

Environmental Impact Evaluation of Legume-Based Burger and Meat Burger

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The industrial development leads to a consumption of natural resources and an increase of environmental impacts. The protection of human well-being and ecosystem are essential to obtain sustainable products. In this scenario, the reduction of environmental impact required for food productions collides with the population increase. A key aspect is the increase of the productivity and the reduction of the greenhouse gases emissions to allow continuity to the industrial development respecting the environmental system. The “Legume Genetic Resources as a tool for the development of innovative and sustainable food Technological system” (LeGeReTe) project is focused on the environmental impact of food products considering in particular legume-based food, which could represent an alternative to the traditional food. The object of the study is the comparison between the environmental impact of the legume-based burger production chain and of the traditional meat burger production chain. The Life Cycle Assessment (LCA) method was applied to assess the environmental sustainability of the analysed case studies. A “from cradle to grave” approach was used, therefore agricultural phase, industrial process and domestic preparation were considered. The functional unit considered is 1 burger (100 g of product). The results of the environmental impact analysis for both the burger typologies showed that the agricultural phase is the most impacting one for most of the impact categories. Analysing the two food chains, the industrial process of legume-based burger provides the higher environmental impact respect to the meat burger. Moreover, the impact assessment of meat burger production chain, for most of the impact categories, reaches a value of 3-4 times greater than a legumes-based burger. Finally, with the aim of considering nutritional aspects to compare the impact values, a quantity of 15 g of protein (corresponding to the protein content of a meat burger of 100 g) was considered as a nutritional functional unit. To reach the same protein content for the meat burger, it's necessary an intake of two legume-based burgers. Nevertheless, doubling the environmental damages of legume-based burger, the environmental impact related to meat burger remains higher.

1. Introduction

Meat products are an interesting choice for a good diet due to the presence of minerals, vitamins, and proteins with high biological value (Pereira et al., 2013; Xiong, 2004). Despite that, the meat and especially red meat contains a high quantity of cholesterol and saturated fatty acids (PUFAs) (Muguerza et al., 2004). Large consumption of these constituents could cause cardiovascular diseases (CVD), cancer, inflammatory and autoimmune diseases (Cengiz & Gokoglu, 2005; Simopoulos, 2002).

Worldwide meat consumption has been modifying in the last years. The rationale of this changing is related not only to healthy aspects. Asgar et al. (2010) proved that consumption changes are driven by fear of animal diseases like the mad cow in 1980, by religious lifestyles choices, by the rising of vegetarianism, by animal rights movement, and by economic and environmental aspects. For these reasons, the food industries have been prompted to move to alternatives foods. The vegetable products, compared to meat products, become a good alternative thanks to their lower price and the large availability all over the world (also in the developing country) (Delgado, 2003).

Among the vegetarian products, legumes play an important role in the food industry. Moreover, they are a good source of energy, minerals, and B vitamins useful for human nutrition (Oboh et al., 2009). Legumes are also part of the dietary habits for thousands of years and they are the unique supply of proteins in the diet for some developing countries (Riascos et al., 2009). Till some years ago legumes were considered the poor man's meat (Serdaroğlu et al., 2005), but recently they have been considered as a healthy alternative, instead of the meat, in the developed countries.

The choice to move from meat products to alternative products is guided also by environmental aspects. Many studies have shown how meat production processes are directly linked to climate change (Peters et al., 2010; Rööß et al., 2013). However, even vegetable crops production processes have an environmental impact not negligible. The livestock request high intake of feeds and produce a high quantity of greenhouse gases (GHG) but, at the same time, the legumes require a high-water usage and a large amount of land occupation due to farming activities. Moreover, as meat products, even legume-based products require several productive steps (Sonesson et al., 2010). In both the production chains there are different processes that have a crucial environmental impact. Few works are published in the literature regarding the comparison of these two production chains, and most of them are mainly focused on a general production chain.

