreted as people having trust scientists in terms of technology, resulting in cost efficient cultured beef (Moritz et al. 2015). Answer to this question was also a main factor discriminating respondents against artificial meat or with no strong opinion. The

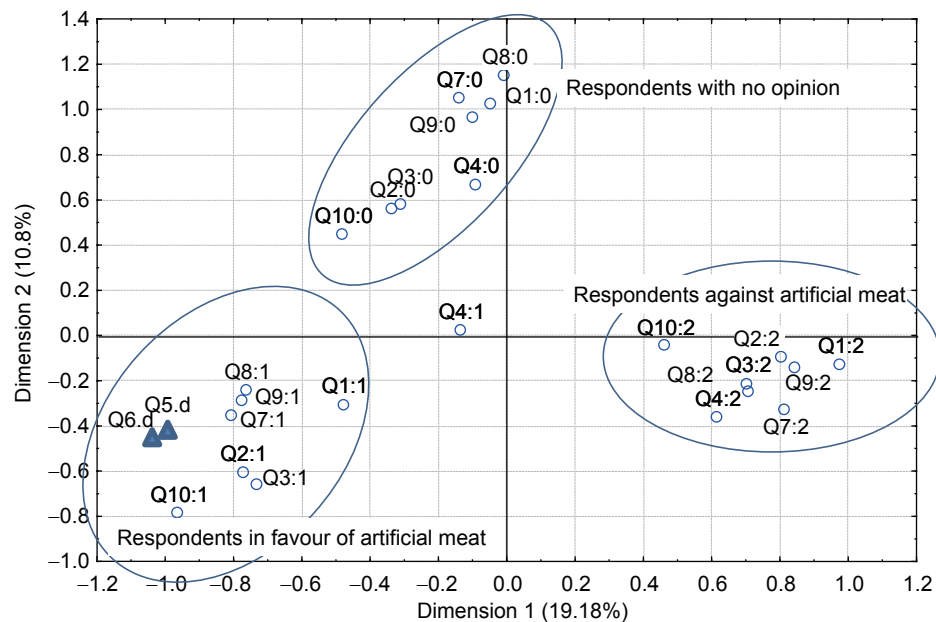


Fig. 6 Multiple correspondence analysis (MCA) performed with questions 1 to 10 (Q1, Q2, Q3, Q4, Q7, Q8, Q9, Q10) except questions 5 and 6 (Q5, Q6) which were projected. Details of the questions are indicated Table 1. Each data point is labeled with the question number e.g., Q1 and the numerical code of the response. The three responses possible “I don’t know”, “Yes” and “No” are indicated by 0, 1 and 2, respectively. Associations between variables are uncovered by calculating the chi-square distance between different categories of the variables and between the individuals (or respondents). Data are represented as points in a Euclidean space to visualize associations between variables. Variables near each other at the periphery of the graph are positively associated, orthogonal variables are independent and variables separated by 180° are negatively associated. The closer to the periphery, the higher is the association between variables. The analysis was performed with answers to questions 1 to 10 (Q1, Q2, Q3, Q4, Q7, Q8, Q9, Q10), excluding questions 5 and 6 (Q5, Q6) which had a different answer format. For these questions answers d, which indicated a preference for eating artificial meat were projected on to the graph.

oral explanations given during the paper survey may have even increased the proportion of convinced people and decreased the proportion of hesitating people. Even people who are not scientists trust researchers to invent new powerful technologies as the one which concerns artificial meat production. Indeed, *in vitro* meat may be a potential method to reduce animal suffering and environmental issues problems, even if artificial meat is commercialized only as ground, processed foods such as hamburgers or hotdogs as a main component or as an additive (Datar and Betti 2010). Interestingly, older females tended to be less accepting of the technology than young females. One can hypothesized that the young females may have a higher scientific culture than older one and may be more opened to new technologies. In addition, females, especially young ones, were more convinced that the meat industry is really facing important problems (environment degradation, animal welfare, inefficient production to feed humanity), which has a positive relationship with the first question regarding the feasibility of artificial meat.

Interestingly, even if the technology is judged feasible and realistic, only a minority of respondents in the two internet surveys thought that artificial meat will be healthy and tasty.

