Consideration of the product quality in the life cycle assessment: case of a meat product treated by high pressure

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ABSTRACT

New technologies play an important role on sustainable food production and to ensure food security for the next decades (Sonesson 2010). High-pressure processing is a promising emerging technology which was considered environmentally friendly in terms of energy consumption (Toepfl et al. 2006). The technology improves food quality that was not included in previous LCA studies. In this case study, the food safety as a quality characteristic was included in the comparison of the environmental impact between a high-pressure treated ham and the traditional one. At the consumption stage, the food safety was considered as the potential damage to human health by *Listeria monocytogenes*. As an additional step of meat processing, the contribution of high-pressure processing to the life cycle of cooked ham was negligible. However, improving food safety could partly compensate for the environmental impact due to the extended shelf life of meat products.

Keywords: Meat product, high pressure processing, Life Cycle Assessment

1. Introduction

Sustainable food processing is a critical element for the future generations to ensure food safety and to preserve food quality with efficient use of resources (Floros et al. 2010). The impact of high pressure processing on food production has been recently explored (Davis et al. 2009; Pardo and Zufía 2011). Previous studies have focused on high pressure processing without considering new characteristics of high-pressure treated products.

Commercialized high-pressure treated products are mainly vegetable products (33%), meat products (30%), seafood and fish (15%) and beverages (12%) (Mújica-Paz et al. 2011). Within those food categories, meat products were reported to have the greatest environmental impact (Tukker et al. 2006). Moreover, there is little knowledge about the environmental impact of high pressure processing on meat products.

Nutritional quality has been considered in sustainable approach of life cycle assessment as functional unit (Shau and Fet 2008). However, other quality features should not be neglected in efforts to evaluate the environmental impact of products. Food safety is a food attribute which is associated to health risk (Röhr et al. 2005). Novel preservation technologies improve food safety and potentially decrease the human risk associated to foodborne illness (Hugas et al. 2002). Likewise, the food recall for microbiological criteria is an important wastage that could be avoided by emerging technologies.

Listeria monocytogenes is a pathogen of public health concern, responsible of listeriosis. For the characteristics of production and consumption, ready-to-eat foods are considered to be a vehicle of listeriosis foodborne (Zhang et al. 2012). High-pressure processing is an alternative to control *Listeria monocytogenes* without using growth inhibitors and post packaging pasteurization. For this reason, we develop an approach to consider the food safety in the comparison of the high pressure treated product with the traditional one. The objective of the study was to evaluate the environmental impact of a sliced ham treated by high pressure and to compare it with the untreated product, considering the quality of products.

2. Methods

2.1. Goal definition, system description and data collection

The life cycle assessment was performed to compare the environmental impact between the sliced cooked ham treated by high pressure and the conventional product. The functional unit is 1 kg of sliced cooked ham consumed. The economic value of the traditional product and the high-pressure treated one was also used to compare their environmental impact. The prices of the products were recorded in countries where the technology is currently employed on commercialized sliced cooked ham.

From a cradle-to-crave perspective, the system consists of 4 subsystems: meat production, cooked ham production, distribution and consumption. Figure 1 shows the studied system and the high-pressure processing as an additional step of cooked ham production. The data were collected from a meat producer (slaughtering and cooked ham production) in France and a high-pressure equipment manufacturer. The data for the meat production in France were obtained from Agribalyse database 1.1. Capital goods, cleaning products and packaging material for transportation were not included. Mass allocation was performed for multi-products system. The high-pressure treatment of the packaged sliced cooked ham is 600 MPa for 3 minutes at room temperature in order to eliminate post processing contamination of *L. monocytogenes*.