In the last years, different formulations of alternative products become available on the market. Therefore, the aim of the work is to quantify the environmental impacts related to the production of one burger, a worldwide highly consumed product; two different typologies were considered: a meat burger (MB) and a legume-based burger (LBB). To perform this comparison the Life Cycle Assessment (LCA) method has been applied (ISO 14040:2006). The comparison between the impacts of the two case studies will be the starting point for the identification of the environmental safer one.

2. Materials and methods

2.1 System description and definition of system boundaries

The functional unit (FU) was defined as 1 burger. A standard production process was considered with productivity equal to 2'400 burgers hour⁻¹, for both the analysed typologies. It was assumed for the allocation of the machinery employed in the process that the production sites work 365 days year⁻¹ and 24 hours day⁻¹. The average lifetime of all the machinery to produce one burger was supposed equal to 10 years.

The studied chains show three different phases:

1. **The agricultural phase:** for the MB the agricultural phase regards all the activities related to the production of food, the guard and the growth of the livestock. Regarding the LBB, it includes farming activities to obtain the legumes and the activities necessary to obtain the secondary ingredients of the LBB.
2. **Transformation phase:** this phase is related to all the activities which are necessary to transform the raw material into the final products. In the case of the MB, this represents the simplest transformation phase, it implies only the mixing and the forming procedures. Concerning the LBB, it requires more than one process due to the different ingredients and the complexity of the formulation.
3. **Cooking phase:** it refers to the activity requiring energy for the transformation of the finished product into edible food.

A *cradle-to-grave* approach was applied, considering all the activities from the farm (livestock and legumes), through the production of the burgers, till the cooking and consumption. In the whole production and consumption chain, no attention was paid to (i) the transport of intermediate products, (ii) the transport and logistics activities of the final product to the mass distribution channel and to the consumers and (iii) the storage activities of the products. The decision to not include in the study these phases is supported mainly by the full comparability of these phases in the two different production chains, resulting in a negligible effect to this comparative study.

2.2 Meat burger Life Cycle Inventory (LCI)

The production of one MB requires 100 g of raw meat. For the formulation of one MB, no secondary ingredients were considered. For the meat input, secondary data were used for impact calculation. The flowsheet of operations considers (i) a mixing phase of the meat, (ii) a shaping phase to create the meat burger using the forming machine and (iii) the packaging using a plastic film followed by refrigerated storage before the selling. Finally, after the transformation, the domestic cooking phase requires the consumption of natural gas. It was estimated that an average of 8 minutes is necessary for the cooking phase, therefore the natural gas consumption was quantified in 0.024 m³ FU⁻¹. Table 1 reports the machines necessary for the steps of the chain. They were characterized in term of weight, the material of construction and power absorption, and then allocated for one burger (FU).

Table 1: Machines required to obtain the MB and the relative subdivision for the FU

Machine	Weight (kg)	Power (kW)	Weight / FU (10^{-4} g)	Energy / FU (Wh)
Mixer	77	0.45	1.8	0.46
Forming machine	65	0.4	0.5	3.58
Packaging machine	1000	9.5	2.3	0.31
Refrigerator	89	1.36	8.4	1.65

2.3 Legume-based burger Life Cycle Inventory (LCI)

The formulation of the LBB was obtained from the literature (Summo et al., 2016). The production of one LBB requires several ingredients:

- 24 g of lentils (*Lens culinaris L.*);
- 12 g of peas (*Pisum sativum E.*);
- 24 g of beans (*Phaseolus vulgaris L.*).

Each ingredient is soaked in water at room temperature for 8 h, followed by a pressure cooking for 30 min and a mashing process. At the same time, 20 g of corn (*Zea mays L.*) are washed with water and 10 g of fresh spinach, after washing, are cooked at 100 °C for 3 min. The legumes are mixed with corn and spinach, and added to 4 g of egg white, to 4 g of cheese and to 2 g of extra virgin olive oil. The mixing (5 mins at 60 rpm) and forming phases are performed after pre-cooking at 130 °C for 15 min in the oven. The pre-cooking phase is followed by a chilling phase at 4 °C. The burger is then rolled in breadcrumbs and baked again at 210 °C for 15 min. Finally, the product with a weight of 100 g is packaged and sent to the mass distribution channel.