The “Yes” answer to this question was also a main factor characterising respondents in favour of artificial meat, who were in addition less discriminated by the next questions. The high proportion of “I don’t know” answers confirmed that respondents were hesitating. In contrast, more respondents believed that artificial meat could be healthy and tasty in the paper survey. This may be explained by the fact that scientists can be progressively convinced by oral explanations in contrast to internet surveys where respondents had some efforts to do by themselves to read the provided abstracts and understand the technology. To summarize, respondents trust scientists to rebuild the muscle tissue, but cultured myocytes is different to meat and the true muscle architecture would be more of a challenge to replicate. It can also be argued that “natural” food was always better than “artificial” one (Hopkins and Dacey 2008; Frewer *et al.* 2011) and that other means will be available to better predict meat quality which is a complex concept aggregating intrinsic quality traits (which are the characteristics of the product itself) and extrinsic quality traits (which are more or less associated to the product for instance how it is produced) (for a review, see Hocquette *et al.* 2012). However, a statement from the University of Maastricht indicated that

technological processes will be employed to create flavor and texture in *in vitro* meat that is similar to standard meat. Similarly, other authors claimed that the implementation of an *in vitro* meat production system creates the opportunity for meat products of controlled and various characteristics to be put onto the market (Datar and Betti 2010).

The next question related to the previously discussed challenges facing the meat industry also had clear trends. Most of the respondents agreed that the meat industry is facing serious problems. This is likely to be due to respondents having been convinced by the circulating ideas in the media (Goodwin and Shoulders 2013) concerning animal welfare or environmental issues regarding livestock and the difficulty to feed the increasing human population. However, there were some concerns that the phrasing of the question led to a higher amount of positive responses. Respondents that were not aware of any issues in the meat industry may have been more likely to answer yes, creating a positive bias in the survey. On the contrary, during the oral presentation and discussions in the paper survey, some respondents were influenced by those working on meat or knowing the meat sector making the proportion of respondents agreeing that the meat industry is facing serious problems lower. On the other way, young people as in the French survey, or more generally young females, were more convinced that we had an important problem to solve regarding meat production. Supporting this interpretation is the high (79.5%) proportion of respondents under 30 thought that the meat industry is facing important problems.

However, one of the major key arguments of Prof. Post (2012, 2014) and by vegetarians (Hopkins and Dacey 2008) that eating artificial meat or eating no meat will solve the lead to increased animal welfare and reduced environmental impact was not confirmed by the respondents' answers. Those respondents who recognized issues within the meat industry, but were unwilling to eat artificial meat may seem a little contradictory. The preferred solution by these respondents was to simply consume less meat than to eat artificial meat or to eat no meat. Some people think that eating less meat could be even more efficient. Curiously, among the people who were ready to recommend artificial meat, not all of them were willing to eat it themselves. In addition, "Yes" answers to questions 7 and 8 were also a main factor discriminating respondents against artificial meat or with no strong opinion, indicating that these questions are key questions to potentially convince people about artificial meat.

Eating less meat is a possible solution that would require the least amount of change to normal consumer habits, and so will generally be the most attractive. The preferences by some consumers to eat less meat in response to the issues within the meat industry are not supported by current consumer behavior at the World level. In fact demand for

meat is increasing and is expected to increase for at least the next 40 years (Godfray *et al.* 2010). This indicates that despite the respondents' answers that they would prefer to eat less meat than eat artificial meat, consumer demand will continue to grow creating a gap between demand and supply that artificial meat has the opportunity to fill.

One possible hypothesis is that respondents needed to be sure that artificial meat will be completely safe, tasty enough and healthy enough, and at present the results of our questionnaire indicate that they are not convinced. For them, human healthiness and safety are also key priorities in addition to animal welfare and environmental issues. In general, respondents indicated that we must first satisfy nutritional and hedonic requirements of consumers, the vast majority of which are regular meat eaters. However even if these requirements are met, there may be competition from other products such as insect (FAO 2013) or plant based proteins (Pimentel and Pimentel 2003), which also have the benefit of reduced environmental impacts and enhanced animal welfare. In any case, the apparent contradiction between the importance of the problems to solve and the relative inefficiency of the solution chosen by respondents (eating less meat) is an important matter for debate.