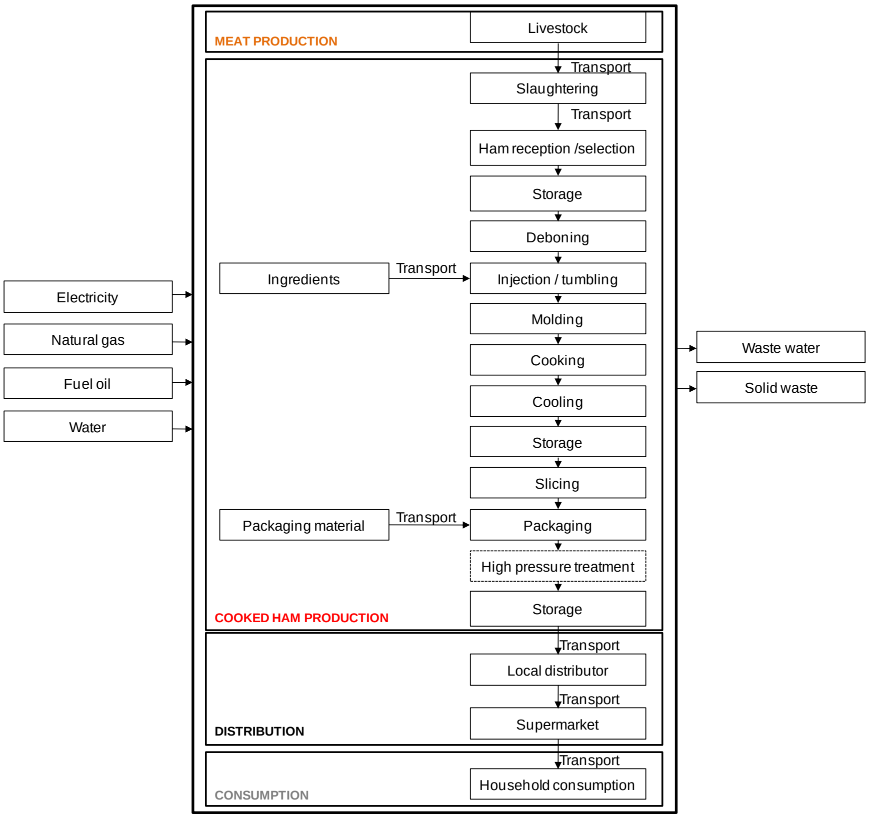

Figure 1. Flow diagram of the life cycle of sliced cooked ham

2.2. Food safety: Health effects due to the exposure to *L. monocytogenes*

Food safety is a food attribute, presented as damage to human health. Food quality in the ready-to-eat meat product is evaluated in terms of the disease burden caused by *L. monocytogenes*. The model refers to the change of Disability Adjusted Life Years (DALY) upon exposure to the pathogen. The comparison between the meat products provides the potential benefit of using high-pressure processing as a listericidal treatment. We proposed to consider this aspect on the human health damage category.

The impact of using high-pressure processing to control *L. monocytogenes* was evaluated by using the risk assessment of *L. monocytogenes* in ready-to-eat food (WHO/FAO, 2004) and the BRAFO tiered approach (Hoekstra et al. 2012). The framework consists of three parts which are: the exposure assessment, the dose-response and the risk characterization.

The exposition factor is the quantitative evaluation of the ingestion probability of *L. monocytogenes*. The prevalence and contamination level of *L. monocytogenes* on ready-to-eat meat products from the report of the European Food Safety Authority (2013) were assumed. The distribution of *L. monocytogenes* in the ready-to-eat meat product was obtained from the serving size (g) and the distribution of the contamination level (European Food Safety Authority 2013).The serving size (g) was calculated from the annual consumption of cooked ham in France. The serving size was assumed to be the same to women and men. The dose is estimated by using the Equation 1.

$$\text{Dose (cfu)} = \text{Average serving (g) x Contamination level (cfu/g)} \quad \text{Eq. 1}$$

The probability of illness ($P_{illness}$) at a specific dose (16 g/day) is obtained from the distribution of *L. monocytogenes* on the ready-to-eat meat (Dose) and the probability of *L. monocytogenes* of causing an infection to a susceptible population (r: 5.85 x 10^{-12}) (WHO/FAO 2004), as presented by the exponential dose-response relation (Eq. 2).

$$P_{\text{illness}} = 1 - e^{-rDose} \quad \text{Eq. 2}$$

The probability of listeriosis due to the annual consumption of packaged sliced ham in France at the prevalence and contamination level reported is 5.1 x 10^{-8}. The probability to develop a specific manifestation was estimated by using equation 3. The factor (F) is the proportion of cases of listeriosis which develop the specific manifestation and it was obtained from government publications and literature data (Institut de veille sanitaire 2012, Lecuit and Leclercq 2013).