For the final phase of the domestic cooking it was not considered the construction of the pan, but, considering the different cooking times required for the two products, for the legume-based burger was estimated a time equal to 3 minutes. In this phase, a quantity equal to 0.009 m³ of gas is required to cook the burger (Senneson et al., 2007). For each phase performed, it was defined the machines weight and the composition of the machine, and the relative energy consumptions (Table 2).

Table 2: Machines required to obtain the LBB and the relative subdivision for the FU

Machine	Weight (kg)	Power (kW)	Weight / FU (10^{-4} g)	Energy / FU (Wh)
Containers	14.3 x 8		0.7	
Cooker	11 x 5	1.5	0.5	3.58
Mixer	50	0.75	2.3	0.31
Cooker	135	16.0	6.4	6.67
Washer	50	0.37	2.4	0.15
Cooker	120	9.0	5.7	3.75
Mixer	45	0.55	2.1	0.23
Forming machine	65	0.4	3.1	0.17
Oven	79.5	4.5	2.9	1.87
Temperature blast chiller	1311	3.8	62.3	1.58
Breading	44.7	0.2	2.1	0.07
Packaging machine	1000	9.5	47.6	3.96
Fridge	89	1.4	8.4	1.65

Alternative scenario

In addition, a variation in the FU was considered. The conventional mass-based FU (1 burger equal to 100 g of product) has been changed in an alternative scenario into a nutritional-based FU, identifying it as 15 g of proteins, corresponding to the average quantity of proteins contained in the meat burger. No assumption related to the quality of the protein in the two products was envisaged.

Life Cycle Impact Assessment

According to Jolliet et al. (2003), the Impact 2002+ method was applied, and the following impact categories were considered: Carcinogens "CARC" (kg C₂H₃Cl eq); non-carcinogens "N-CARC" (kg C₂H₃Cl eq); respiratory inorganics "R-IN" (kg PM_{2.5} eq); ionizing radiation "I-RAD" (Bq C-14 eq); ozone layer depletion "OLD" (kg CFC-11 eq); respiratory organics "R-ORG" (kg C₂H₄ eq); terrestrial ecotoxicity: "T-ETX" (kg TEG

soil); terrestrial acid/nutri "T-ACID" (kg SO₂ eq); land occupation "LO" (m²org.arable); global warming "GW" (kg CO₂ eq); non-renewable energy "NR-EN" (MJ primary); mineral extraction "ME" (MJ surplus).

LCA software SimaPro 8.5 was used to perform the Life Cycle Assessment.

3. Results and discussion

Figure 1 represents the environmental impact related to the life cycle of 1 MB (a) and of 1 LBB (b). For each impact category, the percentage subdivision allows identifying the hotspots related to the production chain.