Saying that artificial meat will solve welfare and environmental issues is a major argument from Prof. Post (2012, 2013). The argument is simply to be understood: we need less and almost no animals to produce artificial meat and its production which will not produce any methane unlike herbivores. However, most of the respondents were not convinced because it can be argued that huge incubators used to produce meat will consume electricity, fossil energy and that the net environmental footprint will not be simple to calculate (Hocquette *et al.* 2013). It can be also argued that the elimination of animals required to produce food will result in different problems. Animals will still be required for dairy and fiber production. If artificial meat production is a sudden success there may be millions of meat animals that no longer have a purpose and are therefore wasted. There will be a large reduction in diversity if all the domesticated meat producing breeds are no longer cultivated, though if these species remain and develop wild populations, there could be devastating ecological consequences for both the natural environment and agricultural land with over population and crop damage.

At the end of the survey, on average, several negative points regarding the production of artificial meat have been pointed out (respondents were not sure it will be tasty, healthy, environmental friendly and better for farm animals). However, some respondents (especially those in favour of artificial meat) would like to support research on artificial meat if they would have the power to decide so as prime ministry or research ministry. Most of the people argued

artificial meat has a great potential, but it must be proven first, before consumers will accept it. In addition, almost all authors agree that more research is required because a major hindrance for a potential success of artificial meat is the difficulty to develop viable mass production techniques (Datar and Betti 2010; Hocquette *et al.* 2013). For many other reasons, the future of artificial meat produced from stem cells was judged uncertain at this time (Bonny *et al.* 2015).

Despite respondents positively responding to public financial support of research into artificial meat, most of them confessed they believed that consumers will neither buy nor consume artificial meat. This is in line with the fact that most authors agree that consumer acceptance, in addition to cost-effectiveness, will determine if artificial meat will become a significant meat alternative on the market (Datar and Betti 2010; Hocquette *et al.* 2013; Verbeke *et al.* 2015). Consumers may be afraid by the word “artificial” and that today, most of them do not like any type of artificial food. Consumer fear regarding artificial meat might be similar to consumer fear relating to GMO’s. Artificial meat is a new product, not yet known by consumers, who may be afraid of it because new, not surely healthy, neither tasty and that the process to make it is unclear or unknown so far (Frewer *et al.* 2011; Verbeke 2011). It can also be argued that eating will always be a pleasure, or must be a pleasure and that pleasure will not be provided by artificial meat. However, other sources of pleasure are now available in our society such as travelling, practicing sports, watching movies or reading books giving less and less space to the pleasure of eating. In fact, there are huge variations in consumers’ perspectives regarding the need for change in meat consumer practices. Understanding more about the diversity of consumer views is probably a main issue in the long term future (Vinnari and Tapio 2009).

5. Conclusion

According to its promoters, artificial meat has the potential to make eating animals unnecessary. It has also the potential to reduce carbon footprint of meat production. In addition, it has the potential to satisfy all the nutritional requirements and hedonic wishes of normal consumers. However, the vast majority of consumers regularly consumes meat, and would continue to do even in the context of an increased human population and therefore in a context of increasing food needs. This survey demonstrates that this apparent illogical way of thinking is common for most respondents. Indeed, while a majority of people trust the artificial meat technology and believe that the meat industry is facing major problems, they do not believe that artificial meat is an evident solution which could be efficient to solve the aforementioned problems with the meat industry. Indeed, accord-

ing to these respondents, artificial meat will not necessarily reduce animal requirements, or will not dramatically reduce carbon footprint for meat production. These arguments are the main ones discriminating hesitating respondents or respondents against artificial meat. In addition, for most respondents, consumers will not buy or consume it in majority. Despite these limitations, respondents would continue to support research on artificial meat. We speculated that the apparent contradictory answers to this survey express the dual feeling of people towards science. On one hand, people trust scientists because researchers continuously discover new technologies potentially useful in a long term future for the society. But, on the other hand, a majority of people express concern for their health. Except respondents already convinced by artificial meat, most respondents are not sure that artificial food will be tasty, safe and healthy enough to be consumed without any doubts.

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