$$P_{meningitis/septicemia/neo-natal listeriosis} = P_{\text{illness}} \times F_{meningitis/septicemia/neo-natal listeriosis} \quad \text{Eq. 3}$$

Listeria monocytogenes is responsible for two forms of listeriosis: non-invasive and invasive listeriosis. The invasive listeriosis is the most severe manifestation form and it may induce meningitis, septicaemia and neonatal infection. In this study, the invasive listeriosis was only considered. The severity of listeriosis was estimated in terms of the indicator of the human health impact category (Disability-adjusted life years, DALY). Similar approach was used to evaluate the impact of foodborne disease on public health in Greece and Netherlands (Gkogka et al. 2011, Havelaar et al. 2012).

Listeriosis, in the invasive form, was evaluated in the susceptible population (older adults and pregnant women). The DALY estimation was according to "BRAFO tiered approach" (Hoekstra et al. 2012) for quantal health effects. The expression (Eq. 4) considers the health recovering, the decease and the sequelae of individuals, which was calculated for each manifestation of listeriosis (meningitis, septicemia and neo-natal listeriosis).

$$DALY_{a,s} = P_{effect} (P_{rec} . YLD_{rec} . w + P_{die}(YLD_{die}. w + LE_{a,s} - CA - YLD_{die}) + (1 - P_{die} - P_{rec}).(LE_{a,s} - CA). w) \quad \text{Eq.4}$$

The $DALY_{a,s}$ is the disability-adjusted life years for a specific age (a) and sex (s). The P_{effect} is the probability of illness by listeriosis. The P_{rec} is the probability of health recovering (Aouaj et al. 2002, Dzupova et al. 2013, Goulet et al. 2012). The P_{die} is the probability to die due to the illness (Varon 2009, Goulet et al. 2012). The YLD_{die} and the YLD_{rec} is the illness duration for the individuals who die and recovers health, respectively (Gerner et al. 2005, Fernandez et al. 2011, Kemmeren et al. 2006). The w is disability weight of the disease (Melse et al. 1998, Melse et al. 2000). The CA is the actual age of diseased individual. The LE is the life expectancy for the individual with an age CA. The Table 1 summaries the parameters used for each manifestation. For neo-natal listeriosis, parameters values ($P_{rec,}$ YLD_{rec}, YLD_{die}, P_{die} and *w*) were assumed since it represents the neonatal death and the abortion due to this manifestation. The data for the concerned population in France were obtained from the INSEE (National Institute of Statistics and Economic Studies). The annual DALY is estimated and summed for each individual of the susceptible population.

Table 1. Values of parameters used for DALY calculation

Diseases	F	P_{rec}	YLD_{rec}	P_{die}	YLD_{die}	*w*
Meningitis	0,28	0,565	0,500	0,22	0,080	0,310
Septicemia	0,65	0,791	0,020	0,209	0,080	0,930
Neo-natal listeriosis	0,315	0	0	1	0	1

The baseline scenario is the current characteristics of distribution and prevalence of *L. monocytogenes* on ready-to-eat meat products (European Food Safety Authority 2013). The worst scenario is based on a challenge test in a cooked ham at the limit of pathogen inactivation by high pressure processing (Myers et al. 2013). It was assumed a lower prevalence of contaminated products (0.001%) for the worst scenario and the potential human health damage due to listeriosis was evaluated for 14 days of storage time at the retail store.

2.3. Life cycle impact assessment

The life cycle assessment was conducted by using the SimaPro 8.0.2 software. Two methodologies of impact evaluation were employed: problem-oriented method (CML IA v 3.0 and Cumulative energy demand v 1.08) and damage-oriented method (Eco-indicator 99 v 2.09). The environmental impact categories selected in the analysis were non-renewable energy, global warming potential, acidification, eutrophication, and photochemical oxidation. The impact categories for the human health damage were also included.

2.4. Sensitivity analysis

A sensitivity analysis was performed to evaluate the impact of input variables on the human health damage due to listeriosis. Likewise, the impact of capital goods and the extended shelf life of products were considered.