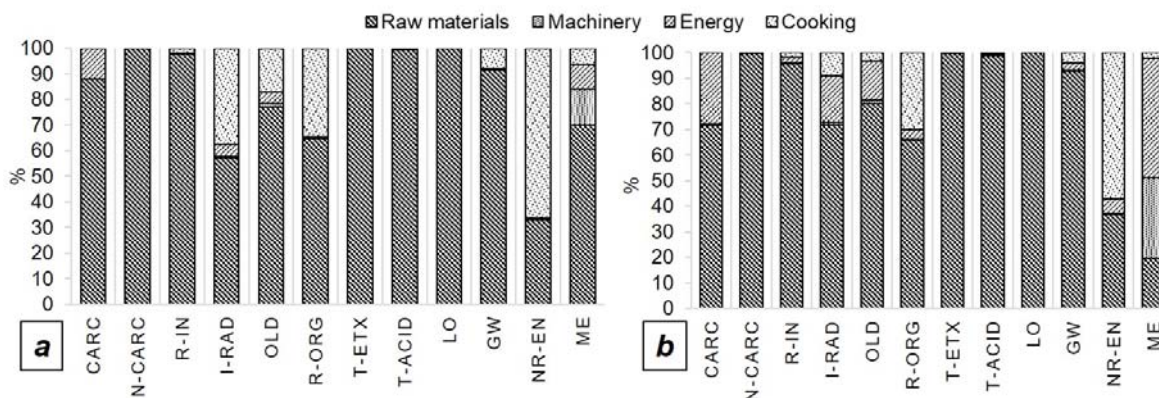


Figure 1: Percentage subdivision of the factors related to the production of one MB (a) and one LBB (b)

For most of the impact categories expressed from the method Impact 2002+, the main hotspot identified is related to the farm phase for both MB and LBB. This high level of responsibilities is due to the agricultural procedures necessary to produce the raw materials. Regarding the MB, these percentages derived from the activities to obtain grass, oat, maize for the livestock or, regarding the LBB, from the practices to produce legumes, maize or peas. Agricultural and farming phases require different activities and land occupation that let the values of these impact categories rise. Therefore, the incidence of the "raw materials" reaches more than 80% in most of the impact categories.

The cooking phase represents the second hotspot in both the production chains. The incidence of this phase, especially for some of the impact categories as for R-IN (37 % MB; 9 % LBB), OLD (17 % MB; 3 % LBB), R-ORG (34 % MB; 30 % LBB) and NR-EN (66 % MB; 57 % LBB), is directly linked to the gas methane production and to its consumption. The differences that can be registered between the two products are strictly correlated to the cooking time. For the MB were assumed 8 minutes while for the LBB only 3 minutes, the LBB is pre-cooked in the oven during the production phase, therefore it does not require real cooking as the MB. For this reason, regarding the LBB, methane gas has a lower incidence.

What really differs between the two products life-cycle is the transformation phase. The MB needs a simple operation to transform the meat into the MB, due to this the machines and the relative energy demand show low percentages. The same considerations cannot be done for the LBB. The technical difficulties to obtain LBB mixture and structure, in comparison to the MB, are mainly due to the higher number of ingredients. The complexity of the flowsheet for the different steps of the transformation phase justifies the number of machines. The percentages related to machinery and relative energy required for the LBB (figure 1b) show higher values respect to the MB (figure 1a). This gap in the transformation phase is highlighted in the ME impact category, where the MB "machinery" and "energy" voices have an impact incidence equal to 23% (14% and 9% respectively), while the LBB reaches 78% (31% and 46% respectively).

3.1 Comparison of the two systems

From the results reported in Figure 1, data were weighted to identify the magnitude of the different impact categories. For both the productions analysed, the most relevant impact categories were identified and reported in Table 3: N-CARC, R-IN, T-ETX, LO, GW and NR-EN. The gap between the two productions is explained with a ratio level which quantifies how much the MB is more damaging respect to the LBB.

All the ratio levels show values higher than 2, considering the terrestrial ecotoxicity "T-ETX" it reports a ratio value equal to 3.64, with the MB production which releases 572.53 kg of triethylene glycol (TEG) in the soil while the LBB 157.43 kg, these values are directly caused by the farming and agricultural phases. Focussing the attention on the global warming (GW) impact category, the production of 1 LBB release 0.47 kg of CO₂

while to produce 1 MB are produced 1.04 kg of CO₂, also in this case the agricultural phase, as showed in figure 1, majorly justifies the difference in the CO₂ released.

Table 3: Comparison of the environmental impact of one MB and one LBB among the most relevant impact categories. The last column shows a ratio value, which shows how many LBB should be produced to obtain the same impact as one MB.