3. Results

3.1. Environmental impact of meat products

Figure 2 shows the contribution of each stage of the life cycle of the meat product untreated (traditional product) and treated by high pressure processing (HP product). The results of the stage contribution to environmental impact categories are expressed in mass of products (vertical axis). The environmental impact of products is quite similar in this case, while no changes of post-processing stage were described. Meat production is the main contributor for the life cycle of the meat products. For the traditional product, 45.3% of non-renewable energy use, 73.1% of global warming potential, 92.4% of acidification, 87.7% of eutrophication and 89.4% of photochemical oxidation were due to meat production. It is in accordance to the composition of final products which contains about 90% of pork meat. Besides, cooked ham production was responsible for 27.5% of the non-renewable energy use and 15.6% of the global warming potential. The contribution of cooked ham production was 5.7%, 9.9% and 6.4% for acidification, eutrophication and photochemical oxidation, respectively. High pressure processing as an additional operation to meat processing represents an increase of 0.7% of non-renewable energy demand. The contribution of high pressure processing was equal or less than 0.1% increase on the results for global warming potential, acidification, eutrophication and photochemical oxidation. The distribution and the consumption phase accounted for 15% and 12% to non-renewable energy use. For global warming potential, the contribution of distribution and consumption was 9% and 2% while for acidification, eutrophication and photochemical oxidation contributed equal or less than 2%.

Food quality is related to human perception and how the product fulfills their expected requirements (Röhr et al. 2005). Considering food quality implies to include its multiple aspects. The results are also presented in terms of the economic value since it reveals the emotional value of a product (Shau and Fet 2008). The economic value of products (price of packaged sliced cooked ham in Europe) is used to compare the environmental impact between the traditional and the treated product as presented in Figure 2. The environmental burden of different impact categories decreased about 16% on the treated cooked ham in comparison to the traditional one.

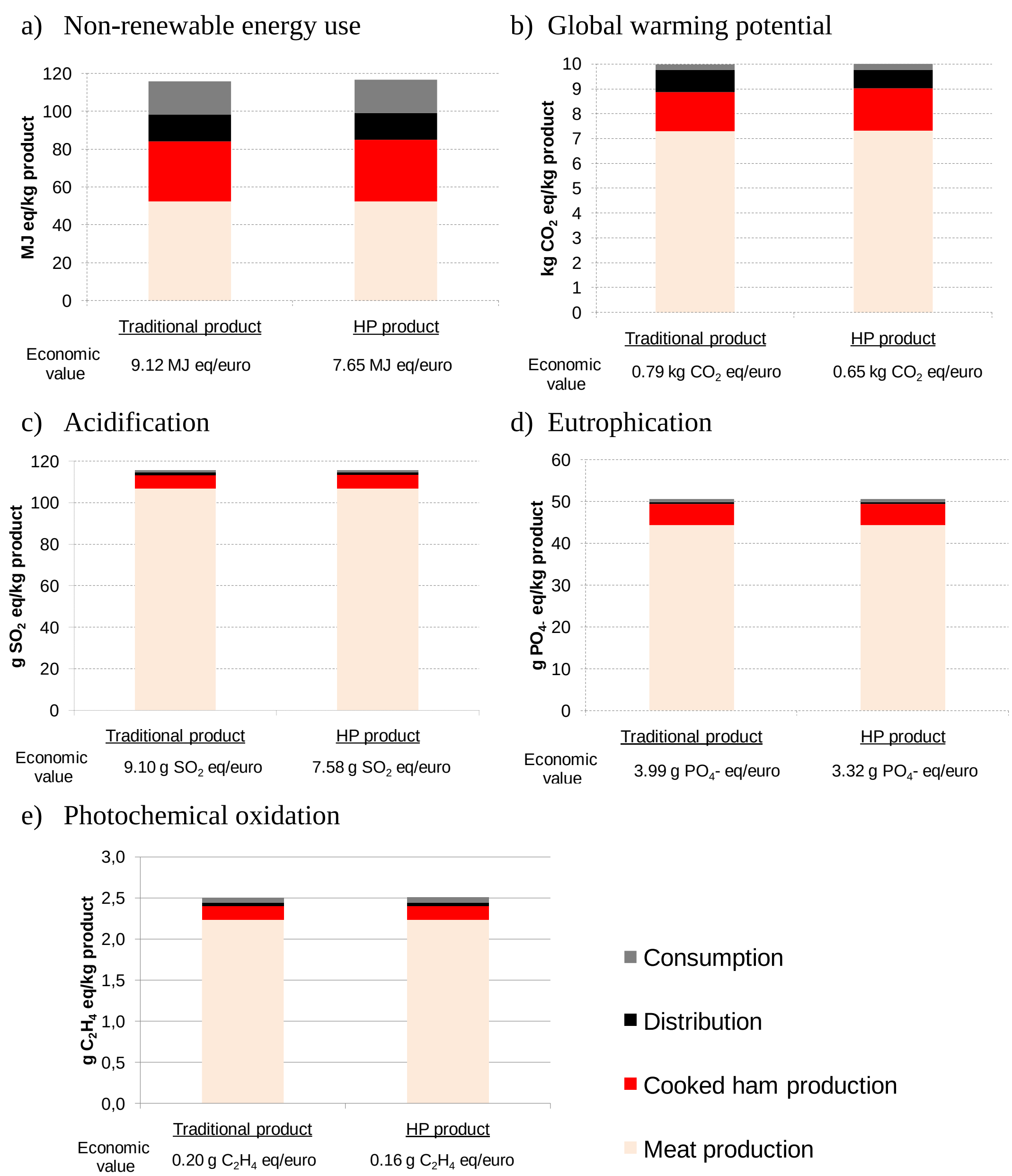

Figure 2. Contribution of stages to the environmental impact categories for the life cycle of the sliced cooked ham per functional unit: bar graphs present results per kg of product and below the figure, the results are presented per euro spent for product.

3.2. Food safety: Health effects due to the exposure to *L. monocytogenes*

The total annual health impact of the exposure to *L. monocytogenes* by the meat product for the susceptible population in France is 2.84 DALY [2.24 – 3.63]. The risk of listeriosis among the older adult population contributed about 66% to the total impact.

The table 2 reports the results of impact categories for human health per 1 kg of product. The baseline considered the actual impact of listeriosis on the susceptible population in France. High pressure processing is able to inactive *L. monoctogenes* up to 10^4 cfu/g (Bajovic et al. 2012, Myers et al. 2013). Considering the actual characteristics of prevalence and contamination of *L. monocytogenes* on the ready-to-eat meat products, high pressure is an efficient listericidal treatment if it is used as final step of meat processing.

In relation to the damage impact categories, the actual exposition to the pathogen presents a more relevant impact for human health than the consequences associated to ozone layer depletion for the life cycle of the meat product. Human health damage is mainly caused by carcinogens, climate change, respiration inorganics and radiation. Minor changes were observed in the endpoint impact categories of the treated product.

For the worst scenario, the potential damage due to listeriosis increases with the pathogen growth at storage conditions. It becomes more relevant than health risk due to exposition to organic particles after 12 days. No growth of *L. monocytogenes* in treated products reduces the potential human health damage due to sliced cooked ham.

Table 2. Results of impact categories of human health damage category for the life cycle of the sliced cooked ham per functional unit

Impact category	**per 1 kg of product**	**Baseline**		**Worst scenario - traditional product**				**HP product**
		Traditional product	**HP product**	**0**	**7 days**	**12 days**	**14 days**	**14 days**
Carcinogens	DALY	2.69E-06	2.69E-06	2.35E-06	2.46E-06	2.51E-06	2.53E-06	2.54E-06
Respiration-organics	DALY	7.55E-09	7.55E-09	7.05E-09	7.27E-09	7.29E-09	7.30E-09	7.30E-09
Respiration-inorganics	DALY	8.87E-06	8.87E-06	8.51E-06	8.71E-06	8.76E-06	8.78E-06	8.78E-06
Climate change	DALY	2.03E-06	2.03E-06	1.81E-06	1.98E-06	1.99E-06	1.99E-06	2.00E-06
Radiation	DALY	1.21E-07	1.23E-07	6.62E-08	8.94E-08	1.05E-07	1.11E-07	1.13E-07
Ozone layer	DALY	6.17E-10	6.19E-10	5.75E-10	5.97E-10	6.00E-10	6.01E-10	6.03E-10
Listeriosis	**DALY**	**2.05E-09**	**0.00E+00**	**5.04E-11**	**1.73E-10**	**9.80E-09**	**4.48E-08**	**0.00E+00**

3.3. Sensitivity analysis

The sensibility analysis showed the influence of product contamination, consumer behavior and characteristics of the concerned population on the results of human health damage due to the microbiological risk; which were evaluated individually. The variations of the prevalence of *L. monocytogenes* on meat products from the actual level (2.07%) increased the human health damage results; about 48.6% for increasing 1% the prevalence level of contamination. The changes on the consumer consumption also influence the human health damage results and it was proportional to the magnitude of serving size change; about 6.3 % for increasing 1 g the actual serving size.