Impact category	1 MB	1 LBB	Ratio
N-CARC (kg C ₂ H ₃ Cl eq)	0.16	0.05	3.08
R-IN (kg PM2.5 eq)	0.002	0.0004	4.32
T-ETX (kg TEG soil)	572.53	157.43	3.64
LO (m ² org.arable)	2.70	0.69	3.90
GW (kg CO ₂ eq)	1.04	0.47	2.19
NR-EN (MJ primary)	16.75	4.70	3.56

Therefore, considering all the impact categories reported in table 3, it is evident how the LBB has a lower impact compared to the MB. These gap between the MB and the LBB is mainly attributable to two processes along the production chains: the farming phase and the transformation phase (figure 1). Regarding the farming phase, the MB production requires many activities as feed cultivation, transformation and livestock breeding. In the case of the LBB, the farming phase refers to all the activities linked to the cultivation and harvesting of the legumes and includes also all the activities necessary to obtain the secondary ingredients as egg and cheese, which represent 8% of the finished product. As for the MB also for the LBB, the level of impact is for most of the impact categories linked to this phase. Otherwise, regarding the LBB, the number of machines and their energy consumption let the transformation phase shows a higher level of incidence respect to the MB. Although the life cycle impact assessment of the two products has identified different hotspots, the high level of incidence resulting from the agricultural phase of 1 MB, compared to the incidence of 1 LBB production phase, results in a greater environmental impact to produce 1 MB compared to 1 LBB.

3.2 Alternative scenario

A new FU of 15 g of proteins was considered. Table 4 reports the most relevant impact categories (T-ETX, GW and NR-EN). The decision to present only these impact categories is enforced by the higher magnitude compared to others and by the better capacity to describe the environmental impact trends of the two products. The variations of the impacts are related only to the LBB, the 15 g of protein, intended as the new FU, is the quantity of protein contented in 1 MB; in order to reach the same quantity of protein in the LBB, its production must be doubled.

Table 4: Impact values switching the FU from one burger to 15 g of protein

Impact category	Product	1 burger	15 g Protein
T-ETX (kg TEG soil)	MB	572.53	572.53
	LBB	157.43	314.87
GW (kg CO ₂ eq)	MB	1.04	1.04
	LBB	0.47	0.95
NR-EN (MJ primary)	MB	16.75	16.75
	LBB	4.70	9.40

From an increase of 100% of the production, the impact categories report doubled values which anyway does not reach or pass the MB values. Considering the GW impact category, the ratio between 1 LBB and 1 MB, which in the mass FU analysis was 2.19, decreased to 1.09. Although doubling the production of the LBB doubles its impacts, this does not exceed the values related to the MB. Overall, considering the 15 g of protein FU, the MB shows the worst environmental performances in all impact categories. The production of the 15 g of protein from LBB saves 0.09 kg of CO₂ and 7.35 MJ of primary energy for the hamburger.

The environmental properties of food products may not be confused with the nutritional aspects, which is better for the environment does not always represent the best choice for human health. Nutritional properties based on objective data were studied and confirmed in previous studies. But from an environmental point of

view, this behaviour is not so clear and this study could give, considering the case studies, a reasonable comprehension of the current scenario, basing the study on objective data. These two products are different in nutritional aspects and are consumed in different quantity, the MB is nowadays largely consumed while the LBB has a marginal consumption yet, and this could have a future impact from an environmental point of view. A diffusion of LBB could be envisaged, raising new questions regarding its sustainability. The proposed study is a starting point to face these environmental questions.

4. Conclusion

Considering the results obtained using a mass FU, the most sustainable option between the two products is represented by 1 LBB. 3.44 LBB must be produced in order to equal the environmental damage of the production of 1 MB. Also studying the two products using the nutritional FU (15 g proteins), the MB represents the worst environmental option. The results showed a medium gap identified equal to 1.70.

The sustainable development models could be the key to study the trends of the consumer's demand. Future studies can focus the attention to demands, considering what could be the results of a continuous increase in demand of the legume products. Moreover, following the lack of this study, future studies could better analyse the environmental impact of the two products not only considering the protein in term of quantity but also considering the same aspect in term of availability for the human health.

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