Considering the projection of population growth from government publications, to 2050, the population in France would increase 6.7% and the older adult (60 years and more) population would represent 31.9% of the estimated population. The human health damage results for the projected population increased 36.6% the indicator value. The increase of older adult population was the main contributor of the indicator variation.

On the other hand, the differences of the environmental load between the traditional product and the treated product increase less than 1% if capital goods are included in the analysis.

The extended shelf life of the treated meat product can increase the storage time at the supermarket. If we consider two-fold the baseline of the storage time, the use of non-renewable energy increases 10% and less than 1% for other impact categories in comparison to the traditional product.

4. Discussion

4.1. Contribution analysis

The meat production has the greatest contribution to the life cycle of meat products. Cooked ham production is the second contributor to environmental impact. The contribution of this stage refers to energy consumption and refrigerant leakages. High pressure processing has a little influence on the environmental profile of the sliced cooked ham if there are no modifications of the behavior at the distribution and consumption stages. Main differences between meat products concern to the storage time that can be prolonged in treated products. The treated meat products with extended shelf life increase the use of non-renewable energy without important change of global warming potential due to electricity mix in France.

4.2. Food quality in the life cycle assessment

The treated meats products commercialized are value-added products (Bajovic et al. 2012). The average price of treated sliced cooked ham and untreated ones recorded in Europe was considered in the analysis. The difference between prices was observed in data collection. Consumers with knowledge of high pressure processing are able to pay an additional cost for the features of the high-pressure treated product (Hick et al. 2009). High pressure processing provides added value to meat products by improving food safety since it allows not only the inactivation of pathogenic microorganisms, but also the reduction of use or the removal of food preservatives.

The comparison of the value performance with regards to the environmental impact is defined as eco-efficiency (Schau and Fet 2008). For treated products, each monetary unit as benefit represents less environmental load. In consequence, the use of high pressure processing on cooked ham production improves the eco-efficiency of the meat product. In fact, the comparison between the traditional and the treated product is greatly influenced by the choice of functional unit.

Food safety is also presented as the human health impact of the disease associated to *L. monocytogenes*. Including other dimensions of sustainability at the endpoint level could lead the identification of the main concerns to human health. Although uncertainties of endpoint methods are large, the comparison of impacts at the endpoint level shows that carcinogens, climate change, effects of respiration inorganics, radiation are the most important contributors to damage to human health. However, the human health effect due to listeriosis is relevant in comparison to effects to human health by ozone layer depletion.

For the worst scenario, the human health effects due to listeriosis raised importantly in two weeks; followed by the radiation impact category which is associated to radiation exposition by the power production of nuclear plants. High pressure processing can prevent the years of life lost due to the disease at the baseline (2.84 DALY) and for the worst scenario (14 days: 62.22 DALY). It is important to note that the results of human health effects of listeriosis correspond to specific geographic conditions, consumer characteristics and for a susceptible population (older adults and pregnant women). The benefit of preservation technologies are not only limited to the actual state of food safety of meat products; but also in the prevention of higher human health damage due to food-borne diseases. Efforts are necessary to decrease the principal contributors to the environmental impact and therefore, the damage to the human health. Reduction of meat content in meat products is complicated without affecting its nutritional value. Finally, novel technologies play a role in minimizing losses by improving food quality.

5. Conclusion

Novel technologies have a great responsibility to improve sustainability on food processing. In this case, increasing food processing steps to improve food quality does not necessary cause a notable increase of environmental load of processed food. The eco-efficiency of the meat product can be enhanced by using high pressure processing. In fact, the food quality can be improved without important contribution to the environmental impact of the meat product. Furthermore, the direct impact of food safety on one of protection areas of LCA, human health, was described. The benefits of high pressure processing on food safety could compensate in part the use of non-renewable resources due to the extended shelf life of products. Other quality features should be included in life cycle assessment for improving comparison between products.

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